Declaration

I do hereby declare that this thesis entitled "Studies on the Contribution of Weeds and their Management to the Prevalence of Pineapple Mealybugs" was written by me and that it is the record of my own research work. It is neither in part nor in whole been presented for another degree elsewhere.

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Abstract

Weeds pose a serious problem to the production of pineapple causing losses of up to 83% on the farm. They compete for nutrients, water, light and other resources as well as harbouring mealybugs and their tending ants which greatly affect production. This research was thus conducted first to catalogue the prominent weeds found in three major pineapple growing Districts in Ghana: Mfantsiman, Gomoa East and Akuapim South Districts. It further sought to determine which of these weed species harboured the pineapple mealybugs and their tending ants and to determine the effect of four weed management methods on the prevalence of pineapple mealybugs and the growth and yield of pineapples. The research was carried out in three phases: the first phase consisted of a survey to identify and quantify the common weeds found on pineapple farms in the three Districts. Cluster sampling method was employed to determine the weed species with the aid of a $1m^2$ quadrat on 15 farms in the three districts. The second phase involved the identification of the pineapple mealybugs and their tending ants, interviews with pineapple farmers on various weed management practices and alternative host of the mealybugs, and a scout for the mealybugs on the weeds within and adjacent the 15 pineapple fields. The last phase was a field experiment to evaluate the various methods of weed management employed by pineapple farmers. The experiment was a Latin square design with 5 treatments and 5 replications. A total of 43 weed species from16 families were recorded from the three districts with Mfantsiman recording the least number of species (29), followed by Gomoa East (34), and Akuapim South (40). Only *Dysmicoccus brevipes* (Homoptera: Pseudococcidae) was found to infest pineapples. Four ant genera (*Crematogaster, Camponotus Pheidole* and *Solenopsis*) were found to attend the mealybugs. No weed was identified as an alternative host to the *D.*

brevipes. Six weed species were rather found to be positively associated with the tending ants of the mealybugs. The Mfantsiman District recorded the highest mealybug infestation with 78 ± 5.2 mealybugs per plant, and this was significantly different from Akuapim South and the Gomoa East Districts. The populations of tending ants and the density of grasses adjacent to field were found to be positively correlated to the population of the pineapple mealybugs. Of the four weed management methods evaluated, plastic mulch + synthetic herbicide was found to be most efficient in weed control (90.6% over weedy check). This was followed by the plastic mulch + manual weeding (80.2% over weedy check), synthetic herbicide only (73.4 % over weedy check), then manual weeding only (69.2% over weedy check) in that order. The same trend was observed in the ability of the weed management method to promote growth and yield, with plastic mulch + synthetic herbicide recording an average fruit weight of 1.95 kg, plastic mulch + manual weeding recording 1.82 kg, synthetic herbicide only, 1.61 kg, manual weeding, 1.56 kg and 1.40 kg for the weedy check. The weed management methods significantly reduced the populations of pineapple mealybugs on pineapple fruits but not on the roots.

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Dedication

I dedicate this work to my precious wife Diana, priceless mother, Mama Christina, and my fantastic siblings, Becky, Sammy and Joseph. God richly bless them for their unending support and love.

Acknowledgement

I am most grateful to the Lord Almighty who gave me good health, protection and abundant blessings throughout my studies.

My sincere gratitude goes to my supervisors, Dr. Joseph Sarkodie-Addo of the Department of Crop and Soil Sciences of the Faculty of Agriculture, KNUST Kumasi, and Prof. A. G. Carson of the University of Cape Coast. Their encouragement, tireless support and constructive criticisms provided the motivation needed to successfully complete this work. Words are not enough to express my gratitude. I am also grateful to my other advisors: Dr. J. V. K Afun and Dr. E. A. Osekre for their enormous help in the Entomological aspects of the work. God richly bless them.

I am also very grateful to all Senior Members and staff of the Department of Crop Science, University of Cape Coast, for their support, encouragement and advice, God bless you. To the management and staff of Bomart, Milani and Koranco farms, I say, a very big thank you for their cooperation and assistance during the research.

The contribution of my family to this accomplishment was enormous. I wish to thank my wife Diana for her patience, encouragement and prayers throughout the time period. I do not have the right words to thank my mother and my siblings for their support, encouragement and prayers. I really appreciate you all. God richly bless you.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Among the various pests of crops, weeds seem to be the most underestimated in tropical agriculture, yet weeds have influenced human social activities more than any other crop pest. One reason given to large family sizes in Africa and other developing countries is that they provide labour for weeding on crop farms (Akobundu, 1987). Weeds compete with crops for nutrients, moisture, and sunlight and thereby reduce growth and yield of crops. Apart from this, some weeds serve as alternative hosts to other pests and diseases of crops. It is difficult thus, to control other pests and diseases without first thinking about the control of the weeds since they habour these pests and diseases and serve as breeding sources. The ultimate effect of weeds on the farming system is thus enormous; ranging from influence on human social life, decreased growth and yield of crops, increased cost of farming (due to cost of control) and serving as breeding sources of other pests and diseases. Pineapple production is no exception as far as the effects of weeds are concerned.

Pineapple (*Ananas comosus* Merr. (L)) is the leading edible member of the family Bromeliaceae which has about 2,000 species, mostly epiphytic and many strikingly ornamental (Morton, 1987). It is a perennial herb which grows up to about 1.5m high with a spread of up to 1.2 m. Pineapple is a very important fruit crop across the globe, usually eaten fresh or processed into fruit juice. It is the third most important tropical fruit in world production after banana and citrus (Rohrbach *et al*, 1988). According to FAO statistics (Baker, 1990; Anon., 2002), total pineapple production was approximately constant in the 1999–2001 period, with a mean world production for these 3 years of 13,527,149 metric tonnes. The leading pineapple producing countries are Thailand (2,311,332 t), the Philippines (1,520,715 t), Brazil (1,504,493 t), China (1,181,169 t), India (1,100,000 t), Nigeria (800,000 t), Mexico (535,000 t), Costa Rica (475,000 t), Colombia (360,000 t), Indonesia (300,000 t), Venezuela (300,000 t), USA (293,000 t) and Kenya (280,000t) (Rohrach *et al*, 2003). Until 2006, pineapple was the most important horticultural non-traditional export commodity in Ghana, fetching the country some US$ 13,475,000 from a total of 40,456 t exported in that year (Statistics Research and Information Directorate of the Ministry of Agriculture, 2007).

Weeds pose a serious problem in the cultivation of pineapples, especially in the rainy season, when they exhibit rapid growth. Weeds compete with the crop for water, light and nutrients and cause yield reduction of up to 83% (Sipes, 2000). They also harbour some nematodes and insect pests of pineapple. Weeds have been found to heighten the establishment and proliferation of Pineapple Mealybugs which constitute one of the most economically important pests of pineapple. Weeds, such as *Panicum maximum, Paspalum urvelli, Cyperus rotundus* and *Chloris gayana*, have been identified as alternative hosts to the pineapple mealybugs. The above weeds, together with others, also host the caretaking ants of these mealybugs, thus, serving as breeding sources for the pineapple mealybugs and their caretaking ants.

Two main species of pineapple mealybugs are known: *Dysmicoccus brevipes* (Cockerell) (commonly called the pink pineapple mealybug) which reproduces asexually and *Dysmicoccus neobrevipes* (Beardsley) (commonly known as the gray pineapple mealybug) which is bisexual (Beardsley, 1959, Mau and Kessing, 2007). These cause four main types of damage on pineapples. First is the transmission of pineapple wilt (also called mealybug wilt or edge-wilt) which is a disease condition brought about by a complex interaction of ants, the mealybugs, viruses, and host plants (weeds and the pineapple plants); secondly, the production of chlorotic spots as a result of prolonged feeding with the underlying tissues exhausted; thirdly, damage to the bottom of the pineapple by the feeding of large mealybug populations which makes the bottom slices unmarketable and may cause the rotting and leaking of the fruits; and fourthly "mealybug stripe" which results from the feeding of a short section of each of 3 or 4 inner whorl leaves. It is characterized by pale green to yellow streaks and by the collapsing of the water storage tissues within these streaks (Mau and Kessing, 2007). Mealybugs are believed to be transferred to the pineapple fields by their tending ants and/or wind, where together with the viruses, (the Pineapple Mealybug Wilt associated Virus (PMWaV)), cause the pineapple mealybug wilt. The wilt has been a continuing problem in Hawaiian pineapple production for over 90 years (Rorhbach *et al*, 1988) and continues to cause the most serious type of damage, making it the principal cause of pineapple crop failure in Hawaii (Mau and Kessing, 2007).

Since its detection in the early 1900's, a number of solutions have been suggested to this complex. A comprehensive review of the proposed control methods was outlined by Rohrbach *et al*, (1988). They commented on various attempts which had been made to control the complex using physical, chemical, biological, and breeding and rouging methods but without much success hence its continuous importance in the pineapple industry.

Not much work has been carried out in Ghana on this complex, hence minimal information exist on the situation. However, reports from a number of farms, especially, those cultivating the smooth cayenne variety, indicate that the situation is a serious problem especially in the dry season when field observations show incidence levels as high as 80 per cent or more on some fields

1.2 Statement of Problem

The increasing importance of pineapple to Ghana's economy demands a holistic approach to its cultivation. Weed control in pineapple cultivation must be targeted at the prominent weeds associated with pineapple cultivation. According to Akobundu (1987), the type of weed and intensity of weed infestation depends on land-use system, cropping system, climatic and soil factors. These factors differ from places to places and management practices adopted in one area might not be effective in another. Hitherto, weed management in pineapple farms in Ghana has been based on foreign information and this probably could account for the difficulty in controlling some weeds on the farms. Prominent weeds associated with pineapple cultivation ought to be identified to serve as baseline information in the design and development of appropriate weed management systems.

Again, some weeds associated with pineapple production in other countries have been identified as promoting the pineapple mealybug complex. Thus, despite many suggested control measures for the pineapple mealybug complex, very little has been achieved in attempts to control it. Morton (1987) observed that it was difficult to control the mealybug because it lives on other plants as Hilo grass, nutgrass, guinea grass, banana, citrus, coffee, cotton, Euphorbia, Gliricidia, and Hibiscus. Their tending ants are also associated with various weeds. It is thus imperative to identify the specific weeds which promote these mealybugs and their tending ants in order to direct control efforts at such. This information gap is probably responsible for the little success achieved in the control of the pineapple mealybugs.

As said above, despite the long list of control measures for this mealybug complex, little has actually been achieved, probably due to its association with the weeds. Weed management therefore, has become an essential component in its control. However, weed management in pineapple fields come in different methods: hand weeding with hoe and other simple implements, mulching with organic (plant materials) and inorganic sources (plastic film), use of herbicides such as ametryn, bromacil, diuron and glyphosate (Akobundu, 1987). Pineapple farmers would thus want to know which of these listed management methods are efficient and yet cost-effective in the control of these mealybugs. Further, how these weed management methods impact growth and yield of pineapple is of much interest.

1.3 Purpose of the Study

The study aims first to catalogue the prominent weeds prevalent in the major pineapple growing areas in Ghana and to identify which of them serve as alternative host to the pineapple mealybugs. Secondly, the study will evaluate the weed management methods currently in use on various pineapple fields so as to recommend an efficient, but cost-effective method to aid the control of the pineapple mealybugs for increased growth and yield of pineapple.

The general objective was to determine the relationship between weeds in pineapple growing areas and the pineapple mealybugs

The specific objectives of this study were to:

1. identify and quantify the weed species in pineapple fields in three major pineapple growing districts of Ghana;
2. evaluate weed flora within and adjacent to pineapple fields as alternative hosts to the pineapple mealybugs and/or their tending ants;
3. determine the effect of five weed management methods on weeds of pineapple fields, and mealybug and ant population densities;
4. determine the effect of four weed management methods on the growth and yield of pineapples.

1.4 Hypotheses

The study will thus test the following hypotheses:

1. Weeds associated with pineapple cultivation contribute to the prevalence of pineapple mealybugs
2. Weed management can control pineapple mealybugs
3. Weed management increases growth and yield of pineapple

1.5 Significance of the study

When completed, the study will provide the list of weeds commonly found in the major pineapple growing areas in Ghana, and this will serve as baseline information for further research into weed biology, ecology and management on pineapple farms. This will ultimately inform the design of control technologies for weeds and improve the management practices employed in the cultivation of pineapple in Ghana.

Further, the project attempts to look at the possibility of controlling two important pests of pineapple (weeds and mealybugs) concurrently. If this becomes possible, cost of production is likely to be reduced because the individual costs of managing these two very important pests will be done concurrently, whiles yield improves. The ultimate gain will be an increase in yield and profitability of the pineapple industry in Ghana and this will go a long way to help improve the economy of the country.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 General Review on Weeds

2.1.1 Definition, Characteristics and Importance of Weeds

Varying definitions have been proposed for weeds, each depending on the particular situation where they occur and the plants involved. Blatchley (1912) defined it as a plant out of place, or growing where it is not wanted; Harper (1944) defined it as a plant that grows spontaneously in a habitat that has been greatly modified by human action, whiles Thomas (1956) also defined a weed as a useless, undesirable and often very unsightly plant of wild growth, usually found in land which has been cultivated, or in areas developed by man for specific purposes other than cultivation. In 1967 the Weed Science Society of America defined a weed as "a plant growing where it is not desired". Aldrich (1984) defined it as a plant that originated under a natural environment and, in response to imposed and natural environments, evolved, and continues to do so as an interfering associate with our crops and activities. Hamill *et al* (2004) defined a weed as plant that is objectionable or interfere with activities or the welfare of humans. In whichever case, the definitions seek to emphasize that according to some human criteria, the weed is a plant that is undesirable.

Weeds pose various degrees of problems to man. Specifically, problems include lower crop and animal yields, less efficient land use, higher costs of insect and plant disease control, poor-quality products, more water management problems, and lower human efficiency (Monaco *et al*, 2002). For these reasons, it is imperative for man to study the biology and ecology of weeds so as to help him develop appropriate control measures. Monaco *et al*, (2002) indicated that knowledge of weed biology and environmental management practices makes it possible to shift plant populations and communities in desired directions. This, they said, is the principle behind crop production that theoretically optimizes the growth environment of the crop but minimizes the potential of unacceptable pest levels.

Weeds are characterized by certain features which make them successful. These were outline by Baker (1965), King (1966), and Baker (1974) as: the ability to germinate in many environments, discontinuous, self-controlled germination and great longevity of seed, rapid seedling growth, early onset of seed production in a range of environments, long period of seed production, self-compatibility, easy cross-pollination, high seed output in favourable circumstances, seed production in adverse conditions, long and short-distance dispersal, special means of competition. Additional features for perennials are: vigorous vegetative reproduction, brittleness of lower nodes or rhizomes and ability to regenerate from fragments.

2.1.2 Biology of Weeds

According to Monaco *et al* (2002), the biology of weeds is concerned with their classification, genetics, establishment, growth and reproduction.

Weeds are classified in several ways including life cycle or life history, habitat, growth form, degree of undesirability or noxiousness, morphology and by scientific classification (systematic class) (Akobundu, 1987).

Life cycle refers to a plant’s life span, season of growth, and method of reproduction and determines the methods needed for management or eradication (Monaco, 2002). On the basis of life cycle, weeds can be classified as annuals, biennials or perennials.

Zimdhal (2007) defined an annual as a plant that completes its life cycle from seed to seed in less than one year or in one growing season. They produce an abundance of seeds, grow quickly and are usually, but not always, easier to control than perennials.

A biennial plant, on the other hand, lives more than one year but less than 2 years. During the first phase of growth, the seedling usually develops vegetatively into a rosette. Following a cold period, vegetative growth is followed by floral initiation, fruit set, and finally, death (Monaco *et al*, 2002).

Perennials are usually divided into two groups: simple and creeping. Simple perennials spread by seed and by vegetative reproduction. If the shoot is injured or cut off, simple perennials may regenerate a new plant vegetatively, but the normal mode of reproduction is seed. Creeping perennials reproduce by seed and vegetatively. Vegetative reproductive organs in this group of perennials include creeping above-ground stems (stolons), creeping below-ground stems (rhizomes), tubers, aerial bulblets and bulbs (Monaco *et al*, 2002).

According to Radosevich *et al* (2007), weeds are also be classified by their habitat and on this basis, weeds may either be terrestrial, (that is, found on land) or aquatic (found in water bodies). Some weeds only infest a particular crop or cropping system, complex of plant communities or growing conditions. Hence, Holzner (1982) divided weeds into agrestrals, ruderals, grassland weeds, water weeds, forestry weeds and environmental weeds.

On the basis of growth form, plants can be classified into 3 categories: *Gymnosperms*, such as pines, have seeds not enclosed in an ovary. Most gymnosperms are not considered to be weeds. *Monocots*, or flowering plants with one seed leaves or cotyledon, generally have narrow leaves with parallel veins; Examples include sedges, grasses, palms, orchids, sugar cane and banana. An important distinction is that all grasses are monocots, but not all monocots are grasses. *Dicots* are flowering plants with two seed leaves or cotyledons. Many of our most serious weed problems are either monocots or dicots (Monaco *et al*, 2002).

On the degree of noxiousness, Radosevich *et al* (2007) explained that the term *noxious weed* is a legal term that refers to any plant species capable of becoming detrimental, destructive or difficult to control. They quoted Sheley *et al*. (1999), as saying that legally, a noxious weed is any plant designated by a federal, state, or county government as injurious to public health, agriculture, recreation, wildlife, or property. Noxious weeds usually create a particularly undesirable condition in crops, forest plantations, grazed rangeland or pastures. On this basis therefore, weeds may be rated by the degree of noxiousness as prohibitive noxious (eg. *Striga* spp.), noxious (eg. *Cyperus rotundus*), or not noxious (Carson, 1995).

2.1.3 Ecology of Weeds

The ecology of weeds is concerned with the development of a single species within a population of plants and the development of all populations within a community on a given site (Monaco *et al*, 2002). Booth *et al*, (2003) also described weed ecology as the study of how problematic plants (weeds) interact with their biotic and abiotic environment. The environment and the living community are considered to be an ecosystem and in an agricultural situation are considered an agro-ecosystem (Monaco *et al.*, 2002).

Cousens and Mortimer (1995) indicated that at any given point in time, a population has a *state*; the set of attributes which can be used to describe it. These attributes, they said, include its spatial limits (range/boundaries), total population size (number of individuals), density at any point within its boundaries, genetic composition and phenotypic composition (such as the frequency distribution of plant sizes of which it is comprised). Further, they explained that from the moment that a new population is founded, (perhaps from a single individual) changes in the state of the population do occur – the dynamics of the population. The causes of the changes ultimately will be either intrinsic to the population, that is driven by interactions amongst individuals in the population and therefore density-dependent, or extrinsic, that is, governed by the environment of the species. The scale and type of response to either intrinsic or extrinsic factors will depend on the particular life history characters of the species and, to a varying extent, will be a reflection of both types of factor.

Zimdhal (2007), detailed the factors affecting weed distribution and population. He indicated that the important climatic factors that determine a weed's ecological interactions are light, temperature, water, wind, humidity and their seasonal aspects. Light intensity, quality, and duration affect weed presence and survival. Photoperiodic responses govern flowering and determine the time of seed maturation. Light and temperature response determines a species' latitudinal limits. Some weeds tolerate shade well and their ability to grow under a crop canopy is one reason they succeed. Soil temperature is a primary determinant of seed germination and survival, especially where soil freezes. Freezing also affects winter survival of vegetative reproductive organs. Air and soil temperatures are important determinants of species distribution and ecological interactions. Seasonal distribution and total supply of water determine species' survival. Shortage of water at critical stages is often responsible for reproductive failure, death, or both. The world's arid areas would produce far less food if man did not affect seasonal distribution and total supply of water by irrigation. Wind can affect water supply through evaporation and an increase of transpiration loss. Wind also affects the microclimate within a plant canopy and the relative concentration of carbon dioxide and oxygen.

Zimdhal (2007) continued that climate will change because of increasing concentration of CO_2 and other tri-atomic gases that interact with radiant energy. There are reliable scientific data that show the world is warming and these changes will affect weeds. Agriculture has always been aided and hindered by climate. Crops are vulnerable to unfavourable weather and weed management may be more difficult during rapid climate change (Patterson, 1995). It is likely that the negative effects of all agricultural pests will increase with rapid climate change, particularly in less intensively managed production systems. Crops affected by environmental (global warming) stress will be more vulnerable to attack by insects and diseases and less competitive with weeds (Patterson, 1995).

Again, Zimdhal (2007) reported that soil water, aeration, temperature, pH, fertility, fertility source and the cropping system and associated practices imposed on a soil determine what weeds survive to compete. Many weeds do well in soils too low in fertility for crop production, but others grow only in well-fertilized soil. Few weed species associate with a soil type. Most weeds can be found in soils differing widely in physical characteristics, moisture content and pH. Soil pH is an important determinant of what plants grow in an area. However, no generalizations can be made about the influence of pH on weeds. LeFevre (1956) reviewed the pH tolerance of 60 weeds and grouped them into Basophile (love high pH, e.g., sow thistles, green sorrel, quackgrass, and dandelion), acidophile (love acid soil, e.g., red sorrel, corn marigold), and neutrophile

Any analysis of a weed species must evaluate the relative role of individual life history features in the biology of the species which enable weed populations to increase in size.

In an agro-ecosystem, agricultural practices impose perturbations on the habitat which variously may promote or inhibit changes to weed population size. At the time of crop harvest, seeds of the weed drop out to the ground surface and during (or at the end of) a fallow, are incorporated into the soil where they augment a buried seed bank accumulated from previous generations. Episodic germination from this bank results in seedling recruitment both prior to and immediately after crop sowing. Thereafter, individuals of each species compete for limiting resources and may exhibit allelopathic interactions, the overall outcome of which is seen in the relative seed yield of each species at harvest. Losses to the weed population occur between cropping cycles, especially during land preparation and cultivation. After crop establishment, weeds may benefit from the input of fertilizer but be selected against by herbicide applications resulting in death of individuals or suppression of growth. At crop harvest, weed species may suffer loss due to the removal of seed in harvesting machinery, yet on the other hand this process may promote dispersal of the weed.

2.2 Pineapple and its Cultivation

2.2.1 Origin, History and Distribution of Pineapple

It is commonly agreed that pineapple might have originated from present-day Southern Brazil and Paraguay where its wild relatives occur (Morton, 1987). Some people believe that the pineapple was first seen by Europeans when Columbus and his men landed on the island of Guadaloupe during the second voyage in 1493 (Paulle and Duarte, 2011), but Bertoni (1919) stated that pineapple was domesticated by the Tupi-Guarani Indians from *Ananas guaranticus (A. comosus* var *ananassoides*) and carried alongwith them in their northward migration to the Antilles, northern Andes and Central America, to Mexico and the West Indies long before the arrival of Europeans. (Coppens d'Eeckenbrugge and Leal 2003; Morton, 1987). This hypothesis has been retained in many reviews on crop origins (e.g. Collins, 1948, 1949, 1960, Purseglove, 1972; Pickersgill, 1976; Sauer, 1993).

The Caribbean Indians placed pineapples or pineapple crowns outside the entrances to their dwellings as symbols of friendship and hospitality. Europeans adopted the motif and the fruit was represented in carvings over doorways in Spain, England, and later in New England for many years. The plant has since become naturalized in Costa Rica, Guatemala, Honduras and Trinidad but the fruits of wild plants are hardly edible (Morton, 1987).

Morton (1987) further deliberated in the subsequent cultivation of the crop. He explained that the Spaniards introduced the pineapple into the Philippines and may have taken it to Hawaii and Guam early in the 16th Century. He said the first sizeable plantation of 5 acres (2 ha)—was established in Oahu in 1885. Portuguese traders are said to have taken seeds to India from the Moluccas in 1548 and they also introduced the pineapple to the east and west coasts of Africa. The plant was growing in China in 1594 and in South Africa about 1655. It reached Europe in 1650 and fruits were being produced in Holland in 1686 but trials in England were not successful until 1712. Greenhouse culture flourished in England and France in the late 1700's. (Morton, 1987)

2.2.2 Botany of Pineapple

Pineapple (*Ananas comosus* (L) Merr.) is a terrestrial perennial monocotyledonous herb belonging to the family Bromeliaceae which embraces about 2,000 species (Coppens d'Eeckenbrugge and Leal, 2003). The mature pineapple plant is 1–2 m high and 1–2 m wide, and it is inscribed in the general shape of a spinning top. The main morphological structures to be distinguished are the stem, the leaves, the peduncle, the multiple fruit or syncarp, the crown, the shoots and the roots (Coppens d'Eeckenbrugge and Leal, 2003).

The leaves are narrow, tapering and pointed, measuring up to 100 cm in length and arranged in a spiral rosette. The leaf margins are usually not always spiny. The leaves may be all green or variously striped with red, yellow or ivory down the middle or near the margins. According to Coppens d'Eeckenbrugge and Leal (2003), the sessile leaves enclose the stem on two-thirds of its circumference. The phyllotaxy varies, being 5/13 in large-fruited cultivated pineapples and 3/8 in small-fruited wild pineapples (Kerns *et al*., 1936). Leaf number is variable between cultivars but generally around 40–80, with the lower leaves originating from the planting material or produced soon after planting, being smaller (5–20 cm) compared with the younger ones, which can reach more than 1.6 m in length and 7 cm in width, depending on the cultivar and ecological conditions (Coppens d'Eeckenbrugge and Leal, 2003). The apical ones are short and erect. The leaves are ensiform and, except for the young apical ones, broader at their base, which forms a non-chlorophyllous sheath around the stem. The blades then taper progressively to a sharply pointed indurated tip. The constriction between the sheath and the blade is more marked in certain wild pineapples (Coppens d'Eeckenbrugge and Leal, 2003).

Coppens d'Eeckenbrugge and Leal (2003) also indicated that the pineapple stem is club-shaped, with a length of 25–50 cm and a width of 2–5 cm at the base and 5–8 cm at the top. Its aerial part is straight and erect, while the shape of the earthed part depends on the material used for planting. It is markedly curved when coming from a slip, as the stems of these propagules are comma-shaped, less curved when coming from a stem shoot and erect when coming from a crown (Coppens d'Eeckenbrugge and Leal, 2003).

Primary roots are only found in very young seedlings. They die soon after germination and are replaced by the adventitious roots which form a short and compact system at the stem base, with numerous strong roots and limited branching (Coppens d'Eeckenbrugge and Leal, 2003). The soil root system may spread up to 1–2 m laterally and 0.85 m in depth (Purseglove, 1972). The number of roots produced after planting is positively correlated with shoot weight, and crowns produce more roots than do shoots (Coppens d'Eeckenbrugge and Leal, 2003; Pursglove, 1972). The root internal anatomy is typical of monocots: the epidermis, with root hair cells; the cortex comprising the exodermis, the outer cortex, with sclerenchyma and aerating canals, and the inner cortex, with a lagunar parenchyma; the endodermis, pericycle, vessels and pith. Their most characteristic trait is the medullar structure given by the aerating canals, formed by the tip-to-tip junction of raphide cells in the outer cortex, and by the air lacunae formed by the disappearance of thin-walled cell groups. Branch roots originate in the pericyclic region of the main roots (Coppens d'Eeckenbrugge and Leal, 2003).

The pineapple flower is an inflorescence that usually develops from the apical meristem in an acropetal (ascending or youngest at the apex) succession and lasts for up to 15 days. The inflorescence consists of 50 to 200 individual flowers borne spirally and capped by a crown made of approximately 150 short leaves on a short stem. The stage of inflorescence emergence is called 'red heart due to the reddish peduncle bracts (usually five to seven) that are produced at its base and are shorter and narrow than the ordinary leaves (Purseglove, 1972; Coppens d'Eeckenbrugge and Leal 2001). The flowers or individual fruits are disposed around the central axis according to an 8/21 phyllotaxy in large-fruited cultivated pineapples (Kerns *et al.*, 1936) and a 5/13 phyllotaxy for small fruited wild pineapples or for young cultivated pineapples flowering prematurely (Kerns *et al.*, 1936).

Individual flowers are composed of three sepals, three petals, six stamens and a tricarpellate ovary. One to several flowers opens each day over a period of 3–4 weeks, starting from the base of the inflorescence (Okimoto, 1948). The fruitlets develop from flowers that do not abscise and each flower is subtended by a fleshy bract. The style, stamens and petals wither and the remaining floral parts develop into the fruitlet (Okimoto, 1948). The ovules and pollen grains are functional but seeds are not normally formed as some varieties (for example, Smooth Cayenne) are strongly self-incompatible.

According to Paulle and Duarte (2011), the fruit, more precisely defined as a coenocarpium (a multiple fruit derived from ovaries, floral parts and receptacles of many coalesced flowers), is topped by a leafy stem referred to as the crown. The fruit 'shell' is composed mainly of sepal and bract tissues and the apices of the ovaries, while the edible flesh is primarily composed of ovaries, the bases of sepals and bracts, and the cortex of the axis, which is an extension of the peduncle. The fruit is a terminal cylindrical, compound structure at the apex of the stem and is formed by the fusion of the berry like fruitlets that develop from flowers (Paulle and Duarte 2011).

The pineapple plant produces different vegetative propagules including: slips, suckers, crowns and ratoon suckers. According to Coppens d'Eeckenbrugge and Leal, (2003), vegetative propagules are classified according to their position on the plant. They indicated that suckers appear on the earthed part of the stem, whiles stem shoots, which appear on the aerial part, are more frequent. Slips appear on the peduncle and are often grouped near the base of the fruit. Sometimes, they are produced from the basal eyes of the fruit (collar of slips). Slips are curved at their base. As they are numerous in most cultivars, they are useful for rapid propagation. The crown can also be used for planting when the pineapple fruit is processed. Some plants may lack a crown or, on the contrary, produce multiple crowns. Also, crownlets may grow at the base of the main crown or from some of the upper fruitlets (Coppens d'Eeckenbrugge and Leal, 2003).

2.2.3 Ecology of Pineapple

2.2.3.1 Latitude and Altitude

Major areas for pineapple cultivation are found between 30^o North and South latitudes with some areas considered marginal for various reasons (Bartholomew and Malézieux, 1994). It can be grown in elevations from 1,100 metres above sea level, as long as the area is free from frost and has a high atmospheric humidity and average rainfall of 760-1,000mm (Ficciagroindia, 2007).

2.2.3.2 Temperature

There is a range of in optimum temperatures as different optimum temperatures are required for different growth stages. For root elongation an optimum soil temperature of 29^0C is required, 32^0C for leaf elongation, 20-30^0C for fruit weight and 29^0C for growth development (Nakasone and Paull, 1998). Frosts and night temperatures below 7-10^0C for a few hours for several weeks during the winter causes leaf-tip necrosis and fruit injury. A range of desirable maximum and minimum temperatures would be 15-20^0C and 25-32^0C with the optimum being close to 30^0C during the day, and 20^0C at night (Nakasone and Paull, 1998).

2.2.3.3 Sunlight

There is a direct relationship between fruit weight and solar radiation intensity. The rule of thumb is that yield decreases about 10% with every 20% decrease in solar radiation (Nakasone and Paull, 1998). Consequently shading at higher plant densities leads to a linear decrease in fruit weight and curvilinear decrease in yield (Nakasone and Paull, 1998). Intense sunlight, particularly during fruit maturation can lead to sun-scalding of the fruit. To prevent this several methods are used including; shading the crop with newspaper and weeds, spraying a reflective coating on the fruit and painting the side exposed to the afternoon sun with lime paste.

2.2.3.4 Rainfall

There is considerable variability in the rainfall in the areas where pineapples are grown. Pineapples are produced under a range from 600 mm to over 3500 mm annually, with optimum for good commercial production being from 1000-1500 mm (Nakasone and Paull, 1998). The pineapple is able to withstand long periods of drought (Xerophytic), as the leaves have a water-storage parenchyma that serve as a water reservoir. Despite the xerophytic characteristics of pineapple, growth can be adversely affected by prolonged dry periods. For pineapple the potential evapo-transpiration rate is 4.5 mm a day^{-1} and with soils water holding capacity rarely exceeding 100 mm, without rains, the water supply for the crop could be exhausted within 3-4 weeks (Nakasone and Paull, 1998). When subjected to prolonged water stress, plants cannot obtain the desired size needed for flower induction.

2.2.3.5 Soil

Pineapples are able to grow in a variety of soils including very poor soil. The plant is however sensitive to water-logged soils. Subsequently good drainage and aeration are important. Generally a pH range of 5.0-6.0 is considered best for pineapple and the flavour quality of pineapple on light soils is considered superior to that grown on other soils. However pineapple can quite adequately be grown on sandy and loamy soils rich in humus (Ficciagroindia, 2007).

2.2.4 Cultivation of Pineapple

2.2.4.1 Land Preparation

This is the first stage in the cultivation process. It is carried out after various physical and chemical soil analyses to ascertain the suitability of the land for cultivation. This stage includes land clearing, field layout and bed design (Hepton, 2003).

If the site has not been cropped previously, the first operation will probably be to remove brush and trees. After the fields have been surveyed, channels should be installed so as to effectively capture and remove excess rainfall in a manner that minimizes erosion. Where rock removal is necessary, rocks larger than about 30 cm in diameter should be removed after ploughing or sub-soiling and after final land preparation (Hepton, 2003). In areas where field operations are machine-assisted, planting areas may be laid out in blocks separated by roads. The dimensions of the blocks are designed to accommodate the equipment, while effectively accomplishing the required field operations (Hepton, 2003).

Once the basic tillage operations have been performed, raised planting beds may be formed as there are known economic advantages (Hepton, 2003). In most cases, pineapple plant growth is enhanced by planting on raised beds due to the increase in the volume of topsoil available to the root system, enhanced aeration and superior drainage. Raised beds may be covered with plastic mulch, usually depending on the need for fumigation (Hepton, 2003). Paulle and Duarte (2011) indicated that black polyethylene mulch (~50 µm thick and 81 cm wide) helps to prevent rapid escape of fumigants, maintains warmer soil temperatures during the cool season, retains moisture at the soil surface, reduces fertilizer leaching during rainy periods, controls weed growth in the beds and increases yield. In many pineapple-growing areas where plastic mulching is too costly, mulching with straw, grass, sugar cane baggasse or other available materials (Paulle and Duarte 2011).

In some cases, where harvesting of sparse rainfall is important, slightly depressed beds direct limited rainfall or overhead irrigation to the planting line. Despite the advantages of raised beds, they are not used where the cost of preparation exceeds the economic benefit (Hepton, 2003).

2.2.4.2 Propagation

The National Agricultural Research Institute (NARI) (1999) indicated that pineapple is propagated vegetatively from planting materials obtained from various parts of the plant. These are identified according to the part of the plant on which they are found.

Ratoon suckers are shoots produced from ground level and, when used, will produce fruit in 12 to 14 months after planting. Side shoots or suckers are produced above ground level and, when used, bear within 18 to 20 months after planting. Basal suckers known as "slips" are located at the base of the fruit. They produce fruit within 14 to 16 months after planting and are the preferred type of planting material. Crowns are situated at the apex of the fruit. This type of planting material is not commonly used by farmers, and even when used, they take as long as twenty-four months after planting to produce fruit (NARI, 1999).

Hepton (2003) also indicated that comparisons of various types of planting materials show that early growth rate and plant size at some future time are influenced primarily by the amount of starch reserve in the piece, the amount of leaf material present and the freshness of the piece of material. He however conceded that there remains some controversy over the relative performance of types of planting material as these variables have rarely been well controlled in field trials comparing various types of planting materials. According to Morton (1987), seeds can be used in propagation but are desired only in breeding programs and are usually the result of hand pollination. The seeds are hard and slow to germinate. Treatment with sulphuric acid achieves germination in 10 days, but higher rates of germination (75-90%) and more vigorous growth of seedlings results from planting untreated seeds under intermittent mist.

2.2.4.3 Planting

Planting is usually done in double rows with spacing of 60 cm x 30 cm with 90 cm path for Singapore Spanish cultivar, and 50 cm x 30 cm with 100 cm path for Smooth Cayenne (FAO, 2004). The planting density to use may vary from as low as 29,000 plants ha^{-1} to as high as 86,000 plants ha^{-1} depending on a number of factors including the environment (especially, solar radiation) and nutrition, plant growth and intra-specific competition for available resources (Hepton, 2003). In small plots or on very steep slopes, planting is done manually using the traditional short-handled narrow-bladed hoe, the handle of which, 30 cm long, is used to measure the distance between plants. Crowns are set firmly at a depth of 5 cm; slips and suckers at 9 to 10 cm. (Morton, 1987)

2.2.4.4 Cultural Practices

The major cultural practices in pineapple production include fertilizer application, weeding, pest and disease control, floral induction and de-greening (mostly of large commercial farms).

According to Evans *et al.,* (2002), pineapple has high requirements for nitrogen (N), potassium (K), and iron (Fe), and relatively low requirements for phosphorus (P) and calcium (Ca). Various published reports on pineapple nutrition indicate that the quantity of N required ranges from 225 to 350 kg/ha (Paulle and Duarte, 2011). The requirements for the other major fertilizer elements are best determined by soil analysis (Malezieux and Bartholomew, 2003). The amount of K applied usually ranges from 225 to 450 kg/ha; (if required) whiles 20 ppm in soil is considered adequate for P (Paulle and Duarte, 2011). Less fertilizer is required during the first five months after planting; requirements increase sharply afterward and peak at two to four months before floral initiation. P and Ca are usually banded in the plant line during bed preparation. K is usually applied to the soil before planting and later may be side dressed. Other nutrients-sometimes including K are applied as foliar sprays or through the drip irrigation system, or by both methods, during the plant growth cycle (Paulle and Duarte, 2011). Paulle and Duarte (2011) also indicated that some idea of pineapple fertilizer requirements may be obtained by analyses of elements immobilized in the various plant parts. Large amounts of N and K are found in the plant, fruit and slips. In ratoon fields, which develop on suckers on the mother plant, nutrients removed by the first fruit crop must be replenished. This amounts to approximately 175 kg N, 27 kg P, 336 kg K, 47 kg Ca and 27 kg Mg per hectare (Paulle and Duarte, 2011).

2.2.5 Pest and Diseases of Pineapple

Donkor and Abgoka (1997) identified a number of constraints which could affect production of pineapple in Ghana. Prominent amongst them were major pests and diseases particularly, *Phytophthora* heart and root rot, mealybug wilt disease, soil pests and weeds.

Pineapple is affected by a wide range of pests, including nematodes (*Rotylenchulus, Meloidogyne, Pratylenchus, Ditylenchus, Helicotylenchus*), insects (scale, mealybugs and ants) symphilids, mites and rodents and diseases such as *Phythophthora* rot, Fusarium stem rot, and a host of others (Evans *et al.,* 2002). The occurrence of these pests and diseases depends on the environmental conditions, the susceptibility of the cultivar and the presence or absence of the organism. High population densities of pineapple pests and diseases occur at different times in the pineapple life and therefore have varying impacts (Rohrbach *et al.*, 2003).

Nematodes cause stunting and degeneration in pineapple plants unless soil is fumigated. In Queensland, nematicides have increased yields by 22-40% (Morton, 1987). Crop rotation has been found effective in Puerto Rico. Turning the field over to Pangola grass (*Digitaria decumbens* Stent.) or green foxtail grass (*Setaria viridis* Beauv.) for 3 years suppresses nematode populations and benefits the soil but may not be practicable unless spare land is available for pineapple culture in the interim (Morton, 1987).

Further, Morton (1987) said that mealybugs (*Dysmiccocus brevipes* and *D. neobrevipes*) attack leaf bases and cause wilt. The leaves turn orange-brown and wither due to root rot. Prevention requires spraying and dusting to control the fire ants (*Solenopsis* spp.) which carry the mealybugs from diseased to healthy plants. Control is difficult because there are many weeds and other local plants acting as mealybug hosts. Some success was achieved in Florida in controlling the mealybugs with the parasitic wasp, *Hambletonia pseudococciaa* Comp., though the general use of insecticides limits the activity of the wasp (Morton, 1987).

According to Rohrbach and Schmitt (1994), *Phytophthora* heart and root rots are limited to areas with fine-textured soils with high pH values and wet environmental conditions. *Phytophthora* heart rot is characterized by failure of young infected plants to elongate, whiles they turn chlorotic. The terminal whorl leans to one side of the plant and can easily be pulled from the mother plant. The economic impact of the heart rot results from plant mortality. Root rot symptoms caused by these pathogens resemble those caused by mealybug wilt and nematode damage, hence they are not diagnostic. Leaf growth slows or stops, leaves redden and leaf tips and margins turn yellow and eventually become necrotic. Affected plants can be pulled from the soil easily (Rohrbach and Schmitt, 1994).

2.2.6 Weed Management in Pineapple Fields

2.2.6.1 Common weeds of pineapple fields

According to Akobundu (1987), weeds associated with pineapple production are similar to those of other field and plantation crops. The type of weed and the intensity of weed infestation, will depend on land-use system, cropping system and climatic and soil factors. In eastern Africa, *Pennisetum clandestinum*, *Cyperus rotundus* and *C. esculentus* are among the most troublesome weeds of pineapples. In other parts of the tropics, perennial weeds such as *Chromolaena odorata, Cynodon dactylon, Imperata cynlinderica, Paspalum conjugatum*, and annual weeds such *Bidens pilosa, Digitaria* and *Eleusine indica* are also problems in pineapples. Similarly, Rohrbach and

Johnson, (2003), reported that each production area has its own particular spectrum of weeds, sometimes determined by historical weed-control practices (St. John and Hosaka, 1932; Barbier and Trapin, 1956; Py, 1959; Silvy, 1962), e.g. wild sugar cane (*Saccharum spontaneum* L.) in the Philippines (Sison and Mendoza, 1993). They observed that the species that are particularly difficult to manage include *Panicum maximum* var. *maximum*, *Sorghum halepense* and the paspalums, (*Paspalum dilatatum* and *Paspalum urvillei*). The sedge *Cyperus rotundus* (nut grass) is also a serious pest. Significant broad-leaved weeds are the morning glories, *Ipomoea cairica, Ipomola plebeia, Ipomola indica, Ipomola purpurea* and *Ipomola triloba* (Rohrbach and Johnson, 2003).

2.2.6.2 Effect of weeds on pineapples

According to Chadha *et al*. (1997), because of its inherent slow growth and the wider space between the rows, pineapple is prone to continual weed germination and growth leading to severe competition and as a result, yield reduction could be high and complete crop failure at worst, is possible. Similarly, Bose and Mitra (1990) reported that weeds pose a serious problem in the cultivation of pineapple especially during the rainy season and manual weeding accounts for up to 40 per cent of the total production cost. Sipes (2000) also reported that weeds can have devastating effects on pineapple yield. Under severe weed problems, plant crop yield can be reduced up to 83%.

2.2.6.3 Methods of weed management on pineapple fields

Weed management in pineapple is especially important during early growth. It includes soil tillage, mulches, and the use of pre-emergence and post-emergence herbicides (Kasasian, 1971; Glennie, 1991). NARI (1999) stated that weeds can be controlled manually by use of cutlass, hoes and other simple implement, mechanically with tractor drawn implements, or by use of chemicals. Important pineapple herbicides have been diuron, bromacil, ametryn, atrazine and paraquat (Glennie, 1991). In practice, however, it is a combination of these operations that is usually conducted. The efficiency of the pineapple weed-management system is affected by plant density, the degree of mulch cover, soil type and natural rainfall and/or the method of irrigation (Rohrbach and Johnson, 2003).

2.3 The Pineapple Mealybug Complex

Two mealybug species are known to attack pineapples (Carter, 1963; Illingworth, 1931; Ito, 1962; Ullman *et al.*, 1989). These are the pink pineapple mealybug, *Dysmicoccus brevipes* (Cockerell) and the gray pineapple mealybug, *D. neobrevipes* (Beardsley). The two were initially thought to be different strains of the same species, (*D. brevipes*) but Beardsley (1959) later discovered that the two were different species and hence proposed the name *D. neobrevipes* for the gray form.

2.3.1 Biology of the Pineapple Mealybug

Mau and Kessing (2007) stated that *D. brevipes* (Cockerell) (the pink pineapple mealybug) reproduces only by parthenogenesis in Hawaii where only females are present, whiles in Brazil, where males are present, both sexual and nonsexual reproductions occur. *D. neobrevipes* (the gray pineapple mealybug) on the other hand, is bisexual and reproduces sexually (Mau and Kessing, 2007).

The life cycle of *D. brevipes* was extensively studied by Ito (1938). According to him, this insect goes through three larval stages before becoming an adult. The life span (first instar to death as an adult) varies from 78 to 111 days, averaging 95 days. The larvae, called "crawlers", are the primary dispersal stage in all mealybug species. They have flattened bodies with long hairs that aid in their dispersal by wind. They remain protected underneath the mother's body for a short time before developing a waxy covering. Larvae moult three times before reaching adult maturity. The first, second, and third instars or larval stages last for 10 to 26 days, 6 to 22 days and 7 to 24 days, respectively. Thus, the total larval period varies from 26 to 55 days, averaging about 34 days. Larvae only feed as a first instar and in the early part of the second instar (Mau and Kessing, 2007).

Mau and Kessing (2007) further explained that adult females are plump and convex in body shape and pinkish in body colour. Lateral wax filaments are usually less than one fourth as long as the breadth of the body, and those towards the back of the insect are one-half as long as the body. There are 17 pairs of these wax processes. Female pink pineapple mealybugs are similar in appearance to the gray pineapple mealybug females. Balachowsky, (1957) gives a detailed description of the female pineapple mealybugs.

The prelarviposition period for adult females lasts for around 27 days. The larviposition (giving birth to larvae) period lasts for an average of 25 days. They birth about 234 progeny but may produce up to 1000 crawlers. She may then live for another 5 days before dying. Duration of adult female life varies from 31-80 days, averaging about 56 days.

Males do not exist in Hawaii. If a male mealybug is found on pineapple in Hawaii, it is most likely the gray pineapple mealybug. Male pink pineapple mealybugs observed from Brazil are approximately 1 mm long. Pink pineapple mealybug males are distinguished from gray pineapple mealybug males by a difference in the number of antennal segments. The pink pineapple mealybug has 8 antennal segments and the gray pineapple mealybug has 10. Also, the pink pineapple mealybug has short clavate setae on its body and appendages in place of digitiform setae that is found on gray pineapple mealybugs.

Pink pineapple mealybugs are secretive in habit and usually inhabit the base of their host plants such as the roots, leaves, stems, fruit, and crowns of pineapple, whereas gray pineapple mealybugs infests only the aerial roots, stems, fruit, and crowns (Beardsley, 1959; Rohrbach *et al*., 1988; Jahn and Beardsley, 2000)

2.3.2 Host Range of Pineapple Mealybug

Pink pineapple mealybugs attack more than 140 plant species throughout the tropical and subtropical parts of the world. In contrast, gray pineapple mealybugs have a smaller geographical distribution, limited to South and Central America, Caribbean, some Pacific Islands, and a few Asian countries bordering the Pacific Ocean, and infests approximately 50 plant species (Beardsley, 1965; Williams and Watson, 1988; Williams and Willink, 1992; Ben Dov, 1994). In addition to pineapple and other bromeliads, important hosts of pink pineapple mealybugs recorded are banana, *Musa paradisiaca* L. (Musaceae), sugarcane, *Saccharaum officinarum* L., Annona (cherimoya, atemoya, sugarapple), celery, citrus, coffee, cotton, Euphorbia, Gliricidia, Hibiscus, Hilo grass, mulberry, Natal soursop, nutgrass, orchid pineapple, Straussia (Mau and Kessing, 2007). Others include rhodesgrass, *Chloris gayana* Kunth, natal grass, *Rhynchelytrum repens* (Willd.) Hubb., guinea grass, *Panicum maximum* Jacq., common sand burr, *Cenchrusechinatus* L., and vasey grass, and *Paspalum urvelii*

Steud (Poaceae) (Carter 1932, 1933a, 1933b, 1951, Beardsley 1959). Gray pineapple mealybugs have a more restricted host plant range, which includes century plant, *Agave sisalana* L. (Agavaceae), in addition to pineapple and bananas (Carter 1933a, 1951)

2.3.3 Relationship between Ants and Pineapple Mealybug

Phillips (1934) hypothesized that mealybugs were associated with ants in pineapple fields because: 1) ants protected mealybugs from natural enemies; 2) ants protected mealybugs from adverse weather by building earthen shelters around them and moving them to protected places; 3) ants transported mealybugs from plant to plant between and within fields, thus facilitating mealybug dispersal; 4) ants stimulated increased feeding by mealybugs; and 5) ants removed honeydew from mealybugs, thereby preventing fungi from attacking mealybugs. Rohrbach *et al*. (1988) hypothesized that honeydew feeding by ants could benefit mealybugs by preventing the accumulation of honeydew on the mealybugs themselves. Presumably, immature mealybugs get stuck in honeydew and die if ants do not remove it.

2.3.3.1 Protection from natural enemies

The observation that ants "protect" mealybugs from natural enemies does not necessarily mean that ants are attacking the natural enemies to save honeydew as a food resource. Possibly, ants are consuming the natural enemies as food and mealybugs benefit by happenstance (Jahn and Beardsley 1994). There are numerous examples of ants deterring the predators and parasites of scales, mealybugs, and aphids (Van der Goot, 1916; Way, 1954; 1963; Wimp and Whitham, 2001). For instance, in the absence of Argentine ants, *L. humile*, parasites suppress populations of lecaniine scale insects (Bartlett, 1961). Ants also reduce parasitism of the cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero (Cudjoe *et al*., 1993). Larval coccinellids eliminate green scales (*Coccus viridis* (Green)) from coffee trees in Hawaii unless *P. megacephala* is present (Reimer *et al*.1993). Green scales in Sri Lanka also cannot survive without ants (*Oecophylla smaragdina* Fabricius), but the ants apparently do not reduce parasite and predator attacks on the scales (Bess, 1958). A wide variety of natural enemies prey on pineapple mealybugs. Ants protect mealybugs from their natural enemies (González-Hernández *et al*., 1999a; 1999b). In laboratory experiments with coccinellids, *D. neobrevipes* did not thrive on pineapples, unless ants were present (Illingworth, 1931). In the absence of natural enemies, laboratory populations of *D. neobrevipes* were not significantly different on pineapples with and without ants (Jahn and Beardsley, 1996). In the field, *P. megacephala* had a positive association with *D. neobrevipes* and a negative association with the predators of mealybugs (Jahn and Beardsley, 1998; 2000). Collectively, these experiments suggest that *P. megacephala* deters predators from attacking *D. neobrevipes*.

2.3.3.2 Distribution of mealybugs from plant to plant

Ants are known to transport homopterans. In Japan, for example, ants carry rice root aphids, *Anoecia fluviabdominalis* (Sasaki), from wild grasses to upland rice fields (Dale 1994). In an experiment to determine if mealybugs transmit wilt, Illingworth (1931) observed *P. megacephala* carrying mealybugs from one cage of pineapples to another. Carter (1933a) supposed that *P. megacephala* moved mealybugs from alternate hosts to pineapple, as well as among pineapple plants. Laboratory experiments suggest that *P. megacephala* do not move mealybugs from one pineapple fruit to another in significant numbers (Jahn and Beardsley 1996). Sticky trap collections in a Hawaiian pineapple fields demonstrate that first instar pineapple mealybugs are dispersed by the wind (Jahn and Beardsley 2000).

2.3.4 Effect of Pineapple mealybugs Complex on Pineapples

On pineapple, four types of damage are possible:

1) the transmission of pineapple wilt (also called mealybug wilt and edge-wilt);
2) the production of chlorotic areas where there has been prolonged feeding and the underlying tissues have been exhausted;
3) damage to the bottom of the pineapple by the feeding of large mealybug populations which makes the bottom slices unmarketable and may cause the rotting and leaking of the fruits; and
4) "mealybug stripe" which results from the feeding of a short section of each of 3 or 4 inner whorl leaves. It is characterized by streaks of pale green to yellow and by the collapsing of the water storage tissues within these streaks.

Pineapple wilt, or mealybug wilt, causes the most serious type of damage and is the principal cause of crop failure in Hawaii. There are two types of wilt, "quick wilt" and "slow wilt". Both types cause the collapse of roots by the invasion of saprophytic organisms or by drying up the root.

CHAPTER THREE

3.0 MATERIALS AND METHODS

The research was carried out in three (3) phases as follows:

I. Surveys to identify and quantify the major weeds of pineapple farms

II. Scouting to determine the prevalence and alternative hosts of pineapple mealybugs and their tending ants

III. Field experiment to determine the impact of five weed management methods on pineapple mealybugs and their tending ants

3.1 Survey of Major Weeds of Pineapples

3.1.1 Study Areas

Pineapple cultivation in Ghana is mainly concentrated in the Central, Greater Accra Eastern and Volta Regions (Takane, 2004). This survey was thus carried out in three major pineapple growing Districts as follows (as shown in Figure 3.1):

- Akuapim South Municipality (Eastern Region),
- Gomoa East District (Central Region)
- Mfantseman Municipality (Central Region)

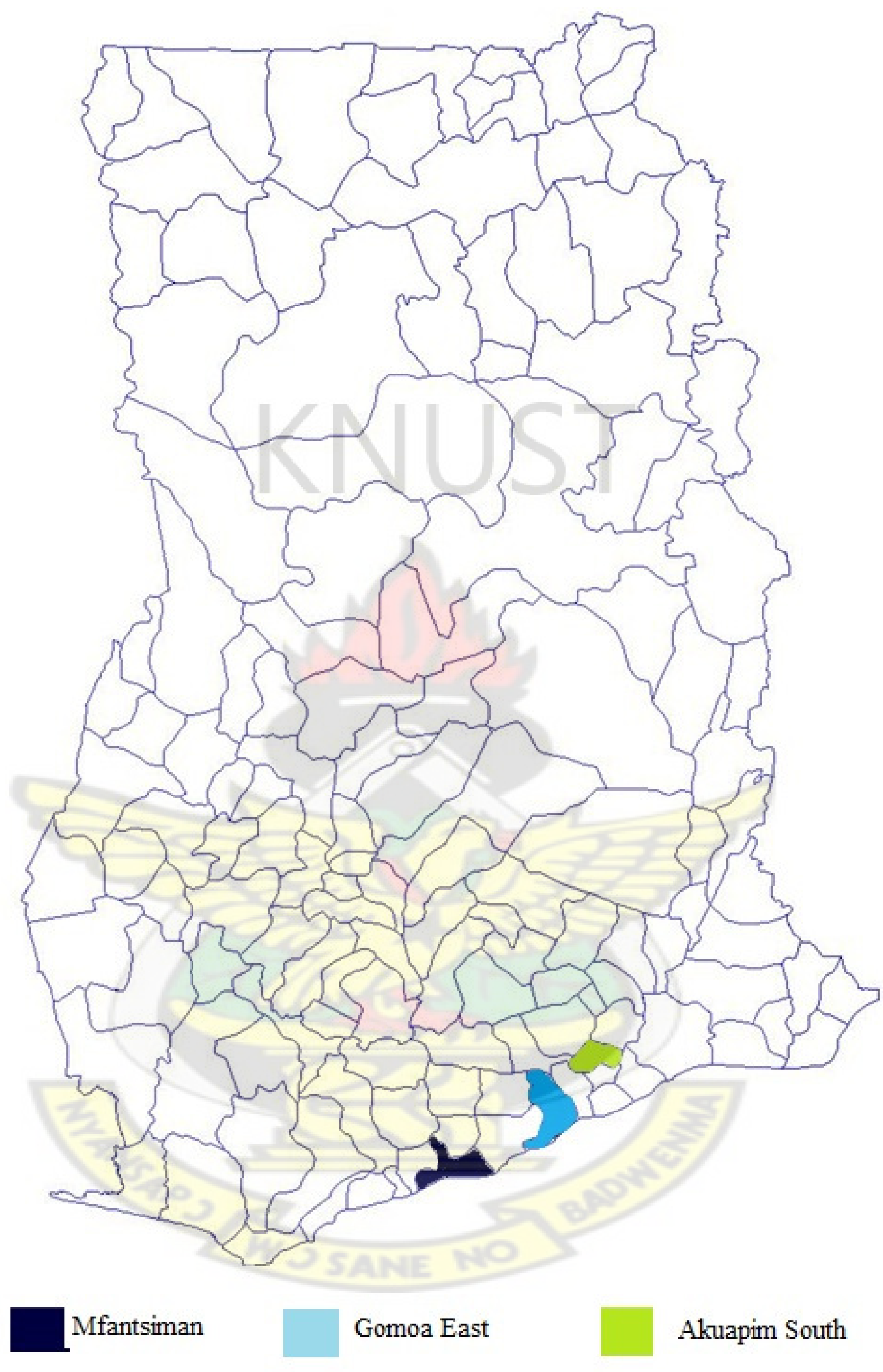

Figure 3.1: District map of Ghana showing the districts surveyed for common weeds of pineapple.

3.1.1.1 Ecology of Survey Areas

Akuapim South municipality lies within the moist semi-deciduous ecological zone of Ghana and is characterized by bimodal rainfall pattern with annual rainfall ranging from 1270 mm to 1700 mm with an average of 1500 mm per annum (Frenken, 2005). Mean annual temperature hovers around 26.6^0C (Nabila and Kofie, 2001) with mean daily temperature ranging from 24.83^0C to 27.53^0C. Relative humidity is generally over 80% during night and early morning, decreasing in the afternoons. It however decreases considerably in the dry season. The soil type is mostly forest ochrosols, consisting of thin (about 20 cm) dark greyish brown, humus-stained sandy loam and silty loam topsoils which are usually moderate fine granular in structure and friable in consistency.

Gomoa East District is predominantly in the coastal savanna agro-ecological zone although some parts in the north lie close to the semi-deciduous forest zone. It is also characterized by the bimodal rainfall pattern with mean annual rainfall hovering around 890 mm. Mean daily temperature ranges between 25^0C to 29^0C. Relative humidity is generally high most of the year with afternoon humidity ranging from 55-67% in the rainy months and falling to around 40% during the dry season, with values below 20% occasionally being recorded. Humidity can rise to almost 100% during the night in most part of the year over the plains. The dominant soil type is tropical black and grey with patches of yellow and skeletal soils.

Mfantseman Municipality also lies in the coastal savanna zone but as a coastal area, is characterized by dense scrub. Rainfall is bimodal as well with characteristics similar to Gomoa East. Soils are however varied including infertile soils always flooded with water and rich clay soils.

3.1.2 Sampling Procedure

Cluster sampling method was used to assess each of the three study areas for prominent weeds associated with pineapple fields. For each location, five fields of about 1ha were selected at random (making sure all areas of production are well represented). Each field was then divided into 4 blocks and then five (5) random samples taken per block with a 1 m^2 quadrat, (making sure all areas of the block are represented). A total of 20 quadrats were thus taken per hectare and 100 quadrats for each District surveyed. For each quadrat, the major weed species were identified (using the weed identification manuals) and the population density (number of individuals per metre square) estimated.

Due to the fact that most commercial pineapple production fields were weed-free, sampling was mostly carried out on sucker plots, where weed management was minimal, or on production plots which had been left unweeded.

3.1.3 Interview with Farmers

Farmers were interviewed to find out the how long the fields had been cultivated and which weed and soil management methods were being employed. The interviews were conducted in the local Akan language guided by questionnaires (Appendix I). The results were summarized with simple frequencies and are presented in the Chapter Four.

3.1.4 Acquisition of Climatic Data

Rainfall and mean monthly temperatures for the period prior to and during the time of surveys were acquired from the Meteorological Services Agency for the areas surveyed to help explain the kinds and quantities of weeds observed in the various areas (Appendix II). In addition, the natural vegetation for the various areas were obtained by interview with the indigenes, observations and from the vegetation map of Ghana (Appendix III). This was also to help explain the kinds and quantities of weeds observed.

3.1.5 Soil Analysis

Five soil samples were taken from each field in the zigzag pattern using 5 cm diameter coring cylinders and taken to the Soil Science laboratory of the University of Cape Coast for analysis. The soil samples, which were taken at 0-15 cm depth, were analysed for organic carbon contents, pH, bulk density, moisture content and texture since these are major contributors to the kinds and abundance of weeds (Zimdhal, 2007). The results are presented in Chapter Four.

3.1.6 Data Analysis

Simple frequencies and means with confidence intervals was used to estimate the population density of major weed plants identified in pineapple fields with respect to areas surveyed. The identified weeds were then grouped according to their morphology and life cycle and compared with the various factors which determine weed populations in an area as determined above.

3.2 Scouting for the alternative hosts of the pineapple mealybugs and their tending ants

3.2.1 Study Area

The scouting was carried out concurrently with the survey for the major weeds on the same pineapple fields. Hence, the study area remains the same as for the survey for the major weeds of pineapple above.

3.2.2 Identification of pineapple mealybugs and their tending ants

To be sure of the particular pineapple mealybugs in question, samples of the pineapple mealybugs were collected from the three areas under study and examined under a stereo-microscope in the Plant Pathology Laboratory of the Department of Crop and Soil Sciences, KNUST. The morphological features of the mealybugs were compared with the descriptions as outlined by Beardsley (1959).

The caretaking ants found with the mealybugs were as well identified using various plates of ants. This was done with the aid of hand lenses.

3.2.3 Estimation of Number of Pineapple Mealybugs per Plant

Ten plants were randomly selected on each hectare of pineapple field in the X pattern. On each of these ten plants, two leaves were pulled out from the middle part, and the leaf bases examined for mealybug and ant infestations (Pesticide Initiative Program [PIP], 2005). The plants were then gently uprooted with a shovel or long knife and the roots examined for infestations as well. The number of mealybugs and ants found on each part were recorded (PIP, 2005).

The number of mealybugs per plants was calculated as the mean number of mealybugs on each plant ± standard error of mean.

3.2.4 Scouting for mealybugs and their tending ants on adjacent weeds

Weeds up to 5 m adjacent the pineapple fields were examined thoroughly for the presence of mealybugs and their caretaking ants. Between 10 and 20 plants of each major weed species were selected at random and examined for the presence of the ants identified on the pineapple fields.

A similar procedure was used to scout for the pineapple mealybugs on the weeds. A more thorough approach was however, employed in the examination; first, their leaf bases were carefully examined and then the whole plant uprooted gently using a long knife or shovel and the roots examined as well for the presence of the mealybugs.

Two-way contingency tables were constructed for each major weed species versus the mealybugs and ants. The G-statistic was used to test for independence of each mealybug and ant from the major weeds. G was compared to $\chi^2_{.05[1]}$, = 3.841 (that is, the critical value for χ^2 for one degree of freedom) to test the null hypothesis that mealybugs and ants are independent of weeds (Jahn and Beardsley, 2000). For $G > \chi^2$, the Dice Index was calculated to determine the direction of association (Dice, 1945).

3.3 Field Experiment

The experiment was conducted to evaluate the efficacy of various weed management methods employed in pineapple cultivation in Ghana in limiting the prevalence of the pineapple mealybugs and their tending ants. It was carried out on-farm, at Bomart farms Ltd located in the northern part of the Ga East District Municipality of the Greater Accra Region.

3.3.1 Study Area

The field was located near a village known as Mayera, about 35 km North West of Accra. It lies in the Coastal zone, with the natural vegetation dominated by shrubs and grasses interspersed with a few timber trees such as mahogany and some non-timber forest trees as well. Due to continuous degradation however, the prominent vegetation on the plot was grasses interspersed with some palm trees and some volunteer maize plants (as a result of the previous cropping).

The area has a total annual rainfall of between 1200 mm and 1400 mm in two rainy seasons starting from April and July (major season) and September and late October (minor season). Temperatures of the area are high and uniform. Mean monthly temperatures hover around 20^0C. Relative humidity is around 90% during the mornings of July, August and September but lower between December and March.

A soil analysis conducted at the beginning of the experiment described the soil as sandy loam with pH of 5.0, bulk density of 1.37 and organic matter content 0.37%. The soil has been classified as Eutric Plinthosol (FAO, 1990).

3.3.2 Treatments and Experimental Design

The treatments used were:

1 weedy check (no weed control),

2 manual weeding (only),

3 Synthetic herbicide (bromacil + diuron),

4 Plastic mulch + manual weeding and

5 Plastic mulch + Synthetic herbicide

These are the weed management practices commonly employed on pineapple fields in the pineapple growing areas (Table 4.1). The weedy check was added to serve as the basis of comparison.

The experiment was arranged in a 5 x 5 Latin square design with 5 replications. Randomization of treatment over the plots for the selected design of experiment was generated using the Genstat Statistical Package (DE3, 2008).

3.3.3 Experimental Procedure:

3.3.3.1 Land preparation and field layout

The land was first ploughed to uproot and bury the weeds on 14th August, 2010 and then left for some time to allow for germination of weed seeds. The few palm trees were also uprooted during this time. It was then ploughed for the second time to loosen the soil and bury the germinated weeds.

A 25 m X 20 m piece of the land was demarcated for the experiment. This was sub-divided into five rows of width 2 m each and five columns, 2.7 m each. The rows and columns were separated by 2 m wide inter-plot spaces. Hence, each of the 25 experimental plots comprised 2.7 m X 2 m length by breadth respectively (Appendix IV).

For plots with plastic mulch (treatments 4 and 5), three ridges, each of width 90 cm, were constructed along the 2.7 m side of the plots. The ridges were then covered with the plastic mulch as required.

3.3.3.2 Planting

Pineapple suckers which had been harvested and graded as 400 g from the sucker plots of Bomarts Farms Ltd. were used for the experiment. These were planted in three double rows on each plot, with seven plants per row to give a total of 42 plants per plot at a spacing of 90 cm X 60 cm X 25 cm. The outer 22 plants were used as border plants whiles data was collected on the inner 20. Planting was done on 27th of August, 2010.

3.3.3.3 Pests and disease management

Ridomil Gold (fungicide) at 0.4 kg dissolved in 200 l of water and Dursban (insecticide) at 360 ml in 200 l of water were applied 58 days after planting.

3.3.3.4 Fertilizer application

Fertilizer application was carried out six times before floral induction (forcing) and once after forcing. First, 4 kg ammonium, 2 kg Urea and 7 kg SoP were dissolved in 200 l of water and applied by drenching 58 days after planting. Then, 6 kg ammonium and 6 kg Magnesium dissolved in 200 l of water was also applied by drenching 103 days after planting. The third application was with 5 kg ammonium, 4 kg Urea and 10 kg SoP dissolved in 200 1 of water also applied by drenching 139 days after planting. Subsequent to these, fertilizer applications were made by foliar applications using the boom sprayer. 90 kg Magnesium, 40 kg ammonium, and 40 kg Urea dissolved in 3000 l of water (one boom sprayer) was applied 169 days after planting, with two doses of 40 kg Urea, 80 kg Potassium nitrate dissolved in 3000 l of water applied 189 and 194 days after planting respectively.

3.3.3.5 Application of treatments (weed management)

After planting, weeds on the plots were monitored and allowed to grow. The respective weed management practices (treatments for the experiments) were first imposed eight weeks after planting. The weedy checks were never weeded until floral induction when the weeds were slashed to make way for forcing. The treatments which included manually weeding (treatments 2 and 4) were carried out four times before floral induction and twice after, due to frequent re-emergence of weeds. Treatments involving synthetic application of herbicides were applied once, since the weeds did not re-emerge quickly enough to warrant re-application. Treatments 2 and 4 were applied with a long hoe whiles the treatments 3 and 4 were carried out with 500 g of diuron + 500 g of bromacil dissolved in 200 l of water with a knapsack sprayer.

3.3.4 Data Collection and Analysis

Four groups of data were collected. These were data on

1. Growth and yield
2. Weeds
3. Mealybug populations
4. Economics of production

3.3.4.1 Growth and Yield

It is a common practice to index the growth of pineapple with an easily identified standard leaf known as the D-leaf (Malézieux et al, 2003), which is defined as the youngest physiologically mature leaf on the plant (Bartholomew, 2008). It also happens to be the tallest leaf on the plant.

Data was thus collected on plant height, D-leaf weight, D-leaf length, D-leaf width and plant weight at forcing. Yield data taken included: fruit weight, and percentage of marketable fruits. For all these, except the plant weight (which required destructive sampling) five plants of intermediate sizes were sampled (Rebolledo-Martinez *et al.*, 2005) from the inner 20 plants at random and the data taken on them. This was done bi-monthly.

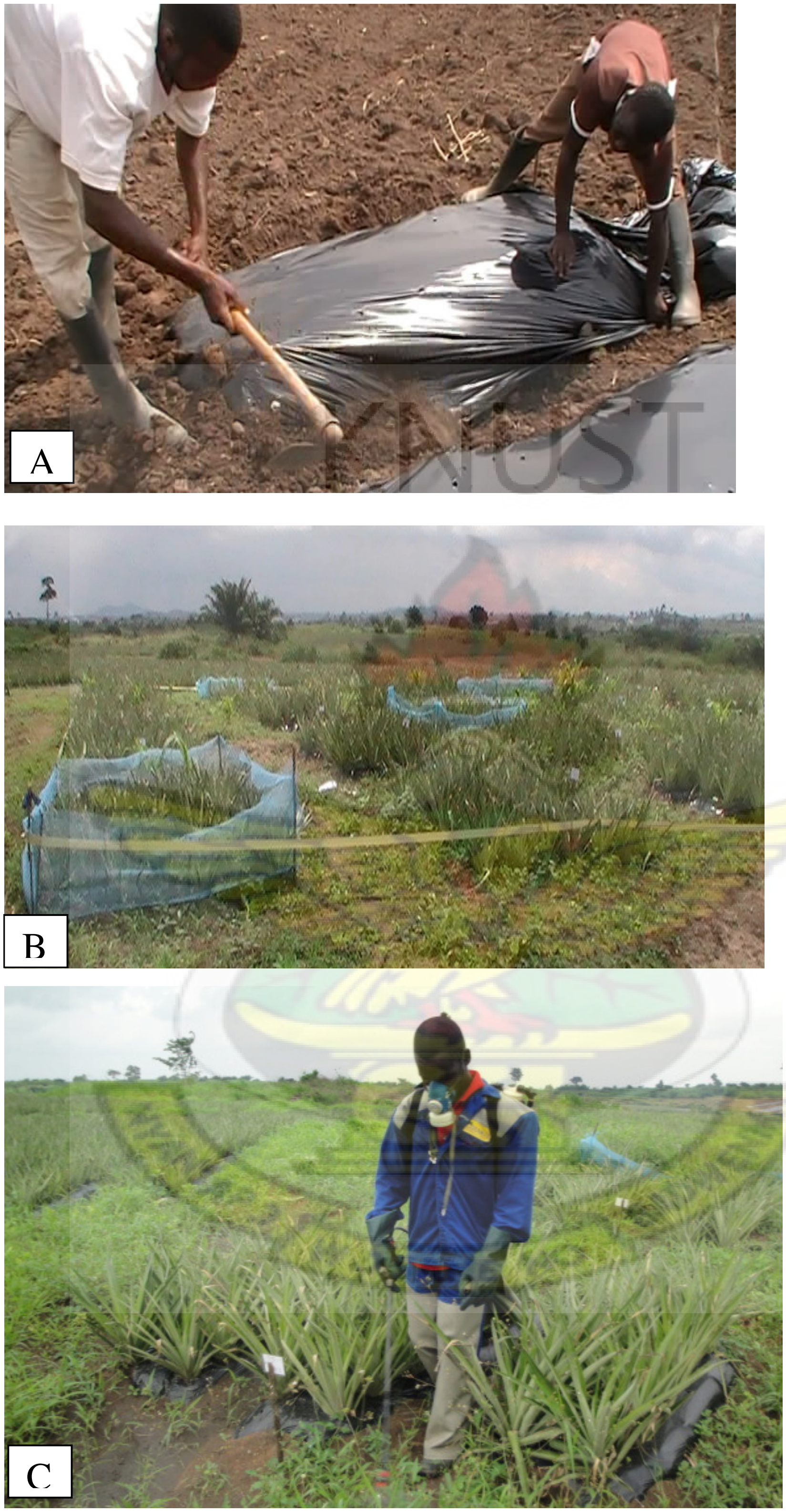

Plate 1**A:** Construction of ridges with plastic mulch; **B:** Experimental plot 1 month after planting with weedy checks fenced with blue nettings; **C:** Application of herbicides on plastic mulch + synthetic herbicide plot

Plant height was measured as height from the ground to the highest point of the plant in its natural orientation. The mean of the five plants heights was determined for each experimental plot.

D-leaves were picked and sent to the Crop Science Laboratory of the University of Cape Coast for the various parameters to the measured. They were weighed with a top pan balance and their lengths and width measured with a meter rule. The D-leaf width was taken as the width of the leaf bases which were virtually uniform (Bartholomew, 2008) in size. For all these, the mean weight, length and width per plot were determined.

Before floral induction, five plants of intermediate sizes from each plot were selected at random, uprooted, cleaned of soil debris and weighed with a spring. The means for five plants were taken as the mean plant weight for each plot.

At harvest, the fruits from 15 plants of the inner rows of each plot were harvested and weighed. The mean fruit weight was calculated.

The percentage of marketable fruits was calculated by first counting the number of fruits which met the criteria for marketing as listed below and expressed as a percentage of the total number of fruits per plot. The criteria included: not diseased or rotten, no missing eyes, fruit not deformed, crowns neither too short nor long (should be about 1/3 of the fruit length), no sunburns, and fruit weight not less than 900 g.

The data collected were subjected to ANOVA using the Genstat statistical package

(Genstat DE3, 2008) and the means compared using the Duncan Multiple Range Test (DMRT) at 5% probability level.

3.3.4.2 Data on Weeds

a. Time taken for weeds to re-emerge

After the first application of weed management methods, the plots were monitored to determine the time taken for the weeds to re-emerge, measured in weeks.

b. Weed species emerged

The weeds which re-emerged after planting were identified using weed identification manuals and recorded for the various plots. Samples of weeds which could not be easily identified with the handbooks were sent to the Herbarium of the Department of Botany, School of Biological Sciences, (University of Cape Coast) for identification. The identification was to help determine if the species of weeds which re-emerged would vary with the method of weed control employed.

c. Weed population and weight

A 25 cm x 25 cm quadrat was used to sample four points at random on each plot to determine the various weed parameters.

For each quadrat, the major weed species identified were counted with the help of a counter. The weed populations were expressed on per square metre basis. The data was transformed using square root transformation after a constant figure of 0.5 was added to each of the figures. Analysis was by ANOVA, using the Genstat Statistical Package (Genstat DE3, 2008) and the means separated using the

Duncan's Multiple Range Test. The transformed means were later back transformed to get the actual means.

The weeds were cleared off, cleaned of soil and dried at 60^0C until uniform weights were attained. They were then weighed with a top pan balance to determine their dry weight. Due to the huge differences obtained, the data was transformed using log transformation (base 10). The transformed figures were analyzed using ANOVA with the Genstat Statistical Package (Genstat DE3, 2008) and the means separated by the Duncan's Multiple Range Test. The means were later back transformed.

3.3.4.3 Entomological Data (Data on mealybugs)

The number of mealybugs per fruit and the root zone were estimated at harvest. This was done by first counting the number of mealybugs observed on the harvested fruits and then uprooting five plants in the X pattern and estimating the number mealybugs on roots and leaf bases. The data was transformed using the square root transformation after the addition of 0.5 to each of the figures. Analysis was by ANOVA, using the Genstat Statistical Package (Genstat DE3, 2008) and the means separated by the Duncan's Multiple Range Test. The means were later back transformed.

3.3.4.4 Economics of production under the various weed management methods

A cost: benefit analysis was carried out with the help of secondary data obtained from Milani Farms Ltd on the costs of various inputs and services and the selling price of marketable fruits per kilogram. The cost of weed control for each treatment, the percentage of fruits marketable and mean fruit weight obtained from the field experiment were factored into the calculation. Appendix V shows the detailed calculation.

CHAPTER FOUR

4.0 RESULTS

4.1 Weeds found in pineapple fields in the Mfantsiman, Gomoa East and Akuapim South Districts

4.1.1 General Information on Farms Surveyed

Table 4.1: Background information on farms surveyed

Site Information	Location		
	Mfantsiman	**Gomoa East**	**Akuapim South**
Natural Vegetation	Mainly shrubs	Mainly perennial grasses interspersed with few trees	Mainly perennial grasses and herbaceous broadleaves with few trees interspersed
Mean age of Farms	3.6	3.9	3.6
Weed Control Methods	Mainly manual weeding without plastic mulch	Mainly Plastic mulch + synthetic herbicide	Varies: some manual, some herbicides, with or without plastic mulch
Percentage of farmers trained in Management of weeds and other Pests	20	100	80
Mean farm size	1.52	1.7	2.0
Mean Annual Rainfall (mm)	750-1000	1000-1250	1250-1500
Mean Daily Temperature (^oC)	27.51	28.34	26.6
Soil Texture	Sandy Loam	Sandy Loam	Loamy
Soil pH	5.0-5.2	5.1-5.3	5.5-6.0
Soil Moisture	4.36	4.82	5.21
Soil Organic Carbon content	0.95	1.11	1.50
Bulk Density of Soil	1.30	1.40	1.45

4.1.2 Species composition of weeds in pineapple fields in the Districts surveyed

Table 4.2 shows the species composition of weeds in the three Districts surveyed. A total of 43 weed species from 16 families were recorded across the three Districts surveyed, with Asteraceae and Poaceae being the dominant families. Mfantsiman District had the least number of species (29) followed by Gomoa East with 34 and then Akuapim South with 40 species.

Table 4.2: Weed species recorded in the three Districts surveyed

Family	Weed Species	Common name	Mfantsiman	Gomoa East	Akuapim South
Amaranthaceae	*Amaranthus spinosus*	Spiny amaranth	-	+	+
Asteraceae	*Ageratum conyzoides*	Goatweed	+	+	+
	Chromolaena odorata	Acheampong Weed	+	+	+
	Emelia praetermissa	Yellow tasselflower	-	+	-
	Aspilia africana	Haemorrhage plant	+	+	+
	Synedrella nodiflora	Nodeweed,	+	+	+
	Vernonia cinerea	Little ironweed	-	+	+
	Tridax procumbens	Tridax, coat buttons	+	-	+
	Erigeron floribundus	Fleabane	-	-	+
	Blumea aurita	-	-	-	+
	Lactuca taraxacifolia	Wildlettuce	-	-	+
Commelinaceae	*Commelina diffusa*	Spreading dayflower	+	+	+
Convovulaceae	*Ipomoea involucrata*	Morning glory weed	-	-	+
Cucubitaceae	*Momordica charantia*	Balsam pear, African cucumber	-	+	+
Cyperaceae	*Mariscus alternifolius*	-	-	+	+
	Mariscus longibracteatus	-	+	+	+
Euphorbiaceae	*Croton lobatus*	-	-	+	+
	Euphorbia hirta	Garden spurge,	+	+	+

Table 4.2: Weed species recorded in the three Districts surveyed (cont'd)

Family	Weed Species	Common name	Mfantsiman	Gomoa East	Akuapim South
	Malotus oppositifolius	-	+	+	+
	Phyllanthus amarus	-	+	+	+
	Acalypha ciliata	Copper-leaf plant	+	+	+
Leguminosae	*Centrosema pubescence*	Centrosema	+	+	+
Leguminosae	*Baphia nitida*	-	+	-	+
	Crotalaria retusa	rattlebox	+	-	+
Loganiaceae	*Spigelia anthelmia*	Wormbush, pink weed	+	+	+
Malvaceae	*Sida rhombifolia*	Wireweed, cubajute	+	-	+
Moraceae	*Ficus exasperata*	Sandpaper tree	+	-	-
Poaceae	*Eleusine indica*	Goosegrass, bullgrass	-	-	+
	Bracharia lata	-	+	+	+
	Panicum maximum	Guineagrass	+	+	+
	Digitaria horizontalis	Digitgrass, crabgrass	+	+	+
	Digitaria insularis	-	+	+	+
	Paspalum orbiculare	Ditch millet	+	+	+
	Rottboellia cochinchinensis	Itchgrass	+	+	+
	Eragrostis ciliaris	Lovegrass	+	+	+
	Setaria barbata	Bristly foxtail	+	+	+
	Bracharia deflexa	-	+	+	+
Portulacaceae	*Talinum triangulare*	Waterleaf	+	+	+
Smilacaceae	*Smilax*	West African sarsaparilla	-	-	+
Urticaceae	*Fluerya aestuans*	Tropical nettleweed	-	+	-
Verbanaceae	*Clerodendrum thomsoniae*	-	+	+	+
	Lantana camara	-	+	+	+
Number of Weeds Identified			**29**	**34**	**40**

- *indicates absent in the District*

+ *indicates present in the District*

4.1.3 Frequencies and distribution of recorded weeds

The frequency of the weed species ranged up to 57 for *Brachiara lata*. Twenty four out the 43 weeds had total frequencies less than 10. Mfantsiman District had a total frequency of 169, Gomoa East, 201 whiles Akuapim South had 242. Out of the 43 weed species recorded, nine were prominent and common to all three Districts. These were *Panicum maximum, Chromolaena odorata, Commelina diffusa, Digitaria horizontalis, Ageratum conyzoides, Rottboelia cochinchinensis, Euphorbia hirta, Talinum triangulare* and *Paspalum orbiculare*. These were independent of location ($\chi^2 < 5.99$) and are thus considered general to pineapple production in Ghana.

Prominent, but specific to location ($\chi^2 > 5.99$) were *Brachiara lata, Centrosema pubescence, Malotus oppositifolius, Croton lobatus, Digitaria insularis, Baphia nitida, Clerodendrum, Mariscus alternifolius, Lantana camara* and *Amaranthus spinosus*. The weed species recorded in the three Districts together with their frequencies are presented in Table 4.3.

4.1.4 Population density of recorded weeds

The Mean Population Density of the weed species ranged from 1 plant per metre square as in the case of *Fluerya aestuans* to about 9 plants per metre square as in the case of *Ageraturm conyzoides* across the three Districts. Majority of the weed species however recorded between 2 to 4 plants per metre square. Mfantsiman District recorded the least mean population density of 2.81 ± 0.17, followed by Akuapim South with 3.57 ± 0.43, whiles Gomoa East had the highest with 4.04 ± 0.57. Within the Districts, *Baphia nitida* had the highest population density in Mfantsiman with 5.4 ± 0.21, just about the same a *Chromolaena odorata* which was 5.3 ± 1.40, with *Rottboelia cochinensis* being the least with 1.3 ± 0.3.

In Gomoa East, *Eragrostis ciliaris* had the highest population density of 16.0 ± 8.00, though with only two cases (Table 4.4). The least mean population density of 1.0 per metre square was recorded by five weed species: *Mormodica charantia*, *Acalypha ciliata*, *Rottboelia cochinchinesis, Fluerya aestuans* and *Lantana camara*. *Ageratum conyzoides* had the highest mean population density of 18.5 ± 16.5 (with only two cases) in the Akuapim South District whiles *Vernonia cinerea* trailed last with a ppulation density of 1.6 ± 0.2. (Table 4.4)

Table 4.3: Frequencies and Chi-squares of prominent weeds identified in the three Districts

Weed Species	Mfantsiman	Gomoa East	Akuapim South	Total	χ^2
Bracharia lata	3	36	18	**57**	**30.25**
Centrosema pubescence	5	25	16	**46**	**12.51**
Panicum maximum	16	15	14	**45**	**1.89**
Chromolaena odorata	15	12	13	**40**	**2.05**
Malotus oppositifolius	16	3	20	**39**	**12.06**
Commelina diffusa	10	9	12	**31**	**0.37**
Croton lobatus	0	17	8	**25**	**17.52**
Baphia nitida	23	0	1	**24**	**57.5**
Digitaria horizontalis	9	7	8	**24**	**1.17**
Digitaria insularis	2	5	15	**22**	**8.37**
Mariscus alternifolius	0	13	7	**20**	**12.43**
Ageratum conyzoides	2	9	8	**19**	**3.43**
Lantana camara	8	1	10	**19**	**6.82**
Rottboellia cochinchinensis	5	3	9	**17**	**2.04**
Euphorbia hirta	4	6	6	**16**	**0.18**
Clerodendrum thomsoniae	9	5	1	**15**	**9.89**
Talinum triangulare	2	3	8	**13**	**2.77**
Paspalum orbiculare	2	4	5	**11**	**0.52**
Others	38	28	63	**129**	
	169	**201**	**242**		

Table 4.4: Population density of weeds recorded from the survey

Weed Species	Mfantsiman		Gomoa East		Akuapim South		Grand mean ±	
	Mean ±	S.E.M	Mean ±	S. E. M	Mean ±	S.E.M	S. E. M	
Bracharia lata	1.4	0.3	8.4	0.82	5.6	3	**5.13**	**1.52**
Centrosema pubescence	1.8	0.6	3	0.39	3.2	0.34	**2.67**	**0.34**
Panicum maximum	1.5	0.5	2.3	0.79	1.8	0.1	**1.87**	**0.28**
Chromolaena odorata	5.3	1.4	4.9	2.68	5.1	2.3	**5.1**	**0.98**
Malotus oppositifolius	4.3	0.24	2.3	0.33	4.4	0.62	**3.67**	**0.47**
Commelina diffusa	4.5	0.54	2.2	0.32	3.2	0.67	**3.3**	**0.48**
Croton lobatus	0	-	2.1	0.3	1.8	0.51	**1.95**	**0.26**
Baphia nitida	5.4	0.21	0	-	2	0	**3.7**	**0.99**
Digitaria horizontalis	2.8	0.6	4.4	2.91	4.2	0.75	**3.8**	**0.85**
Digitaria insularis	1.8	0.5	4.6	0.95	5.2	1.6	**3.87**	**0.83**
Mariscus alternifolius	0	-	4.6	0.66	3.2	0.35	**3.9**	**0.51**
Ageratum conyzoides	3.5	0.5	4.7	1.47	18.5	16.5	**8.9**	**5.25**
Lantana camara	3.2	0.62	1	0	3.5	1.3	**2.57**	**0.62**
Rottboellia cochinchinensis	1.3	0.3	1	0	2.5	0.12	**1.6**	**0.3**
Euphorbia hirta	2.8	0.32	3.3	1.2	3.1	0.72	**3.07**	**0.38**
Clerodendrum thomsoniae	3.8	0.75	2.6	0.68	3	0	**3.13**	**0.34**
Talinum triangulare	3	0.5	12	6.08	3.5	1.43	**6.17**	**2.46**
Paspalum orbiculare	2.1	0.65	7.5	0.96	3.9	0.52	**4.5**	**1.06**

4.1.5 Classification of weeds by morphology

When the weeds were grouped by morphologically, broadleaves dominated in all three Districts with Mfantsiman recording 72.8%, Gomoa East, 54.2% and Akuapim South recording 63.6%. Sedges, on the other hand, were minimal across all three Districts; none was found at Mfantsiman, only 8.5% at Gomoa East and 3.7% at Akuapim South (Figure 4.1)

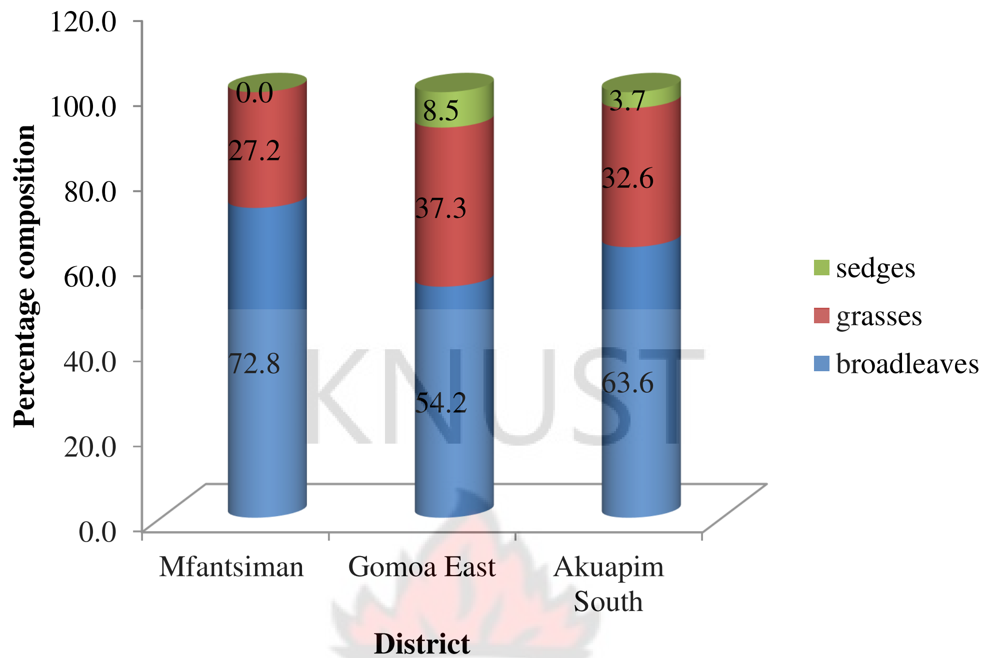

Figure 4.1: Weed species composition classified morphologically

4.1.6 Classification of weeds by life cycle

On disaggregating the total percentage of weeds of each District according to their life cycles (perennials, biennials and annuals), it was evident that perennial weeds dominated in the Mfantsiman District with 71.6%. The situation was, however, different in Gomoa East which recorded more annuals (53.7%) than perennials (46.3%). In Akuapim South, perennial weeds were similar in proportion to the annuals. Biennials were not recorded from any of the Districts in the survey. The results are presented in Figure 4.2.

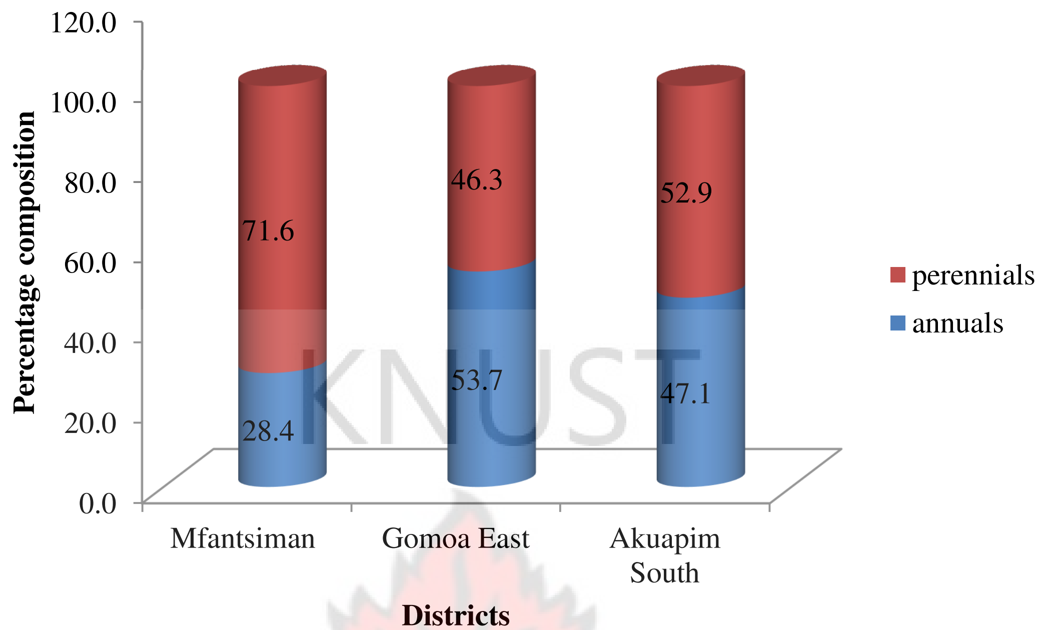

Figure 4.2: Species of weed composition classified by life cycle

4.2 Relationship Between Weeds and the Pineapple Mealybugs

4.2.1 Identification of Pineapple mealybugs and their tending ants

Of the two important mealybugs associated with pineapples throughout the world, only the Pink Pineapple Mealybug (*Dysmiccocus brevipes*) (Hemiptera: Pseudococcidae) was found in the areas of survey.

Four ant genera were, however, found across the three Districts, with *Crematogaster* (the heart shaped ant) and *Solenopsis* (the fire ant) being present in all three Districts. *Pheidole* ants were not found associated with pineapple mealybugs in Akuapim South and neither was *Campanotus* found associated with pineapple mealybugs in Mfantsiman and Gomoa East. The results are presented in Table 4.5 and 4.6 respectively.

Table 4.5: Species of Mealybugs Found on Pineapples in the three Districts

	Gray Pineapple Mealybug	**Pink Pineapple Mealybug**
Mfantsiman	-	+
Gomoa East	-	+
Akuapim South	-	+

Table 4.6: Ant Genera Associated with Pineapple Mealybugs in the three Districts

	Crematogaster	***Pheidole***	***Campanotus***	***Solenopsis***
Mfantsiman	+	+	-	+
Gomoa East	+	+	-	+
Akuapim South	+	-	+	+

4.2.2 Prevalence of mealybugs and their tending ants

Mfantsiman District recorded the highest number of mealybugs per plant (78), being significantly different from the other two Districts which hovered between 20 and 30 mealybugs per plant (Figure 4.3).

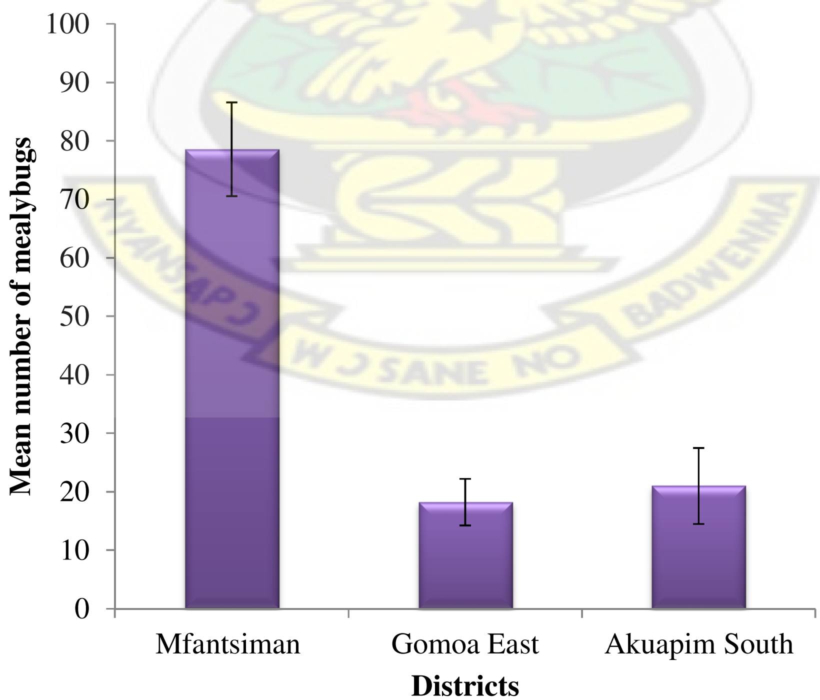

Figure 4.3: Mean Number of *D. brevipes* per plant in the three Districts

4.2.3 Success rate in the control of the pineapple mealybug in the three Districts

All farmers in the Mfantsiman District conceded not being able to control the mealybugs. Eighty per cent of farmers in Gomoa East District claimed to have successfully controlled the mealybugs with the remaining 20% being partially successful in its control. In the Akuapim South District, 60% of the farmers indicated partial success in the control whiles 20% indicated full control with the remaining 20% indicating no success in the control (Figures 4.4).

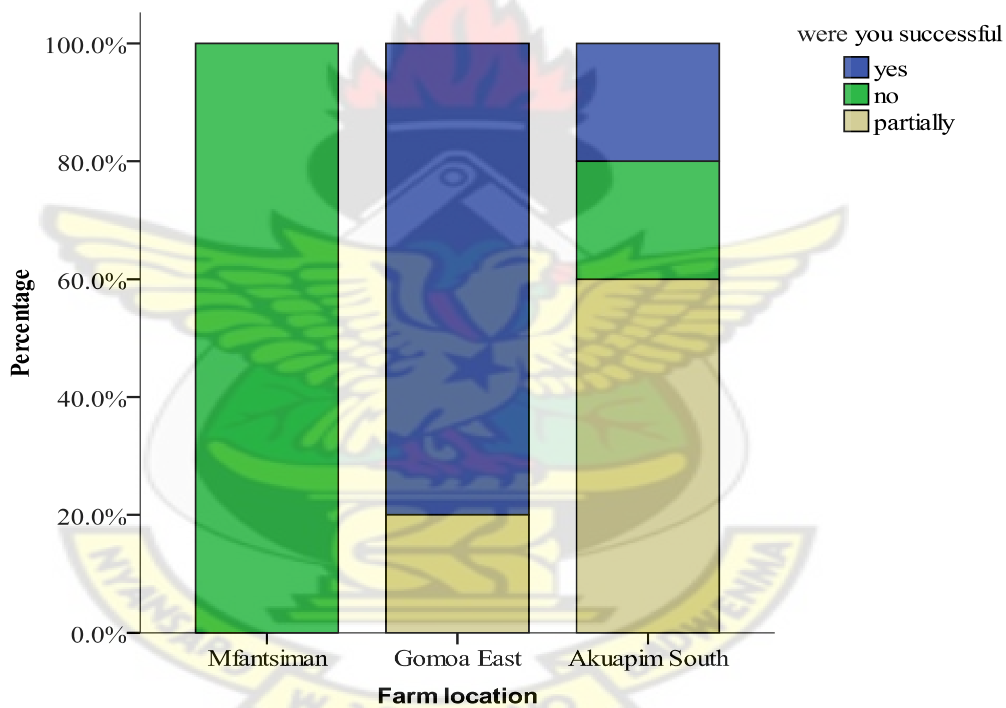

Figure 4.4: Success in the control of mealybugs by farmers

4.2.4 Farmers observation of part of pineapple plant infested by the mealybugs

All farmers interviewed had some knowledge of the pineapple mealybug and had had a first-hand experience of them. Differences, however, existed between which part of the plant they observed them and the stage of the plant when observed. All the respondents had seen them on fruits, 15% had seen them on leaves whiles another 15% had seen them the stem. Seventy five per cent said they had seen them on roots and leaf bases (Figures 4.5).

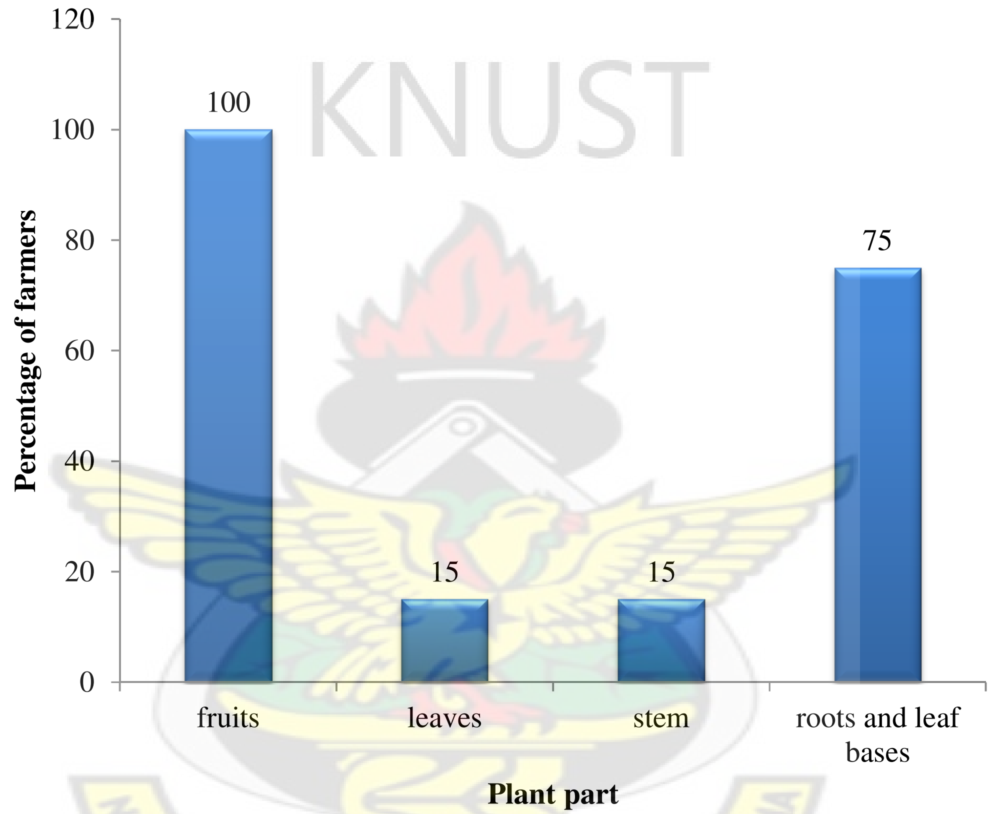

Figure 4.5: Parts of pineapple plant habouring mealybugs as observed by farmers

4.2.5 Farmers observations on period of attack by mealybugs

Majority (73%) of the farmers indicated that the mealybugs attack the crop both before and after forcing, while 27% indicated that the mealybugs are prevalent only after forcing. None of them indicated the mealybug attack was only before forcing and not after (Figure 4.6).

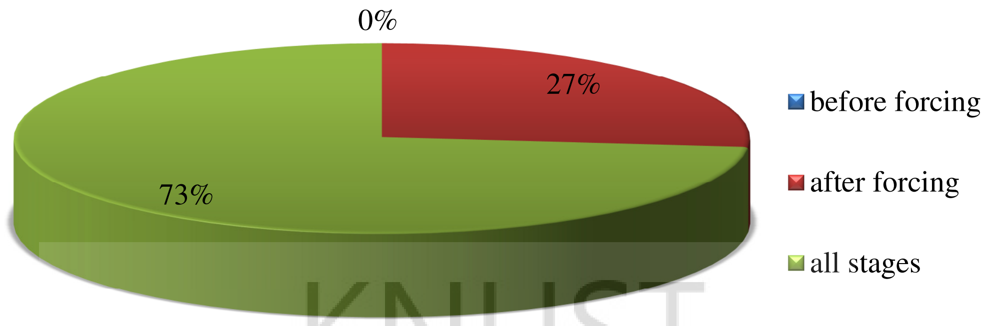

Figure 4.6: Period of infestation of mealybugs as observed by farmers

4.2.6 Farmers perception of economic importance of Pineapple mealybugs

Although farmers had a fair knowledge of the pineapple mealybugs, they had little to say about their economic importance. Whiles 53.3% admitted that the mealybugs reduce market value of the fruits, 40% believed that the mealybugs reduce growth and yield of pineapples. 13.3% raised issues about quarantine importance of the mealybugs. 6.7% of the farmers did not know of any effect of the mealybugs on the pineapples. None of the farmers interviewed associated the mealybugs with pineapple wilt (Figure 4.7).

4.2.7 Farmers observations of pineapple mealybugs on weeds

When asked whether they had observed the pineapple mealybugs on any weed, all the farmers responded in the negative. A few, however, indicated they had seen some mealybugs on some plants such as cassava, pawpaw and some ornamental plants, but could not confirm whether they were the same as on the pineapples.

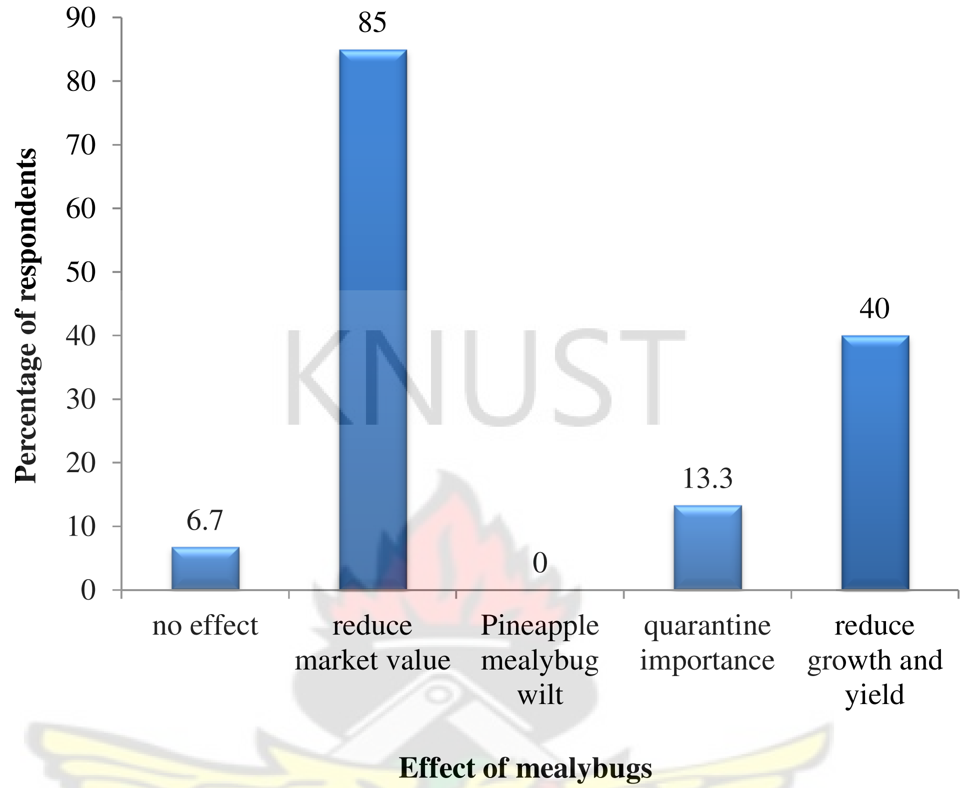

Figure 4.7: Economic importance of pineapple mealybugs as observed by farmers

4.2.8 Relationship between method of weed control and success in control of the pineapple mealybug

Table 4.7 is a cross-tabulation between method of weed control and success in control of mealybugs. Four out of the five farmers practising solely manual weeding have not been able to control the mealybug, with the remaining percentage achieving only partial success. The two farmers who were combining manual weeding with herbicides had both not been successful in the control of the mealybug whiles five out of eight farmers combining plastic mulch and herbicides had been successful. Three of these, however, were only partially successful. In all, only five farmers claimed to have been successful and were all using plastic mulch with herbicides. Of the six who had not been successful, four were using manual means to control weeds with the other two combining manual weeding and herbicides. Method of weed control did not seem to have a direct relationship with success in the control of the mealybug.

Table 4.7: Cross-tabulation between methods of weed control and success in control of mealybugs

	Success in mealybug control			
	yes	**no**	**partially**	**Total**
Manual	0	4	1	**5**
Both manual and herbicides	0	2	0	**2**
Plastic mulch and herbicides	5	0	3	**8**
Total	**5**	**6**	**4**	**15**

4.2.9 Relationship between method of insect pest control and success in control of the pineapple mealybug

From Table 4.8, method of insect pest control seems to have a good relationship with success in control of the mealybug. All the 5 people who were successful in the control of the mealybugs were using an integrated approach (combining cultural and chemical methods). The three using only chemical approach were only partially successful whiles two out of three people using only cultural methods had not been successful with the last being only partially successful.

4.2.10 Relationship between training in pest management and success in control of the pineapple mealybug

Training of farmers had good impact on the success in the control of the mealybugs. Only one out of 10 trained farmers had not been successful in controlling the insects.

Four out of these had been partially successfully with five been completely successful. All untrained farmers had not been successful in controlling the mealybugs (Table 4.9)

Table 4.8: Cross-tabulation between methods of insect pest control and success in control of mealybugs

	Success in mealybug control			Total
	yes	**no**	**partially**	
Chemical	0	0	3	**3**
Cultural	0	2	1	**3**
Both cultural and chemical	5	0	0	**5**
None	0	4	0	**4**
Total	**5**	**6**	**4**	**15**

Table 4.9: Cross-tabulation between training in pest management and success in control of mealybugs

	Success in mealybug control			
	yes	**no**	**partially**	**Total**
Trained	5	1	4	**10**
Untrained	0	5	0	**5**
Total	**5**	**6**	**4**	**15**

4.2.11 Correlation between weeds, mealybugs and tending ants

Table 4.10 shows the correlation between tending ants, various weed groups and mealybug populations. It is clear that only the population density of the tending ants and adjacent pineapple fields were significantly correlated with the population of mealybugs. Population density of grasses was also significantly correlated with ant populations per plant but not with mealybugs populations per plant.

Table 4.3: Correlations with mealybug and ant populations per plant

	Population of Mealybugs per plant	**Population of Tending ants per plant**
Tending ants	0.59**	-
Density of weeds within field	0.45	0.37
Density of grasses within field	0.36	0.38
Density of broadleaves within field	0.39	0.35
Density of weeds adjacent to field	0.41	0.40
Density of grasses adjacent to field	0.47	0.49*
Density of broadleaves adjacent to field	0.34	0.41

4.2.12 Weeds Habouring Pineapple Mealybugs and their Tending Ants

Although weeds in some parts of the world have been implicated as habouring pineapple mealybugs, no weed was found habouring the mealybugs in this survey. A good number of weeds were however, found with the tending ants of the pineapple mealybugs and those which were found to be associated with them are shown in the contingency tables (Tables 4.11-15). *Panicum maximum*, *Chromolaena odorata* and *Fagara xanthxyloides* were found to be positively associated with the *Crematogaster* spp., whiles *Rottboelia cochinchinensis*, *Cassia occidentalis* and *Blumea aurita* were found to be associated with the *Camponotus* spp.

Table 4.4: Association between *Panicum maximum* and *Crematogaster* sp.

	Crematogaster	**No Crematogaster**	**Total**
Panicum	16	5	**21**
No *Panicum*	8	10	**18**
Total	**24**	**15**	**39**
[z]G-test	**4.186**		
[y]Dice index	**0.76**		
[x]Association	**+**		

[z] If $G < \chi^2_{.05[1]}$, then accept the null hypothesis that *Crematogaster* is independent of *Panicum*; if $G > \chi^2_{.05[1]}$, then reject the null hypothesis. $\chi^2_{.05[1]} = 3.841$.

[y] Values above 0.5 indicate a positive association.

[x] "+" indicates that two species are found together more frequently than probable by chance.
"0" indicates that two species are probably found together or apart by chance.

Table 4.5: Association between *Chromolaena odorata* and *Crematogaster* spp.

	Crematogaster	No Crematogaster	Total
Chromolaena	11	3	**14**
No *Chromolaena*	5	8	**13**
Total	**16**	**11**	**32**
[z]G-test	**4.267**		
[y]Dice index	**0.79**		
[x]Association	**+**		

[z] If $G < \chi^2_{.05[1]}$, then accept the null hypothesis that *Crematogaster* spp. is independent of the *Chromolaena* weed;

if $G > \chi^2_{.05[1]}$, then reject the null hypothesis. $\chi^2_{.05[1]} = 3.841$.

[y] Values above 0.5 indicate a positive association.

[x] "+" indicates that two species are found together more frequently than probable by chance.

"0" indicates that two species are probably found together or apart by chance.

Table 4.6: Association between *Fagara xanthoxyloides* and *Crematogaster* sp.

	Crematogaster	No Crematogaster	Total
Fagara	14	3	**17**
No *Fagara*	6	7	**13**
Total	**20**	**10**	**18**
[z]G-test	**4.402**		
[y]Dice index	**0.82**		
[x]Association	**+**		

[z] If $G < \chi^2_{.05[1]}$, then accept the null hypothesis that *Crematogaster* spp. is independent of the *Fagara* weed;

if $G > \chi^2_{.05[1]}$, then reject the null hypothesis. $\chi^2_{.05[1]} = 3.841$.

[y]Values above 0.5 indicate a positive association.

[x]"+" indicates that two species are found together more frequently than probable by chance.

"0" indicates that two species are probably found together or apart by chance.

Table 4.7: Contingency table of the association between *Blumea aurita* and *Camponotus* sp.

	Camponotus	No *Camponotus*	Total
Blumea	12	4	**16**
No *Blumea*	6	9	**15**
Total	**18**	**13**	**31**
[z]G-test	**3.98**		
[y]Dice index	**0.75**		
[x]Association	**+**		

[z] If $G < \chi^2_{.05[1]}$, then accept the null hypothesis that *Camponotus* is independent of *Blumea aurita*;
if $G > \chi^2_{.05[1]}$, then reject the null hypothesis. $\chi^2_{.05[1]} = 3.841$.
[y] Values above 0.5 indicate a positive association.
[x] "+" indicates that two species are found together more frequently than probable by chance.
"0" indicates that two species are probably found together or apart by chance.

Table 4.8: Contingency table of the association between *Cassia occidentale* and *Camponotus* sp.

	Camponotus	No *Camponotus*	Total
Cassia	12	5	**17**
No *Cassia*	4	9	**13**
Total	**16**	**14**	**30**
[z]G-test	**4.81**		
[y]Dice index	**0.71**		
[x]Association	**+**		

[z] If $G < \chi^2_{.05[1]}$, then accept the null hypothesis *Camponotus* is independent of *Cassia occidentale*;
if $G > \chi^2_{.05[1]}$, then reject the null hypothesis. $\chi^2_{.05[1]} = 3.841$.
[y]Values above 0.5 indicate a positive association.
[x]"+" indicates that two species are found together more frequently than probable by chance.
"0" indicates that two species are probably found together or apart by chance.

4.3 Field Experiment

4.3.1 Time taken for weeds to re-emergence

After the application of the treatments, weeds on the manually weeded plots after re-emerged 8 to 10 weeks. Weeds on the herbicide treated plots re-emerged after 39 weeks. Plots with plastic mulch suppressed re-emergence longer than their corresponding unmulched plots. Thus plastic mulch + synthetic herbicide recorded the longest period to re-emergence with 42 weeks (Table 4.16).

Table 4.9: Weeks to re-emergence of weeds after initial treatment in pineapple fields

TREATMENTS	Weeks to weed re-emergence after treatment
Weedy Check	-
Manual Weed	8
Synthetic herbicide	39
Plastic mulch + Manual Weeding	10
Plastic Mulch + Synthetic herbicide	42

4.3.2 Major weed species emerged

The major weed species which re-emerged after the application of treatments are presented in Table 4.17. It shows that *Panicum maximum* dominated in all the plots. The weeds were mainly of the Poaceae and Asteraceae families. Grasses dominated in the herbicide treated plots, whiles the manually weeded plots and the weedy check recorded both grasses in broadleaves in similar proportions.

Table 4.10: Major weed species recorded on the various treatments in pineapple fields

Treatments	Botanical name of weed	Family	Growth habit and morphology
Weedy Check	*Panicum maximum*	Poaceae	Perennial grass
	Desmodium scorpiurus	Leguminosae	Perennial broadleaf
	Digitaria insularis	Poaceae	Annual grass
	Tridax procumbens	Asteraceae	Annual broadleaf
	Talinum triangulare	Portulacacea	Perennial broadleaf
	Euphorbia hirta	Euphorbiaceae	Annual broadleaf
	Boerhavia erecta	Nyctaginaceae	Perennial broadleaf
	Syndrella nodiflora	Asteraceae	Annual broadleaf
	Eragrostis ciliaris	Poaceae	Annual grass
	Rynchelytrum repens	Poaceae	Annual grass
Manual Weeding	*Tridax procumbens*	Asteraceae	Annual broadleaf
	Syndrella nodiflora	Asteraceae	Annual broadleaf
	Boerhavia erecta	Nyctaginaceae	Perennial broadleaf
	Talinum triangulare	Portulacacea	Perennial broadleaf
	Panicum maximum	Poaceae	Perennial grass
Synthetic herbicide	*Panicum maximum*	Poaceae	Perennial grass
	Paspalum conjugatum	Poaceae	Perennial grass
	Cyperus		
Plastic mulch + Manual Weeding	*Syndrella nodiflora*	Asteraceae	Annual broadleaf
	Tridax procumbens	Asteraceae	Annual broadleaf
	Panicum maximum	Poaceae	Perennial grass
Plastic Mulch + Synthetic herbicide	*Panicum maximum*	Poaceae	Perennial grass
	Paspalum conjugatum	Poaceae	Perennial grass

4.3.3 Effect of weed management on diversity of weeds

The effects of the weed management methods on weed diversity, measured by the mean number of weed species, are presented in Table 4.18. The weedy check recorded the greatest number of species (7.1) followed by the manually weeded treatments with 4.8 and 4.6, respectively for manual weeding and plastic mulch + manual weeding. The herbicide treated plot recorded the least weed diversity of 1.8 and 1.3 for the synthetic herbicide and plastic mulch + synthetic, respectively. Except for the manually treated plots which did not show any significant difference ($p>0.05$), all other treatments were significantly different from each other.

Table 4.11: Effect of weed management on number of weed species recorded in pineapple fields

TREATMENTS	Number of weed species	
Weedy Check	2.8a	(7.1)
Manual Weed	2.3b	(4.8)
Synthetic herbicide	1.8c	(2.8)
Plastic mulch + Manual Weeding	2.2b	(4.6)
Plastic Mulch + Synthetic herbicide	1.3d	(1.2)
s. e. d.	**0.19**	
CV(%)	**28.54**	

Means followed by the different letters within a column are significantly different at the 5 % level according to DMRT.

Back transformed means are presented in brackets

4.3.4 Effect of weed management on population density of weeds

The population density at harvest was significantly affected by the weed management methods (Table 4.19). From the Table, the weedy check recorded the highest population density (11.8) and this was significantly different ($p< 0.05$) from the other treatments. Plastic mulch + synthetic herbicide recorded the least population density of weeds (1.11), significantly different ($p<0.05$) from the other treatments.

Table 4.19: Effect of weed management on number of weeds per m^2 in pineapple fields

TREATMENTS	Mean number of weeds/m^2 (before floral induction)	
Weedy Check	3.5a	(11.8)
Manual Weed	2.03b	(3.6)
Synthetic herbicide	1.91bc	(3.1)
Plastic mulch + Manual Weeding	1.79c	(2.3)
Plastic Mulch + Synthetic herbicide	1.27d	(1.1)
s. e. d.	**0.08**	
CV (%)	**36.78**	

Means followed by the different letters within a column are significantly different at the 5 % level according to DMRT

Back transformed means are presented in brackets

4.3.5 Effect of weed management on weed biomass

Table 4.20 shows the effect of weed management on the dry weight of weeds. The mean dry weight per m^2 ranged from 175.8 weeds/m^2, which was recorded by the plastic mulch + synthetic herbicide; to 3013.0 weeds/m^2, which was recorded by the weedy check. The various weeds management methods were all significantly different ($p<0.05$) from each other.

Table 4.12: Effect of weed management methods on dry weight of weeds

TREATMENTS	Mean dry weight of weeds (g/m^2) (before floral induction)	
Weedy Check	3.47a	(3013.0)
Manual Weed	3.25b	(1778.3)
Synthetic herbicide	2.66d	(457.1)
Plastic mulch + Manual Weeding	2.86c	(719.5)
Plastic Mulch + Synthetic herbicide	2.25e	(175.8)
s. e. d.	**0.0358**	
CV (%)	**15.43**	

Means followed by the different letters within a column are significantly different at the 5 % level according to DMRT

Back transformed means are presented in brackets

4.3.6 Efficiency of various weed management method

Table 4.21 shows the efficiency of the weed management methods over the weedy check. The results show that Plastic mulch + synthetic herbicide achieved the highest efficiency of 90.6%. This was followed by the Plastic mulch + manual weeding with 80.2%, synthetic herbicide with 73.4% and the manual weeding in that order.

4.3.7 Effect of weed management on plant height

Table 4.22 shows the effect of the weed management methods on the height of the pineapple plants. The treatments did not have any effect on the height of pineapple plants until eight months after planting (floral induction). Plastic mulch + synthetic herbicide recorded the highest plant height at forcing, but was not significantly different from Plastic mulch + manual weeding and synthetic herbicide treatment. The two plastic mulched treatments were however significantly different from the weedy check and manual weeding, although the synthetic herbicide alone was not.

Table 4.13: Efficiency of weed management methods over control

TREATMENTS	Weed control efficiency over weedy check (%)
Weedy Check	-
Manual Weed	69.2
Synthetic herbicide	73.4
Plastic mulch + Manual Weeding	80.2
Plastic Mulch + Synthetic herbicide	90.6

Table 4.14: Effect of Weed Management Methods on height of pineapple plants

TREATMENTS	Mean plant height (cm)			
	2MAP	**4MAP**	**6MAP**	**8MAP**
Weedy Check	57.2a	57.3a	75.1a	76.7a
Manual Weed	54.5a	60.3a	75.4a	82.5ab
Synthetic herbicide	59.1a	59.4a	78.0a	89.0bc
Plastic mulch + Manual Weeding	56.6a	60.1a	82.7a	90.5c
Plastic Mulch + Synthetic herbicide	58.2a	60.3a	80.3a	91.5c
s. e. d	**1.85**	**1.89**	**2.92**	**3.77**
CV (%)	**6.72**	**5.92**	**7.35**	**8.81**

Means followed by the different letters within a column are significantly different at the 5 % level according to DMRT

4.3.8 Effect of weed management on length of 'D' leaf

Table 4.23 shows the effect of weed management on the length of 'D' leaf. Although the two treatments with plastic mulch generally recorded longer 'D' leaves, differences were not significant until the fourth month. Significant differences were observed from the sixth month after planting. At floral induction, (8MAP) 'D' leaves from Plastic mulch + synthetic herbicide and the Plastic mulch + manual weeding were significantly longer than the weedy check and the manual weeding.

Table 4.15: Effect of Weed Management Methods on 'D' leaf length of pineapple plants

TREATMENTS	Mean 'D' leaf length (cm)			
	2MAP	**4MAP**	**6MAP**	**8MAP**
Weedy Check	59.5a	68.0a	70.6a	87.4a
Manual Weed	59.9a	67.0a	73.3ab	92.3ab
Synthetic herbicide	60.7a	74.2a	74.9ab	96.7bc
Plastic mulch + Manual Weeding	60.4a	72.7a	76.8bc	98.9bc
Plastic Mulch + Synthetic herbicide	61.2a	74.2a	79.0c	101.8c
s.e.d	**1.81**	**3.03**	**1.88**	**3.33**
CV (%)	**5.35**	**8.49**	**6.53**	**7.55**

Means followed by the different letters within a column are significantly different at the 5 % level according to DMRT

4.3.9 Effect of weed management on width of 'D' leaf

The result of the effect the weed management methods on the width of 'D' leaves are presented in Table 4.24. From the Table, significant differences were observed from the second month after planting with plastic mulch + synthetic herbicide recording the highest ‘D’ leaf width throughout the vegetative growth period. This was followed by the plastic mulch + manual weeding, though it was not significantly different from the former. Weedy check recorded the least ‘D’ leaf width through the vegetative growth period but was not significantly different (p>0.05) from the manual weeding.

Table 4.16: Effect of Weed Management Methods on ‘D’ leaf width of pineapple plants

TREATMENTS	Mean ‘D’ leaf width (cm)			
	2MAP	**4MAP**	**6MAP**	**8MAP**
Weedy Check	3.6a	3.6a	5.4a	6.2a
Manual Weed	3.8ab	4.0b	5.6a	6.5a
Synthetic herbicide	3.7ab	4.3c	6.7b	7.3bc
Plastic mulch + Manual Weeding	3. 8b	4.5cd	6.9b	7.7c
Plastic Mulch + Synthetic herbicide	3.9b	4.6d	6.9b	7.9c
s.e.d	**0.08**	**0.14**	**0.43**	**0.46**
CV (%)	**4.91**	**10.10**	**14.1**	**10.63**

Means followed by the different letters within a column are significantly different at the 5 % level according to DMRT

4.3.10 Effect of weed management on weight of ‘D’ leaf

Significant differences were observed in the weight of ‘D’ leaves from the sixth month after planting (Table 4.25). The two mulched treatments gave the highest weights and did not show any differences throughout the growth period. The weedy check recorded the least weight which was significantly different from the two plastic mulched treatments, but not the manual manually weeded and synthetic herbicide treated plots.

Table 4.17: Effect of Weed Management Methods on 'D' leaf weight of pineapple plants

TREATMENTS	Mean 'D' leaf weight (g)			
	2MAP	**4MAP**	**6MAP**	**8MAP**
Weedy Check	28.25a	28.59a	38.38a	40.63a
Manual Weed	28.71a	29.42a	39.43a	43.11ab
Synthetic herbicide	29.03a	29.38a	40.67a	46.34bc
Plastic mulch + Manual Weeding	28.03a	31.92a	46.38b	47.52bc
Plastic Mulch + Synthetic herbicide	29.52a	32.73a	46.78b	49.15c
s. e. d.	**1.21**	**2.50**	**2.17**	**2.58**
CV (%)	**10.08**	**15.01**	**11.78**	**11.49**

Means followed by the different letters within a column are significantly different at the 5 % level according to DMRT

4.3.11 Effect of weed management on weight of plant

The two plastic mulched treatments recorded the highest plant weight with no significant differences between them. The two were, however, significantly higher in their effect than the weedy check and the manually weeded treatments. The synthetic herbicide only treatment recorded figures between the two plastic mulched treatments on one hand, and the weedy check and manual weeding on the other hand, but was not significantly different from either sides (Table 4.26).

Table 4.18: Effect of Weed Management Methods on weight of pineapple plants

TREATMENTS	Mean plant weight at forcing (kg)
Weedy Check	2.25a
Manual Weed	2.51a
Synthetic herbicide	2.84ab
Plastic mulch + Manual Weeding	3.08b
Plastic Mulch + Synthetic herbicide	3.45b
s. e. d	**0.31**
CV (%)	**18.42**

Means followed by the different letters within a column are significantly different at the 5 % level according to DMRT

4.3.12 Effect of weed management on weight of fruits

The mean fruit weight recorded from the various treatments are presented in Table 4.27. The results show that the highest yield was recorded from the plastic mulch + synthetic herbicide though it was again not significantly different from the effect of the plastic mulch + manual weeding. Weedy check and the manual weeding did not show significant difference. The fruit yield from the synthetic herbicide treatment was significantly higher than that of the weedy check, but was significantly lower than the two plastic mulch treatment effects.

Table 4.19: Effect of weed management methods on mean fruit weight of pineapple plants

TREATMENTS	mean fruit weight (kg)
Weedy Check	1.40a
Manual Weed	1.56ab
Synthetic herbicide	1.61b
Plastic mulch + Manual Weeding	1.82c
Plastic Mulch + Synthetic herbicide	1.95c
s. e. d	**0.09**
CV (%)	**14.78**

Means followed by the different letters within a column are significantly different at the 5 % level according to DMRT

4.3.13 Effect of weed management on marketability of fruits

Table 4.28 shows the mean percentage marketable fruit recorded from the various treatments. It indicates that the least percentage marketable fruits was recorded from the weedy check and this was significantly lower than the manual weeding. The highest record from the plastic mulch + synthetic herbicide and this was significantly higher than the plastic mulch + manual weeding. The synthetic herbicide (only) treatment was recorded significantly higher percentage marketable fruit than the weedy check and manual weeding, but was not significantly different from the plastic mulch + manual weeding.

Table 4.20: Effect of weed management methods on percentage exportable pineapple fruits

TREATMENTS	Percentage marketable fruits	
Weedy Check	35.02a	(32.90)
Manual Weed	44.2b	(48.56)
Synthetic herbicide	60.82c	(76.18)
Plastic mulch + Manual Weeding	62.48c	(78.60)
Plastic Mulch + Synthetic herbicide	66.49d	(84.04)
s. e. d	**1.36**	
CV (%)	**23.26**	

Means followed by the different letters within a column are significantly different at the 5 % level according to DMRT

Back transformed means are presented in brackets

4.3.14 Effect of weed management on number of mealybugs per fruit

Table 4.29 shows the effect of weed management methods on the mean number of mealybugs per fruit recorded during the experiment. Weedy check recorded the highest number and this was significantly different from the other treatments. No significant differences were observed among the other four treatments.

4.3.15 Effect of weed management on number of mealybugs in root zone

The treatments did not show any significant differences in the mean number of mealybugs in the root zone. (Table 4.30)

Table 4.29: Mean number of mealybugs per pineapple fruit at harvest

TREATMENTS	Mean number of mealybugs per fruit	
Weedy Check	8.9a	(78.9)
Manual Weed	7.1b	(50.3)
Synthetic herbicide	7.3b	(53.0)
Plastic mulch + Manual Weeding	7.6b	(57.6)
Plastic Mulch + Synthetic herbicide	7.5b	(55.2)
s. e. d.	**0.24**	
CV (%)	**9.89**	

Means followed by the different letters within a column are significantly different at the 5 % level according to DMRT

Back transformed means are presented in brackets

Table 4.30: Mean number of mealybugs in root zone at harvest

TREATMENTS	Mean number of mealybugs per fruit	
Weedy Check	6.04a	(35.98)
Manual Weed	5.94a	(34.78)
Synthetic herbicide	5.58a	(30.64)
Plastic mulch + Manual Weeding	5.96a	(35.02)
Plastic Mulch + Synthetic herbicide	6.31a	(39.32)
s. e. d.	**0.49**	
CV (%)	**11.54**	

Means followed by the different letters within a column are significantly different at the 5 % level according to DMRT

Back transformed means are presented in brackets

4.3.16 Cost: benefit analysis of pineapple production under the weed management methods

Table 4.32 shows the gross revenue, the total cost and profit margins estimates for cultivating pineapple under the weed management method evaluated. The calculations assume that all other expenses, apart from the weed management, are the same. It shows that production under plastic mulch + synthetic herbicide is most profitable, though most expensive. This is followed by the plastic mulch + manual weeding, the synthetic herbicide, the manual weeding and then the weedy check in that order.

Table 4.21: Profitability of production under weed management methods

TREATMENTS	Gross Revenue (GH¢)	Total cost (GH¢)	Profit (GH¢)
Weedy Check	5535.55	2756	2779.55
Manual Weed	9068.02	3656	5412.02
Synthetic herbicide	14755.16	2906	11849.16
Plastic mulch + Manual Weeding	17129.58	3167	13962.58
Plastic Mulch + Synthetic herbicide	19706.66	3092	16614.66

CHAPTER FIVE

5.0 DISCUSSION

5.1 Weeds species composition of found in pineapple fields in the three Districts

A total number of 43 weed species from 16 families were recorded across the three Districts during the survey. This indicates a wider range of weed species associated with pineapple production in Ghana, as compared to the 20 weed species from 10 families reported in Australia by the Office of the Gene Technology Regulator of the Government of Australia (OGTRGA) (2008). However the number reported in this study is much lower than the 209 species from 59 families recorded in South Eastern Cote d'Ivoire (Mangara *et al.,* 2008). The wide variation in the number of weed species found in pineapple fields from across the globe is indicative of the fact that each production area has its spectrum of weeds, determined by the land-use system, cropping system and the soil and climatic factors (Rohrbach and Johnson, 2003; Akobundu, 1987). This variation in number of weed species associated with pineapple production was also observed between the three Districts surveyed. As stated above, this is as a result of the differences in soil and climatic factors, and the management practices carried out on the farms in the three Districts.

Despite the variations, the plant families of Asteraceae and Poaceae were dominant in all three locations. This was expected, since these two families are actually the largest families of the dicotyledons and monocotyledons, respectively. The other frequently occurring families: Euphorbiaceae, which had five species, and Cyperaceae and Verbanaceae, both of which had two species each, together with Amaranthaceae and Leguminosae have been reported to constitute important weed families in Cote d'Ivoire's pineapple plantations and perhaps may be attributed to the fact that they have better survival mechanisms in the areas of pineapple production (Mangara *et al.*, 2008).

Twenty four out of the 43 weed species, however, recorded frequencies less than 10 and hence may be considered less important. Nevertheless, Naylor (2002) indicated that though the occurrence of a single weed in a field may not be considered important to the yield of the crop, it can give rise to a large population of weeds which can greatly affect yield with uninterrupted growth. It thus becomes necessary to consider them in control programmes.

Table 4.2 shows that *Panicum maximum, Chromolaena odorata, Commelina diffusa, Digitaria horizontalis, Ageratum conyzoides, Rottboelia cochinchinensis, Euphorbia hirta, Talinum triangulare* and *Paspalum conjugatum* were prominent (frequency $\geq$ 10) and independent of the three Districts surveyed ($\chi^2 < 5.99$). These weeds have been named as problem weeds in pineapple production in various parts of the world (Akobundu, 1987; Rohrbach and Johnson, 2003; Mangara *et al.*, 2008). Their presence in all three Districts indicates their ability to grow in a wide range of conditions and this is made possible by various survival mechanisms.

Panicum maximum has been described as a highly successful invader in the tropics (Anonymous, 2011). It is very competitive, highly resistant to fire, and quickly invades gaps left in natural vegetation after fire (Anonymous, 2011). Duke (1983) stated that *Panicum maximum* grows well on a wide range of well-drained soils and is suited to areas of 870 mm to 1000 mm of rainfall. With sufficient moisture, Duke

(1983) noted that, *Panicum maximum* grows extremely rapidly and for this reason, *P. maximum* could be a very troublesome weed in pineapple in view of the slow growth of pineapple. From Table 4.2, *P. maximum* is among the 10 most frequent occurring weeds in the pineapple fields and this gives cause for action.

Chromolaena odorata has been listed among the major invasive alien species in Ghana (Council for Scientific and Industrial Research (CSIR), 2010), where it forms dense stands that prevent the establishment of other plant species. It also interferes with small-crop agriculture and forestry activities. Dense thickets restrict access to infested areas and markedly reduce grazing. Oils in the leaves make the plants highly inflammable. The high frequency of occurrence of this weed also needs to be looked at since it can devastate large plantation of the crop with time.

The main differences between the three Districts surveyed rests within the climate, the natural vegetation, the soil type and the agronomic practices carried out on the pineapple farms (Table 4.1). These are perhaps the major contributing factors to the differences in distribution and abundance of weed species in the three Districts (Akobundu, 1987).

From Table 4.1, Mfantsiman District has the least amount of rainfall, and the soils are mainly unfertile marginal soils which do not support most heavy feeding arable crops. The natural vegetation however, is mainly made up of perennial shrubs. Most farmers in the Mfantsiman District do not have access to heavy duty machines and hence often clear the land by the slashing and burning. The remaining stumps are hardly gotten rid off, hence it is clear that the dominant weeds are woody perennial weeds like *Baphia* *nitida*, *Clerodendrum thomsoniae*, *Lantana camara*, *Malotus oppositifolius* and *Chromolaena odorata*, with a few perennial grasses such as *Panicum maximum*. Once the initial land clearing is partially carried out, plastic mulches can hardly be used, as ridges cannot be formed easily. The presence of stumps (which subsequently sprout again into full shrubs) first reduce planting density since they occupy spaces meant for the pineapple plants and soon shade out the slow growing pineapple plants, depriving them of sunlight. Control of these shrubs is mainly by manual means, thus it is a quite common to see farmers in this area hire labourers at huge costs to weed their fields. Chemical control of such shrubs is ineffective and manual control lasts only for a while. The cost of weed control in pineapple fields in the Mfantsiman District thus constitutes a high percentage of the total cost of production of pineapples.

The net effect of these weeds however, is not clear. *Baphia nitida* is a legume and thus, fixes nitrogen to the soil. *Chromolaena* has been reported by Gnonhouri *et al.* (2002) as having nematicidal abilities against the *Pratylenchus brachyurus* which is a major nematode pest of pineapple across West Africa. The presence of *Chromolaena* could thus be beneficial in the control of this nematode.

Gomoa East District is characterized by better soil types (Table 4.1) and moderate amount of rainfall compared to the Mfantsiman District. The natural vegetations seems to have been depleted and taken over by perennial grasses (mainly *Panicum maximum*), making the land easier to cultivate than in Mfantsiman District. Thus a wider range of weed species was recorded for Gomoa East because of better soil and climatic conditions which support a wider range of weeds. Again, farmers in the District are mostly large scale producers who employ bigger farm machinery, especially the tractor mounted boon sprayer to carry out most cultural practices. The use of the boon sprayer in the application of fertilizers results in spillovers in between the plastic-mulched ridged where the weeds grow. The survey indicated that *Brachiaria lata* was the most frequently occurring weed species, although the Chi-square test of independence shows that it is localized to the Gomoa East and Akuapim South Districts. This is probably because *Brachiaria* spp, is highly responsive to nitrogen fertilizer (Boonman, 1993) and thus easily establishes after application of fertilizers to the field by the boon sprayer. According to Boonman (1993), *Brachiaria* spp easily establishes to form a dense, and rather aggressive sward and is difficult to eradicate.

The Akuapim South District consists of areas with high rainfall (the semi-deciduous forest) as well as areas with moderate rainfall amounts comparable to the Gomoa East. Pineapple cultivation is common in the drier areas than in the forest areas. Again, the undulating nature of the land demands that pineapple be cultivated on the lower portions of the slope, and in the valley bottom. Soils here are also of better quality than Mfantsiman (Table 4.1) and comparable to the Gomoa East District. The natural vegetation of the areas where pineapple is grown is as well similar to Gomoa East: mainly perennial grasses and herbaceous broadleaves with few trees interspersed. Weed management in this District varies from farm to farm: small scale farmers use a combination of herbicides and manual weeding whiles the large scale farmer mainly use plastic mulches and herbicides.

The varying factors in the area, compared to the first two Districts, presents the reason for a wider range of weed species observed here. Varying rainfall, altitude, natural vegetation and management practices are expected to leave a wider range of weed species. Thus prominent weeds here are a combination of woody shrubs such as *Chromolaena odorata, Lantana camara, Mallotus oppositifolious*, and grasses such as *Brachiaria lata, Panicum maximum*, and *Digitaria insularis*. It is necessary to note the wide range of weeds demand an integrated approach in their control in order to promote the growth of the slow growing pineapple plant.

5.2 Relationship between Pineapple mealybugs, ants and weeds

Though a number of mealybug species have been declared as pests of pineapples, *Dysmiccocus brevipes* and *Dysmiccocus neobrevipes* have been named as the two most important mealybug species associated with pineapple production across the globe (Jahn *et al.*, 2003). The results from the survey indicated that only *D. brevipes* was found in the areas surveyed. This confirms earlier findings (Beardsley, 1993; Jahn*et al.*, 2003) that only *D. brevipes* is known to attack pineapples in Africa. *D. neobrevipes*, along with the other species of mealybugs which attack pineapples in other parts of the world, have not yet been recorded in Africa.

Four ant genera were recorded from the survey. Three out of the four genera (*Crematogaster, Camponotus* and *Pheidole*) identified have already been reported as been associated with the pineapple mealybugs in West Africa (Real, 1959; Jahn *et al.,* 2003). *Solenopsis*, though known to be associated with the mealybugs in other parts of the world had not yet been reported in West Africa prior to this study.

The fact that all famers interviewed had some knowledge about the mealybugs indicates that the insect pest is widespread and of concern to farmers. This is confirmed by the high percentage of farmers who claimed to have been unsuccessful in controlling the mealybug.

Farmers however had different views on the plant part they attack apart from the fruit. Majority of them confirmed seeing the insects on the leaves and roots as well, with a few saying they have observed them on leaves and peduncle. Their observation confirms what has been reported by Jahn *et al.* (2003) who noted that the mealybug is usually found below and just above the ground; on the roots and stems. González-Hernández (1995), however, reported that in the absence of *D. neobrevipes*, *D. brevipes* may also occur on the aerial parts of the plant.

Farmers also had divergent views on the economic importance of the mealybug. Whiles majority of them rather complained about reduction in growth and yield of the plant, others were worried about the reduction of the market value of the fruits. The farmers however, did not associate the pineapple wilt to the mealybugs. This may have been so because the farmers did not observe increased populations of the mealybugs in the dry periods when the wilt was most severe. Trials conducted in the dry season showed that the pineapple mealybugs rather hid from the scorching sun to avoid dessication (field surveys, unpublished), hence were not easily observed.

5.3 Weeds associated with the pineapple mealybugs and their tending ants

Despite the widely accepted notion that some weeds serve as alternative hosts to the pineapple mealybugs, the situation seemed different in the areas surveyed. No weeds were found with the mealybugs. This was confirmed by the inability of the farmers to point to any weed which haboured the mealybug despite their varying long years of farming experience. This disagrees with the findings of Pandey and Johnson (2006) who found a number of weeds which haboured the pineapple mealybugs including *Panicum maximum* and *Paspalum* spp which are common weeds in pineapple farms as stated earlier. This may due to the fact that the population of mealybugs on the farms had not built up to high levels to make their preferred hosts (the pineapple) inadequate. Thus, with the abundance of the preferred substrate, the pest will have no need to visit an alternative substrate.

The tending ants of the mealybugs, as identified earlier, were rather haboured by some weeds. Perhaps then, the mealybugs are transmitted from generation to generation by propagating materials and rather attract the ants from the weeds to protect them.

5.4 Effect of weed management methods on weeds

The primary aim of weed management is to keep weeds below the economic threshold (Naylor, 2002) for as long as possible especially during the early growing and fruiting stages. Hence, one major criterion for measuring the effectiveness of a weed management system is the time taken for weeds to re-emerge. The results show that Plastic mulch + synthetic herbicide was able to suppress weed growth for the longest period. This is the result of the use of the pre-emergent herbicide, diuron which is reportedly able to suppress weed growth up to a year (Anonymous, 2005). This was enhanced by the plastic mulch which also prevented the germination of weed seeds. Plots treated with synthetic herbicide also last almost the same length of period for the same reason of the pre-emergent herbicide. Nevertheless, they lacked the enhancement by the plastic mulch and thus could not suppress weed growth for as long as the plastic mulch + synthetic herbicide did. Manual weeding could not suppress weed growth for long because there was no sustainable measure to prevent germination of weed seeds, although the plastic mulch + manual weeding lasted a bit long because of the plastic mulch. Weed growth in the plastic mulched plots only occurred in between the ridges.

The weed flora which emerged after the application of treatments was different from the initial flora observed before the start of the experiment. This trend of weed succession is due to the presence of weed seeds in the soil which had not germinated as a result of unfavourable conditions. Thus, at the onset of the better conditions, the weed seeds could germinate. *Panicum maximum* however dominated, and was present in all the treatments. This is because the initial weed flora before planting was mainly made up of this perennial grass which, by then, had flowered and dispersed a large number of its seeds. The other weed species recorded were possibly part of the weed seed bank on the field.

Weed diversity was highest on the weedy check followed by the two treatments with manual weeding. This indicates that the weed management methods had an effect on the range of weeds. The two treatments which included manual weeding may have reduced the diversity by uprooting and exposing the weeds to sun burn, preventing regeneration, whiles those with the synthetic herbicides may have killed the weeds to prevent regeneration and again prevented the re-germination of the weed species recorded in the weedy check. The few grasses which could germinate after some time may have had more resistance to the herbicides than the other weeds. The domination by the Poaceae and the Asteraceae families were, as discussed earlier, was probably as a result of the abundance of the two families in the area, compared to the other weed families.

After re-emergence of weeds, weed abundance (population density) also varied with the treatments applied. Plastic mulch + synthetic herbicide recorded the least population density of weeds which was significantly different from Plastic mulch + manual weeding. The difference, as discussed above was due to the persistence of the pre-emergent herbicide, diuron which was applied. Significant differences however, did not occur between the manually weeded plots (without plastic mulch) and the synthetic herbicide treated plots (without plastic mulch) although weeds were more abundant on the manually weeded plots. This was unexpected considering the difference between their corresponding mulched plots. This raises questions on the persistence of the pre-emergent herbicide on unmulched plots. This similarity may have occurred because as at the time of data taken, weeds on the herbicide treated plots (without plastic mulch) had emerged to almost the same population as that of the manually weeded plots. There was however no need to reapply the herbicides since fruiting had, by then, started.

In effect, the efficiencies of the weed management methods evaluated over the weedy check showed that the best method was the plastic mulch + synthetic herbicide, followed by the plastic mulch + manual weeding, the synthetic herbicide and then the manual weeding. Much as the herbicides remain persistent in the soil and thus suppressed weed growth, the long effect of the herbicides may be realized in the inability of subsequent crops to do well on the same fields, especially when they are applied in large quantities. Again their ability to reduce weed diversity may imply loss of biodiversity which will not auger well for sustainable agriculture.

5.5 Effect of weed management on growth and yield of pineapple

The desire of every farmer is to produce crops that will grow well and produce a good harvest. Thus, in choosing a weed management system, the growth and yield of the pineapple is of prime importance. The results presented in the previous chapter show that growth occurred in three phase. Rate of growth was generally slow until the fourth month, after which it rose sharply through the sixth month and then reduced afterwards. The initial slow growth may have occurred because the first few months were used for root initiation and development, thus above ground growth was minimal. The rapid increase on growth rate then was a result of increase in the amount of dry matter partition allocated to the above ground portion of the plant after the initial root development, whiles the slowdown in the latter months represents the transition from the vegetative growth to the reproductive stage.

In all the growth parameters measured, the two plastic mulched treatments showed the best growth and were not different from each other. This confirms earlier findings (Rebolledo-Martinez, 2005; Py *et al*, 1984) that the plastic mulch improves the conditions for plant development especially by providing a better conservation of soil moisture (Dole and Dole, 1991; Rebolledo *et al.,* 1997). The synthetic herbicide (only) treated plots followed the two plastic mulched treatments in all the growth parameters measured. This was expected because the growth on these plots was not limited by competition from weeds, compared to the manual weeding and the weedy check despite the fact that its growth was not enhanced by plastic mulch. The manually weeded (only) plot could not perform as the synthetic herbicide because it was faced with weed competitions intermittently since weed control was done on monitored bases. Thus, intermittent weed competition, coupled with the lack of enhancement by plastic mulch may have stressed the growth of the crops though they seemed to have performed better than the weedy check.

Estimates of growth made before forcing provides information on the progress of growth which also determines when to force the plants and as well, give an idea on the yield at harvest. Many studies have shown that fruit weight at harvest is highly correlated with growth measured at the time of forcing (Py, 1953; Py and Lossois, 1962; Wee *et al*, 1979). Consequently, the differences in yield from the various treatments appeared to follow the same pattern in the growth; the two plastic mulched treatments recording the highest yield, significantly different from the weedy check and the manual weeding, with the synthetic herbicide recording yields between the two sides. As indicated by Paulle and Duarte (2011), plastic mulch helped to prevent rapid escape of fumigants, maintained warmer soil temperatures during the cool season, retained moisture at the soil surface, reduced fertilizer leaching during rainy periods, controlled weed growth in the beds and thereby increased the yields for the plastic mulched plots. The others did not have the enhancement by the plastic mulch and hence could not yield as much as them. The lower yields recorded by the weedy check and manually weeded plots could also have resulted from the competition for nutrient, light and space from the weeds.

In spite of the insignificant differences in the weight of fruits, plastic mulch + synthetic herbicide recorded significantly higher percentage marketability than plastic mulch + manual weeding. This difference may have resulted from insect damage caused to the fruits in the periods of high weed populations in the plastic mulch +

manually weeded plots, reducing the percentage marketability of the yield from the plots. The synthetic herbicide (only) treated plot recorded lower percentage marketability than the two plastic mulched treatments basically because of lower yields (fruit weight) as indicated earlier. Insect attacks could not have accounted for this since the plot had reduced weed populations. The weedy check recorded the lowest percentage marketability mainly due to lower yields (fruit weight) and high amount of insect damage caused by insects pests which were haboured by the weeds. The manually weeded (only) plot also recorded low percentage marketability, possibly for similar reasons as the weedy check. The severity of damage by the insect pests and the low yields, however were not as much as that of the weedy check and this made percentage marketability significantly for the manual weeding significantly higher, than that of the weedy check.

5.6 Effect of weed management on the population of pineapple mealybugs (*D. brevipes*)

The prime importance of the pineapple mealybug, *D. brevipes* (Hemiptera: Pseudococcidae) on the pineapple farms lies in the role it plays in causing the pineapple mealybug wilt, the reduction of market value due to its presence and the rejection of exported fruits (and possible ban on export), if found on them. Its control is thus of much importance. The results show that weed management in general, irrespective of the method, reduced the mealybug populations on the fruits. Thus no significant differences were observed among the four weed management method, but all the methods significantly had lower mealybug populations on the fruits than the weedy check. Two reasons may account for this. First weed management exposes the mealybugs on the fruits to their natural enemies, making it difficult for them to increase in population as compared to the weedy check which resulted in a heavily crowed plot, providing a secret hiding place for the mealybugs. Secondly, the large weed biomass in the weedy check may have provided a good habitation for the tending ants of the mealybugs and in so doing ensured the proliferation of the mealybugs since the ant population is highly correlated with the mealybug populations.

No significant differences were observed in the mealybug populations in the root zones (leaf bases and roots) among the treatments. This implies that weed management methods did not impact on the mealybug populations in the root zone. Possibly, the habitation of root zone by mealybugs was largely affected by soil conditions rather than above ground conditions and the insignificant differences implied that weed management did not affect soil conditions enough to significantly reduce or increase the mealybug populations. The mealybugs thus, were adapted to all the soil conditions provided by the various treatments. By extension, the plastic mulch also did not impact on the population of the mealybugs in the root zone. This was rather not expected because it was thought that the plastic mulch could provide a safe hiding place for the mealybugs for them to proliferate, but it turned out not to be so.

5.7 Economic analysis of production under various weed management methods

The results presented assumed all other expenses, apart from weed management, were equal. It is obvious that the most profitable is to produce with the plastic mulch + synthetic herbicide system. However, the initial capital may not be available and the use of synthetic herbicides may also impact negatively on the environment, for which reasons, the farmer may want to opt for another method. The weed management methods which include manual weeding, spread the cost of weed management over time, making it more flexible, however the farmer pays more for weed control by the end of production. In whichever case, the use of plastic mulch is highly important and farmers should, in the best of their interest endeavour to use it.

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The study first sought to identify the weeds prominent in pineapple fields in the Mfantsiman, Gomoa East and Akuapim South Districts. A total of 43 weed species from 16 families were recorded across the three Districts surveyed, with Asteraceae and Poaceae families being the dominant families. Mfantsiman District had the least number of species with 29 species, followed by Gomoa East with 34 and then Akuapim South with 40 species recorded. Broadleaves dominated in all three Districts, followed by grasses, with sedges, being minimal across all three Districts. Prominent among the weeds were *Brachiaria lata*, *Panicum maximum*, *Chromolaena odorata*, and *Croton lobatus*.

The study also sought to provide baseline information on the prevalence of pineapple mealybugs and the contribution of weeds to their prevalence. Only the *Dysmiccocus brevipes* was identified on pineapples in the three Districts surveyed. The *D. neobrevipes* and the other known mealybugs of pineapples were not found. Four ant genera: *Crematogaster*, *Camponotus*, *Pheidole*, and *Solenopsis*, were found to be associated with the *D. brevipes* on pineapples. Farmers considered the *D. brevipes* a serious problem which reduced the market value of the pineapple fruits. No weed was identified as an alternative host to *D. brevipes*. The weeds were rather found to habour the tending ant of the mealybugs.

The field experiment was setup to evaluate the efficiencies of various weed management methods employed by farmers in the Districts, and to assess their impact on the growth and yield of pineapples, and the mealybugs. The results showed that

Plastic mulch + synthetic herbicide was the most effective in the control of weeds. It was also the best in terms of growth and yield of the pineapple. The economic analysis also showed that it was most profitable to cultivate pineapple with plastic mulch + synthetic herbicides even though, the most capital intensive. Weed management in general, irrespective of the method employed, reduced mealybug populations on the fruits of pineapples, but not on the roots.

It is therefore recommended that emphasis should be placed on the listed weeds in the development of weed management strategies for pineapple fields. This will help reduce wastage and ensure effective control of the weeds.

Panicum maximum seems to have developed some amount of resistance to the herbicides in use. This development will need to be investigated since the weed is one of the most prominent weeds in the areas of cultivation.

Again, Effective weed management should be carried out on pineapple fields to reduce mealybug populations on fruits.

For farmers who can afford high initial capital, plastic mulch + synthetic herbicides is recommended whiles plastic mulch + manual weeding is recommended for those who may not be able to afford the initial capital. The latter, if carried out effectively could give as much yield as the former and can easily be employed by organic farmers.

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APPENDIX I

INTERVIEW GUIDE

1. Farm location…………………… Farm size…………………
2. How long has the farm been in cultivation?
3. Have you had any special training in weed and pest management in pineapple farms?
4. Have you observed any mealybug (plate 1) on the pineapples?
5. If yes,
    a. At what stage was the pineapple?
    b. On which part was it located?
    c. Were ants present? (Which type?)
6. Have you observed them (mealybugs) on any weed?
7. If yes,
    a. Which weed?
    b. What stage was the weed?
    c. On which part was it located?
    d. Were ants present? (which type?)
8. Do you think the mealybugs have any effect on the pineapples
9. Have you attempted to control them in any way?
10. If yes,
    a. How did you do it
    b. Were you successful
    c. How do you control weeds on your field

APPENDIX II – CLIMATIC DATA

MONTHLY RAINFALL AND MEAN MONTHLY TEMPERATURES

FOR GOMOA EAST FOR THE YEARS 2006 TO 2010

	MONTHLY RAINFALL					AVERAGE MONTHLY TEMPERATURES				
	2006	**2007**	**2008**	**2009**	**2010**	**2006**	**2007**	**2008**	**2009**	**2010**
JAN	129.1	0	20.2	14.8	64.6	29.1	29.4	28.1	28.3	27.2
FEB	67.5	22.8	34.2	57	16.1	29.2	29.3	28.9	28.6	27.7
MAR	43.2	161.4	167.3	47.8	91.4	29.5	28.7	29.1	29.7	28.2
APR	147.1	237.8	218.7	126	159.2	29.4	28.8	28.6	29.5	30
MAY	303	104.4	261.7	138.7	102.7	27.9	28.7	28.5	29	29.8
JUN	346.1	230.8	143.4	159.7	384.5	27.8	27.3	27.6	28	29.6
JUL	42.2	112.2	195.3	175.3	80.3	27.5	27.1	29.1	28.6	29.4
AUG	18.8	66.9	111.5	22.6	100.6	26.7	26.6	29	26.5	27.7
SEP	148.2	191.2	63.2	20.4	142.1	28.1	27.7	28.2	27.1	27.3
OCT	159.1	240.4	57.7	122.7	306.2	28.7	28.3	28.4	27.6	27.4
NOV	67.7	79.6	127.2	163.6	77.5	28.1	28.3	27.8	27.8	27.8
DEC	9.9	4.3	155.6	63.3	91.5	29.2	28.9	27.4	28.1	28.5

Source: Ghana Meteorological Agency

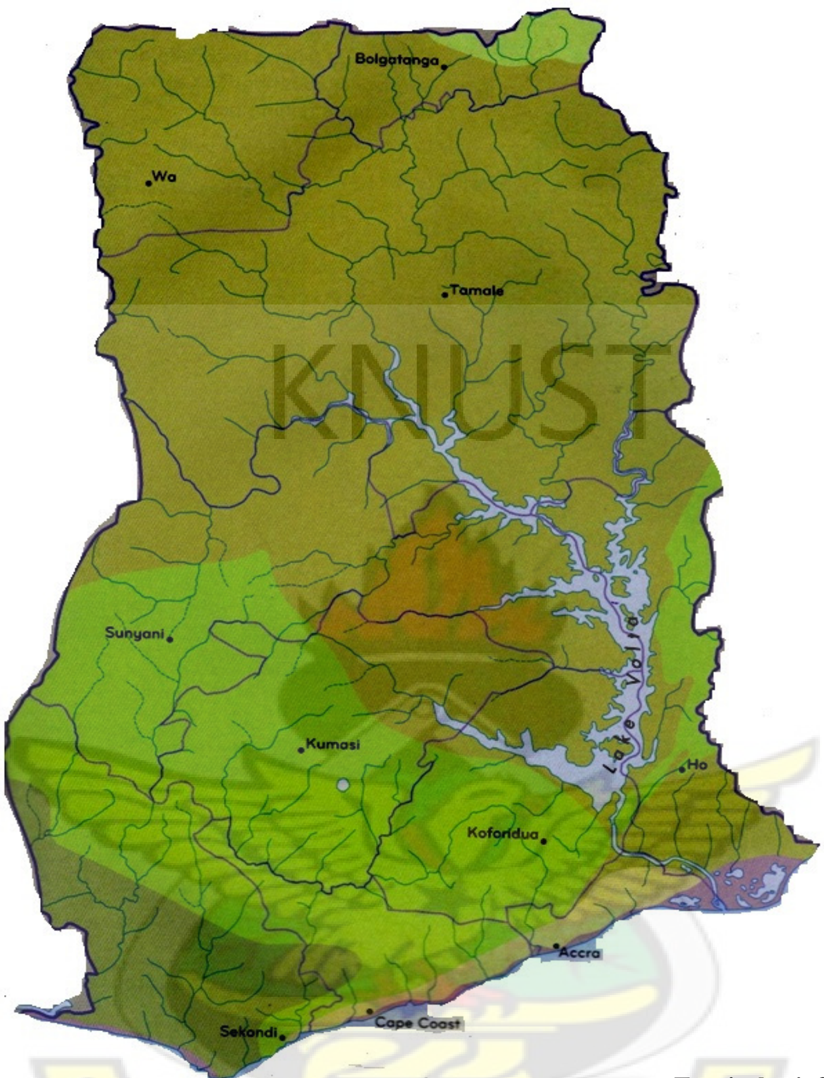
MONTHLY RAINFALL AND MEAN MONTHLY TEMPERATURES

FOR MFANTSIMAN FOR THE YEARS 2006 TO 2010

	MONTHLY RAINFALL					AVERAGE MONTHLY TEMPERATURES				
	2006	**2007**	**2008**	**2009**	**2010**	**2006**	**2007**	**2008**	**2009**	**2010**
JAN	2.4	0	2.7	20.1	4.6	27.4	25.3	24.6	26.7	28
FEB	3	19.3	6.7	39.2	36.9	28.7	28.8	28.2	28.1	29
MAR	20.7	76.6	32.7	37.9	38.1	29.2	29.1	29.2	29	29.6
APR	72.3	108.2	135.5	125.6	38.2	29.5	28.9	28.7	28.4	28.5
MAY	337.9	99.5	245.8	93.6	31.1	28.7	28.9	28	28.3	28.1
JUN	179.8	220.1	160	320.4	259.1	27.2	26.7	27.1	26.8	26.9
JUL	15.3	85	38.2	286.8	52.2	26.2	26	26.2	25.6	25.9
AUG	55.8	47.7	40.4	2.3	39.3	25.4	25.7	25.9	25.1	25.5
SEP	22	101.4	23.8	4.4	67.2	26.3	26.1	26.3	26	26.5
OCT	211.2	209.3	65.6	10	62.3	27.3	27.2	28.1	27.4	27.9
NOV	22.2	25.6	160.5	11.9	44.5	28.6	28.4	28.6	28.8	27.8
DEC	3.8	32.9	69.4	34		27.7	27.9	27.9	28.7	28.2

Source: Ghana Meteorological Agency

APPENDIX III: VEGETATION MAP OF GHANA



Sudan savanna woodland
Mainly open grassland with tall grasses and scattered baobabs and acacias

Tropical rainforest
Several layers of trees, with middle layers forming dense cover, blocking essential light

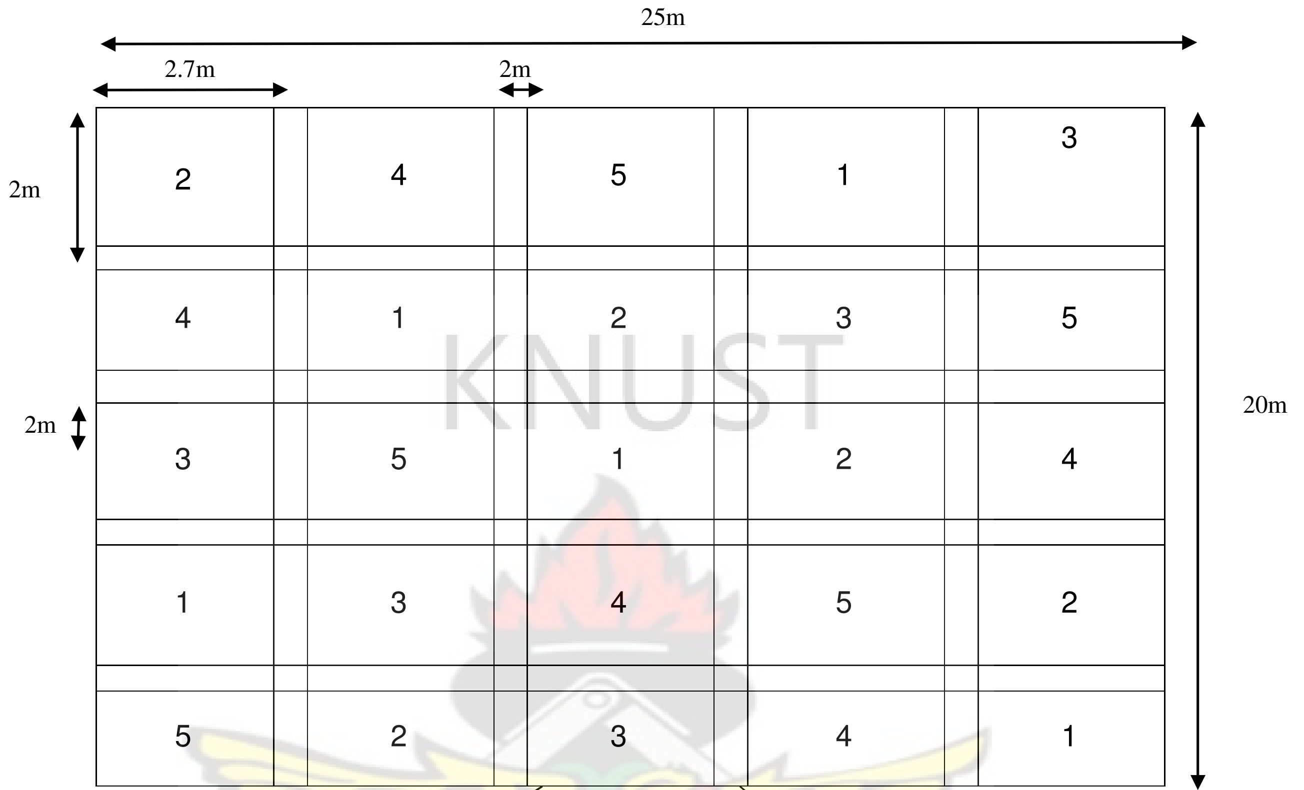
Guinea savanna woodland
Baobab and acacia, suited to the long dry season, along thorny bushes and grasses

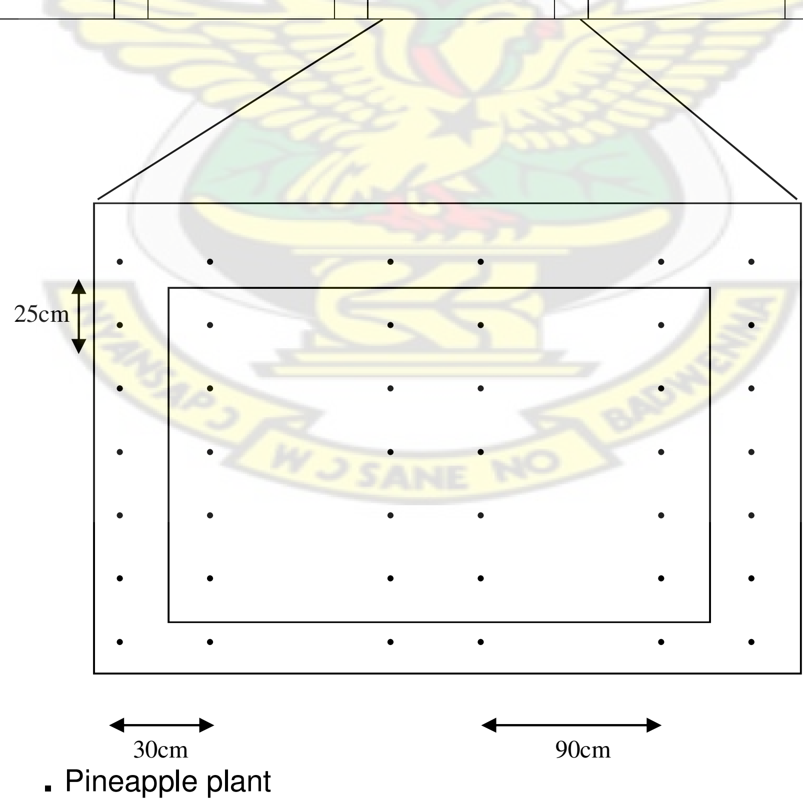
Coastal scrub and grassland
Dense scrub in the west but patchy scrub in the east with grass and wild oil palms

Mangrove swamp
Red and white mangrove trees grow here closely packed in soil, always flooded with salt water

Moist semi-deciduous forest
Several valuable timber trees grow here including obeche, sapele and mahogany.

APPENDIX IV – FIELD LAYOUT OF THE EXPERIMENT





TREATMENTS

1 WEEDY CHECK

2 CLEAN MANUAL WEED

3 SYNTHETIC HERBICIDE

4 PLASTIC MULCH + MANUAL WEED

5 PLASTIC MULCH + SYNTHETIC HERBICIDE

Appendix V: Details of economics of production of pineapple

Break down of production cost of pineapple for 1 acre

Activity	Unit price (GH¢)	Total amount (GH¢)
Removal of stumps	100 per acre	100
Two times ploughing	30 per acre	60
One harrow	20 per acre	20
Ridging	20 per acre	20
Plastic mulch (60kg per acre)	4.36	261
Labour cost for plastic covering (5 persons required)	5	25
Sucker (20,000 per acre)	0.05	1,000
Chemical for sucker treatment Alliette (1kg) Mancozeb (1kg) Pyrical (1L)	 12.5 17.5 11	 12.5 17.5 11
Cost of labour for sucker treatment (4 persons required)	5	20
Cost of sucker planting (6 persons required)	5	30
Cost of agrochemicals and application		**1440**

Breakdown of cost: benefit analysis of production under the various weed management methods

Treatment	Percentage marketable	Mean fruit weight (Kg)	Fruit price per kg (GH¢)	Total benefit	land prepa ration	Agro chemicals	weed manage ment	Total cost	Gross profit
1	32.90	1.402	0.6	**5535.55**	1316	1440		2756	2779.55
2	48.56	1.556	0.6	**9068.02**	1316	1440	900	3656	5412.02
3	76.18	1.614	0.6	**14755.16**	1316	1440	150	2906	11849.16
4	78.60	1.816	0.6	**17129.58**	1577	1440	150	3167	13962.58
5	84.04	1.954	0.6	**19706.66**	1577	1440	75	3092	16614.66