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DEPARTMENT OF CROP AND SOIL SCIENCES

IMPACT OF PESTICIDES APPLICATION AND FARM MANAGEMENT PRACTICES ON SOIL DWELLING ARTHROPODS IN SELECTED COCOA FARMS IN THE EASTERN REGION OF GHANA

BY

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(MSc. Crop Protection)

AUGUST, 2015.

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MASTER OF PHILOSOPHY

IN

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By

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AUGUST, 2015.

DECLARATION

I hereby declare that this submission is my own work towards the MPhil and that, to the best of my knowledge, it contains no materials previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been in the text.

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DEDICATION

This piece of work is dedicated to my mother, Miss Isatu Tenneh Kawa for been there for me night and day.

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I acknowledge the good work of God in giving me the strength, knowledge and wisdom to carry out this work.

If I see beyond men, it is because I have stood on the shoulders of other men.

‘’Albert Einstein’’

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ABSTRACT

Soil arthropods are very vital links in the food chain as decomposers. In Ghana, the control of insect pests in cocoa farms is mainly by the use of synthetic pesticide. The impact of these applied pesticides and farm management practices on abundance and richness of soil arthropods within the litter and 0-10 cm depth of the soil in cocoa farms at New Tafo-Akim and Akwadum in the Eastern Region of Ghana was monitored for four months (October 2014 – January 2015). Berlese Tullgren extraction method was used for the extraction of the litter and soil arthropods. Collembola, Acarina, Hymenoptera, Araneae, Diptera, Coleoptera, Blattaria and Myriapoda were collected from the litter and soil. Collembola, Acarina and Hymenoptera constituted the most abundant while Araneae and Blattaria were the least abundant in both the litter and soil. Comparatively, cocoa farms where organic pesticides were used harboured numerically higher arthropod numbers than farms where synthetic pesticides were applied. There were no significant differences ($P > 0.05$) in the number of Collembola, Acarina, Hymenoptera, Diptera, Coloeptera, Blattaria and Myriapoda collected from farms subjected to the two pest management systems. There were significant differences ($P < 0.05$) in the number of arthropods collected from the Cocoa Research Institute of Ghana's (CRIG) plots with respect to the Diptera and Myriapoda. The use of herbicides as a farm management practice to control weeds had a significant effect on Collembola, Acarina and Araneae in the litter and on Diptera and Myriapoda in the soil. The soil physicochemical parameters (soil pH, soil moisture content and soil hydrocarbon) had no significant effect on the abundance and richness of soil arthropods. However, soil pH within the farm management system was observed to have a significant effect on the richness and abundance of soil arthropods.

The results showed that pesticides application over the years have not adversely affected the abundance and richness of soil arthropods within the studied cocoa farms.

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CHAPTER ONE

1.0 INTRODUCTION

The "chocolate tree" Cocoa *Theobroma cacao* L. is cultivated as an economic crop in 58 countries and on more than 17 million acres (6.9 million ha) worldwide, with 72% of the production in West and Central Africa (Clay, 2004; C&CI, 2012). About six million people depend on its farming for their livelihoods (Baah and Garforth, 2008; Fairtrade Foundation, 2015).

Cocoa is by far Ghana's most important agricultural export crop (Bulír, 2003; Dormon *et al.*, 2004; Tutu, 2011), contributing more than 40% of total export revenue and about 20% of Ghana's GDP (Fiamor, 2005). In 2010/11, Ghana cocoa exports reached a record high of 1,004,000 MT. Ghana continues to maintain its position as the world's second largest exporter of cocoa after Ivory Coast (Kessel, 2002; Cocoa Report, 2012; Fairtrade Foundation, 2015). The popular saying ''cocoa is Ghana, Ghana is cocoa'' depicts the significance of cocoa production in Ghana (GCB, 2009).

The bean is the economically important portion of the crop and is the raw material for chocolate, cocoa powder and different sorts of confectioneries and beverages. By-products from cocoa are used for beverage, pomade and detergents. The pod husk is processed into feed for livestock production (Asare, 2011), and potash for soap and fertilizer.

Regardless of the efforts to revamp cocoa production in Ghana and other producing countries, the incidence of pests and diseases continues to remain a major problem

(Dormon *et al.*, 2004; ICCO, 2010). As reported by Dormon *et al.* (2007), 30% of the cocoa produced in Ghana annually is lost to pests and diseases.

Sarpong-Akosa (2001) observed that pests and diseases management practices especially mirids attack and black pod disease in cocoa production is heavily dependent on synthetic pesticides and as a result, the Cocoa Diseases and Pests Control Programme (CODAPEC), dubbed "Mass Spraying", was re-introduced in 2001. The programme has also enhanced the effective and efficient application of good agriculture practices alongside fungicides spraying to achieve improved yields.

The agricultural use of chemical agents to control pests such as weeds, insects, rodent, nematodes, fungi and bacteria has been practiced since the latter part of 19^{th} century (Cherry, 2006). Over 98% of the herbicides reach a destination other than their target species, because they are sprayed or spread across an entire agricultural field (Miller, 2004). Worldwide pesticide use in 1997 was estimated at 2.58 billion kg (Aspellin *et al.*, 1992; Kumar and Kumar, 2007).

Soil represents one of the most important reservoirs of biodiversity, reflecting ecosystem metabolism since all or most bio-chemical processes of different ecosystem components are combined within it. Soil fauna is an important reservoir of biodiversity and play essential role in several soil ecosystem functions (Cole *et al.*, 2005). Soil arthropods are abundant small invertebrates that live in the soil and litter layer. Typical arthropods include mites, springtails, pseudoscorpions, ants, termites, Isopoda, Myriapoda and insect larvae (Ruiz *et al.*, 2008).

As stated by Addison *et al.* (2007), frequent pesticide application has caused soil degradation and environmental conditions and this has led to a substantial reduction

and the simplification of animal and plant communities. Species that are able to withstand stress predominate and those taxa that were once abundant and not resistant, disappeared.

With increased pesticide use, questions on potential effects regarding public health and the environment have emerged, especially as pesticide application at rates higher than recommended, accidental spills or long *in-situ* residence time in soil is common.

Little information is available on the relationship between pesticide and soil fauna (Larson and Pierce, 1994; Lindsey *et al.,* 2013). It is in the light of this that this study with the objective to determine whether pesticide application and farm management practices in cocoa farms adversely affect soil dwelling arthropods, was undertaken.

The specific objectives were to determine the impact of;

i. Pesticides application on the abundance of soil dwelling arthropods
ii. Pesticides application on the richness of soil dwelling arthropods
iii. Farm management practices on the abundance of soil dwelling arthropods
iv. Farm management practices on the richness of soil dwelling arthropods

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cocoa

2.1.1 Origin of cocoa

Cocoa, *T. cocoa* is one of 22 species that constitute the genus *Theobroma*, a member of the family Sterculiaceae and the principal commercially important member of the genus (Mann, 2007). Cocoa originated from the lower Amazon Basin of Brazil in South America and was brought to Ghana by a blacksmith, Tetteh Quarshie, in 1879 from Fernando Po. The initial establishment was at Akwapim Mampong in the Eastern Region (COCOBOD, 2000). Cocoa has three distinct groups: Criollo, Forastero and Trinitario (Toxopeus, 1987; Motamayor *et al.*, 2002). The most valued, rare and expensive is the Criollo group; Forastero is rated as the type with a poorer quality but more resistant to diseases. Trinitario is a hybrid of Criollo and Forastero (Asare, 2011). Amelonado Forestero cocoa was the first cocoa to be introduced in Ghana. This takes more than five years to mature and start bearing. Amazonian cocoa matures much earlier (3-4 years) and was introduced into the country in the 1950's (Acheampong, 2012).

2.1.2 Brief history and important of cocoa production in Ghana

The first recorded export of beans from Ghana was in 1891 and since then, cocoa has become a very important export crop and a major source of foreign exchange and domestic income earner (Adjinah and Opoku, 2010). Approximately 70% of the world's cocoa comes from West Africa (C&CI, 2012; Baah and Garforth, 2008), though it is essentially a small-holder crop. It is cultivated on 1.2 to 1.5 million farms ranging in size from 1.2 to 2.8 ha and employs about 10 million people (Padi and

Owusu, 1998). Ghana was the world's largest cocoa producer until she was overtaken by La Cote d'Ivoire in the 1976/77 season. The country has since held to the number two position with more than 1 billion dollars in foreign exchange receipts in 2006, representing 27% of total exports (Brown and Crawford, 2008). Currently, European Union, United States of America and Japan are Ghana's main exporting country of raw cocoa beans.

2.1.3 Economic and nutritive Importance of Cocoa

The bean constitutes the main ingredient of chocolate. Each dry bean contains a significant amount of fat (40–50%) as cocoa butter and polyphenols, which make up about 10% of the whole bean's dry weight and make mature cocoa beans bitter. Cocoa beans contain approximately 380 known chemicals and 10 psychoactive compounds (Fold, 2001). The most noted active constituent is theobromine, a compound that is similar to caffeine. About 90% of production is used in the chocolate industry with the remaining 10% used in the production of flavourings, beverages and cosmetics (Ecosystem Market, 2008).

Reports on the nutritional benefits of cocoa and chocolate are extensive. Mossu (1992) mentions cocoa as a rich source of calcium, phosphorus, iron and vitamins A and D. Addai (2010) hypothesized natural cocoa as a diet–mediated anti-malarial prophylaxis and Bayard *et al.* (2010) reported that flavonol rich chocolate may boost blood flow in the brain and reduce the risk of dementia. The by-products from cocoa could be used as feed supplements in the rations of livestock (Agyante-Badu and Oddoye, 2005).

2.1.4. Insect Pests and Diseases of Cocoa in Ghana

Cocoa is highly susceptible to attack by numerous insect pests and fungal diseases with potential yield loss of 30% (Dormon *et al*., 2007). In West Africa, mirids are recognized as the most important pest of coca. There are four species: *Sahlbergella singularis* (Haglund) (Hemiptera: Miridae), *Distantiella theobroma* (Distant) (Hemiptera: Miridae), *Helopeltis bergrothi* (Reuter) (Hemiptera: Miridae) and *Bryocoropsis laticollis* (Schumacher) (Hemiptera: Miridae). Of the four species, *S. singularis and D. theobroma* are the ones of economic importance. Young cocoa is particularly vulnerable to mirid attack and this can prolong the establishment period for several years (Padi *et al*., 2001). Other harmful insect pests to cocoa are the cocoa stem borer, *Eulophonotus myrmeleon* (Felder) (Lepidoptera: Cossidae), pod borer, *Conopomorpha* cramerela (Snellen) (Lepidoptera: Gracillariidae), mealybugs, *Planococcoides njalensis* (Laing) (Hemiptera: Pseudococcidae), and the stink bug, *Bathycoelia thalassina* (Herrich–Schaeffer) (Hemiptera: Pentatomidae), termites and defoliators (*Anomalis leona* and *Earias biplaga*) (Padi *et al*., 2001).

Black pod disease which is an important disease of cocoa is caused by a number of *Phytophthora* species especially *Phytophthora megakarya*. Other fungal diseases include witches broom caused by *Crinipellis perniciosa*, frosty pod caused by *Moniliophthora roreri* and vascular streak die-back caused by *Onchobasidium theobromae*. The cocoa swollen shoot virus disease is caused by several strains of viruses and vectored by mealybugs.

Mirid and fungal related dieback cause more than 20% yield loss (Adu-Acheampong, 2009). The main viral disease of cocoa is the swollen shoot disease caused by the cocoa swollen shoot virus (CSSV) and transmitted by different species of mealybugs.

Mistletoes and rats and other vertebrate pests such as squirrels, woodpeckers, etc. also inflict damage on cocoa.

2.1.5 Control of Insect Pests of Cocoa

One of the most appropriate method recommended by the Cocoa Research Institute of Ghana (CRIG) for mirid control has been the use of synthetic insecticides (Owusu-Manu, 2001). Leston (1970) revealed that insecticide treatment of cocoa mirids also alleviated damage attributed to swollen-shoot virus, perhaps through control of mealybug vectors of swollen shoot viruses.

Aside synthetic insecticides, the use of natural enemies could also give good control. In 1995/1996 cocoa season, two pathogenic fungi were discovered by scientists in CRIG. These are *Entomophaga grilli* and *Fusarium* spp. *Oecophylla longinoda* Latr. was found to be exhibiting predatory tendencies against the two mirid species (Ackonor and Nkansah, 1997).

Adu-Acheampong (1997) and Ayernor *et al*. (2007) assessed the potential of botanicals as alternate insecticides for mirid control and found crude neem seed extracts effective, and suggested that neem could be integrated in pest management programmes to promote the abundance of natural enemies. When the canopy is well formed, most of the mirids are confined to the pods and die off after harvesting. Maintenance of a complete canopy, removal of chupons regularly and maintenance of a healthy and balanced ecosystem were suggested by Boateng (2011), as option to avoid gaps in the canopy to manage mirids.

2.2 Pesticides

Pesticide can be defined in several ways according to its functions. It can be defined as a chemical substance, biological agent (virus or bacterium), antimicrobial, disinfectant or device used against any pest including vectors of human or animal disease, unwanted species of plants or animals causing harm during or otherwise interfering with the production, processing, storage, transport or marketing of agricultural commodities, wood and wood products or animal feedstuffs, or substances which may be administered to animals for the control of insect, arachnids or other pests. The term pesticides also includes substances intended for use as plant growth regulator, defoliant, desiccant or agent for thinning fruit or prevention the premature fall of fruit and substances applied to crops either before or after harvest to protect the commodity from deterioration during storage and transportation (EPA, 2005).

Pesticides encompass a great range of diverse substances, falling into several broad grouping such as herbicides, insecticides, fungicides, molluscides, nematicides etc. according to the target organism (Gevao-Amengor and Tetteh, 2008). Insecticides approved by COCOBOD for use on cocoa in Ghana are shown in Table 2.1.

Table 2.1. Insecticides currently approved by Ghana Cocoa Board for mirid management in Ghana and their recommended rates

A.I	**Imidacloprid**	**Bifenthrin**	**Thiamethoxam**
Trade Name	Confidor®	Akatemaster®	Actara®
Year of introduction	2001	2004	2007
Manufacturer Importer	Bayer Crop Science Wienco Ghana	FMC Chemical Co Tema Chemicals Ltd	Arysta Life Science Calli Ghana
A.I. per Litre (g)	200	27	240
A.I. per ha (g)	30	13.5	20.4
Vol. of Chemical per ha (ml)	150	500	85
Recommended concentration (mg/l)	540	240	370

2.3 Pesticide Use and Effects on the Environment

2.3.1 Pesticides usage

According to FAO assessment on forest resources in 2000, worldwide, agricultural land comprises 50% of all usable land (FAO, 2001). From 1961 to 1999, pesticides usage increased by 854%. These evidences brought to light the likely problems in saving biodiversity in agricultural ecosystem where synthetic pesticides are applied (Reinecke and Reinecke, 2007)

2.3.1.1 Intensification of Pesticides Use

Humans utilized pesticides to protect crops and agricultural product before 2000 BC. The first known pesticide was elemental sulphur dusting used in ancient Sumer about 4500 years ago in ancient Mesopotamia. By the 15th century, toxic chemicals such as arsenic, mercury and Lead were being applied to crops to kill pest. In the 17th century, nicotine, sulfate as extracted from tobacco leaves for use as insecticides. The 19th century saw the introduction of two more natural pesticides, pyrethrurn, which is derived from chrysanthemum, and rotenone, which is also derived from the roots of tropical vegetables (Miller, 2004). In the 1940s, manufacturers began to produce large amount of synthetic pesticides and their uses became widespread (Daly *et al.*, 1998).

Until the 1950s, arsenic-based pesticides were dominant (Ritter, 2009). Organochlorides such as dichlorodiphenyltrichloroethane (DDT) dominated and were very effective insecticide, but they were replaced by chemicals like organophosphates and carbamates in USA by 1975 due to its bioaccumulation properties. Since then, pyrethrin compounds have become the dominant insecticides to control pests (Ritter, 2009). During the latter half of the 20th century the

development and use of pesticides had increased tremendously and pesticide use has now become an integral component of agricultural farming systems in most developed countries (AATSE, 2002). It is worth noting that the use of pesticides in modern agriculture to control pests and diseases has significantly increased global food production.

Pesticides use has become an integral part of Ghanaian agriculture, being used on cocoa and cotton plantations, vegetable farms, rice and corn fields. It is estimated that 87% of farmers in Ghana use pesticides to control pests and diseases on vegetable farms alone (Dinham, 2003). Usage of pesticides has increased steadily worldwide since the 1960s. It has largely been responsible for the green revolution, i.e. the massive increase in food production obtained from the same surface of land with the help of mineral fertilizer (nitrogen, phosphorus and potassium), more efficient machinery and intensive irrigation. The use of pesticides has help to significantly reduce crop losses and improved the yield of crops such as corn, vegetable, potatoes and cotton (Dinham, 2003).

2.4. Effect of Pesticide on the Environment

Pesticides application is generally expected to have little adverse effect on the environment when used as directed by the manufacturers. Unfortunately, problems are encountered with some pesticides, due to their build-up in the environment and subsequently the food chain. Notwithstanding the beneficial effects of pesticides, their adverse effects on the environment and human health have been well documented worldwide and constitute a major issue that gives rise to concerns at local, regional, national and global scale (Kidd *et al.*, 2001; Ntow, 2001; Cerejaire *et al.*, 2003).

In the 1990s, it was discovered that DDT was preventing many fish-eating birds from reproducing which was a serious threat to biodiversity. According to Carson (1962), the harmful effect that chemical pesticides had had on the environment magnifies biologically and that many of the long term effect that these chemicals might have had on the environment, as well as on humans, were still unknown.

The agricultural use of DDT is now banned under the Stockham Convention on Persistent Organic Pollutants because of their persistence and potential to bioaccumulate. However, it is still used in some developing nations to prevent malaria and other tropical diseases by spraying on interior walls to kill or repel mosquito (Lobe, 2006).

Residues of pesticides contaminate soils and water, persist in crops, enter food chains, and finally are ingested by organism with foodstuffs and water. Furthermore, pesticides can be held responsible for contributing to biodiversity losses and deterioration of natural habitats (Sattler *et al*., 2007). Pesticides application could alter the structure (species richness, density and biological diversity) and functional activities of ecosystems. It may also alter the self-sufficient nature of natural ecosystems that include plants, herbivores, parasites and decomposers. Some pesticides are capable of destroying some species totally or significantly reducing the populations of others. When the diversity of the ecosystem is reduced sufficiently, then food chains may be shortened or altered in diverse ways (Morley, 2015).

There have been reported instances of pest resurgence, development of resistance to pesticides, secondary pest outbreaks and destruction of non-target species. High pre- and post-harvest losses due to pests are a major problem for productivity in the agricultural sector (Asante and Ntow, 2009). It has been established that pesticide

could become a nuisance if they are misused or misapplied. Some of the negative effects include low crop yield, destruction of soil micro-fauna and flora, and undesirable residue accumulation in food crops (Glover-Amengor and Tetteh, 2008)

2.5 Soil and Soil Fauna

Soil can be referred to as a world of its own life and biodiversity, consisting of various forms of life in an endless series of interlinked caves with lots of food and stable environmental conditions like a rainforest (Williams, 1999). Soil is a natural body, comprised of solids, liquids and gases that occur on the land surface, occupies space and is characterized by one or both of the following horizons, or layers that are distinguishable from the initial materials as a result of additional losses, transfer and transformations of energy and matter or the ability to support rooted plant in a natural environment (Coleman, 2000).

The soil environment provides a habitable place for three groups of soil organism; water dwellers (Prrotozoa, Rotifer, and Targigrades), Soil pore dwellers (micro arthropods and other micro fauna species) and Real soil dwellers (Earthworms and macro-arthropods) (Ghilarov, 1994). Generally, soil organisms have been classified into five major groupings based on the size, time spent in the soil, location in the soil profile, feeding strategies and methods of locomotion (Wallwork, 1970). On the basis of this classification, soil fauna are generally regarded as small animals with appendages and are divided into three groups, which are micro fauna, meso fauna and macro fauna (Wallwork, 1970).

Hugie and Passy (1990) identified the special features of soil that are fashioned by soil arthropods to include the thumb and sized blocky soil pits shaped by cicada nymphs while tunnelling through the soil horizon. They stated that, among the

most abundant arthropod are the micro arthropods, which include the mites (Acarina), followed by springtail (collembolla) and some other families of insect and then arachnids.

Soil arthropods are a vital link in the food chain as decomposers and without these organisms, nature would have no way of recycling organic matter on its own (Trombetti and Williams, 1999). The process of decomposing is controlled largely by soil arthropods in conjunction with some soil invertebrate like protozoa and earthworms which contribute to the soil community by mixing, loosening and aerating the soil (Evans, 1992). Arthropods also serve as the largest prey base for small predators (Fitser, 1995). Without arthropods most terrestrial ecosystem would rapidly collapse (Filser, 1995). An investigation of the role of micro-arthropods in decomposing forest litter found that 69% of the total decomposing was as a result of micro-arthropods activities (Seastedt, l984). The direct ecological effects of these micro-arthropods include the reduction in the mass of organic matter and microbial tissue as a result of their ingestion and assimilation of such materials, their respiration and excretion which is important in influencing oxygen-carbon dioxide ratio of the soil and nutrient made available from the breakdown of the faecal pellet (FiIser, 1995).

2.5.1 Soil Arthropods

Soils may harbour a huge number of arthropod species, which may rival or exceed the numbers estimated to inhabit the canopies of tropical forests (André *et al.*, 1994). According to Decaëns *et al.* (2006), soil fauna may represent as much as 23% of all described organisms, or about 360,000 species, with arthropods comprising 85% of that number. However, accurate figures have been difficult to come by,

hampered, at least in part, by limitations in sampling methodology (Stork and Eggleton, 1992). Because of this, it has been suggested that, in some groups, the actual species richness may be an order of magnitude greater than the number of the species that have been described (André *et al.*, 2002).

Arthropods comprise a large proportion of the meso- and macrofauna of the soil, animals with body lengths range from about 200 µm to 16 cm or more (Van der Drift, 1951; Wallwork, 1970) of the hemiedaphon and euedaphon, organisms that live within the litter/humus boundary and lower in the soil profile (Eisenbeis and Wichard, 1987). Five groups are chiefly represented: Isopoda, Myriapoda, apterous Insecta, Acari, and Collembola, the latter two being by far the most abundant and diverse. Species of Protura, Diplura, and Pauropoda are of lesser importance in the soil community (Copeland and Imadaté, 1990) and have little influence on soil processes.

2.5.1.1 Micro-arthropods

This group consists principally of species of the Acarina taxa Oribatida, Prostigmata, and Mesostigmata, and the Collembola. Large numbers of microarthropods are found in most soils (Wallwork, 1976a; Hale, 1967), including those under cultivation (Behan-Pelletier, 1999; Behan-Pelletier, 2003), and these animals may be the dominant arthropods in a variety of environments from equatorial to Polar Regions and from temperate and tropical forests and grasslands to hot and cold deserts (Petersen and Luxton 1982; Curry, 1994). As part of the mesofauna, the microarthropods comprise the important middle links of soil food webs, serving, in their role as both predator and prey, to channel energy from the

soil microflora and microfauna to the macrofauna on higher trophic levels (Coleman *et al.*, 2004)

2.5.1.1.1. Acarina

The Acari of the soil includes members that feed on dead plant materials, as well as on the microflora (bacteria, fungi); in addition, species of Prostigmata and Mesostigmata may prey upon elements of the micro-and mesofauna (e.g., nematodes, collembolans, enchytraeid worms) (Wallwork, 1976b, 1970; Petersen and Luxton 1982). Curry (1994) and Wallwork (1983), observed that oribatids are numerically the dominant group of Acarina in forest and grassland soils and the most important in decomposition processes.

A major abiotic factor constraining the distribution of oribatids is adequate moisture, with the requisite soil humidity for euedaphic forms probably near saturation (Mitchell, 1979). With more than 9000 species in 172 families, most of which inhabit the soil/litter system (Norton and Behan-Pelletier, 2009), the oribatids are considered the most successful of all soil arthropods.

The feeding ecology of oribatids is diverse. Four main groups, based on modes of feeding, are commonly recognized: macrophytophages, which feed mainly on decaying higher plant material and rarely on fungi; microphytophages, those types feeding on fungi, bacteria, and other microflora; panphytophages, which have an expanded diet breadth, including plant matter as well as fungi; and coprophages, the diet of which includes fecal material (Luxton, 1972). However, the majority of oribatids are obligate or facultative fungivores (Wallwork, 1983).

2.5.1.1.2. Collembola

Collembola (springtails) are hexapods formerly classified as primitively wingless insects (Boudreaux, 1979), but now widely recognized as a lineage closely related to, but distinct from, the Insecta (Giribet and Edgecombe, 2012). About 6500 species in 18 families have been described (Hopkin, 1997). Like the oribatids, they also are extremely abundant in soil and leaf litter, with densities typically on the order of 10^4–10^5 individuals m^{-2} and, again, higher in coniferous forests (Petersen and Luxton, 1982), but are more numerous than oribatids in many soils (Culliney, 2013). Agricultural soils may be rich in Collembola (Christiansen, 1964). Like soil-dwelling oribatids, euedaphic Collembola require a soil atmosphere approaching saturation (Christiansen, 1964).

The diet of Collembola is of considerable breadth, including moss protonema, bacteria, fungal hyphae and spores, algae, protozoans, arthropod faeces, pollen, decaying plant materials and humus and other Collembola (living or dead).The species are divided between those that masticate their food and those that are fluid feeders (Christiansen, 1964). However, the majority of species are primarily or largely fungivorous belonging to masticators (Hopkin, 1997).

2.5.1.1.3. Myriapoda

The Diplopoda (millipedes) and Symphyla are the most important myriapodous groups within the soil. About 12,000 species of millipede have been described and assigned to 2947 genera (Sierwald and Bond, 2007). Millipedes are known often to be dominant arthropods in forest soils with a mull-type humus; also are numerous in deciduous forests with a mor formation, but are rare in coniferous forest mor. They tend to be more abundant and diverse in calcareous soils, in fairly moist habitats, and

typically in the upper soil horizons (Hoffman, 1990). Densities of 1000–3000 m^{-2} have been recorded for various species (Hopkin and Read, 1992). Most millipedes are detritivores, feeding on dead plant matter, such as leaf litter and wood, some also browsing on fungal mycelia.

The Symphyla are a rather small group of arthropods, with a reported 208 species in 13 genera and two families (Chapman, 2009; Szucsich and Scheller, 2011). Populations, however, may be large in some environments, on the order of 10^3–10^4 individuals m^{-2}, and reach highest densities in cultivated soils (Edwards, 1958). Species also are common in grassland and forest soils. By one estimate, they may represent as much as 86% of the total myriapod population in some soils but are often overlooked because of their small size and wide dispersion through the soil profile. The group appears to reach its greatest diversity in warm temperate and tropical regions. These animals are highly hygrotactic, and survive only in a soil atmosphere of 100% R.H. (Edwards, 1961). Symphyla are said to be extremely voracious, and will attack vegetable matter at an earlier stage of decomposition than will many other soil-inhabiting invertebrates (Edwards, 1990).

2.5.1.1.4. Isopoda

These terrestrial crustaceans of the suborder Oniscidea are commonly known as woodlice or sowbugs. More than 3500 species in 518 genera have been described (Schmalfuss, 2003). Despite their diversity, these animals are imperfectly adapted to a terrestrial existence. In particular, a set of structural (e.g., permeable cuticle) and physiological (gills) traits little modified from a marine ancestor means that the maintenance of water balance is of paramount importance to survival, and is largely achieved through behavioural means (Edney, 1954).

Oniscidae attain their greatest abundance in unmanaged temperate grasslands, numbers typically ranging from about 500–1000 m^{-2} (Curry, 1994).

According to Kühnelt (1976), the main dietary component is well-moistened detritus (leaves and wood residues), as well as their own faeces, feeding on which permits the recycling of essential nutrients, such as inorganic copper

2.5.1.1.5. Termites

Termites are members of the Blattodae, epifamily Fermitoidae, an order with over 2600 described species in 281 genera (Kambhampati and Eggleton, 2000). These social insects are said to dominate soil arthropod assemblages across much of the dry tropics and into dry temperate regions, although they attain their highest diversity in the tropics (Bignell and Eggleton, 2000). Two broad groups of termites may be distinguished on the basis of diet (Kühnelt, 1976). Species that feed on humus, which are commonly found in tropical rain forests and build subterranean nests, depend entirely on partly decomposed plant matter in the soil. Wood- and litter-feeders, more abundant in savannas, nest either in the wood itself or in conspicuous above-ground structures. Termite nests are founded cooperatively by a male and female of the reproductive caste following a nuptial flight from the parent colony; the colony workforce that issues from this union consists of non-reproductive males and females. Colony sizes of 3 million individuals have been reported from the tropics (Lee and Wood, 1971).

2.5.1.1.6. Ants (Hymenoptera: formicidae)

Ants, comprising a single family, the Formicidae, the dominant arthropods in most terrestrial environments (Hölldobler and Wilson, 1990). More than 12,000 species in 288 genera and 20 subfamilies have been described (Ward, 2007). As in the termites,

all species are social. Ants are efficient exploiters of food resources, and the evolution of cooperative foraging undoubtedly has been a key to their success (Traniello, 1989). The majority of ants are generalist predators and scavengers; a few species specialize in culturing fungi for food. Ant colonies essentially are female societies, in which a single individual, the queen, is responsible for reproduction, all other duties being performed by the sterile female worker caste; the sole contribution of males is as sperm donors during mating flights (Hölldobler and Wilson, 1990).

2.6 Functional Roles of Arthropods in Maintaining Soil Fertility

The term "soil fertility" denotes the degree to which a soil is able to satisfy plant demands for nutrients (including water) and a physical matrix adequate for proper root development, which is significantly influenced by biological processes. Arthropods function on two of the three broad levels of organization of the soil food web (Lavelle *et al.*, 1995); they are "litter transformers" or "ecosystem engineers." Litter transformers, of which the microarthropods comprise a large part, fragment, or comminute, and humidify ingested plant debris, improving its quality as a substrate for microbial decomposition and fostering the growth and dispersal of microbial populations. Ecosystem engineers are those organisms that physically modify the habitat, directly or indirectly regulating the availability of resources to other species (Jones *et al.*, 1994). In the soil, this entails altering soil structure, mineral and organic matter composition, and hydrology.

2.7 Influence of Arthropods on Nutrient Cycling

Saprophagous arthropods affect decomposition directly through feeding on litter and adhering microflora, thus converting the energy contained therein into production

of biomass and respiration, and indirectly, through conversion of litter into faeces and the reworking (re-ingestion) of faecal material, comminution of litter, mixing of litter with soil, and regulation of the microflora through feeding and the dissemination of microbial inoculum (Lavelle, 1997). With the exception of some termite groups (Wood, 1976), only a small proportion of net primary production is assimilated by soil arthropods (e.g., <10% in oribatids, 4%–20% in millipedes and isopods) (Berthet, 1967; Van der Drift, 1965). Thus, the indirect influences of these consumers on decomposition and soil fertility are considered, in general, to be of greater importance.

The impact of the soil fauna on decomposition process is greatest in the humid tropic, where plants litter decomposition occurs most rapidly. This is due largely due to the action of the microarthropods (Culliney, 2013). In cold temperate zones, rates of biological turnover are curbed by low winter temperatures and the slow breakdown of toxic plant secondary compounds. However, most of the studies concerning the contribution of arthropods to nutrient cycling have focused on soils in temperate regions; comparatively little information is available from the tropics (Lal, 1987; Culliney, 2013).

2.8. Methods for Extraction of Soil Arthropods

Berlese Tullgren instrument is one of the most frequently used in the assessment of micro soil dwelling arthropods. Hopkins (2000) stated that the Berlese Tullgren instrument is the best for extracting soil micro arthropods with efficiency of about 90%.

CHAPTER THREE

3.0. Materials and Methods

3.1 Location and climate of experimental site

The study was conducted at the Cocoa Research Institute of Ghana (CRIG), New Tafo-Akim, in the Akyem Abuakwa district, in the Eastern region and the Entomology laboratory of the Department of Crop and Soil Sciences of the Faculty of Agriculture, KNUST, Kumasi, Ghana. New Tafo-Akim was chosen for the study because there is documentation on the farming activities and pesticides use. Pesticide application in these cocoa farms is all-year-round due to the CODEPEC spraying programme. Additionally, the region was selected because it a key area for cocoa production in Ghana since the early 1920's (Dade, 1937), and also hosts the Cocoa Research Institute of Ghana (CRIG). Map of the study areas is shown in (Figure 3.1)

The region is in the forest zone. The soil of the region belongs to the forest ochrosol (Adu and Mensah-Ansah, 1969). The region experiences semi-equatorial climate with relief rainfall. The region has a bimodal rainfall pattern with a mean range between 1200 mm and 1930 mm. The major rainy season is between April and July with short dry spell in August. The minor rainy season begins in September and ends in November, followed by a dry, very hot period from December to March (CRIG Meteorological Station, 2005). The relative humidity is high during the rainy season reaching its peak of 90% between May and June. Maximum temperature of 30^0 C is experienced between March and April with the mean monthly temperature of about 27^0 C (Dickson and Benneh, 1988)

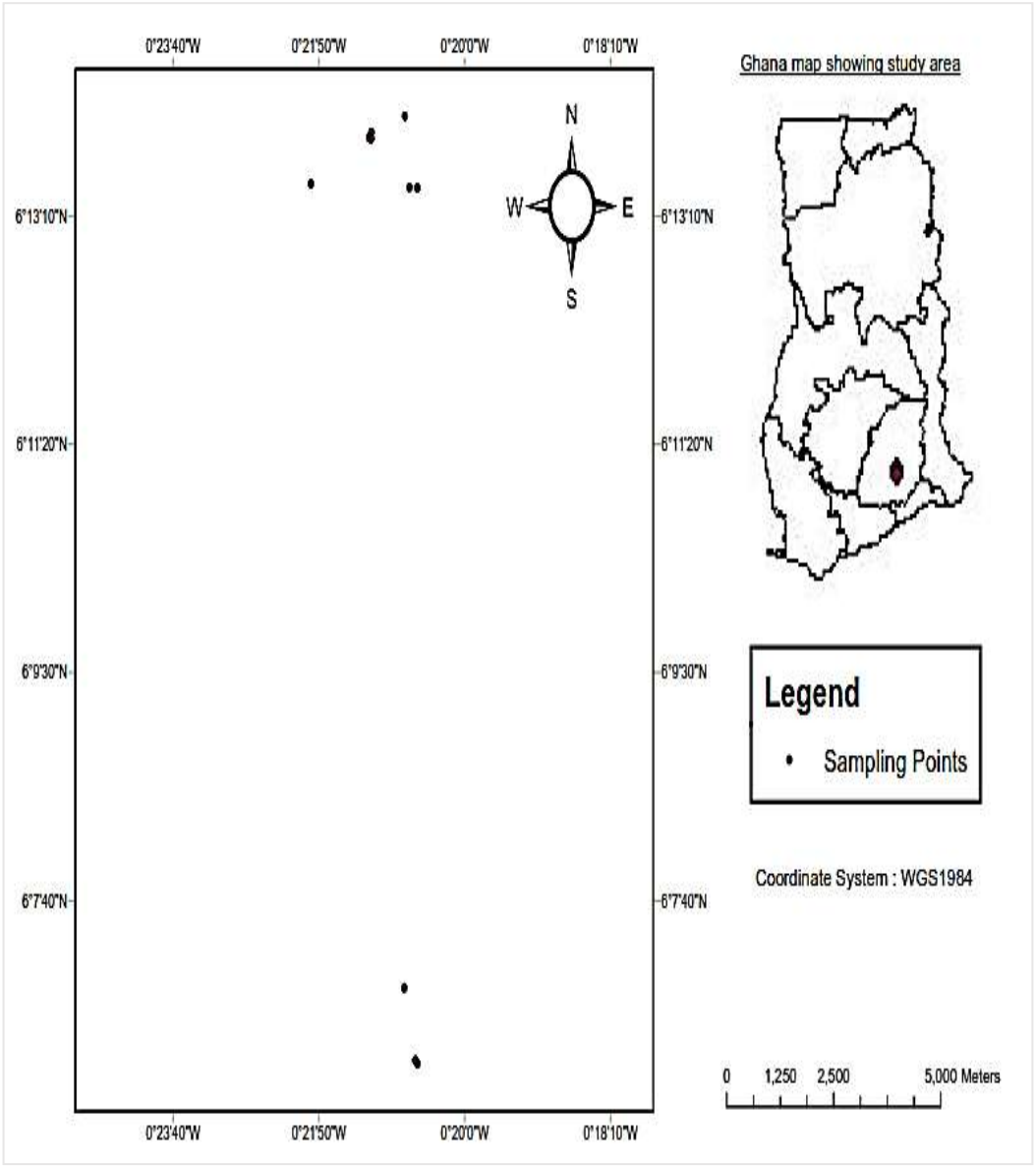

Figure 3.1. Map of study areas

3.2. Vegetation and the Soil Characteristic

The vegetation of the district is moist semi deciduous forest. The soil is developed from different plant materials. The soil present in the area is forest ochrosol which are developed from granite and are deep, well drained and permeable. They are suitable for the cultivation of food crops such as yam, cassava, maize, vegetables and tree crops (Dickson and Benneh, 1988)

3.3 Farm Management

Four plots from CRIG were selected to determine the effect of farm management practices on soil dwelling arthropods. The plots were:

1. **Plot N18;** this plot is managed by the Pathology unit of CRIG, and is used mainly for fungicide trial to manage black pod disease. The farm, located at N 06^0 13.794'', W 00^0 21. 200'', elevation: 222 m is sparely shaded and weeds on it are managed using glyphosate.
2. **Plot J8A;** this plot is managed for fungicide screening and earthworm cast study. The farm is located at N 06^0 13.839'', WO 00^0 21.172'', elevation: 233 m. The cocoa trees are matured and consist of mixture of hybrids with continues canopy. Overhead shade is mainly provided by tall *Terminalia ivorensis* and *T. superba* (A. Chev). There is no undergrowth.
3. **Plot K6-02;** this plot is used for fertilizer experiment. The plot is situated at N 06^0 13.787'', WO 00^0 21.172'' elevation: 236 m. The cocoa trees are matured and consist of mixture of hybrids with continues canopy. It has no overhead shading and there are a lot of undergrowth since weeding is done by under-brushing.
4. **Plot C6;** this plot is assign for the study of physiological effect of shade or growth development on the yield of cocoa. The plot coordinates are N 06^0 13.966'', W 000 20.750'', elevation: 236 m. The cocoa trees are matured and consist of mixture of hybrids with continues canopy. Overhead shading is mainly provided by *Gliricidia sepium* (Jacq), which is a nitrogen fixing tree.

All these plots are managed with the same insect pest management system by spraying insecticides. The spraying of confidor 200 SL (a.i. imidacloprid) is done every four weeks, starting in August and repeating in September, October and

December. November was normally omitted since a lot of crop harvesting and other farm activities were done during this period.

3.4 Pesticide Application

To determine the effect of pesticide application on soil dwelling arthropods, three cocoa farmers' farms that used conventional pest management (use of synthetic pesticide) to manage insect pests were selected from New Tafo Village. The various farms are situated at; N 06^0 13.424 W 00^0 21.930 elevation: 224 m, N 06^0 13.393 W 00^0 20.693 elevation: 231 m and N 06^0 13.389 W 00^0 20.597 elevation: 235 m.

Also, three cocoa farmers' farms that use organic pesticide (Pyrethrum) to control insect pests from Akwadum village were sampled. Akwadum was chosen because about 60% of the farmers' in the village use organic pesticides and the cocoa farmers belong to an association call the Akwadum Organic Cocoa Farmers Association (AOCFA). The various farms coordinates are; N 06^0 03.964 W 00^0 20.755 elevation: 170 m, N 06^0 06.351 W 00^0 20.593 elevation: 183 m and N 06^0 06.382 W 00^0 20.620 elevation: 193 m.

3.5 Data Collection

3.5.1 Collection and Extraction

3.5.1.1 Soil Surface Litter

From each of the farms and plots, soil surface litter was collected from five randomly selected spots from a 0.3 X 0.3 m quadrat (Owusu-Manu, 1999). It mainly consisted of undecomposed and partly decomposed cocoa leaves and other undergrowth. These were put into a polythene and labelled (Plate 3.1). They were then taken to the insect laboratory for processing and identification of the macro- and meso- arthropods after

which a multifaceted extractor (Berlese Tullgren funnel) was used for the extraction of the micro-arthropods.

Plate 3.1. A) Collection of surface litter with a 0.3 X 0.3 m quadrat. B) Labelled collected surface litter.

3.5.1.2 PVC Soil Sampler

Five randomly collected soil samples were taken from the various cocoa farms using a PVC Core sampler with a diameter of 76.2 mm and height 10 cm. Collection was done between October 2014 and January 2015. Four farms from CRIG were selected to determine the impact of farm management on soil dwelling arthropods. Also, three cocoa farmers' farms from New Tafo-Akim that use conventional pesticides (confidor) and three cocoa farmers' farms that use organic pesticide were sampled to determine the impact of conventional (synthetic) and organic pesticide (Pyrethrum) on soil dwelling arthropods. Sixty samples were taken per month and a total of 240 were collected for the four-month of sampling. Samples were taken by pushing PVC core sampler into the soil (Plate 3.2). It was then pulled up with its content and then placed in Ziplock polythene bags and labelled accordingly. They were then

transported to the Insect laboratory at KNUST where the multifaceted Berlese Tullgren funnel (Plate 3.4) was used for the extraction of the soil arthropods. The extraction method was design to suit behaviours and body structures of the organism (Wallwork, 1976b). The Berlese Tullgren Funnel extractor is the best extracting method for soil arthropods with an efficiency of 90% (Frith and Frith, 1990: Hopkins, 1997). The soil in the PVC samplers was placed on a sieve of 1 mm size at the top of the each funnel and the organisms were collected in containers containing 70% ethanol over a 96-hour period.

Plate 3.2. The use of PVC core sampler. A) PVC sample being buried into the soil to a height of 10 cm. B) Labelling the PVC sampler containing the soil

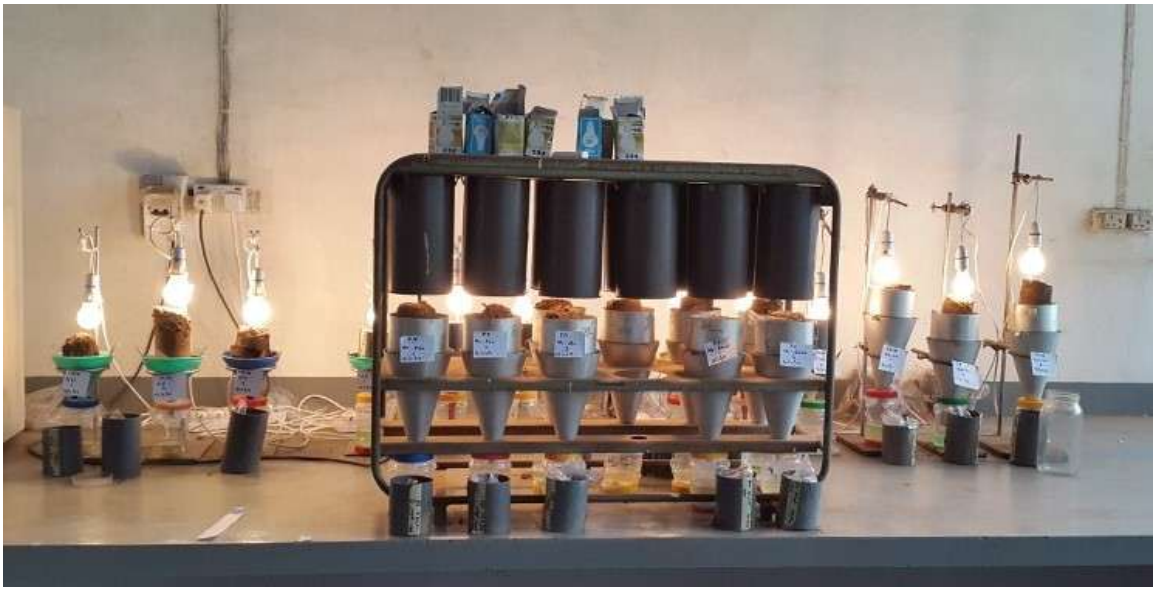

Plate 3.3. The Berlese Tullgren Funnel apparatus used for the extraction of the soil arthropods

3.6 Sorting And Identification

After the organisms were extracted and collected, they were immediately sorted and counted under a stereo microscope at 20X magnification using the method described by Ogedegbe and Egwuonwu (2014). The species contained in the debris were removed by carefully pouring the content in a petri dish and observing under the microscope.

Due to the microscopic nature of many of the arthropods, identification was done when they are mounted on a microscopic slide and observed under a stereo microscope (Hopkin, 2000; Ogedegbe and Egwuonwu, 2014)

All arthropods were identified to the Order level. The extraction and identification were carried out at the Entomology Laboratory of the Department of Crop and Soil Sciences, KNUST, Kumasi.

3.7 Measurement of Soil Physicochemical Properties

The following parameters were monitored and measured monthly; soil pH, soil moisture content and soil total hydrocarbon. These parameters were determined at the soil Microbiology Laboratory of the Faculty of Agriculture, KNUST.

3.7. 1 Soil pH

This was determined using glass electrode (Schott Instruments Lab 860) pH meter in a 1:2.5 soil to distilled water ratio (Mclean, 1982). Ten grams of the soil was weighed into a 100 ml beaker. To this, 25 ml distilled water was added, stirred thoroughly and was allowed to stand for 30 minutes. After calibrating the pH meter with buffer solution at pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension.

3.7.2 Soil Moisture Content

The moisture content of the soils was determined using the procedure described by the America Association of Cereal Chemists (AACC, 2000). Twenty grams of the sample was weighed into a moisture dish which had been previously dried in an oven and weighed. The uncovered dish was then dried in the oven for 24 hours at a temperature of 105 ± 5˚C. The dish was covered and transferred to desiccators and weighed quickly as soon it was cooled. The moisture content was determined using the formula below;

$$\text{Moisture (\%)} = \frac{\text{weight loss}}{\text{weight of sample}} \text{ x } 100$$

3.7.3 Soil total hydrocarbon

Five grams of the soil samples taken from a depth of 0-10 cm from the various farms were dried and kept in bottle containers. Then 25 ml of n-hexane was added to each

container in order to extract the soil total hydrocarbon. These were shaken for 10 minutes with a mechanical shaker in order for the content to be thoroughly mixed and then left to stand. The prepared n-hexane standard was used to standardize the spectrophotometer before introducing the soil total hydrocarbon content (SHC) from the soil into the spectrophotometer for the absorbance reading. The SHC concentration in part per million for each sample was then calculated as follows;

Soil SHC content (ppm) = instrument reading x reciprocal of slope x 25 ml/5g

The instrument reading (IR) was derived from the spectrophotometer. The reciprocal of slope was calculated for each of each sample based on the reading of the spectrophotometer. Volume of extraction reagent was 25 ml and the weight of each sample used was 5 g (Iloba and Ekrakene, 2009).

3.8 Data analysis

Data collected were subjected to ANOVA using SAS software (2010), after square root transformation. Treatment means were separated using Tukey at 5% level of probability. Correlation analysis was done to determine the relationship between the soil physicochemical parameters and the arthropods.

CHAPTER FOUR

4.0 Result

The result of all the experiment conducted in this study are presented in this chapter.

4.1. Soil Dwelling Arthropods Sampled from the Litter

Monthly mean number of arthropods from the conventional and organic pesticides cocoa farms are presented in Table 4.1. There was significant difference ($P < 0.05$) in the number of arthropods between the organic and the conventional pest management farms in October. However, there were no significant differences ($P > 0.05$) in the number of arthropods between the pest management systems in November, December and January.

Table 4.1. Monthly mean number of soil dwelling arthropods in the litter of cocoa farms managed under conventional and organic pest management systems.

Sampling months	Pest Management	Mean number of arthropods (± SEM)
October	Organic	2.45 ± 0.25 [a]
	Synthetic	2.05 ± 0.12 [b]
November	Organic	4.05 ± 0.16 [a]
	Synthetic	3.67 ± 0.42 [a]
December	Organic	1.75 ± 0.09 [a]
	Synthetic	1.56 ± 0.03 [a]
January	Organic	1.39 ± 0.19 [a]
	Synthetic	1.35 ± 0.11 [a]

Each value is the mean of five replications. Means followed by the same letter are not significantly different ($P < 0.05$) from each other, using Tukey test

4.1.1.2 Soil dwelling arthropods sampled from the litter

Eight arthropods orders; Collembola, Acarina, Hymenoptera, Araneae, Diptera, Coleoptera, Blattodea and Myriapoda were collected across the farms (Table 4.2).

There was significant difference ($P < 0.05$) in the number of Araneae collected with respect to the organic and synthetic pest management systems (Table 4.2). There were no significant differences ($P > 0.05$) in the number of Collembola, Acarina, Hymenoptera, Diptera, Coleoptera, Blattodea and Myriapoda collected from farms subjected to the pest management systems (Table 4.2).

Table 4.2. Mean number of soil dwelling arthropods sampled from the litter of cocoa farms managed under conventional and organic pest management systems.

Arthropod order	Pest Management	Mean number of arthropods (± SEM)
Collembola	Organic	3.85 ± 0.69 [a]
	Synthetic	2.57 ± 0.37 [a]
Acarina	Organic	3.14 ± 0.25 [a]
	Synthetic	2.96 ± 0.18 [a]
Hymenoptera	Organic	1.94 ± 0.25 [a]
	Synthetic	1.73 ± 0.12 [a]
Araneae	Organic	0.99 ± 0.19 [a]
	Synthetic	0.62 ± 0.11 [b]
Diptera	Organic	1.71 ± 0.13 [a]
	Synthetic	1.44 ± 0.19 [a]
Coleoptera	Organic	1.38 ± 0.12 [a]
	Synthetic	1.21 ± 0.09 [a]
Blattodea	Organic	0.57 ± 0.09 [a]
	Synthetic	0.48 ± 0.08 [a]
Myriapoda	Organic	1.50 ± 0.15 [a]
	Synthetic	1.11 ± 0.13 [a]

Each value is the mean of five replications. Means followed by the same letter are not significantly different ($P < 0.05$) from each other, using Tukey test

4.1.2 Soil Dwelling Arthropods Sampled from the Soil

4.1.2.1 Monthly Arthropods Means

There were no significant differences ($P > 0.05$) in the number of arthropods in the soil in the four months (Table 4.3).

Table 4.3. Monthly mean number of soil dwelling arthropods in the soil of cocoa farms managed under conventional and organic pest management systems.

Sampling months	Pest Management	Mean number of arthropods (± SEM)
October	Organic	2.19 ± 1.03 [a]
	Synthetic	2.06 ± 0.09 [a]
November	Organic	3.55 ± 0.11 [a]
	Synthetic	3.32 ± 0.10 [a]
December	Organic	1.84 ± 0.16 [a]
	Synthetic	1.64 ± 0.09 [a]
January	Organic	0.37 ± 0.22 [a]
	Synthetic	0.34 ± 0.09 [a]

Each value is the mean of five replications. Means followed by the same letter are not significantly different ($P < 0.05$) from each other, using Tukey test

4.1.2.2 Arthropods Sampled from the Soil

There were no significant differences ($P > 0.05$) between the means of all the arthropod orders sampled within the four months (Table 4.4).

Table 4.4. Mean number of soil dwelling arthropods sampled from the soil of cocoa farms managed under conventional and organic pest management systems.

Arthropod order	Pest Management	Mean number of arthropod (± SEM)
Collembola	Organic	4.20 ± 1.16[a]
	Synthetic	3.94 ± 1.00 [a]
Acarina	Organic	2.32 ± 0.27 [a]
	Synthetic	2.16 ± 0.18 [a]
Hymenoptera	Organic	1.13 ± 0.11 [a]
	Synthetic	1.41 ± 0.14 [a]
Araneae	Organic	0.47 ± 0.11 [a]
	Synthetic	0.22 ± 0.07 [a]
Diptera	Organic	1.95 ± 0.15 [a]
	Synthetic	1.76 ± 0.10 [a]
Coleoptera	Organic	0.89 ± 0.12 [a]
	Synthetic	1.16 ± 0.10 [a]
Blattodea	Organic	0.76 ± 0.11 [a]
	Synthetic	0.76 ± 0.08 [a]
Myriapoda	Organic	1.80 ± 0.11 [a]
	Synthetic	1.45 ± 0.15 [a]

Each value is the mean of five replications. Means followed by the same letter are not significantly different ($P < 0.05$) from each other, using Tukey test

4.2 Effect of Farm Management Practices

Eight orders of Arthropods were sampled within the litter and soil.

4.2.1 Soil Dwelling Arthropods Sampled from the Litter

For November, significant differences ($P < 0.05$) were obtained in the number of arthropods collected from the various plots (Table 4.5). Significantly more arthropods were collected from the litter from J8A plot than from K6-02 and N18 plots. For the months of October, December and January, there were no significant differences ($P > 0.05$) in the number of arthropods collected.

Table 4.5. Monthly mean number of soil dwelling arthropods sampled from the litter from cocoa plots (farms) under different agronomic management system at the Cocoa Research Institute of Ghana, New Tafo-Akim.

Sampling months	Farm management (plots)	Mean number of arthropods (± SEM)
October	K6-02	1.94 ± 0.21 [a]
	C6	2.34 ± 0.18 [a]
	J8A	2.45 ± 0.26 [a]
	N18	2.01 ± 0.33 [a]
November	K6-02	2.17 ± 0.19 [bc]
	C6	2.64 ± 0.05 [ab]
	J8A	2.89 ± 0.15 [a]
	N18	1.86 ± 0.21 [c]
December	K6-02	1.57 ± 0.21 [a]
	C6	1.62 ± 0.06 [a]
	J8A	1.65 ± 0.18 [a]
	N18	1.65 ± 0.10 [a]
January	K6-02	1.28 ± 0.21 [a]
	C6	1.55 ± 0.13 [a]
	J8A	1.56 ± 0.11 [a]
	N18	1.31 ± 0.16 [a]

Each value is the mean of five replications. Means followed by the same letter are not significantly different ($P < 0.05$) from each other, using Tukey test

4.2.2 Arthropods Orders Sampled from the Litter.

Significant differences ($P < 0.05$) were observed between plot J8A and N18 for Collembola and Hymenoptera, while significant difference was observed between plot C6 and N18 for Araneae collected from the litter. There were no significant differences ($P > 0.05$) in the number of Acarina, Diptera, coleopteran, Blattodea and Myriapoda collected from all plots (Table 4.6)

For Collembola, significantly more soil arthropods were in plot J8A than N18. However, the number of arthropod collected from J8A plot was similar to K6-02 and C6. No significant difference ($P > 0.05$) was obtained between plot J8A, K6-02 and C6 in terms of number of Hymenoptera collected (Table 4.6), but significant difference ($P < 0.05$) was obtained between plot J8A and N18. With respect to Araneae, significantly more was collected from plot C6 than N18.

Table 4.6. Mean number of soil dwelling arthropods sampled from the litter from cocoa plots (farms) under different agronomic management system at the Cocoa Research Institute of Ghana, New Tafo-Akim.

Arthropods order	Farm Management (Plots)	Mean number of arthropods (±SEM)
Collembola	**K6-02**	2.23 ± 0.24 [ab]
	C6	3.03 ± 0.31 [ab]
	J8A	3.19 ± 0.30 [a]
	N18	2.11 ± 0.20 [b]
Acarina	**K6-02**	2.08 ± 0.24 [a]
	C6	2.59 ± 0.27 [a]
	J8A	2.69 ± 0.32 [a]
	N18	2.05 ± 0.20 [a]
Hymenoptera	**K6-02**	1.76 ± 0.19 [ab]
	C6	2.21 ± 0.22 [ab]
	J8A	2.45 ± 0.23 [a]
	N18	1.55 ± 0.12 [b]
Araneae	**K6-02**	0.89 ± 0.19 [ab]
	C6	1.42 ± 0.15 [a]
	J8A	1.15 ± 0.26 [ab]
	N18	0.68 ± 0.17 [b]
Diptera	**K6-02**	1.55 ± 0.25 [a]
	C6	1.57 ± 0.20 [a]
	J8A	1.33 ± 0.22 [a]
	N18	1.48 ± 0.23 [a]
Coleoptera	**K6-02**	1.42 ± 0.22 [a]
	C6	1.38 ± 0.19 [a]
	J8A	0.97 ± 0.19 [a]
	N18	1.23 ± 0.18 [a]
Blattodea	**K6-02**	1.00 ± 0.19 [a]
	C6	0.57 ± 0.16 [a]
	J8A	0.97 ± 0.22 [a]
	N18	0.46 ± 0.13 [a]
Myriapoda	**K6-02**	1.17 ± 0.21 [a]
	C6	1.13 ± 0.19 [a]
	J8A	1.29 ± 0.18 [a]
	N18	1.45 ± 0.38 [a]

Each value is the mean of five replications. Means followed by the same letter are not significantly different ($P < 0.05$) from each other, using Tukey test

4.2.3. Soil Dwelling Arthropods Sampled from the Soil

The results for the monthly number of soil arthropods in the soil show significant differences ($P < 0.05$) between the plots for the month of November, with no significant differences in October, December and January (Table 4.7). However, plot N18 harboured significantly less number of the arthropods than plot J8A in November but not significant for all other months.

Table 4.7. Monthly mean number of soil dwelling arthropods sampled from the soil from cocoa plots (farms) under different agronomic management system at the Cocoa Research Institute of Ghana, New Tafo-Akim.

Sampling months	Farm Management (Plots)	Mean number of arthropods (± SEM)
October	**K6-02**	1.80 ± 0.17 [a]
	C6	1.96 ± 0.28 [a]
	J8A	2.40 ± 0.21 [a]
	N18	1.77 ± 0.19 [a]
November	**K6-02**	1.98 ± 0.19 [ab]
	C6	2.20 ± 0.27 [ab]
	J8A	2.75 ± 0.17 [a]
	N18	1.78 ± 0.26 [b]
December	**K6-02**	1.60 ± 0.10 [a]
	C6	1.53 ± 0.22 [a]
	J8A	2.06 ± 0.11 [a]
	N18	1.68 ± 0.21 [a]
January	**K6-02**	1.27 ± 0.21 [a]
	C6	1.36 ± 0.13 [a]
	J8A	1.28 ± 0.21 [a]
	N18	1.36 ± 0.22 [a]

Each value is the mean of five replications. Means followed by the same letter are not significantly different ($P < 0.05$) from each other, using Tukey test

4.2.4 Arthropods order Sampled from Soil

There were significant differences ($P < 0.05$) in the number of arthropods collected from the plots with respect to the Diptera and Myriapoda (Table 4.8). Plot J8A harboured significantly Diptera than plot N18. For Myriapoda, plot C6 had

significantly more ($P < 0.05$) than plot K6-02. For the arthropods orders Collembola, Acarina, Hymenoptera, Araneae, Coleoptera and Blattodea, there was no significant between ($P > 0.05$) among the plots.

Table 4.8. Mean number of soil dwelling arthropods sample from the soil from cocoa plots (farms) under different agronomic management system at the Cocoa Research Institute of Ghana, New Tafo-Akim.

Arthropods orders	Farm Management (Plots)	Mean number of arthropods (± SEM)
Collembola	**K6-02**	2.87 ± 0.23 [a]
	C6	2.85 ± 0.28 [a]
	J8A	3.17 ± 0.32 [a]
	N18	2.76 ± 0.29 [a]
Acarina	**K6-02**	2.08 ± 0.19 [a]
	C6	2.12 ± 0.27 [a]
	J8A	2.15 ± 0.27 [a]
	N18	2.00 ± 0.25 [a]
Hymenoptera	**K6-02**	1.39 ± 0.19 [a]
	C6	1.36 ± 0.23 [a]
	J8A	0.94 ± 0.22 [a]
	N18	1.14 ± 0.19 [a]
Araneae	**K6-02**	0.20 ± 0.09 [a]
	C6	0.41 ± 0.15 [a]
	J8A	0.53 ± 0.14 [a]
	N18	0.35 ± 0.11 [a]
Diptera	**K6-02**	1.70 ± 0.19 [ab]
	C6	1.95 ± 0.22 [ab]
	J8A	2.47 ± 0.25 [a]
	N18	1.45 ± 0.22 [b]
Coleoptera	**K6-02**	1.09 ± 0.19 [a]
	C6	1.05 ± 0.18 [a]
	J8A	0.66 ± 0.18 [a]
	N18	0.81 ± 0.16 [a]
Blattodea	**K6-02**	0.74 ± 0.18 [a]
	C6	0.43 ± 0.16 [a]
	J8A	0.76 ± 0.18 [a]
	N18	0.60 ± 0.19 [a]
Myriapoda	**K6-02**	0.96 ± 0.17 [b]
	C6	1.87 ± 0.25 [a]
	J8A	1.56 ± 0.30 [ab]
	N18	1.09 ± 0.17 [ab]

Each value is the means of five replication. Means followed by the same letter by the same letter are not significantly different ($P < 0.05$) from each other, using Tukey test

4.3 Soil Physicochemical Parameters

The following soil physicochemical parameters (soil pH, soil moisture content and soil hydrocarbon) were monitored for the four months period of sampling.

4.3.1 Soil Physicochemical Parameters of Cocoa Farmers' farms under Organic and Synthetic Pesticides Management

There were no significant differences ($P > 0.05$) between the cocoa farms in terms of the soil hydrocarbon, soil moisture content and soil pH (Table 4.9)

Table 4.9. Mean values of soil physicochemical properties of farms under the two pest management systems

Parameters	Pest Management	Mean Value (± SEM)
Soil total Hydrocarbon	Organic	0.007 ± 0.0024 [a]
	Synthetic	0.008 ± 0.0022 [a]
Soil moisture content (%)	Organic	17.42 ± 5.05 [a]
	Synthetic	16.51 ± 6.89 [a]
Soil pH	Organic	6.51 ± 0.73 [a]
	Synthetic	6.24 ± 0.58 [a]

The correlation between soil arthropods and the soil physicochemical properties of cocoa farms under organic pesticides management was not significant (Table 4.10). There was a positive correlation between soil arthropods and pH, moisture content and soil hydrocarbon, but negative correlation between moisture content, pH and soil hydrocarbon.

Table 4.10. Correlation matrix of arthropods and soil physicochemical properties of cocoa farms under Organic pest management

	Arthropods	MC	pH	SHC
Arthropods	-			
MC	0.2891^{ns}	-		
PH	0.2253^{ns}	-0.1850^{ns}	-	
SHC	0.3645^{ns}	-0.0534^{ns}	-0.1043^{ns}	-

ns= not significant. MC = Moisture content, SHC = Soil Hydrocarbon.

The correlation between soil arthropods and the soil physicochemical properties of the cocoa farms under organic pesticides management was not significant (Table 4.11). There was a positive correlation between soil arthropods and pH, moisture content and soil hydrocarbon. However, negative correlation existed between moisture content and pH but positive correlation between moisture content and soil hydrocarbon, which was not significant.

Table 4.11. Correlation matrix of arthropods and soil physicochemical properties of cocoa farms under synthetic pest management.

	Arthropods	MC	pH	SHC
Arthropods	-			
MC	0.3117^{ns}	-		
PH	0.2290^{ns}	-0.0622^{ns}	-	
SHC	0.0547^{ns}	0.0429^{ns}	0.4211^{ns}	-

ns= not significant. MC = Moisture content, SHC = Soil Hydrocarbon.

4.3.2. Soil Physicochemical Parameters of Research plots of the Cocoa Research Institute of Ghana

The soil pH of plot C6 was significantly different ($P < 0.05$) from that of plot J8A and N18 but not significantly different from plot K6-02 (Table 4.12). There were no significant differences ($P > 0.05$) between the plots in terms of the soil total hydrocarbon and soil moisture.

Table 4.12. Mean value of soil physicochemical parameters of the Cocoa Research Institute of Ghana's Research plots.

Parameters	Farm management Plots	Mean value (± SEM)
Soil Total hydrocarbon	K6-02	0.012 ± 0.0024^{a}
	C6	0.011 ± 0.0031^{a}
	J8A	0.024 ± 0.0247^{a}
	N18	0.012 ± 0.0077^{a}
Soil pH	K6-02	5.85 ± 0.51^{ab}
	C6	5.15 ± 0.24^{b}
	J8A	6.08 ± 0.18^{a}
	N18	6.00 ± 0.29^{a}
Soil moisture content (%)	K6-02	20.80 ± 8.77^{a}
	C6	14.47 ± 5.29^{a}
	J8A	15.60 ± 8.06^{a}
	N18	13.65 ± 9.12^{a}

Each value is the means of the five replication. Means followed by the same letter are not significantly different ($P < 0.05$) form each other according to Tukey.

The correlation matrix of soil arthropods and soil physicochemical properties of the CRIG cocoa plots under different farm management practices are presented in Table 4.13.

There was positive correlation between arthropods and soil moisture content, but a negative correlation between arthropod, pH and soil hydrocarbon but all were not significant (Table 4.13)

Table 4.13. Correlation matrix of arthropods and soil physicochemical properties of Cocoa Research Institute of Ghana's Research plots.

	Arthropods	MC	pH	SHC
Arthropods	-			
MC	0.0027^{ns}	-		
PH	-0.3820 ^{ns}	-0.1153 ^{ns}	-	
SHC	-0.1712 ^{ns}	-0.1517 ^{ns}	-0.0603 ^{ns}	-

ns= not significant. MC = Moisture content, SHC = Soil Hydrocarbon.

CHAPTER FIVE

5.0 Discussion

Soil arthropods are very vital links in the food chain as decomposers (Mattson, 1977), and according to Trombetti and William (1999), without these organisms, nature would have no way of recycling organic material. Therefore, it is essential to monitor the activities of these vulnerable soil dwellers with the view to determine the impact of pesticide application and farm management practices on them and soil health as a whole.

The backdrop of this study was hinged on the fact that, the management of pests in cocoa farms in Ghana is heavily dependent on the use of synthetic pesticides, as a result of the introduction of CODAPEC by the Government of Ghana in 2001, which entails the mass spraying of cocoa farms with synthetic insecticides and fungicides against mirids and black pod, respectively (Sarpong-Akosa, 2001; Dormon *et al.,* 2007).

The collection of soil arthropods lasted for a period of four months (October – January) and eight orders (Collembola, Acarina, Hymenoptera, Araneae, Diptera, Coleoptera, Blattodea and Myriapoda) were recorded across cocoa farms selected for the sampling.

The application of pesticides is one of the practices associated with agricultural activities and this has strong influence on the diversity and abundance of soil fauna (Graham-Bryce, 1981; Subias *et al.*, 1985; Adan *et al*., 1991).

There was a gradual decrease in arthropods abundance from October to January. This might be attributed to the several factors, one of which might be the difference in

environmental conditions per the seasons and the toxic effect of the chemical applied. The toxic effect of these synthetic chemicals has the ability to create unfavourable conditions that could cause death of the organism especially during the dry season (December and January). This observation agreed with the ones previously made by Jones and Hopkins (1998) and Frouz (1999) that environmental conditions are highly affected by pesticides and as a result, affect the number of micro-arthropods existing in such treated areas. October and November had a higher arthropod mean and this may probably be due to the dilution effect of rain (since it coincided with the latter part of the wet season). Iloba and Ekrakene (2009) also observed a significant increase in arthropod population during the wet season.

On general soil fauna abundance, Collembola, Acarina and Hymenoptera were numerically the most abundant in both the litter and soil across the pesticide regimes. The results are in agreement with findings by Frampton (1994) who reported more Collembola in tree growing soil, followed by mites which colonized nearly every terrestrial environment. Trombetti and Williams (1999) and Brown and Gange (1989) as well as Iloba and Ekrakene (2008) also recorded more Collembola in the top layers of the soil (0-10 cm), the litter and soil surface layers of many forest trees.

In both litter and soil, relatively, cocoa farms where organic pesticides were sprayed to manage pests had a higher number of soil arthropods compared to those cocoa farms where conventional (synthetic) pesticides are used. Similar observation was made by Abudulai *et al*. (2013) when they looked at the field efficacy of neem (*Azadirachta indica* A. Juss) to manage soil arthropods and Cercospora Leaf Spots damage for increased yield in peanut.

Significant differences ($P < 0.05$) were observed in Araneae abundance in the litter (Table 4.2). According to Pekár (2012) and Feber *et al.* (1998), Araneae, been one of the most abundant groups of natural enemies occurring in all agro ecosystems, are occasionally affected by pesticide applications. spiders are primarily affected by insecticides and acaricides specifically the neurotoxic substances such as bifenthrin. This is in line with similar finding made by Adu-Acheampong and Ackonor (2005).

There were no significant differences ($P > 0.05$) among the various arthropod orders sampled from the soil (Table 4.4). This could be attributed to several factors. Firstly, pesticides used over the years in cocoa farms, be it organic or synthetic, have not adversely affected soil dwelling arthropods. This, according to Owusu-Manu (1999), normal routine of application of insecticides sprays on cocoa farms in Ghana did not adversely affect the soil and litter fauna. This may be explained by the fact that during normal spraying exercise, spray droplets are directed at the cocoa canopy where about 50% of droplets are deposited while the minute droplets float or escape into the atmospheres (Marchart, 1968; Anon, 1980). Iloba and Ekrakene (2009) made similar observation that the application of an organophosphate pesticide to the soil did not have a significant effect on the soil arthropods. They noted that, arthropods reduction with time and re-colonization after a period is imminent. Thus soil ecosystem imbalance may be a temporary phenomenon with no much adverse effect on the productivity ability of the soil in the long run when pesticides are not indiscriminately applied.

It appears that cocoa farmers who use organic pesticides to manage pests and diseases also apply some synthetic chemicals. Blankson (2011) evaluated the concentration of pesticides residues in fermented dry cocoa beans, and reported no

significant difference between pesticide residues in the synthetic and the organic cocoa farms in Asukese and its environs. Out of the eighteen active ingredients of pesticides detected in the fermented dry cocoa beans samples, the organic cocoa farms had fifteen active ingredients including Ethoprophos, Dimethoate, Fenitrothion, Malathion, Chlorpyrifos, Parathion, DDE, alpha endosulfan, DDD, DDT, and Fenvalerate.

Again, Agyen (2011) who evaluated pesticide residues and levels of some metals in soils and cocoa beans in selected farms in the Kade area in the Eastern Region of Ghana, similarly found in general, sixteen different pesticide residues in the soil samples from both the organic and synthetic cocoa farms.

5.1. Monthly Trend of Arthropods Sampled in the Litter and Soil from CRIG plots

In this study, results in the month of November showed significant differences ($P < 0.05$) in arthropod number (Collembola, Hymenoptera and Araneae) between the plots (for both the litter and soil samples) (Table 4.5 and 4.7). There was significant differences ($P < 0.05$) between plot J8A and N18. This difference might probably be due to the fact that in November, cocoa farmers do not apply pesticides due to harvesting activities (Awudzi *et al*., 2012), and as a result, arthropods tend to start the recolonization of the environment. According to Iloba and Ekrakene (2008, 2009), who evaluated the recovery rates of soil arthropods following dichlorov pesticides treatment over a five-month period, there was a quick recovery ability of plot previously treated. And this according to them, implies that, the micro-arthropods show a greater tendency of re-colonizing an area which was previously uninhabited due to pesticide application.

The use of earthworm caste as soil amendment impacted positively on plot J8A arthropods activity resulting in significantly more arthropod numbers than in N18 where herbicides was used to manage weed. This significant difference can be due to use of the herbicides in addition to the fungicide and confidor 200 SL for plot N18. Pereira *et al.* (2007) noted that the application of Glyphosate, which is a non-selective herbicide can affect predatory arthropods (spiders, ground beetle, springtails, mites and earthworms) in agricultural field, cause behavioural changes and influence long-term survival even in residual exposure. In addition, herbicides can affect arthropod community dynamics, apart from their impact on the plant community and may influence biological control in agroecosystems.

Much difference was not seen between plot K6-02 which is used for fertilizer trial, and J8A which is used for earthworm caste and fungicides trial and C6 that has nitrogen fixing trees which also provide shade. These management practices augment the soil properties and improve the microclimate for conducive atmosphere for the arthropods to strive. According to Hati *et al.* (2007), the application of fertilizer tends to improve the population of Collembola.

5.3.1 Soil Physicochemical Parameters for Cocoa Farmers that use Organic and Synthetic Pesticides

The physicochemical parameters (soil moisture content, soil pH and soil hydrocarbon) did not significantly differ among the farms. This might be as a result of the changes in the environmental conditions associated with the transition from the rainy into dry season (Badejo, 1982; Iloba and Ekrakene, 2008).

Positive non-significant correlation between arthropods and soil physicochemical parameters corroborated previous observation made by Ogedegbe and Egwuonwu (2014) and they attributed it to the seasonal variation in environmental conditions.

5.3.2. Soil Physicochemical Parameters for Cocoa Farm Management

There were positive correlation between the arthropods and the Soil moisture content (Table 4.12), even though there were no significant differences ($P > 0.05$) between the two farms (Table 4.11) in the soil physicochemical parameters.

With respect to the various farm management practices, there were significant differences ($P < 0.05$) between the various practices and soil pH. Also there was weak and negative correlation between soil pH and soil arthropods. These indicate that as the soil pH decreases, the soil arthropod population increases and vice versa. The changes in pH might be as a result of the changes in chemical properties perticularly the carbon content of the soil as a result of the pesticides and this slightly determines the abundance of the soil arthropods (Michelle and Hopkin, 2004).

There were also weak negative correlation between soil arthropod and soil hydrocarbon, although the values recorded seem very low. Similar result was observed by Iloba and Ekrakene (2008). They stated that the low soil hydrocarbon could be as a result of the excessive leaching of the top soil occasioned by the series of rainfall.

There was positive correlation between the arthropods and the soil moisture content. This implies that as the soil moisture content was increasing, the arthropods population was increasing as well. Similar observation was made by Ogedegbe and Egwuonwu (2014), and was attributed to the rainy season.

CHAPTER SIX

6.0 Conclusion and Recommendation

6.1 Conclusion

Pesticides application over the years has not adversely affected the abundance and richness of soil dwelling arthropod within the cocoa farms sampled.

The study also revealed that Collembola, Acarina and Hymenoptera constitute the most abundant while Araneae and Blattaria were least in abundance in both the litter and soil sampled from the selected cocoa farms.

There was a relative reduction in the number of arthropods population across the sampled farm and management practices from October to January.

The use of herbicides as a farm management practices to control weeds had a significant effect on Collembola and Hymenoptera in the litter and on Diptera in the soil. Fertilizer application, shade management, nitrogen fixing trees and earthworm caste all as soil amendment seem to have a positive effect on the soil arthropods' abundance and richness.

The soil physicochemical parameters (soil pH, soil moisture content and soil hydrocarbon) had no significant effect on the abundance and richness soil arthropods sampled across the pest management practices. However, soil pH within the farm management system was observed to have a significant effect on the richness and abundance of soil arthropods.

6.2 Recommendation

- This work must be repeated to cover a 12-month period to reveal the trend for a year.
- Other extraction methods such the pitfall trapping and Winkler should be combined with the Berlese Tullgren extraction method to capture very fast arthropods in the litter in a future study.
- With little information available on the relationship between pesticides and soil dwelling arthropods in cocoa farms, researchers should consider conducting research in these areas. Also the population dynamics of soil arthropods should be studied in more detail to provide more useful and reliable data so that better sampling and management protocol can be recommended.

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