KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

SCHOOL OF RESEARCH AND GRADUATE STUDIES

DEPARTMENT OF CROP AND SOIL SCIENCES

ROLE OF INTERCROPS IN PROLIFERATION OF *ARMILLARIA* ROOT-ROT OF TEAK [*TECTONA GRANDIS* (LINN. F.)] IN TAUNGYA PLANTATION:

A CASE STUDY AT THE OPRO FOREST RESERVE

BY

EDMUND OSEI OWUSU (BSc HONS)

APRIL, 2011

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A THESIS SUBMITTED TO THE SCHOOL OF RESEARCH AND GRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN PLANT PATHOLOGY

BY

EDMUND OSEI OWUSU (BSc HONS)

APRIL, 2011

DECLARATION

I declare that the results of this study except otherwise cited were obtained from my own work and have not been submitted for any degree other than that of my Master of Science in the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

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DATE.....................................

DEDICATION

This thesis is dedicated to, Mr. Lawrence Osei Owusu, Rebecca Adoma and Madam Akua Tanoah, my father, mother and grandmother, respectively.

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ABSTRACT

Teak (*Tectona grandis* Linn. F.) is currently the most planted tree species in forest plantations in Ghana, with over 73,916 hectares of plantation established at the end of 2008. Majority of the plantations are established, using the taungya system with various intercrops. However, *Armillaria* (Fr.: Fr.) Staude root-rot symptoms have been observed on teak in teak taungya plantations, especially in the dry semi-deciduous forest zone. This study was conducted to identify the role of intercrops cultivated by the teak taungya plantation farmers in the Opro Forest Reserve of the Offinso Forest District of Ashanti Region in proliferation of *Armillaria* root-rot of teak and farming practices that could predispose teak to the disease. Mycoflora of rhizosphere soils of teak in teak plantation with only one intercrop (Pepper, Okra, maize, yam or cassava) were analyzed for *Armillaria* colonies in one to three-year-old plantations and compared with growth of teak and incidence of *Armillaria* root-rot infection of teak in the plantation. More *Armillaria mellea* (Vahl: Fr.) colonies were isolated from rhizosphere soils of teak intercropped than teak grown with no intercrops. There were significantly higher numbers of *A. mellea* colonies in rhizosphere soils of teak intercropped with cassava. Strong negative correlations existed between growth and incidence of *Armillaria* root-rot of teak and also between growth and number of *A. mellea* colonies isolated from rhizosphere soils of teak in one to three-year-old teak trees. However, infection of *Armillaria* root-rot of teak declined in the two and three-year-old plantations as less intercrops were involved. Farmers engaged in the teak taungya plantation in the Opro Forest Reserve had inadequate knowledge about *Armillaria* root-rot of teak and hence encouraged farming practices such as excessive pruning of teak and use of fire to control weeds in the plantation which predisposed teak to *Armillaria* root-rot infection.

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CHAPTER ONE

1.1.1 INTRODUCTION

Armillaria (Fr.: Fr.) Staude belongs to the Basidiomycetes in the family Tricholomataceae, Agaricales (Sicoli *et al.*, 2003) that causes root-rot on various plant species. Generally, its species do not show strong host specificity and occur worldwide in natural forests and on planted woody crops (Hood *et al.*,1991; Kile *et al.*, 1991; Termorshuizen, 2000). *Armillaria* species have been regarded as primary pathogens, stress-induced secondary invaders and saprophytes (Wargo and Shaw, 1985; Shaw and Kile, 1991). Group death, wilt, yellowing of leaves, stem resin exudation, and white rhizomorph beneath the bark of infected trees are common symptoms of *Armillaria* infections (Morrison *et al*., 1992). The impact of *Armillaria* root-rot is aggravated by the ability of *Armillaria* species to survive either as saprobes or necrotrophs (Gregory *et al.*, 1991), depending on the available substrate and niche. Consequently, *Armillaria* root-rot poses a serious threat to forestry and agricultural industries worldwide.

Armillaria root-rot has been reported on different hosts in many parts of Africa. Cortzee *et al*. (2000) reported that *Armillaria* root-rot affects *Tectona grandis* (Linn. F.) (teak) in Zambia, pine in South Africa, Kenya and Ethiopia, *Acacia* species in Tanzania and *Cypress* species in Zimbabwe. According checklist of plant pest in Ghana (Oduro, 2000), *Armillaria mellea* (Vahl: Fr.) could affect cassava, okra, pepper, cocoyam, citrus, cocoa, coffee, mango, oil palm, and coconut. *Armillaria* root-rot has also been reported from several countries in South, Central, East and West Africa (Mohammed *et al*., 1989). In these regions, the disease is known to infect both cash crops such as coffee, tea, rubber and cocoa and forest plantation species including Pine, Eucalyptus, Acacia and Grevillea (Shaw and Kile, 1991). The disease has generally been ascribed to *A. mellea* (Ivory, 1987; Mohammed *et al*., 1989). Adu-Bredu *et al.* (2008) noted in their study that there are isolated cases of teak tree die-back and stem borers of teak in West Africa.

Armillaria root-rot infection of teak is of concern in Ghana in view of the huge capital invested in teak plantations nationwide. According to the Forestry Commission of Ghana Annual Report (2008), an estimated 123,193 ha of forest plantation had been established throughout the country under the National Forest Plantation Development Program (NFPDP). More than 60% of the trees planted were teak and most of the teak plantations were established under the taungya system. Establishing teak plantation with the taungya system is a means of maximizing land utilization for economic benefits (Djabletey and Adu-Bredu, 2007). The economic results of intercropping coffee with pineapples and bananas at a farm in Butuan Agusan del Sur in the Philippines and the benefits of intercropping coffee with *Acacia* species, bananas and black pepper were found to be beneficial (Pava, 1993). Lalramnghinglova and Jha (1996) reported a very successful practice of intercropping *Oryza sativa* (paddy) with teak.

Uses of teak in Ghana are profound in the furniture and construction industries. Teak serves as excellent replacement for concrete and metal poles for carrying electric cables, telephone lines and street lights in many parts of the country. The leaf of teak is believed to have medicinal properties (FAO and UNEP, 1981). Report on export of wood products by the Timber Industry Development Division of the Forestry Commission of Ghana (2011), indicated that 7614.11 cubic metres of teak were exported from January to May, which yielded €2,422,799.73 as revenue for Ghana.

Forest plantations that have been established in the dry semi-deciduous forest zones of Ghana are mostly teak plantations because teak has the ability to tolerate bush fire. Distinctive oily feel of teak make it highly resistant to acid and fire (Hart, 1973). In taungya plantations, intensive intercrop cultivation is undertaken until the teak canopy closes. The practice causes severe disturbance to the land and depletes the soil of its nutrient and water resources. The practice of taungya is also believed to create a stressful condition for teak because of competition with intercrops for water and nutrients. *Armillaria*, being a stress-induced secondary invader, can take advantage of the stress conditions created by taungya system to cause infection in teak.

The study is aimed at identifying the role(s) that intercrops could play to predispose teak to *Armillaria* root-rot infection in taungya plantations.

1.1.2 OBJECTIVES

- Assess the knowledge of taungya plantation farmers on *Armillaria* root-rot of *Tectona grandis.*
- Identify the effect of intercrops on growth and *Armillaria* root-rot infection of *Tectona grandis.*
- Determine the relationship between age of *Tectona grandis* and *Armillaria* root-rot infection in taungya plantation.

CHAPTER TWO

2.00 LITERATURE REVIEW

2.1.1 Distribution of *Armillaria,* its habitat and importance

Distribution of *Armillaria* spans the globe with 42 described species (Fox, 2000). The fungi attack about 700 plant species, mostly woody plants. Woody plants that have previously been weakened by drought, flooding, poor drainage, frost, repeated defoliation by insects or diseases, other poor soil conditions, excessive shade, polluted air or other chemical injury, or mechanical injury are most susceptible to attack (Hood *et al*., 1991). *Armillaria* is also a known killer of pine, spruce, and fir, especially in plantations where inoculum centres exist prior to planting (Hood *et al*., 1991).

The loss of fine feeder roots from *Armillaria* root-rot disease deprives affected plants of sufficient nutrients and water, and often results in branch dieback and stag head (Hood *et al*., 1991). The fungus can be of considerable importance in the final death of weakened trees and shrubs. Serious radial and terminal growth reduction of affected plants may occur. The fungus is also responsible for butt rot in some species of trees (Shaw and Kile, 1991). *Armillaria mellea* (Vahl: Fr) and other species have been identified as having a significant secondary role in disease complexes such as oak decline, maple blight, and ash die back (Bruhn *et al*., 2000).

Armillaria is commonly found in most forest soils, so *Armillaria* root-rot may occur in forested areas or areas that were previously forested. Diseased trees may be found scattered throughout a forest stand or infection centres composed of one or several declining trees may be scattered in the stand.

2.1.2 Biology of *Armillaria*

The life cycle and biology of *Armillaria* is very complex (Fox, 2000). Fruiting bodies of *Armillaria* are usually present only for a short time in the rainy season. Reproductive extensions called basidiomes produce basidiospores that can persist in soil for many years and possibly cause future infections of exposed roots or tree stumps (Fox, 2000). The most common way certain species of *Armillaria* spread throughout the forest is the aggregation of hyphae into structures called rhizomorphs. Rhizomorphs are partly composed of a gelatinous sheet and mucilage layer that protects the leading edge while it grows through forest soil; a melanized cortex for protection against fungi and bacteria; a medulla for nutrient transport; breathing pores for oxygen uptake; and a central canal for gas translocation (Fox, 2000).

Rhizomorphs have potential to create huge networks that when provided with enough nutrition, can persist for hundreds of years. Once a rhizomorph has come into contact with a root, infection will occur either mechanically or with the assistance of the enzyme suberinase, which helps penetrate the waxy waterproof suberin layer of host tissue (Shaw and Roth, 1978). After infection is established, rhizomorphs will differentiate into a white fan-shaped mat of mycelia that will spread throughout the root system of the host.

Mycelia of *Armillaria* invade cambium usually radially along parenchyma ray cells, cutting off nutrient flow between roots and leaves of the host (Anderson *et al*., 1987). Upon interaction with tissues of infected hosts, the mycelia of *Armillaria* form pseudosclerotized plates called pseudosclerotia, which act like the melanized cortex of rhizomorphs. Pseudosclerotia are important structures necessary for protecting mycelia from invasion by other fungi and bacteria.

Armillaria is a white-rot fungus, which metabolizes cellulose and lignin (Baucom *et al*., 2004). According to Baucom *et al*. (2004), this provides large amounts of nutrition for spread of the mycelial fan throughout the root system, and with sufficient decomposition causes tree death or wind-throw.

Armillaria can persist for several decades after the host has died and if a healthy neighbouring root comes into contact with an infected root, mycelia could spread to the healthy root, causing the infection cycle to begin again (Baumgartner and Rizzo, 2001). This action could lead to widespread die-off of trees in the immediate vicinity, especially when coupled with vigour loss of the host from shade, drought, defoliation, old age, or competition.

2.1.3 Conditions favourable for *Armillaria*

Armillaria root rot disease is often associated with trees under stress. It is most commonly found on sites with compacted soils, along skid roads, where trees have been poorly planted, where many trees have been wounded, or where there has been a poor match of stock to site. *Armillaria ostoyae* (Romagn.) is often found in association with other root pathogens on the same tree. When *A. mellea* is encountered on conifers, it is usually in an area where they are growing close to hardwoods.

Armillaria may behave like a saprobe or cause a non-lethal butt rot until the trees are stressed (Cruickshank *et al*., 1997) and then, host physiology is altered and the fungus can successfully attack and kill vital tissues. This tends to be the case more often in hardwoods. In conifers, killing of vigorous trees is more often observed. However, killing of hardwoods can be seen without apparent stress (Cruickshank *et al*., 1997).

2.1.4 Ecological role of *Armillaria*

Armillaria is a necrotroph, (an organism that infects and kills its host) which continues to decompose host tissue after the death of the host (Termorshuizen, 2000). This behaviour leads to long-term persistence of inoculum sources in a forest stand. For example, an oak stump in Southern England contained *A. bulbosa* (Barla) Kile and Watling 53 years after felling and was still producing rhizomorphs from a very small amount of inoculum at the time of observation (Rishbeth, 1985). In healthy trees, *A. mellea* creates small lesions and rarely colonizes the entire tree (Kile *et al*., 1991). However, after trees are cut, *A. mellea* can spread throughout the entire root system, creating a large inoculum centre that has the ability to persist for decades, and possibly infect and kill healthy nearby trees (Baumgartner and Rizzo, 2001). If *A. mellea* does not cause death directly, then it certainly weakens the tree which might lead to death from other biotic and physical causes.

2.1.5 Pathogenicity of *Armillaria*

Species of *Armillaria* have different degrees of pathogenicity; some are considered saprophytic, whereas few species are symbiotic with certain species of orchids (Bruhn *et al*., 1997; Terashima *et al*., 2006). Bruhn and Mihail (2003) reported that some species of *Armillaria* such as *A. gallica* (Marxmuller and Romagn.) put more energy into the production of monopodial, branching rhizomorphs, making this species more exploratory, less pathogenic and less aggressive. Other more pathogenic species such as *A. mellea* and *A. ostoyae* put more energy into mycelia production. They produce dichotomously branched rhizomorphs and, as a result, are less effective in exploring the forest floor. *Armillaria tabescens* (Scop.) is considered moderately pathogenic, producing short and sparingly branched rhizomorphs except during periods of saturation, when they produce rhizomorphs similar to that of *A. gallica*. *Armillaria gallica* depends more on penetration of host root systems by rhizomorphs for infection to be established. *Armillaria tabescens* infects new hosts with either rhizomorph or mycelial contact to new roots. *Armillaria mellea* and *A. Ostoyae* depend more on root-to-root contact for spread of mycelium to uninfected roots or on basidiome production for basidiospore dispersal.

2.1.6 Mode of infection of *Armillaria*

Infection occurs when *Armillaria* mycelium comes in contact with, and adheres to, young roots of a susceptible plant by means of a gelatinous secretion. The mycelium penetrates a root by the action of secreted enzymes that partially digest the cell walls of the young root. The fungus then grows into the root tissue between the cells. Once a plant has been invaded, the *Armillaria* mycelium continues to ramify through the root and trunk tissues, even after the host plant has been dead for several years.

According to Rishbeth (1985), *A. mellea* has a wide host range, encompassing a variety of deciduous and coniferous trees and shrubs. It also has the greatest ability to penetrate unblemished root bark and invade tissues displaying residual resistance. *A. tabescens* is known to attack *Quercus* (Oak) in the southern United States, and it has been observed to decompose Oak roots, rendering them more susceptible to wind-throw (Rishbeth, 1985). *Armillaria mellea* and *A. tabescens* focus energy into production of mycelia, leading to complete colonization of hosts, eventually compromising host defenses and killing trees (Volk *et al*., 1996).

A tree or shrub may die in one to several years after initial infection, depending on the vitality of the plant and environmental conditions (Whitney, 1988). *Armillaria* can pass from tree to tree via root grafts and roots of trees under stress are most easily infected. *Armillaria* is generally inhibited at soil temperatures above 26°C (Whitney, 1988).

2.1.7 Symptoms of *Armillaria* root-rot disease

The above-ground symptoms of *Armillaria* root-rot disease cannot be differentiated easily from those produced by other root or trunk injury. The most noticeable external symptoms are premature colouration and leaf drop, stunting of growth, yellowing or browning of the foliage, a general decline in the vigour of the plant, and twig, branch, and main stem die-back (Shaw and Kile, 1991).

These declines usually occur over several years but may appear to progress very quickly as the tree shows advanced symptoms of decline and death. As decline progresses, decay of the buttress roots and the lower trunk becomes evident. Small plants die quickly after the first symptoms appear with large trees surviving for a number of years (Shaw, 1980). A severely infected tree exudes resin, gum, or a fermenting watery liquid from the lower trunk.

Internally, the disease may develop as butt rot in some situations and as cambial killing in others. The difference may be related to stress and host differences. If the host is resistant, a major wound may be required for infection, and the fungus would be restricted to inner, inactive wood (butt rot) (Shaw, 1980). If the host becomes stressed, the fungus is then able to attack cambial regions, even of unwounded trees.

2.1.8 Signs of *Armillaria* root-rot disease

Signs of *Armillaria* in *Armillaria* root-rot disease are found at the trunk base or in the main roots near the root collar. White or creamy white, paper-thick, fan-shaped sheets of *Armillaria* mycelium can be seen growing over the water-soaked sapwood when exposed. The *Armillaria* mycelium has a strong mushroom odour. By the time a tree or shrub wilts and dies, the trunk is usually encircled by the fungus. With time, diseased wood becomes light yellow to white, soft and spongy, often stringy in conifers and marked on the surfaces by black zone lines (Hadfield *et al*., 1986).

The death of only a few branches can result from the killing of one or several main lateral roots. After the plant dies, rhizomorphs develop beneath the bark. The rhizomorphs are 1 to 3 mm in diameter, round or flattened and branched, and they consist of hyphal strands bundled together and enclosed within suberized cells (Jahnke *et al*., 1987). The cordlike rhizomorphs grow over infected roots and outward from a dead tree into the soil approximately 50 cm per month (Guillaumin *et al*., 1996). In nature, not all strains or species of *Armillaria* form rhizomorphs (Shaw and Kile, 1991).

2.1.9 Mode of spread of *Armillaria* root-rot disease

Spread of *Armillaria* root-rot disease among trees occurs most commonly via fungal growth across root contacts and to a much lesser extent by rhizomorphs. Rhizomorphs can grow short distances through soil to cause infection on nearby susceptible roots. Some trees can effectively resist the fungus at the time of initial infection by walling it off. However, if the tree subsequently becomes stressed or is cut, the fungus may break out of the callus tissues formed around infected areas on roots and spread rapidly in the wood. Once in a root, the fungus spreads proximally and distally within it. Fungal mycelia can survive for at least 35 years in old-growth stumps and roots before being replaced by other organisms (Roth *et al*., 2000). Survival of the fungus is influenced by stump size, tree species, and habitat type (Roth *et al*., 2000). Larger infected stumps provide a more substantial food base and longer survival. Small stumps of pre-commercial size (less than 15 cm) are not effective inoculum sources. The fungus survives longer in stumps of resinous hosts than in those of non-resinous hosts (Rosso and Hansen, 1998). Spore spread can occur but is not common.

Armillaria root-rot disease infection centres may form and develop over many years due to spread between roots in contact in stands with high components of susceptible hosts. Spread rate is about 30 cm per year (Romagnesi, 1970). Some infection centres spontaneously become inactive whilst others attain very large size.

The spread of *Armillaria* root-rot is usually not by means of the fungus growing toward the roots of a healthy tree or shrub as it is of a healthy plant's roots growing through the soil to wood already infected with *Armillaria*. Some species within *Armillaria* are virulent parasites while others are opportunistic and act selectively on weak individual plants or trees killed by other diseases, such as Dutch elm disease, *Annosus* root-rot caused by *Heterobasidium annosum* (Fr. Bref.) and *Phytophthora* root-rot leading to severe local outbreaks of the disease (Pegler, 2000).

2.2.0 Introduction of teak

Teak is a tropical hardwood tree in the family Lamiaceae (Verbenaceae), a native to South and Southeast Asia and commonly found as a component of monsoon forest vegetation (Kadambi, 1972). There are three species of the genus *Tectona*; *Tectona grandis* (Linn. F.), *Tectona hamiltoniana* (Dahat.) and *Tectona philippinensis* (Benth and Hook F.). *Tectona grandis* is however, referred to as the true Teak and has a wide distribution. Teak (*Tectona grandis*) is one of the most valuable timber species in the world because of its outstanding wood properties. The sapwood is white to pale yellow-brown, narrow to moderately wide. The heartwood is a dark golden golden-yellow when cut fresh, turning to a dark golden brown, sometimes with darker markings. On prolonged exposure to the weather, the colour becomes lighter. The grain is generally straight, but may occasionally disfigure. Texture is moderately coarse and uneven due to growth rings. The wood is hard and moderately heavy, weighing approximately one tonne per 1.5 cubic metres of seasoned sawn timber (Robertson, 2002). At 12% moisture content, the density is 670 kg per cubic metre (Robertson, 2002). Plantation material may be lower in density.

2.2.1 Botany of teak

A mature Teak is a very large deciduous tree having height up to 35 meters. The bark is brown or grey in colour with shallow longitudinal furrows. The leaf is simple, opposite, broadly elliptical or obovate, acute or acuminate, coriaceous, possessing minute glandular dots. Flower is white, many, small, having pleasant smell, in large erect terminal branched tomentose cymose bladder-like calyx. Seed is ovate and marble white (Kadambi, 1972).

2.2.2 Propagation of teak

Seeds from the dry and the moist climates vary greatly in the ease with which they can germinate. Almost all Teak seeds show some degree of dormancy. This makes it difficult to germinate evenly and adequately. The main cause of delay in the germination of Teak seeds as with many other seeds is its thick pericarp which does not soften quickly for the embryo cells to sprout (Kadambi, 1972). The seed structure, seed maturity and seed biochemistry may also contribute to dormancy (Kaosa-ard, 1991).

Pre-treatment of the seed is necessary to break the dormancy. This may involve alternate wetting and drying of the seed before sowing. The seed is placed in a Hessian bag and soaked in a running stream for 12 hours. The seeds are then spread out in the sun for 12 hours to dry. The process is repeated 10-14 days before the seeds are sown on raised germination bed.

Seed germination bed is raised about 5 cm above ground by filling with a layer of 5 cm gravel on the bottom, 35 cm of clean coarse sand in the centre and 10 cm of a 50/50 mixture of peat and coarse sand on the top (Heywood *et al*., 2007). Seed is pushed into the top layer of sand and peat and watered twice a day. Germination starts from 10-15 days after sowing and reach its peak between 35-45 days (Heywood *et al*., 2007).

2.2.3 Planting material of teak

Seedlings, stumps or tissue culture can be used as a planting material. Seedlings can be picked out in poly-pots to the field after they have germinated and grown to 30-40 cm high. Seedlings should be planted after rains. It is advisable to raise seedlings close to the planting site. Carting seedlings over long distances to planting sites can cause shocks in the seedlings which may reduce their survival when planted (Heywood *et al*., 2007).

To prepare stumps, the seedlings are left to grow on the germination beds until they reach about 15-20 mm in diameter, the shoots and the roots are then pruned (Kadambi, 1972). About 25-50 mm of the shoot and 150-200 mm of the root are left intact (Kadambi, 1972). This is called a stump. It can be stored in a cool dry area for sometime before planting. It can also be transported for a long distance to the planting site. It is, therefore, the appropriate planting material when the planting field is very far.

Tissue culture plantlets are very costly. However, they have superior genetic quality over seedlings and stumps. The initial cost is very high but the resultant trees are of excellent traits (Kaosa-ard, 1991).

2.2.4 Soil requirements of teak

In its natural state, teak grows on a variety of geological formation, but the quality of growth depends on the depth, structure, drainage, porosity and moisture holding capacity of the soil. Teak is calcicolous species and requires a large amount of calcium in the soil for proper growth and development (White, 1991). Many fine absorbent roots are formed by young teak on the uppermost soil layer during the wet season, but mostly die off in the dry season and are replaced by roots that develop in deeper layers, provided the soil is well aerated (White, 1991).

In deep loamy soils, a taproot develops early and becomes the main water supplier. In older trees, the taproot, though long, is not very thick. The water availability of the soil has a positive correlation with fine rootlets and their distribution (Kadambi, 1972).

2.2.5 Nutrient utilization of teak

Nutrient cycling between soil and plant is much complicated and is a biological phenomenon. Trees take up available nutrients from the forest floor and soil and release through litter fall, stem flow, root death and root exudation (Miller *et al.*, 1994). The rate of nutrient cycling changes with stand development. Initially, cycling is dominated by uptake for the want of growth and development until canopy closure. It declines slightly when internal cycling mechanism begins to operate. According to Lalman (1985), from year one up to 30 years of teak plantation, the rate of nutrient requirement is greater than nutrient return which is reflected by gradual decrease of soil organic matter.

Teak grows well on deep, porous, fertile, well-drained alluvial soil and grows poorly on hard limestone with shallow soil (Walterson, 1971; Kadambi, 1972).The distribution of nutrients in teak has been investigated by many scientists (Walterson, 1971; Weaver, 1993). Percentage of nutrients in one-year-old teak seedlings decreases in the following order N > Na > Ca > K > P (Lalman, 1985). Nutrient concentrations are higher in leaves, stem and roots. Seedling nutrient composition increases from eight to nine months (Drechsel and Zech, 1994)

2.2.6 Growth and management of teak trees

Teak can grow in a variety of soils. The rate and quality of its growth is, however, dependent on the type and quality of the planting material (seedlings, stumps or tissue culture); the physical and chemical characteristics of the soil, including topography and drainage; on environmental variables such as rainfall, temperature and humidity; the calcium content of the soil and on management techniques (Kaosa-ard, 1986). Teak establishes best on terrain cleared of competing vegetation. An important aspect of plant competition may be sought in the relatively large need for aeration of the root system, and in the requirements for light and nutrients (Shukla, 2009). The early growth rate of teak is quite good, but the average growth rate on very long rotations is low (Kaosa-ard 1998). Teak trees develop thick tap root system which may persist or disappear. Strong lateral roots may also be formed. Exposed teak suffers from wind, which causes branching, but this may be minimized if protected with shelterbelts. Seedlings of teak are very sensitive to abnormal drought, fire, and drainage (Kadambi, 1972; Keogh, 1987; White, 1991; Borota, 1991).

A viable option for the production of high volumes of quality teakwood is to establish pure plantations on well-prepared and well-drained soils, and to manage them to reach a good average height before flowering sets in, making branching more profuse. Spacing should be relatively wide, to promote rapid development of the saplings. The usual 1,200 to 1,600 plants per hectare is a good range, with closure of the canopy commonly taking place between the third and fourth year, suppressing the development of weeds (Kadambi, 1972; Centeno, 1997).

The management of pure stands where a protective understorey is maintained after canopy closure tends to avoid the deterioration of the soil, particularly when the undergrowth contributes to the fixation of nitrogen (Shukla, 2009). It has been demonstrated that pruning in commercial teak plantations has a positive impact on stand growth and wood quality. Viquez and Perez (2005) reported in Costa Rica that under an intensive pruning regime, a teak tree at a rotation age of 20 years may yield over 60% of the tree volume as merchantable wood, and over 40% as knot-free volume.

2.2.7 Uses of teakwood

Teak possesses excellent properties and so has a wide range of uses (Keogh, 1987). Teakwood seasons without splitting, cracking, warping nor physically altering shape and it is employed in a wide range of uses such as exterior and interior joinery, window and door frames, flooring, cabinet work, garden furniture, decking, boat building, bridges and railway carriages (Borota, 1991; White, 1991).

It is very useful in the boat building industry; for decking, deck houses, bulwarks, hatches, weather doors and planking. Teak can also be cut into poles for carrying electric cables, telephone lines and street lights (FAO and UNEP, 1981).

2.2.8 Pests and diseases of teak

Teak is affected by a few serious diseases both in nurseries and plantations. Leaf spot caused by *Phomopsis* sp., *Colletotrichum gloeosporioides* (M.B. Dickman), *Alternaria* sp. and *Curvularia* sp., leaf rust by *Olivea tectonae* (T. S. Ramakr) and teak root-rot by *Armillaria mellea*, powdery mildew by *Uncinula tectonae* (Damle, K.) (Perez *et al*., 2008). *Amylosporus campbellii* (Berk.) root-rots, *Fusarium pallidoroseum* (Cooke) Sacc. canker and *F. oxysporum* (Schlecht.) Snyder and Hansen root-rot have been reported from high-input plantations (Jamaluddin, 2005).

Insect damage is a serious problem in teak plantations, the most common insects being defoliators and stem borers. Defoliation reduces growth rates and apical dominance. The most important defoliators causing severe damage in teak plantations throughout the tropics are *Hyblaea puera* (Cramer) and *Eutectona machaeralis* (Walker) (Kaosa-ard

1998). Outbreaks of these insects may occur two or three times during the growing season and the plantation growth rate may be reduced by as much as 75%. Leuangkhamma and Vongsiharath (2005) reported that although defoliation did not kill the trees, *H. puera* attack caused an average loss of 44% in potential increment in plantations 4–9 years old. Nair (2001) reported some 187 insects on teak, with *H. puera*, the most serious, causing extensive defoliation in India each year. Stem borers can cause severe damage; in young plantations (1–5 years old), damaged trees may die-back or their top may break, reducing growth rate and stem quality. The most important borer in young teak plantations is the red or coffee borer *Zeuzera coffeae* (Nietner). In older plantations (over 10 years of age), the beehole borer *Xyleutes ceramicus* (Walker) is the most important. It causes severe damage to the standing trees and also reduces the value of timber (Kaosa-ard, 1998).

2.3.0 Taungya plantation system

Taungya plantation system is an agro-forestry practice where food crops and trees are planted on the same piece of land. The system has been reported to be an economical way of increasing agricultural productivity whilst ensuring sustainable production of timber in areas where land for agriculture is scarce. Lalramnglova and Tha (1996) and Roy *et al.* (1990) reported that teak was very successful when intercropped with rice, maize and *Leuceana* in India. Rachadi (1981), describing the silvicultural and socio-economic advantages of intercropping food crops with teak in Indonesia, advocated intensification of its use. However, there are instances when negative interaction results from competition for resources; water, mineral salt, and light amongst intercrop and between crops and trees. According to Kramer and Kozlowski (1960), trees and non-woody components in dense stand continually compete amongst themselves above-ground for light, below-ground for water, minerals and oxygen. Ong (1991) also reported that there are four basic biophysical elements affecting crop productivity in agro-forestry system, namely light, water, nitrogen and other nutrients, particularly, phosphorus and potassium.

Competition amongst crops for resources occurs on all agricultural lands. However, competition between the components of soil is the interactive interception of growth factors in mixed or row intercrops (Trenbath, 1983). Competition for water may lead to wilting and growth reduction due to water stress (Salter and Goode, 1967; Slatyer, 1967).

CHAPTER THREE

3.00 MATERIALS AND METHODS

The study was conducted in the Opro Forest Reserve of the Offinso Forest District of Ashanti Region and at the Plant Pathology laboratory of the Department of Crop and Soil Sciences, KNUST, Kumasi.

3.1.0 Survey: Assessment of farmers' knowledge and perception on teak Taungya plantation system and *Armillaria* root-rot infection of teak in the Opro Forest Reserve in the Offinso Forest District of Ashanti Region.

Teak taungya plantation establishment in the Opro Forest Reserve of the Offinso Forest District is part of activities the Forestry Commission of Ghana in association with farmers have embarked on to reforest degraded parts of the reserve. Farmers engaged in the teak taungya plantation are from four communities that fringe the reserve namely; Nkwakwa, Asempaneye, Asuoso and Ankaase. The degraded parts of the reserve where the teak taungya plantation was established have been divided into four compartments for the four communities.

The Opro Forest Reserve is located in the dry semi-deciduous forest zone of Ghana. The area has mean annual rainfall of between 1000 mm and 1500 mm. The major rainy season starts from middle of March to July, and the minor season from August to November.

The Reserve is approximately 128.94 square kilometers and located between 1^{o} 53'7.078"W, 7^{o} 5'58.111"N and 1^{o}44'37.903"W, 7^{o}15'8.202"N.

3.1.1 Selection of farmers for the study

Forty farmers that cultivated only one intercrop in their teak tuangya plantation were randomly selected out of the farmers engaged in the teak tuangya plantation at the Opro Forest Reserve from the four communities mentioned above. Ten farmers were selected from each community. The selected farmers were interviewed individually with the aid of a questionnaire (Appendix 1) to capture information including educational background, experience in farming, source of teak planting material, crops cultivated, ability to recognize *Armillaria* root-rot of teak, and perception on effect of bush fire on survival of teak. Reponses were recorded for analyses. In total, 40 questionnaires were administered.

3.3.0 Study 2: Assessment of growth and *Armillaria* root-rot infection of teak trees in the Taungya plantation of the Opro Forest Reserve

Experimental area of 225 m^2 which contained 25 teak trees was demarcated in the taungya plantations and used for teak growth and *Armillaria* root-rot infection assessments. The assessments were conducted in randomly selected one-year-old, two-year-old and three-year-old teak taungya plantation which had sole pepper, sole okra, sole maize, sole cassava and sole yam as intercrop. The assessments were also conducted in one-year-old, two-year-old and three-year-old teak plantation with no intercrop served as control. The assessments were replicated four times, one in each community (Nkwakwa, Asempaneye, Asuoso and Ankaase). The assessments were done between May and July, 2009. The intercrops selected were the major crops cultivated by the farmers interviewed during the survey.

There were six treatments, namely;

a. Teak taungya plantation with sole okra as intercrop (To)

b. Teak taungya plantation with sole pepper as intercrop (Tp)

c. Teak taungya plantation with sole maize as intercrop (Tm)

d. Teak taungya plantation with sole cassava as intercrop (Tc)

e. Teak taungya plantation with sole yam as intercrop (Ty)

f. Teak plantation with no intercrop (T) served as the control

3.2.1 Measurement of teak growth in the Taungya plantations

Teak growth was assessed by measuring height (cm) and diameter (cm) of its trunk at 1.3 m from the base of the teak tree. Where the height of teak is below 1.3 m, a pair of calipers was used to measure the girth at 10 cm from the base of the teak and converted to diameter with the formula $d = g / \pi$ (Mackie and Mathews, 2006) where;

d = diameter of teak, g = girth of teak and π (Pi) = (22/7)

Measurement from the base to the apex of teak was considered the height. Using tape measure and diameter tape, height (cm) and diameter (cm) of ten randomly selected teak trees were measured and their means calculated. The ten teak trees were then tagged for assessment of *Armillaria* root-rot infection.

The growth assessments were conducted on one-year-old, two-year-old and three-year-old teak trees for each treatment and replicated four times, one in each community (Nkwakwa, Asempaneye, Asuoso and Ankaase).

3.2.2 Assessment of *Armillaria* root-rot infection of teak trees in the Taungya plantations

Armillaria root-rot infection of teak trees were measured by assessing incidence of *Armillaria* root-rot infection of teak trees in the taungya plantation and scoring frequency of occurrence of *Armillaria* colonies from rhizosphere soils of teak trees.

3.2.2.1 Assessment of incidence of *Armillaria* root-rot of teak trees in the Taungya plantations

The ten-tagged teak trees for each treatment were observed for above-ground symptoms of *Armillaria* root-rot and signs of *Armillaria*. Teak tree parts observed for assessment were root collar, bark, stem, branches, leaves and twigs. Teak that showed symptoms of *Armillaria* root-rot, signs of *Armillaria* or both were considered infected. The above-ground symptoms of *Armillaria* root-rot that were recorded included premature colouration and leaf drop, stunted growth, yellowing or browning of the foliage and main stem , twig and branch die-back (Shaw and Kile, 1991). Signs of *Armillaria* that were observed included rhizomorph at the root collar and beneath the bark of teak trees and presence of *Armillaria* fruiting body at the base of teak trees (Guillaumin *et al*., 1996).

Incidence of *Armillaria* root-rot of teak trees was calculated as follows;

$$\text{Incidence} = \frac{Number\ of\ infected\ teak\ trees}{Total\ number\ of\ teak\ trees\ assessed} \times 100$$

Assessment of incidence of *Armillaria* root-rot of the teak trees were conducted on one-year-old, two-years-old and three-years-old teak trees for each treatment and replicated four times, one in each community (Nkwakwa, Asempaneye, Asuoso and Ankaase).

3.2.2.2 Experimental design and data analysis

The experimental design used was completely randomized design (CRD). Data were analyzed using analysis of variance (ANOVA). Least significant difference (LSD) at 5% was used to compare mean differences. Pearson correlation matrix was run to show the relationship between growth of teak, incidence of *Armillaria* root-rot of teak and the number of *Armillaria mellea* colonies isolated from the rhizosphere soil of teak. All statistics were performed using Genstat statistical package.

3.2.2.3 Sterilization of glasswares, working benches and laboratory tools

Beakers, 9 cm Pyrex Petri dishes, conical flasks, measuring cylinders, test tubes and pipettes were washed with detergent and air-dried in the laboratory. They were then hot-air oven sterilized at 160^{o}C for two hours. The Petri dishes were packed in canisters before sterilizing. Cork borer, inoculation needles and forceps were sterilized by dipping the tip in absolute ethanol and then flamed using methanol or spirit lamp.

3.2.2.4 Preparation of Potato Dextrose Agar

Potato Dextrose Agar was the medium used to isolate and culture mycoflora of the rhizosphere soil of teak trees. The medium was prepared from Irish potato tubers obtained from a local grocery in Kumasi. The tubers were peeled and cut into pieces and washed clean with tap water. A 200 g weight of the washed peeled potato tuber pieces was put into 2500 ml. Pyrex beaker and 500 ml of distilled water was added and then boiled on a hot plate stove until the potato pieces became very soft. The supernatant was strained through a cheese cloth into a 2500 ml flat bottom flask and then 20 g dextrose and 20 g agar were added and whirled to mix. The potato extract in the 2500 ml flat bottom flask was topped with distilled water to 1000 ml and amended with chloramphenicol (25 mg/l) to check bacterial contaminations and then stoppered with cotton wool and autoclaved at 121^{o}C, 15 psi for 15 minutes to sterilize.

3.2.2.5 Collection of teak rhizosphere soil for isolation of *Armillaria*

Rhizosphere soils of the ten-tagged teaks were collected within 20 cm radii and 15 cm deep from the base of the teak trees. Hand trowel was used to dig out the soil. The soil samples were bulked, and then mixed thoroughly with the hand and subsampled. Subsamples were placed in polyethylene bags and labeled and then spread on a laboratory bench for seven days to air-dry under ambient conditions at the Plant Pathology laboratory, Department of Crop and Soil Sciences, KNUST. The air-dried rhizosphere soils were analyzed for mycoflora at the Plant Pathology laboratory.

Collection of rhizosphere soil was conducted in one-year-old, two-year-old and three-year-old teak trees for each treatment and replicated four times, one in each community (Nkwakwa, Asempaneye, Asuoso and Ankaase).

3.2.2.6 Isolation of *Armillaria mellea* from teak rhizosphere soil

Isolation of mycoflora from rhizosphere soils was done using the dilution plate techniques (Watanabe, 2000). Ten grams of the air-dried rhizosphere soil was added to 100 ml distilled water in a 500 ml conical flask and shaken by hand for 10 minutes. This was taken as dilution 10^{-1}. Using a sterile pipette, 1 ml of the dilution 10^{-1} suspension was transferred to a test tube with 9 ml of distilled water to obtain dilution 10^{-2}. One ml of dilution 10^{-2} suspension was transferred to a test tube with 9 ml of distilled water to obtain dilution 10^{-3}. Using a sterile pipette 0.5 ml of dilution 10^{-3} suspension was pipetted and inoculated on a 9 cm Pyrex Petri dish which contained potato dextrose agar medium amended with chloramphenicol (25 mg/l) and gently swirled to spread the water suspension on the medium. Isolation of mycoflora from teak rhizosphere soil was conducted on one-year-old, two-year-old and three-year-old teak trees for each treatment. The Pyrex Petri dishes were then kept under ambient conditions of the laboratory for 14 days, after which the fungal colonies were identified and counted using a colony counter.

The treatments were replicated four times, one in each community (Nkwakwa, Asempaneye, Asuoso and Ankaase).

3.2.2.7 Identification and scoring of *Armillaria mellea* for frequency of occurrence

Identification of *Armillaria mellea* isolated was done with the aid of a compound microscope and standard identification manuals (Booth, 1971; Barnett and Hunter, 1972; Watanabe, 2000). Fungi isolated were scored for frequency by using colony counter to count their colonies.

The identification and scoring of frequency of *A. mellea* were also conducted in one-year-old, two-year-old and three-year-old teak trees for each treatment in the four replications (Nkwakwa, Asempaneye, Asuoso and Ankaase).

CHAPTER FOUR

4.0.0 RESULTS

4.1.0 Survey: Assessment of farmers' knowledge and perception on teak Tuangya plantation system and *Armillaria* root-rot infection of teak in the Opro Forest Reserve in the Offinso Forest District of Ashanti Region.

Teaks in the taungya plantation at the Opro Forest Reserve were planted at planting distance of 3 m x 3 m. Teak planting materials (seedlings and root cuttings) were provided to farmers by the Forestry Commission of Ghana, who demarcated the farm and helped farmers to peg for teak planting. Planting materials of crops used as intercrops were, however, provided by the farmers. The farmers cultivate their crops and then planted teak when there were enough rains. Farm sizes of individual farmers ranged from 1.5 ha to 4 ha.

4.1.1 Crops cultivated by the 40 farmers selected in the teak taungya plantation of the Opro Forest Reserve

Of the 40 farmers interviewed in the teak taungya plantation in Opro Forest Reserve, 38% of them cultivated maize, 22% cultivated pepper, 15% cultivated yam, 13% cultivated cassava and 12% cultivated okra (Fig 1). All the farmers cultivated only one intercrop in their farms.

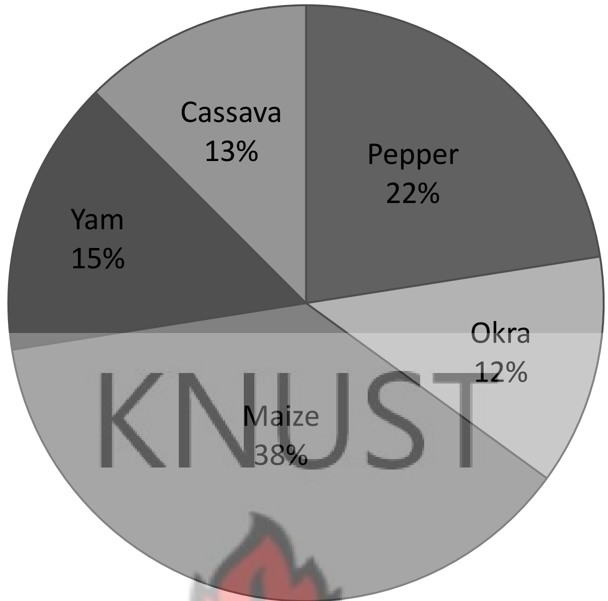

Figure 1: Percentage of farmers that cultivated various intercrops in the teak taungya plantation in Opro Forest Reserve.

4.1.2 Educational level of the farmers interviewed in the teak taungya plantation of the Opro Forest Reserve

Of the 40 farmers interviewed, 30 % had basic formal education and 70 % of them had no formal education (Table: 1).

Table 1: Educational level of the farmers interviewed during the survey

Level of education	Percentage (%) of farmers
Basic formal education	30
No basic formal education	70
Total	100

4.1.3 Perception of the farmers interviewed in the teak taungya plantation of the Opro Forest Reserve on the causes of *Armillaria* root-rot of teak

Of the 40 farmers interviewed, 37.5 % reported of *Armillaria* root-rot of teak in their farms and different views were expressed as the cause of the disease. 7.5 % of the farmers stated that the disease manifests when teak is excessively pruned (Plates 1A and 1B), 12.5 % of the farmers reported that the disease manifests when teak roots hit rock and 17.5 % of the farmers believed that when moisture in the soil is drastically reduced the disease manifests. However, 62.5 % of the farmers interviewed had no knowledge of the cause of the disease (Table: 2).

Table 2: Perception of farmers on the causes of *Armillaria* root-rot of teak

Causes of teak die- back	Percentage (%) of farmers
When teak roots hit rock	12.5
When teak is pruned excessively	7.5
When soil moisture is drastically reduced	17.5
Unknown causes	62.5
Total	100.0

Plate 1A: A well managed teak taungya plantation

Plate 1B: An excessively pruned teak taungya plantation

4.1.4 Knowledge of the 40 farmers selected in the teak taungya plantation of the Opro Forest Reserve on *Armillaria* root-rot of teak

Majority (62.5 %) of the farmers, out of the 40 interviewed had no knowledge of *Armillaria* root-rot of teak (Table 3). Farmers that had knowledge of *Armillaria* root-rot of teak could identify teak that showed signs or symptoms of the disease (Plates 2 and 3).

Table 3: Farmers' knowledge on *Armillaria* root-rot of teak

Armillaria root-rot of teak	Percentage (%) of Farmers
Knowledge of the disease	37.5
No knowledge of the disease	62.5
Total	100

Plate 2: Rhizomorph of *Armillaria* at the root collar of teak identified by farmers

Plate 3: Advancing *Armillaria* root-rot symptoms of teak identified by farmers

4.1.5 Perception of the 40 farmers selected in the teak taungya plantation of the Opro Forest Reserve on the effect of bush fire on growth of teak trees.

It was observed that 87.5 % of the 40 farmers interviewed believed that bush fire promoted growth of teak and therefore set fire in their weedy teak plantations as a means of weed control. Below indicates burnt parts of teak in plantation where fire was used to control weeds (Plate 4).

Plate 4: Teak plantation in which fire was used to control weeds with burnt parts in red rings

4.2.0 Study 2: Assessment of Growth (Height and Diameter) and *Armillaria* root-rot infection of teak trees in the Taungya Plantation of the Opro Forest Reserve

4.2.1.1 Height and Diameter of one-year-old teak trees of all the treatments.

Teak with maize as intercrop (Tm) recorded the highest height followed by teak with no intercrop (T). However, teak with cassava as intercrop (Tc) had the least height (Table 4). The highest diameter was recorded in teak with okra as intercrop (To) followed by treatment T (control). The least diameter was however, recorded in teak with pepper as intercrop (Tp) (Table 4). Treatments differed significantly ($P \leq 0.05$) in height and diameter.

Table 4: Mean height and mean diameter of one-year-old teak trees of all the treatments

Treatments	Mean height (cm)	Mean diameter (cm)
Tp	71.0	4.8
To	72.0	5.5
Tm	83.0	5.3
Ty	78.0	5.2
Tc	67.0	4.9
T (Control)	79.0	5.4
lsd (5%)	6.3	0.3
CV (%)	7.9	5.0

Tp = teak with sole pepper as intercrop, To = teak with sole okra as intercrop, Tm = teak with sole maize as intercrop, Ty = teak with sole yam as intercrop, Tc = teak with sole cassava as intercrop and T = teak with no intercrop

4.2.1.2 Height and Diameter of two-year-old teak trees of all the treatments.

Teak with no intercrop (T) recorded the highest height and, teak with cassava as intercrop (Tc) had the least height (Table 5). The highest diameter was recorded in treatment T and the least diameter in treatment (Tc) (Table 5). Treatments differed significantly ($P \leq 0.05$) in height and diameter.

Table 5: Mean height and mean diameter of two-year-old teak trees of all the treatments

Treatments	Mean height (cm)	Mean diameter (cm)
Tp	144.0	7.2
To	133.0	7.2
Tm	122.0	6.8
Ty	170.0	8.8
Tc	119.0	6.0
T (Control)	186.0	10.3
lsd (5%)	28.4	1.6
CV (%)	18.5	20.2

Tp = teak with sole pepper as intercrop, To = teak with sole okra as intercrop, Tm = teak with sole maize as intercrop, Ty = teak with sole yam as intercrop, Tc = teak with sole cassava as intercrop and T = teak with no intercrop

4.2.1.3 Height and Diameter of three-year-old teak trees of all the treatments.

Height of teak with no intercrop (T) was the highest whilst that of teak with cassava as intercrop (Tc) was the least (Table 6). Diameter was largest in treatment T and smallest in treatment Tc (Table 6). Treatments differed significantly ($P \leq 0.05$) in height and diameter.

Table 6: Mean height and mean diameter of three-year-old teak trees of all the treatments

Treatments	Mean height (cm)	Mean diameter (cm)
Tp	329.0	11.7
To	312.0	10.8
Tm	238.0	10.0
Ty	215.0	9.6
Tc	211.0	8.7
T (Control)	341.0	18.0
lsd (5%)	62.5	3.5
CV (%)	21.7	29.3

Tp = teak with sole pepper as intercrop, To = teak with sole okra as intercrop, Tm = teak with sole maize as intercrop, Ty = teak with sole yam as intercrop, Tc = teak with sole cassava as intercrop and T = teak with no intercrop

4.2.2.0 Assessment of *Armillaria* root-rot infection of teak trees in the Taungya plantation of the Opro Forest Reserve

4.2.2.1 Incidence of *Armillaria* root-rot in one-year-old teak trees of all the treatments

Armillaria root-rot occurred most in teak with cassava as intercrop (Tc). Teak with maize as intercrop (Tm), teak with yam as intercrop (Ty) and teak with no intercrop (T) recorded the least incidence of *Armillaria* root-rot (Table 7). Treatments Tc and To differed significantly ($P \leq 0.05$) in incidence of *Armillaria* root-rot from the other treatments.

Table 7: Incidence of *Armillaria* root-rot in one-year-old teak trees

Treatments	Percent Incidence of *Armillaria* root-rot
Tp	20.0
To	30.0
Tm	10.0
Ty	10.0
Tc	40.0
T (Control)	10.0

Tp = teak with sole pepper as intercrop, To = teak with sole okra as intercrop, Tm = teak with sole maize as intercrop, Ty = teak with sole yam as intercrop, Tc = teak with sole cassava as intercrop and T = teak with no intercrop

4.2.2.2 Incidence of *Armillaria* root-rot in two-year-old teak trees of all the treatments

Teak with cassava as intercrop (Tc) recorded the highest incidence of *Armillaria* root-rot. However, teak with no intercrop (T) had no incidence of *Armillaria* root-rot (Table 8). Incidence if *Armillaria* root-rot differed significantly ($P \leq 0.05$) between Tc and the other treatments but did not differ amongst teak with pepper as intercrop (Tp), teak with okra as intercrop (To), teak with maize as intercrop (Tm) and teak with yam as intercrop (Ty) (Table 8)

Table 8: Incidence of *Armillaria* root-rot in two-year-old teak trees

Treatments	Percent Incidence of *Armillaria* root-rot
Tp	20.0
To	20.0
Tm	20.0
Ty	10.0
Tc	40.0
T (Control)	10.0

Tp = teak with sole pepper as intercrop, To = teak with sole okra as intercrop, Tm = teak with sole maize as intercrop, Ty = teak with sole yam as intercrop, Tc = teak with sole cassava as intercrop and T = teak with no intercrop

4.2.2.3 Incidence of *Armillaria* root-rot in three-year-old teak trees of all the treatments

Incidence of *Armillaria* root-rot was highest in teak with cassava as intercrop (Tc). Teak with pepper as intercrop (Tp), teak with maize as intercrop (Tm), teak with yam as intercrop (Ty) and teak with no intercrop (T) had equal and least incidence of *Armillaria* root-rot (Table 9). Incidence of *Armillaria* root-rot differed significantly (P ≤ 0.05) between Tc and the other treatments but did not differ amongst the other treatments.

Table 9: Incidence of *Armillaria* root-rot in three-year-old teak trees

Treatments	Percent Incidence of *Armillaria* root-rot
Tp	20.0
To	30.0
Tm	20.0
Ty	20.0
Tc	50.0
T (Control)	20.0

Tp = teak with sole pepper as intercrop, To = teak with sole okra as intercrop, Tm = teak with sole maize as intercrop, Ty = teak with sole yam as intercrop, Tc = teak with sole cassava as intercrop and T = teak with no intercrop

4.2.3.0 Frequency of *Armillaria mellea* colonies from teak rhizosphere soils

4.2.3.1 *Armillaria mellea* colonies isolated from rhizosphere soils of one-year-old teak of the different treatment.

A total of 125 colonies of *Armillaria mellea* were isolated from rhizosphere soil of one-year-old teak in all the treatments. Of the 125 colonies teak with cassava intercrop (Tc) had 50 colonies. However teak with yam as intercrop (Ty) had five colonies (Table 10). Number of *Armillaria mellea* colonies differed significantly (P ≤ 0.05) between teak with cassava as intercrop and the other treatments but did not differ amongst the other treatments (Table 10).

Other fungi that were isolated from rhizosphere soil of one-year-old teak included *Aspergillus* species, *Fusarium verticilliodes* (Sacc.), *Lasiodiplodia theobromae* (Pat.), *Trichoderma viride* (Pers.) and *Rhizopus* species (Appendix 2).

Table 10: Number of *Armillaria mellea* colonies isolated from rhizosphere soil of one year teak plantation of the different intercrops.

Treatments	Number of *Armillaria mellea* colonies
Tp	29.0
To	19.0
Tm	11.0
Ty	5.0
Tc	50.0
T (Control)	11.0
lsd (5%)	4.4
CV (%)	79.3

Tp = teak with sole pepper as intercrop, To = teak with sole okra as intercrop, Tm = teak with sole maize as intercrop, Ty = teak with sole yam as intercrop, Tc = teak with sole cassava as intercrop and T = teak with no intercrop

4.2.3.2 *Armillaria mellea* colonies isolated from rhizosphere soils of two-year-old teak of the different treatments.

A total of 85 colonies of *Armillaria mellea* were isolated from rhizosphere soil of two-year-old teak in all the treatments. Most *Armillaria mellea* colonies were isolated from teak with cassava as intercrop (Tc) (Table 11). Teak with no intercrop (T) had no *Armillaria mellea* colony in its rhizosphere soil. The number of *Armillaria mellea* colonies differed significantly ($P \leq 0.05$) between the intercrops.

Other fungi that were isolated from rhizosphere soil of two-year-old teak included *Aspergillus* species, *Fusarium verticilliodes*, *Lasiodiplodia theobromae*. *Trichoderma viride*, *Rhizopus* species and *Mucor hiemalis* (Wehmer) (Appendix 3).

Table 11: Number of *Armillaria mellea* colonies isolated from rhizosphere soil of two-year-old teak of the different treatments.

Treatments	Number of *Armillaria mellea* colonies
Tp	21.0
To	17.0
Tm	5.0
Ty	8.0
Tc	34.0
T (Control)	0.0
lsd (5%)	1.6
CV (%)	87.7

Tp = teak with sole pepper as intercrop, To = teak with sole okra as intercrop, Tm = teak with sole maize as intercrop, Ty = teak with sole yam as intercrop, Tc = teak with sole cassava as intercrop and T = teak with no intercrop

4.2.3.3 *Armillaria mellea* colonies isolated from rhizosphere soils of three-year-old teak plantation of the different intercrops.

Of the 101 colonies of *Armillaria mellea* isolated from rhizosphere soil of three-year-old teak in all the treatments, 28 colonies were from teak with cassava as intercrop (Tc) and eight from teak with no intercrop (T) (Table 12). The number of *Armillaria mellea* colonies differed significantly ($P \leq 0.05$) between the intercrops.

Other fungi that were isolated from rhizosphere soil of three-year-old teak included *Aspergillus* species, *Fusarium verticilliodes*, *Lasiodiplodia theobromae*. *Trichoderma viride*, *Rhizopus* species and *Mucor hiemalis* (Appendix 4).

Table 12: Number of *Armillaria mellea* colonies isolated from rhizosphere soil of three year-old teak of the different treatments.

Treatments	Number of *Armillaria mellea* colonies
Tp	22.0
To	20.0
Tm	11.0
Ty	12.0
Tc	28.0
T (Control)	8.0
lsd (5%)	2.0
CV (%)	45.8

Tp = teak with sole pepper as intercrop, To = teak with sole okra as intercrop, Tm = teak with sole maize as intercrop, Ty = teak with sole yam as intercrop, Tc = teak with sole cassava as intercrop and T = teak with no intercrop

4.2.3.4 Correlation matrix for growth and *Armillaria* root-rot infection of one-year-old teak of all the treatments

There were negative correlations (r = -0.90, r = -0.86) between height of teak (HT), incidence of *Armillaria* root-rot of teak (IMT) and number of *Armillaria mellea* colonies isolated from rhizosphere soil of teak (NAC), respectively. There were also negative correlations (r = -0.29, r = -0.62) between diameter of teak (DT), incidence of *Armillaria* root-rot of teak and number of *Armillaria mellea* colonies isolated from rhizosphere soil of teak, respectively. However, there was a positive correlation (r = 0.88) between incidence of *Armillaria* root-rot of teak and number of *Armillaria mellea* colonies isolated from rhizosphere soil of teak (Table 13)

Table 13: Correlation matrix for growth and *Armillaria* root-rot infection of one-year-old teak trees

	HT	DT	IMT	NAC
HT	1.00			
DT	0.52	1.00		
IMT	-0.90	-0.29	1.00	
NAC	-0.86	-0.62	0.88	1.00

HT – Height of teak

IMT - Incidence of *Armillaria* root-rot of teak

DT – Diameter of teak

NAC – Number of *Armillaria mellea* colonies isolated from 10g rhizosphere soil of teak

4.2.3.5 Correlation matrix for growth and *Armillaria* root-rot infection of two-year-old teak of all the treatments

There were negative correlations (r = -0.88, r = -0.64) between height of teak (HT), incidence of *Armillaria* root-rot of teak (IMT) and number of *Armillaria mellea* colonies isolated from rhizosphere soil of teak (NAC), respectively. There were also negative correlations (r = -0.93, r = -0.76) between diameter of teak (DT), incidence of *Armillaria* root-rot of teak and number of *Armillaria mellea* colonies isolated from rhizosphere soil of teak, respectively. However, there was a positive correlation (r = 0.90) between incidence of *Armillaria* root-rot of teak and number of *Armillaria mellea* colonies isolated from rhizosphere soil of teak (Table 14)

Table 14: Correlation matrix for growth and *Armillaria* root-rot infection of two-year-old teak trees

	HT	DT	IMT	NAC
HT	1.00			
DT	0.98	1.00		
IMT	-0.88	-0.93	1.00	
NAC	-0.64	-0.76	0.90	1.00

HT – Height of teak

IMT - Incidence of *Armillaria* root-rot of teak

DT – Diameter of teak

NAC – Number of *Armillaria mellea* colonies isolated from 10g rhizosphere soil of teak

4.2.3.6 Correlation matrix for growth and *Armillaria* root-rot infection of three-year-old teak of all the treatments

There were negative correlations (r = -0.42, r = -0.17) between height of teak (HT), incidence of *Armillaria* root-rot of teak (IMT) and number of *Armillaria mellea* colonies isolated from rhizosphere soil of teak (NAC), respectively. There were also negative correlations (r = -0.44, r = -0.55) between diameter of teak (DT), incidence of *Armillaria* root-rot of teak and number of *Armillaria mellea* colonies isolated from rhizosphere soil of teak, respectively. However, there was a positive correlation (r = 0.79) between incidence of *Armillaria* root-rot of teak and number of *Armillaria mellea* colonies isolated from rhizosphere soil of teak (Table 15)

Table 15: Correlation matrix for growth and *Armillaria* root-rot infection of three-year-old teak trees

	HT	DT	IMT	NAC
HT	1.00			
DT	0.77	1.00		
IMT	-0.42	-0.44	1.00	
NAC	-0.17	-0.55	0.79	1.00

HT – Height of teak

IMT - Incidence of *Armillaria* root-rot of teak

DT – Diameter of teak

NAC – Number of *Armillaria mellea* colonies isolated from 10g rhizosphere soil of teak

CHAPTER FIVE

5.0.0 DISCUSSION

5.1.0 Survey: Assessment of farmers' Knowledge and Perception on teak Tuangya plantation system and infection of *Armillaria* root-rot of teak in the Opro Forest Reserve in the Offinso Forest District of Ashanti Region.

Most of the farmers interviewed in the teak taungya plantation farmers in the Opro Forest Reserve cultivated maize as intercrop. Crops cultivated by the farmers were traditional food crops of their communities. Educational level of the farmers was low. Djabletey and Adu-Bredu (2007) reported that farming has been restricted to illiterates and semi-literates in the West Africa sub-region.

Generally, the farmers had little knowledge of *Armillaria* root-rot of teak. However, their perception of the causes of the disease agreed with observations by Hood *et al*. (1991) that woody plants weakened by drought, poor soil conditions, excessive shade and mechanical injury are most susceptible to attack by *Armillaria*. Majority of the farmers believed that bush fire promoted growth in teak. This might be due to destruction of *Armillaria* inoculum in the soil by fire. Rishbeth (1985) reported that reduction of *Armillaria* in the soil could promote growth of trees since *Armillaria* root-rot retards growth in trees. Kile *et al*. (1991) however, reported in their study that water stress and injury caused by the fire are prerequisite for *Armillaria* infection.

5.2.0 Study 2: Assessment of Growth (Height and Diameter) and *Armillaria* root-rot infection of teak trees in the Taungya Plantation of the Opro Forest Reserve

5.2.1 Measurement of Teak Growth in the Taungya Plantation

Results of the study indicated that growth of teak plantations with no intercrop was better than teak plantations with intercrops. Teak plantations with only cassava as intercrop had the poorest growth. According to Kramer and Kozlowski (1960), trees and non-woody components in dense stand continually compete amongst each other above-ground for light, below-ground for water, minerals and oxygen which could reduce general vigour of trees and intercrops. Shukla (2009) reported that teak establishes best on terrain cleared of competing vegetation. However, Lalramnghinglova and Jha (1996) observed that growth of teak was economically sound when intercropped. Rachadi (1981) also advocated intensification of intercropping teak with food crops. Djabletey and Adu-Bredu (2007) reported that indiscipline and lack of supervision in Ghana has partly led to the failure of taungya plantations in natural forest. Teak growth was higher in plantations with pepper intercrop than plantations with yam, maize or okra intercrop. A study conducted by Djagbletey (2002) concluded that intercropping teak with pepper and maize produced high yield.

5.2.2 Assessment of *Armillaria* root-rot infection of teak trees in the Taungya plantation of the Opro Forest Reserve

5.2.2.1 Incidence of *Armillaria* root-rot of teak trees in the treatments

Incidence of *Armillaria* root-rot was observed to be higher in teak with intercrops than teak with no intercrop, which suggested that intercrops might have promoted infection of teak by *Armillaria mellea*. Stress, generally, predisposes trees to attack by *Armillaria mellea*. Trees that do not receive enough water, soil nutrient and injured from partial cutting may have reduced resistance to *Armillaria* attack (Shaw and Kile, 1991). *Armillaria* easily affects host whose physiology has altered due to stress (Cruickshank *et al*., 1997). Studies by Shaw and Kile (1991) indicated that serious radial and terminal growth reduction may occur in plant infected by *Armillaria* root-rot.

5.2.2.2 Rhizosphere mycoflora analysis of teak trees of the treatments

Armillaria mellea colonies were isolated from teak rhizosphere soil of all the treatments. However, more colonies were isolated from teak with intercrops. Hood *et al*. (1991), Kile *et al*. (1991) and Termorshuizen (2000) concluded from their studies that *Armillaria* species occur worldwide in natural forests and on planted woody crops. Higher numbers of *A. mellea* colonies in teak with intercrops suggested that the intercrops promoted *Armillaria* infection of teak in the teak taungya plantations in the Opro Forest Reserve. However, there were significant differences ($P \leq 0.05$) between the numbers of *A. mellea* colonies isolated from teak with different intercrops. According to the results of the study, cassava as intercrop promoted proliferation of *Armillaria* in the soil the most hence, could promote *Armillaria* root-rot infection of teak faster than the other intercrops.

5.2.3 Effect of age on growth and *Armillaria* root-rot infection of teak tress in the taungya plantation of the Opro Forest Reserve.

Results of the study indicate that age of teak does not affect role intercrop play in promoting *Armillaria* infection since the correlations amongst growth of teak, incidence of *Armillaria* infection of teak and number of *Armillaria* colonies isolated from rhizosphere of teak did not change with age of the plantation. However, stronger negative correlations amongst growth of teak, incidence of *Armillaria* infection of teak and number of *Armillaria* colonies isolated from rhizosphere of teak in one-year-old plantations suggested that effects of intercrops are greater in younger plantations. Djabletey and Adu-Bredu (2007) reported in their study that number of intercrops is reduced in older teak taungya plantations as the teak canopy widens. Less penetration of light to the floor of taungya plantations reduce productivity of intercrops (Tewari, 1992). Reduction of number of intercrops in older teak plantations might have resulted in the weaker negative correlations.

CHAPTER SIX

6.0.0 CONCLUSIONS

Farmers had inadequate knowledge about *Armillaria* root-rot of teak. Wrong perception of farmers about teak including tolerance of teak to bush fire encouraged bad farming practices such as slash and burn method of controlling weed in teak plantations. Such practice induced stress to teak which could predispose it to *Armillaria* infection as the ability of *Armillaria* to penetrate and progressively invade roots is enhanced when hosts are stressed.

The results of this study revealed that intercropping teak does not enhance growth of teak and also promoted *Armillaria* root-rot infection in taungya plantations at the Opro Forest Reserve. Intercropping with cassava caused more reduction in teak growth and more *Armillaria* root-rot infection. However, teak plantations with no intercrop promoted growth and reduced *Armillaria* root-rot infection.

The results also indicated that age of teak does not affect the impact of intercrops on the plantation in the first three years of plantation establishment.

CHAPTER SEVEN

7.0.0 RECOMMENDATIONS

- Intercropping teak with cassava should not be encouraged in the Opro Forest Reserve since cassava rapidly promoted *Armillaria* root-rot in teak. However, planting teak with no intercrops should be encouraged.

- Farmers in the Opro Forest Reserve should be educated about *Armillaria* root-rot disease and advised to eschew farming practices that could predispose teak to *Armillaria* root-rot infection.

- Further research, if undertaken on *Armillaria* and intercropping system, could provide useful information that would help improve yield in the Opro Forest Reserve.

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APPENDICES

Appendix 1

Questionnaire to assess knowledge and perception of Taungya plantation farmers on *Armillaria* root-rot of teak in the Opro Forest Reserve

Date:................................... Location of farm:...

1. Name of farmer..
2. Educational level...
3. What crop do you cultivate?...
4. What is the size of your teak taungya plantation?...
5. Did you plant the teak yourself?..
6. Where did you acquire the teak planting material?...
7. Did you plant the teak before or after you have cultivated your crops?..................
8. Have you ever experienced bush fire or burnt the farm before?.............................
9. If yes to question 11 above, how did the bush fire affect the teak?........................
10. Are the conditions of teak the same in all seasons? ....
11. Have any of your teak had leaves turn yellow even in rainy season?.....................
12. Has there been any white mushroom close to your teak tress?...............................
13. Has any of your teak had stem, branch or twig wilt?...
14. Can you find a similar look on the trees?..
15. How are the teaks in your farm performing?...

Appendix 2:

Number of fungal colonies isolated from 10g of rhizosphere soil of one-year-old teak of all the treatments

Fungal species	Number of fungal colonies of the treatments					
Basidiomycetes	Tp	To	Tm	Ty	Tc	T
Armillaria mellea	29	19	11	5	50	11
Deuteromycetes						
Aspergillus niger	0	10	2	11	9	0
A. candidus	4	0	5	3	0	0
A. flavus	0	8	0	0	0	0
A. ochraceus	3	4	0	17	13	12
A. tamari	13	9	6	15	2	0
A. versicolor	13	3	7	8	0	8
Fusarium verticilliodes	0	15	5	16	13	0
Lasiodiplodia theobromae	0	0	8	0	11	20
Penicillium spp	18	11	2	21	1	0
Rhizopus spp	18	0	0	0	0	0
Trichoderma viride	0	0	4	9	8	0

Tp = teak with sole pepper as intercrop, To = teak with sole okra as intercrop, Tm = teak with sole maize as intercrop, Ty = teak with sole yam as intercrop, Tc = teak with sole cassava as intercrop and T = teak with no intercrop

Appendix 3:

Number of fungal colonies isolated from 10g of rhizosphere soil of two-year-old teak of all the treatments

Fungal species	Number of fungal colonies of the treatments					
Basidiomycetes	Tp	To	Tm	Ty	Tc	T
Armillaria mellea	21	17	5	8	34	0
Phycomycetes						
Mucor hiemalis	0	0	7	0	0	8
Deuteromycetes						
Aspergillus niger	0	11	8	20	8	0
A. candidus	5	0	0	7	0	9
A. flavus	0	2	5	5	5	0
A. ochraceus	5	9	2	19	6	0
A. tamari	5	1	0	19	12	0
A. versicolor	9	0	1	8	2	0
Fusarium verticilliodes	2	7	6	0	7	0
Lasiodiplodia theobromae	0	4	8	0	3	0
Penicillium spp	19	9	4	2	5	29
Rhizopus spp	14	0	11	0	0	0
Trichoderma viride	2	11	18	9	6	2

Tp = teak with sole pepper as intercrop, To = teak with sole okra as intercrop, Tm = teak with sole maize as intercrop, Ty = teak with sole yam as intercrop, Tc = teak with sole cassava as intercrop and T = teak with no intercrop

Number of fungal colonies isolated from 10g of rhizosphere soil of three-year-old teak of all the treatments

Fungal species	Number of fungal colonies of the treatments					
Basidiomycetes	Tp	To	Tm	Ty	Tc	T
Armillaria mellea	23	20	11	11	28	8
Phycomycetes						
Mucor hiemalis	0	0	0	0	4	0
Deuteromycetes						
Aspergillus niger	12	6	5	14	23	0
A. candidus	4	9	8	0	0	0
A. flavus	2	6	2	4	0	0
A. ochraceus	4	2	5	10	10	29
A. tamari	0	4	9	7	10	30
A. versicolor	8	0	0	5	18	0
Fusarium verticilliodes	7	11	15	0	3	0
Lasiodiplodia theobromae	4	0	0	0	3	0
Penicillium spp	18	6	15	10	6	7
Rhizopus spp	0	2	11	14	8	0
Trichoderma viride	0	0	16	11	0	0

Tp = teak with sole pepper as intercrop, To = teak with sole okra as intercrop, Tm = teak with sole maize as intercrop, Ty = teak with sole yam as intercrop, Tc = teak with sole cassava as intercrop and T = teak with no intercrop