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IMPACT OF LAND USE ON NEMATODE ASSEMBLAGE IN THREE AGRO-ECOLOGICAL ZONES OF GHANA

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BSC (HONS) AGRICULTURE

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(BSc. (Hons) Agriculture)

A THESIS SUBMITTED TO THE DEPARTMENT OF CROP AND SOIL SCIENCES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

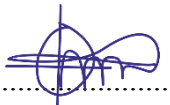
MASTER OF PHILOSOPHY

IN

CROP PROTECTION (NEMATOLOGY)

DECLARATION

I certify that this thesis does not incorporate, without acknowledgement, any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief, does not contain any material previously published or written by another person, except where due reference has been made in the text.



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ABSTRACT

Understanding the types of biological and nutritional degradations is critical in developing practical soil health management strategies in Ghana. To understand the types of biological and nutritional degradations in disturbed and undisturbed landscapes; and the impact of change in land use on soil physicochemical and biological properties, 90 farms (maize and tomato agro-systems) and nine undisturbed sites were sampled in 2012 and 2013 from the semi-deciduous forest, forest-savannah transition and guinea savannah agro-ecological zones of Ghana for laboratory investigations. Farmers were also interviewed to ascertain prevailing cultivation practices in the study areas. This study used nematode assemblage analysis to determine ecological disturbance (PPI, MI and ΣMI), community diversity (H′, λ, N0 and N1), and soil food web structure (BI, CI, SI and EI). Samples were also analysed for soil pH (H_2O), organic carbon (OC) total nitrogen (%N), available nitrogen (NO_3^-+NH_4^+), P_2O_5, K_2O_5, Ca^{2+}, Mg^{2+} and effective cation exchange capacity (ECEC) to evaluate the levels of physicochemical degradations. Results from the laboratory analysis of 396 and 99 samples for physicochemical and biological properties respectively, were analysed by Residual Maximum Likelihood (RELM) Linear Mixed Model (VSN International, 2011). Results from the study show that the soils were inherently poor, in terms of plant nutrients and naturally fragile, in terms of soil food web condition which were further worsened by cultivation practices. Most farmers continuously cultivated their fields for over 9 years in the Semi-Deciduous Forest and Forest-Savannah Transition zones yet their cultivation practices, were not directed towards maintaining good soil health. Soils from undisturbed sites of all the three agro-ecological zones recorded significantly higher maturity index (ΣMI) than soils from maize and tomato fields, indicating that the current cultivating practices are disturbing the soil's ecosystem.

DEDICATION

This thesis is dedicated to Dr. Eric Asare; may his soul rest in perfect peace.

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CHAPTER ONE

1.0 INTRODUCTION

Crop cultivation has direct effects on the soil which in turn affects farm productivity. A healthy soil offers ecosystem functions including primary productivity (plant growth and yield), decomposition and nutrient cycling, disease suppression, and biological control (Neher, 2010). Soil health is, therefore, necessary for sustained productivity of agriculture.

Farm practices, apart from influencing soil's physical and chemical properties, disturb and destabilize the soil ecosystem (FAO, 2001). Paton (1978) reported that continuous disturbance of the soil gradually degrades the soil's biodiversity which, in turn, degrades soil fertility and soil health. Crop cultivation, therefore, becomes a threat to the soil and the future of food security.

Agriculture in Ghana has evolved over the years from cultivation practices which had minimal negative effects on the soil to practices which have deleterious effects on soil health. The fallow system has almost disappeared as towns become more densely populated and demand for land becomes greater. In the Interior Savannah and Forest-Savannah-transitional zones, for example, most farms have been cultivated at least once in the last 11 years (Ragasa *et al.*, 2013).

According to Ragasa *et al.* (2013), insignificant percentage of farmers in Ghana undertake agronomic practices that are necessary for improving soil quality; for example, only 3% of maize area was applied with animal manure. Only 3% of maize area was intercropped with legumes, 1% of maize area had cover crops, 17% of maize area was ploughed in with crop residue, and 11% was planted in mulch. Almost no

maize area was under any form of land management practice that would maintain or improve soil fertility.

Some fallowing, usually for short period, is still practiced in the Forest and Coastal Savannah Zones, but that is rapidly disappearing due to population growth pressures and greater demand on land. Continuous cropping and the limited adoption of soil fertility management practices put much stress on the land (Ragasa *et al.*, 2013).

In areas where farmers are reported to apply mineral fertilizers, this is done at rates far below the recommended. Ragasa *et al.* (2013) reported that even though fertilizer application on maize has significantly increased, the application rate (47 kg/ha of nitrogen) is half the recommended (90 kg/ha) despite a national subsidy programme to encourage more users and greater rates of application on crops. Thirty-three percent of maize farmers in Ghana reported that lack of funds or high cost of fertilizers as the reason for the non-use. Herbicide use on the other hand, is more popular. This, according to Ragasa *et al.* (2013), is as a result of the influx of cheap herbicides formulations from China to Ghana: about 73% of farmers in maize growing areas in Ghana apply herbicides at the rate of 9.2 L/ha which is higher than the recommended rate.

Land shortage, poverty, non-sustainable land management practices, together with climate change impair the struggle for food security. Identifying the root causes of degradation of farm lands is key in mitigating poverty and hunger. This would aid in the development strategies more relevant and practical to the smallholder farmer in improving soil health and fertility.

Mwangi (1996) reported that Africa would have the world's largest net deficit in cereals, both in absolute and in relative terms by 2021. With population continuously

and rapidly increasing in all parts of Africa, the need to reverse these declining trends has become urgent. Improving soil fertility could trigger rural and national economic development, achieve long-term food security and improve farmers' standards of living, whilst mitigating environmental degradation and rural migration.

Identifying the types of human-induced land degradation as well as their causes, including the related socio-economic factors, is a prime requirement for developing mitigation technologies. Figure 1 below, illustrates how the indirect causes of land degradation are associated with each other. Continuous population increase and increase in food demand have placed tremendous pressure on land. Poverty and land tenure problems which are prevalent in developing countries have pushed the priority of land management practices to the background in recent times ((FAO, 2001).

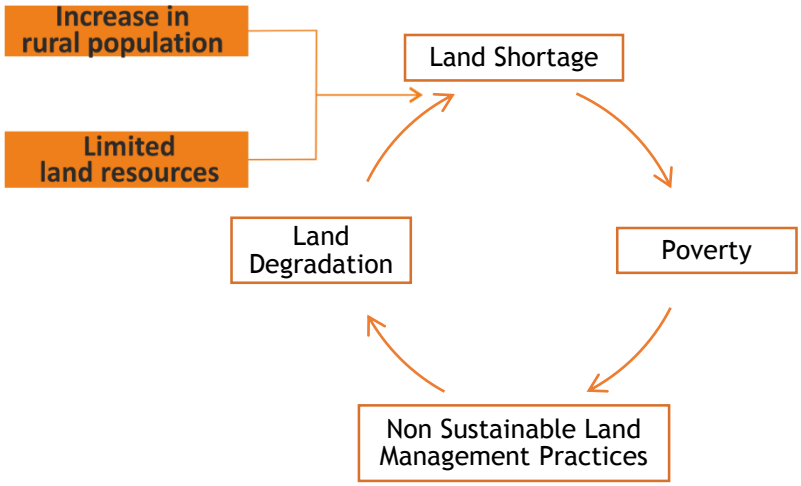


Figure 1.1: Causal nexus among land resources, population, poverty and land degradation (FAO, 2001).

Studying the diversity, distribution and behaviour of soil microorganisms is important in understanding soil health. Soil nematode communities can provide unique information about many aspects of soil processes and can provide a holistic measure of the biotic and functional status of soils (Liang *et al.*, 2005).

There are pieces of evidence of increase in poor cultivation practices in Ghana which threaten soil health and, in turn, threaten the future of agriculture and food security. However, information on the impact of crop cultivation on soil ecosystem in Ghana is very scanty, though technologies are available to capture this information.

Inadequate information on soil ecosystem has led to a one-size-fits-all approach in tackling most biologically degraded soils which have several limitations as every type of biologically degraded soil requires unique management strategies to recover, improve, or maintain the soil, depending on the level of degradation.

Soil nematode community analysis offers a good opportunity for studying the impact of cultivation practices on soil ecosystems. This research focused on studying physicochemical properties of soils and analysed existing nematode communities to ascertain the extent of nutritional and biological degradation of the soils.

The main objective of this study was to establish the impact of cultivation practices in Ghana on soil nematode community, and the nutritional and physicochemical properties of soils of maize and tomato agro-ecosystems.

The specific objectives were to:

i. outline the agricultural practices across three agro-ecological zones of Ghana,
ii. establish the levels of nutritional and physicochemical degradations across the three agro-ecological zones of Ghana, and
iii. determine the level of biological degradation in cultivated soils using nematode community analysis.

The above objectives were formulated based on the hypothesis that land cultivation practices in Ghana are not directed towards improving soil health and that this has led to biological, physicochemical and nutritional degradation of the soils.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Background

The foundation of food security and global ecosystem lies in the biological, physicochemical, nutritional and structural health of soil in natural, managed and disturbed ecosystems (Melakeberhan, 2010). An overview of the level of biological, physicochemical and nutritional degradation is key to sustainably reversing the current trend of drop in soil fertility and health. Melakeberhan (2013) suggested that the *one-size-fits-all* approach to soil-driven needs to be reconsidered. There is the need to understand the major players in soil health and the relationship among these major players in order to design soil management practices directed towards a given scenario.

2.2 Climate and agro-ecology of Ghana

Ghana is 239,469 km^2 and located in West Africa on the Gulf of Guinea Coast. Ghana lies within latitudes 4° 30′N and 11° N, and longitudes 1°12′E and 3^0 15′W. The climate of Ghana is tropical monsoon, and strongly influenced by Inter Tropical Convergence Zone (ITCZ), which gives rise to alternate wet and dry seasons (Stanturf *et al.*, 2011). Seasonal variations in temperature in Ghana are greatest in the northern part, with highest temperatures in the dry season (April to June) at 27-30°C, and lowest in July to September at 25-27°C. In the Southern part, temperatures reach 25-27°C in the warmest season (January to March), and 22-25 °C at their lowest in July to September (McSweeney *et al.*, 2010).

Ghana is divided into six agro-ecological zones (Table 2.1). A bimodal rainfall pattern in the Rain Forest, Deciduous Forest and Forest-Savannah Transition Zones results in

major and minor seasons, in contrast to a single growing season in the Guinea Savannah and Sudan Sudan Savannah Zones, resulting from a unimodal rainfall distribution. The rainfall generally decreases from the south to the north with the wettest being the extreme south-western part (Rain Forest Zone) of the country receiving over 2,000 mm rainfall per annum, as compared to 1100 mm in the extreme north and 750 mm in the south-eastern coastal tip (Oppong-Anane, 2006).

Table 2.1: Agro-ecological zones of Ghana

Agro-ecological zone	Area (km^2)	Average annual rainfall (mm)	Growing period (days)	
			Major season	Minor season
Rain Forest	9,500	2200	150-160	100
Deciduous Forest	66,000	1500	150-160	90
Transitional zone	8,400	1300	200-220	60
Coastal Savannah	4,500	800	100-110	60
Guinea Savannah	147,900	1,100	180-200	0
Sudan Savannah	2,200	1,000	150-160	0

Source: (FAO, 2005).

2.3 Cropping systems

A wide range of cropping systems exists in Ghana. At one end of the range is an interventionist approach, in which most aspects of production are controlled by technological interventions such as soil tilling, protective or curative pest and weed control with agrochemicals, and the application of mineral fertilizers for plant nutrition. At the other end are production systems that take a predominantly ecosystem approach and are both productive and more sustainable (Doran and Zeiss, 2000). These agro-ecological systems are generally characterized by minimal disturbance of the natural environment, plant nutrition from organic and non-organic sources, and the use of both

natural and managed biodiversity to produce food, raw materials and other ecosystem services. Crop production based on an ecosystem approach sustains the health of farmland already in use, and can regenerate land left in poor condition by past misuse (Doran and Zeiss, 2000).

FAO (2011) argues that irrespective of local conditions, farm practices generally associated with conservation agriculture are necessary to ensure productivity, socio-economic and environmental benefits. These practices need to: minimize soil disturbance by minimizing mechanical tillage in order to maintain soil organic matter, soil structure and overall soil health; enhance and maintain a protective organic cover on the soil surface, using crops, cover crops or crop residues, in order to protect the soil surface, conserve water and nutrients, promote soil biological activity and contribute to integrated weed and pest management; cultivate a wider range of plant species – both annuals and perennials – in associations, sequences and rotations that can include trees, shrubs, pastures and crops, in order to enhance crop nutrition and improve system resilience.

2.3.1 Cropping systems in Ghana

In Ghana, agriculture used to be dominated by shifting cultivation (Land rotation), but the increase in demand for food and the limited access to land for food production; both resulting from the continuously increasing human population, has led to the intensification of agriculture and the continuous cultivation of parcels of land season after season (Boahen *et al.*, 2007). A survey by Ragasa *et al.* (2013) revealed that in the Savannah and Transitional zones of Ghana, most farms have been cultivated continuously for 11 years. They concluded that the fallow system has almost disappeared and towns have become more densely populated (Table 2.2).

Table 2.2: Percentage distribution of maize area cultivated by duration of fallow period in some agro-ecological zones of Ghana

Agro-ecological zones	Duration of fallow period in years				
	1 >	1 – 3	4 – 6	7 – 9	10 – 11
	%	%	%	%	%
Forest	39	33	15	3	10
Transitional	71	22	5	1	2
Northern Savannah	82	13	3	2	0
Coastal Savannah	40	30	18	3	9

Source: Ragasa *et al.* (2013)

With regard to the above scenario, conscious soil management strategies and proper soil amendment applications are necessary for good soil health and sustainable food production. On the contrary, poor soil management practices and inadequate fertilizer application have been reported. For example, the current average application rate (47 kg/ha of nitrogen) is half the recommended (90 kg/ha) despite a national subsidy programme to encourage more users and greater rates of application on maize (Ragasa *et al.*, 2013).

Table 2.3 gives a vivid illustration of the general overview of poor soil management practices that exist across the agro-ecological zones of Ghana. Application of animal manure, ploughing in of crop residue, intercropping with nitrogen-fixing crops, planting in mulch, crop rotation which are all practices which enhance soil health and fertility are generally on the low side.

Table 2.3: Percentage distribution of maize area by land preparation and planting methods during the 2012 major season in Ghana

Management practices	Agro-ecological zones			
	Forest	Transitional	Northern Savannah	Coastal Savannah
	%	%	%	%
Applied animal manure	1	1	11	4
Ploughed in crop residue	11	19	21	49
Practiced ridging	4	12	27	0
Intercropped with nitrogen-fixing crops	0	0	16	2
Intercropped with any crops	45	38	30	37
Planted in mulch	8	21	7	44
Practiced relay cropping or crop rotation	1	1	1	0

Source: (Ragasa *et al.*, 2013)

It has been emphasized that agriculture in Ghana has a net negative effect on soil health and fertility which calls for a critical and comprehensive cross discipline approach in handling the situation. This would allow for the development of practicable technologies compactible with the operations of small holder farmers.

2.4 Soil health

Healthy soils are the foundation of sustainable agricultural production. The underlying principle in the use of the term “soil health” is that soil is not just a growing medium, rather it is a living and dynamic system which contains one of earth’s most diverse assemblage of living organisms linked together by a complex food web; and can either

be sick or healthy, depending on the structure of the soil ecosystem. A basic soil food web has a similar structure to food webs of other environments (FAO, 2011; Neher, 2010; Wikipedia, 2014). According to FAO (2008), soil health is defined as the capacity of a soil to sustain biological productivity, maintain environmental health, and promote plant, animal, and human health. Ecosystem functions offered by a healthy soil include primary productivity (plant growth and yield), decomposition and nutrient cycling, disease suppression, and biological control (Neher, 2010).

Soil organic matter serves as the fuel that powers the soil ecosystem machinery. Practices which promote organic matter build-up are necessary for soils to be healthy. Undisturbed soils such as soils under forest, bush or grasslands are healthy with its ecosystem in equilibrium. Such soils have a lot of organic matter which builds up over many years. Within 10 years after opening virgin land for cultivation, more than half the organic matter is lost (IIRR and ACT, 2005).

A healthy soil upon disturbance is better positioned to recover its health status and phenomenon referred to as soil resilience. Continuous soil perturbation gradually reduces soil resilience until a point is reached when the soil can no longer recover to a healthy status. At this point, the soil is said to be degraded (Paton, 1978).

A number of agronomic practices have deleterious effect to soil health. FAO (2011) suggests that agriculture must, literally, return to its roots by rediscovering the importance of healthy soil, drawing on natural sources of plant nutrition, and using mineral fertilizer wisely.

Soil cultivation in itself disturbs and destabilizes the soil ecosystem. This threatens soil health if conscious efforts are not made to improve the soil's health (FAO, 2001). The soil's ecosystem is capable of restoring its health status if left to rest and/or when soil

management practices are tilted towards the improvement or maintenance of good soil health. Continuous disturbance of the soil gradually degrades the soil's biodiversity until a point is reached where the soil is incapable of restoring its biota. Soil cultivation, therefore, has resulted in various levels of biological, physicochemical and nutritional degradations of soils.

2.5 Soil ecosystem

2.5.1 Role of soil organic matter in soil health

Soil organic matter encompasses the soil biota, and plant and animal tissues at various stages of decomposition. Crawsell and Lefroy (2001) reported that the most important component of soil organic matter is humus, the well-decomposed, dark-coloured organic material in soil.

Soil organic matter affects the physical and chemical properties of the soil and its overall health. Organic matter decomposition and rate of decomposition affect: the soil structure and porosity; the water infiltration rate and moisture holding capacity of soils; the diversity and biological activity of soil organisms; and plant nutrient availability (Bot and Benites, 2005). Soil organic matter has central role in sustainable land management, but perspectives of role of soil organic matter differs widely among farmers, consumers, scientists and policy makers (Crawsell and Lefroy, 2001).

Tropical soils are not necessarily lower in organic matter content than temperate soils but, with the exception of wetland rice soils, agricultural intensification, through clearing and clean cultivation of soils for annual cropping almost universally causes a decline in soil organic content (Greeland *et al.*, 1992).

2.5.2 Nematodes as soil ecosystem monitoring tools

Soil nematodes occupy key position in soil ecosystem and play a central role in the soil food web (Ritz and Trudgill, 1999). Nematode community analysis is a powerful tool for studying soil food webs. This makes nematodes good bio-indicators for studying the soil ecosystem in terms of soil biodiversity and maturity among others. In addition, they can be captured and enumerated by standardized extraction procedures and are readily identified from morphological and anatomical characters. Further, since their feeding habits are clearly related to oral structure, their trophic roles are readily inferred. Each soil sample contains an abundance and diversity of nematodes and, consequently, has high intrinsic information value (Bongers, 1999; Bongers and Bongers, 1998; Bongers and Ferris, 1999; Yeates *et al.*, 1993). The above qualities make nematodes preferred candidates when studying the soil ecosystem.

Nematode abundance and the composition of nematode ecosystems have served as soil health indicators in different environments (Neher, 2001). Sánchez-Moreno *et al.* (2006), in investigating the effect of soil management on soil food webs, linked soil properties and nematode community composition. It was concluded from their study that; different tillage practices and cropping systems determine the soil properties and thus nematode abundance.

Soil nematode faunal analysis provides indices condensed with information regarding the structure and composition of nematode communities. Soil health and quality can be inferred from such indices by assuming that communities with different structure and composition function differently. Thus, these indices can be instrumental in monitoring soil and sediment quality as well as assessing ecosystem sustainability and biodiversity (Neher and Darby, 2006).

2.5.2.1 Nematode community and soil ecological disturbance (maturity indices)

Maturity indices are based on the principle that different taxa of nematodes have different levels of sensitivity to stress and are used as a measure of the ecological successional status of a soil. This contrasting sensitivities are as a result of varying life-history characteristics of different taxa of nematodes. Nematode taxa maturity indices, therefore, serve as a measure of the ecological successional status of a soil community. (Neher and Darby, 2006).

The index is represented by a colonizer-persister (c-p) value that ranges from a colonizer (c-p = 1) to a persister (c-p = 5) with the index values representing life-history characteristics associated with r- and K-selection, respectively. Those with a c-p = 1 are r-selected or colonizers, with short generation times, large population fluctuations, and high fecundity. Those with a c-p = 5 are K-selected or persisters, produce few offspring, and generally appear later in succession (Bongers and Ferris, 1999). Nematode taxa with c-p = 1 are considered enrichment opportunists as their population densities increase rapidly in response to additives of nutrients to soil and may not necessarily reflect long-term changes in soil ecological condition (Neher and Darby, 2006).

A maturity index for free-living nematodes (MI) takes into consideration all free living nematodes, with smaller values being indicative of more disturbed environment. Other variants of maturity index which vary in sensitivity, are used to indicate the level of ecological disturbance of the soil ecosystem. MI25 (free-living nematodes excluding nematodes with cp=1) differentiates MI-decrease caused by enrichment (Neher and Darby, 2006). Maturity index calculation which takes into consideration only plant parasitic nematodes (PPI) may (Neher and Campbell, 1994) or may not (Bongers *et al.*, 1997) correlate positively with MI.

2.5.2.2 Diversity indices

Diversity integrates number of taxa (richness) and equitability among taxa (evenness) (Hurlbert, 1971). A generalized diversity index outlined by Good (1953), incorporates richness and evenness into a single value that generally increases with both richness and evenness;

$$H(\alpha,\beta) = \sum_{i=1}^{S} p_i^{\alpha}\{-\ln(p_i)\}^{\beta}$$

Where p_i is the relative abundance of taxon *i*, *S* is the total number of taxa present, and α and β define structural attributes of the algorithm. Shannon's diversity index can be interpreted as a variant of Good's diversity index using values of 1 and 1 for α and β, respectively (or H(1,1)). Simpson index can be interpreted as H(2,0). Shannon and Simpson indices are influenced by rare and common nematode taxa respectively (Neher, 2001).

Hill's diversity numbers N0, N1 and N2 are defined as numbers of all taxa, abundant taxa, and very abundant taxa, respectively (Ludwig and Reynolds, 1988). N1 is calculated as an antilog of a Shannon index, and N2 equals the reciprocal of a Simpson index. N0 equates to taxa richness by simple count of taxa irrespective of their abundance. Hill's family of diversity numbers are easy to interpret ecologically because the indices define units as taxa (Neher, 2001).

2.5.2.3 Structure, enrichment and channel indices

These indices are descriptors of the soil's food web condition. Soil nematode community also provides information on two major characteristics of the soil environment and its resident communities. One characteristic is the flow of resources

into the food web system as indicated by enrichment opportunist species; the other is the trophic connectance of the system as indicated by prevalence and abundance of higher trophic level organisms. (Neher and Darby, 2006).

A graphic representation of the faunal profile indicates whether the soil community is enriched but unstructured (Quadrat A), enriched and structured (Quadrat B), resource-limited and structured (Quadrat C), or resource-depleted with minimal structure (Quadrat D) (Fig. 2)

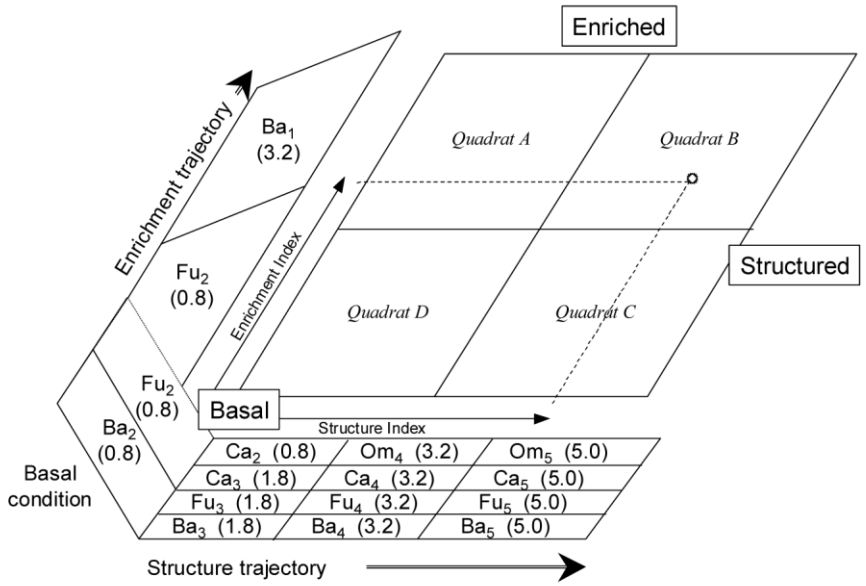


Figure 2.1: Indicator guilds of soil food web condition (basal, structured, enriched) are designated and weightings of the guilds along the structure and enrichment trajectories are provided, for determination of the Enrichment Index and Structure Index of the food web.

Source: (Neher and Darby, 2006).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study areas

The study was conducted in three of the six agro-ecological zones of Ghana; between latitudes 4^o 44'N and 11^o11'N, and longitudes 3^o11'W and 1^o11' E. The agro-ecological zones chosen were the Semi-Deciduous Forest, Forest-Savannah Transition and Guinea Savannah agro-ecological zones (Table 3.1). Locations chosen within the zones for this study were done such that locations within adjacent agro-ecological zones were at least 70 km longitudinally apart. Communities within a given agro-ecological zone were selected such that they were at least 40 km apart.

Table 3.1: Annual rainfall and length of growing period of agro-ecological zones and locations within which the study took place

Agro-ecological zone	**Annual Rainfall (mm)**	**Length of Growing Period (days)**	**Research Locations**
Semi-Deciduous Forest	1500	270	Kwaso Nkawkaw Nyinahin
Forest-Savannah Transition	700 – 1500	180 – 269	Amantin Nkoranza Subinja
Guinea Savannah	700 – 1500	180	Langbinsi Namansi Kunkwa, Mushio

Adapted from FAO (2005)

The three agro-ecological zones covered four administrative regions of Ghana, namely; Ashanti, Eastern, Brong Ahafo and Northern regions. The Ashanti and Eastern regions fall within the Semi-Deciduous Forest. The Brong Ahafo and Northern regions fall within the Forest-Savannah Transition and Guinea Savannah agro-ecological zones, respectively. The inhabitants of communities selected in Ashanti, Brong Ahafo and Eastern regions were twi speaking whilst those selected in the Northern region were predominantly Mamprusis.

Tomato (*Solanum lycopersicum*) and maize (*Zea mays*) agrosystems were the focus of this research. For uniformity, the major soil groups Acrisols were sampled in Semi-Deciduous Forest and Lixisols in the Forest-Savannah Transition and Guinea Savannah zones.

Within each agro-ecological zone, 15 maize farms, 15 tomato farms and three undisturbed sites were sampled (Fig. 3.1). A total of 90 farms (30 from each zone) and nine undisturbed sites were sampled; four replicate soil samples were taken from each farm for nematode community and physiochemical analyses. Each replicate sample was bulked from five auger samples randomly taken from a 10 x 10m quadrat. A structured questionnaire was administered to each farmer for socioeconomic data. A grand total of 369 samples were obtained and for the nematode community and physicochemical analysis. The samples were labelled with alphanumeric codes to reflect the zone, community, landscape and replication number (Fig. 3.1)

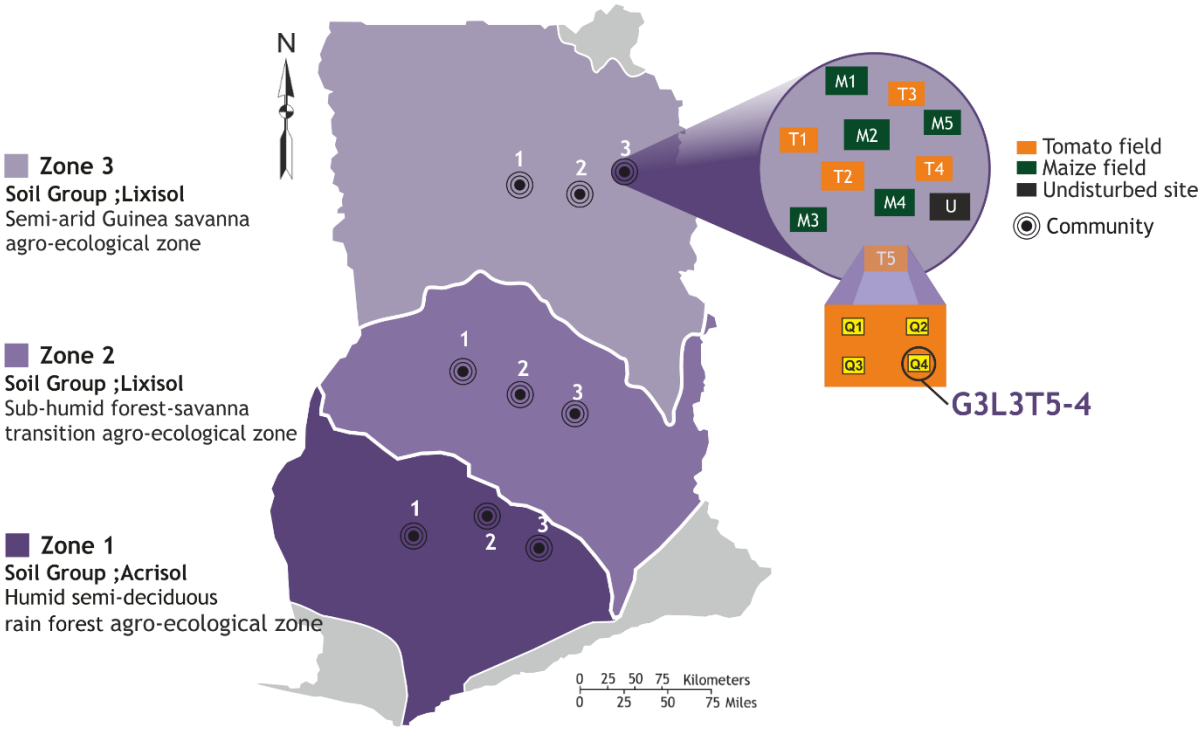


Figure 3.1: Soil samples labelled with an alphanumeric code to reflect the following: Zone, community, land use, Sample Replicate. Source: Map adapted from FAO *(2005)*.

3.1.1 Socio-economic data collection

Farmers were interviewed to extract information on soil management practices. Questionnaire also touched on farm household size and income. Ninety farmers were interviewed. The questionnaire (Appendix 5) was designed to get information on:

- Farmer demographics and farm history
- Cultivation practices
- Soil Amendment application
- Biocide application
- Farm yield and income

3.1.2 Soil sampling

Four soil samples were taken from each farm and each undisturbed site. Four randomly located 10 × 10 m quadrats were demarcated on each farm and each undisturbed site. Within each quadrat, 5 core soil samples were taken at a depth of 0 – 20 cm with a soil

auger and mixed thoroughly to obtain a composite sample from which 700 - 1000 g was taken to represent that quadrat, using a Garmin GPS handset. The GPS coordinates were taken from the centre of each quadrat. The temperature of the soil was also recorded within each quadrat with a digital soil thermometer. Details of each sample (e.g. sample code, GPS coordinates, soil temperature at sampling) were recorded on a sample sheet attached to the questionnaire of the farmer from whose farm the sample was taken.

3.1.3 Soil sample handling

Samples from the field were immediately placed in labelled plastic bags with detailed sample codes as explained above (Figure 3.1). Soil samples were then stored on ice until they arrived the same day at the Department of Crop and Soil Sciences, KNUST, where they were further stored at 10^{o}C for partitioning the following day.

3.1.4 Sample partitioning

Samples were sieved independently through a 2 mm sieve mesh to remove stones and debris. Three hundred millilitres of each sample was submitted to the Soil Science laboratory of the Department of Crop and Soil Sciences, KNUST for physicochemical analyses. About 200 cc of each sample was saved for nematode extraction and the remaining 200 ml was stored as backup at 10^{o}C in a refrigerator. Figure 3.2 shows how samples were partitions by volume and the purposes each sample.

Precautionary measures were taken from sampling to extraction and analysis to avoid contamination, mixing and mislabelling of samples. Sampling and mixing tools were cleaned before new samples were taken. Sieves were cleaned thoroughly with water before each sample was sieved. Labelling was strictly adhered to avoid mix-ups.

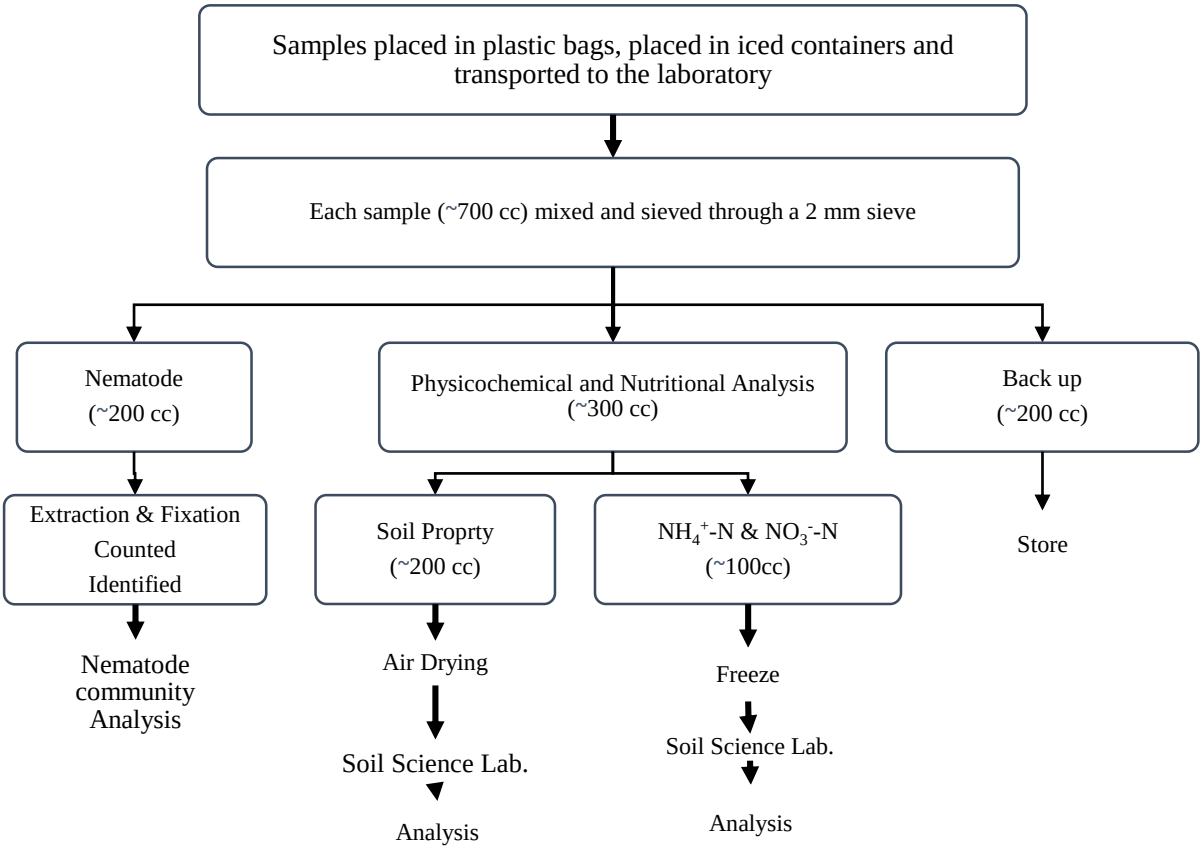


Figure 3.2: Sample partitioning, storage and processing.

3.2 Nematode extraction

Two extraction methods were employed to efficiently extract nematodes from the soil samples. The extraction tray method (Coyne *et al.*, 2007) was used in tandem with the sieving-sucrose centrifugation method (Van Bezooijen, 2006) to ensure efficient extraction of both sluggish and mobile nematodes.

3.2.1 Nematode extraction by the tray method (Coyne *et al.*, 2007)

Two-ply paper napkins were placed in a plastic basket (18 cm diameter; 6.5 cm deep) such that the entire base of the basket was covered by the paper napkin. About 100 ml of thoroughly-mixed and sieved soil sample was measured, using a 100 ml beaker. The measured soil sample was then placed and spread gently on the paper napkins in the basket to avoid spill-over of soil.

The basket with the soil sample was stacked in an identical basket and then placed in an extraction plate (20 cm diameter; 3 cm deep). 200 ml of tap water was gently added to the setup via the gap between the edge of the plate and the edge of the basket. The setup was left in the dark for 48 h. Setups were periodically monitored to ensure that plates drying out were topped up with water. After 48 hours, the solution in the extraction plate was poured into a labelled beaker and the plate rinsed with a wash bottle into the beaker.

3.2.2 Extraction of nematodes by the sieving-sucrose centrifugation method

The leftover soil sample from the extraction tray method was mixed in 500 ml water by pouring between beakers ten times. Residues in the second beaker was rinsed into the beaker with the sample which was then swirled and allowed to stand for 15 seconds to allow sand particles to settle. The supernatant was poured through 833 μm / 25 μm stacked sieve and gently tapped to facilitate drainage.

Heavy soil particles were left behind in the beaker and debris were caught by the 833 μm sieve which were all discarded. Using a coarse-spray wash bottle, the content of the 25 μm sieve was washed carefully into one sector of the sieve and then washed with a fine spray in a labelled 50 ml centrifuge tube.

The contents of the centrifuge tubes were equalised to the 50 ml mark on the centrifuge tube with tap water and then placed in centrifuge in four pairs. Samples were spun at 1700 rpm for five minutes without brake and allowed to settle for five minutes. The supernatant was aspirated to approximately 1 cm above the pellet.

Centrifuge tubes were then topped up to 50 ml with sucrose solution; which was prepared by dissolving 454 g of sugar in 1 litre of distilled water at room temperature. Pellet at the bottom of a tube was completely dispersed by breaking up the pellet and

stirring using a spatula. The mixture was spun again by accelerating centrifuge from zero rpm to 1000 rpm in 30 sec after which brake was applied. The supernatant was poured through a 25 μm sieve and nematodes trapped in the sieve were carefully transferred into labelled vials.

3.2.3 Counting of nematodes

Nematode aliquots derived from the extraction tray and sieving-sucrose centrifugation methods for each sample was combined and diluted to 100 ml and mixed thoroughly by swirling and gentle shaking. Pipette was used to take 5 ml from the middle of the aliquot after mixing by alternatively sucking and pumping 4 times. The 5 ml aliquot was poured into a clean counting tray and counted under an inverted compound microscope at a magnification of ×20; with the aid of a tally counter. Counting was repeated twice unless the difference between counts exceeded two, where counting was repeated a third or fourth time and the mean subjected to the formula (Coyne *et al.*, 2007) below to estimate the population density of nematodes of a particular farm.

$$N_{vol} = \left(\frac{v2}{v1} \times n1\right) \times \frac{100}{v3} \quad , \qquad \text{(Coyne et al., 2007)}$$

With n1 = number of nematodes in v1 (nema/5 ml)

v1 = volume (ml) of the counted suspension from v2 (5 ml)

v2 = volume (ml) of the extracted sample total suspension (100 ml)

v3 = volume (ml) of the of soil sample (100 ml)

3.2.4 Killing and fixing of nematodes

All four nematode suspensions from each farm/site were combined and concentrated by passing the suspension through a 25 μm mesh sieve. Nematodes in the sieve were then gently washed with a fine spray of water into a labelled tube, ensuring that a

nematode suspension of volume of about 2.5 ml was obtained. This was done to ensure a high concentration of nematode suspension.

Killing and fixing of nematodes was done by the hot fixative method. The fixative used was a solution of formalin (37% formaldehyde), glycerol and distilled water at the ratio of 10:1:89 (Coyne *et al.,* 2007). The fixative was heated to about 70 ℃ by heating in a test tube immersed in near boiling water. A portion of the fixative was chilled to about 4 ℃. About 3 ml of the hot fixative was added to nematode suspension, followed by an immediate addition of about 3 ml of the chilled fixative (Van Bezooijen, 2006). The vials were tightly closed to prevent the evaporation of the fixative.

3.2.5 Nematode identification

Nematodes were identified with the aid of a 3030 ACCU-SCOPE Microscope equipped with 3.2 megapixel CMOS colour camera connected to a computer. Two millilitres of nematode suspension were transferred into a counting tray after thoroughly mixing by alternatively sucking and pumping four times, and then viewed under the inverted microscope. One hundred nematodes were identified to the genus level by viewing and comparing with reference images. Nematodes which were not easily identified were picked unto slides and with the CMOS colour camera, their images taken for further careful identification. Reference images (C.I.H, 1900; Luc *et al.,* c2005; Jairajpuri and Ahmed, 1992) were used for the identification of the nematodes.

Nematodes were classified by trophic groups prescribed by Yeates, *et al.* (1993). With this classification, the identified nematodes were grouped into; plant parasitic, fungivorous, bacterivorous, omnivorous and predators. Within each trophic group, nematode genera were further assigned colonizer-persister (c-p) value according to Bongers (1999). The c-p value ranged from c-p = 1 to c-p = 5. Those with a c-p = 1 are r-selected or colonizers, with short generation times, large population fluctuations, and

high fecundity. Those with a c-p = 5 are K-selected or persisters, produce few offspring, and generally appear later in succession (Bongers and Ferris, 1999).

3.2.6 Nematode community analysis

Based on the number of nematode genera and their frequencies in each sample, the following indices were calculated.

3.2.6.1 Maturity indices

Maturity indices were calculated as weighted mean frequency of nematode genera (Neher and Darby, 2006) at a given site to determine the level of ecological disturbance of the soil community of a farm or undisturbed site. The maturity index was calculated as follows.

$$\text{Maturity Index} = \sum_{i=1}^{n=100} \frac{v_i \times f_i}{n} \quad , \quad \text{(Neher and Darby, 2006)}$$

where,

$\mathbf{v_i}$ = c-p value assigned to genus; $\mathbf{f_i}$= frequency of genus **i** in sample; **n** = total number of individuals in a sample.

Four variants of the maturity index were calculated for each nematode community.

- Maturity index of free-living nematodes only, all five c-p values **(MI)**
- Maturity index of free-living nematodes only, excluding nematodes with c-p=1 **(MI**25)
- Maturity index of plant parasitic nematodes only **(PPI)**
- **ΣMI**25 (combined free-living and plant-parasitic nematodes without c-p= 1)

3.2.6.2 Diversity indices

Table 3.2: Diversity indices used to characterize the distribution of abundance within a community

Diversity Index	Formulae	Reference
Shannon (*H'*)	$-\Sigma P_i(\ln P_i)$	(Shannon and Weaver, 1949)
Simpson (λ)	$\sum \left(\frac{n_i}{N}\right)^2$	(Simpsom, 1949)
Hills N1	$\exp[-\Sigma P_i(lnP_i)]$	(Hill, 1973)
Hills N2	$\frac{1}{\sum \left(\frac{n_i}{N}\right)^2}$	
Genus Richness (Hills N0)	Number of genera	

N = Total number of genera per sample = 100

n_i = i^{th} genus

P_i = proportion of genera i in the total nematode community

3.2.6.3 Structure, enrichment and channel indices

The structure index is an indicator of food web state affected by stress or disturbance. Enrichment index is a measure of opportunistic bacterivore and fungivore nematodes. Channel index indicates the predominant decomposition pathways. The three indices were calculated as follows (Neher and Darby, 2006).

$$\text{Structural index (SI)} = 100 \times \frac{\text{s}}{\text{s} + \text{b}}$$

$$\text{Enrichment index (EI)} = 100 \times \frac{\text{e}}{\text{e} + \text{b}}$$

$$\text{Channel index (CI)} = 100 \times \frac{\text{Fu}_2\text{W}_2}{\text{Ba}_1 + \text{W}_1 + \text{Fu}_2 * \text{W}_2}$$

Where,

b = (Ba_2 + Fu_2) W_2 where W_2 = 0.8,

e = (Ba_1W_1) + (Fu_2W_2) where W_1.= 3.2 and W_2 = 0.8

s = (Ba_nW_n)+ (Ca_nW_n) + (Fu_nW_n) + (Om_nW_n) where n = 3-5, W_3= 1.8, W_4= 3.2, W_5= 5.

3.3 Soil physicochemical analysis

Soil particle size distribution, pH, organic carbon, total nitrogen, nitrate-nitrogen, ammonium-nitrogen, phosphorus, potassium, calcium, and magnesium for each of the 396 samples were determined at the Soil Science laboratory of the Department of Crop and Soil Sciences, KNUST, Kumasi. All analytical methods used were as prescribed by Mostsara and Roy (2008) with slight modifications where necessary.

3.3.1 Particle size distribution analysis

Particle size distribution was determined by the hydrometer method (Bouyoucos, 1962). Fifty one grammes of air-dried soil was weighed into a shaking bottle. Fifty millilitres of 5% Sodium hexamethaphosphate solution and 100 ml distilled water were added; and the suspension shaken with a mechanical shaker at 300 rpm for 60 min. The stirred mixture was then transferred into a 1 L measuring cylinder. Distilled water was added to the 1 L mark after placing the hydrometer into the suspension. The hydrometer was removed and the suspension shaken vigorously, then placed on a laboratory bench. After 20 seconds, the hydrometer was carefully reinserted into the suspension and read (H_1) at the end of 40 seconds after shaking. Temperature of the suspension (T_1) was also recorded by inserting a thermometer into the suspension. Suspension was re-shaken and kept on a bench undisturbed. A second hydrometer reading (H_2) was taken two hours later and temperature of the suspension (T_2) recorded.

The percentage clay, sand and silt were calculated as follows:

$$\text{Percentage Clay} = \frac{H_2 + [(T_2 - 20) \times 0.36]}{W} \times 100$$

$$\text{Percentage Sand} = 100 - \left(\frac{H_1 + [(T_1 - 20) \times 0.36]}{W} \times 100\right)$$

$$\text{Percentage Silt} = 100 - (\%\ \text{Sand} + \%\ \text{Clay})$$

where;

H_1 = hydrometer reading at 40 seconds

T_1 = temperature of solution at 40 seconds

H_2 = hydrometer reading at two hours

T_1 = temperature of solution at two hours

W = weight of dry soil

3.3.2 Soil pH determination

Soil pH was determined with a Eutech P700 pH meter calibrated with two buffer solutions of pH 7.0 and pH 4.0. A 10 g soil sample was weighed into 100 ml beaker and 10 ml distilled water was added. The suspension was stirred thoroughly with a magnetic stirrer for 30 min and pH was read by immersing the pH meter electrode into the upper part of the suspension.

3.3.3 Nitrate – nitrogen (NO_3^- – N) determination

Nitrate-nitrogen in the soil sample was determined, using 0.5 *M* K_2SO_4. Ten grammes of fresh soil was shaken in 30 ml of the extractant (0.5 *M* K_2SO_4) for 30 min. The soil-extractant suspension was filtered through Whatman No. 42 filter paper to obtain a clear solution. Nitrate in the clear solution was determined by the colorimetric method. A 2ml aliquot of the extract was pipetted into a test tube and 1 ml of salicylic acid solution was added. Salicylic acid solution was prepared by dissolving 5 g salicylic acid in 95 ml concentrated sulphuric acid (Anderson and Ingram, 1998). The resulting solution was allowed to stand for 30 min, after which 10 ml of 4.0 *M* Sodium hydroxide solution

was added and mixed thoroughly. After 1 hour, when colour was fully developed, the absorbance of the yellow colour was read at a wavelength of 410 nm on an electronic 21 D spectrophotometer.

A standard series of 0, 2, 4, 6 and 8 mg/l NO_3^- -N was prepared in 50 ml volumetric flasks from a 50 mg/l NO_3^- -N stock solution. The absorbance for each standard was then read on the spectrophotometer. A standard curve was obtained by plotting a graph of absorbance against standard concentrations. The solution concentrations for sample and blank were determined from the curve. The blank value was then subtracted from the sample value to give a value for the corrected concentration, C.

Nitrate-nitrogen was calculated as follows:

NO_3^--N (mg/kg soil) = $\frac{C \times V}{W}$

where,

C = corrected concentration (mg/l)

V= extract volume (ml)

W = weight of sample (g)

3.3.4 Ammonium – nitrogen (NH_4^+ – N) determination

The NH_4^+-N was determined from the same extract as NO_3^- -N above. A 2ml aliquot of the extract (filtrate) was pipetted into a test tube to which two different reagents (RI and RII) were added. RI was prepared by mixing three separately prepared solutions namely: 4 % EDTA (5 ml), 0.05 g/ml Sodium nitroprussite (100 ml) and 1.12 g/ml Sodium salicylate (50 ml). RII was prepared by dissolving 0.2 g of Sodium dichlorocyanate in 10 ml of distilled water and transferred to a 200 ml flask. The volume was made up to the mark with a buffer solution of 0.0746 *M* $Na_2HPO_4.12H_2O$ (adjusted

to pH 12.3. The resulting solution was allowed to stand for 2 h after the addition of 3 ml and 5 ml of RI and RII, respectively.

Working standards of 0, 5, 10, 15 and 20 mg/l were prepared from 1 g/l NH_4^+-N stock solution. The absorbance of the sample, blank and working standards were read on the spectrophotometer at a wavelength of 660 nm. A graph of absorbance against standard concentrations was plotted. Solution concentrations for the sample and blank were then determined. The blank value was subtracted from the sample value to give a value for corrected concentration, C.

Ammonium-nitrogen was calculated as follows:

NH_4^+-N (mg/kg soil) = $\frac{C \times V}{W}$

where

C = corrected concentration (mg/l)

V = final digest or extract volume (ml)

W = weight of sample (g)

3.3.5 Determination of organic carbon / organic matter

Wet combustion method (Motsara and Roy, 2008) was used in the determination of soil organic carbon and organic matter. One gramme of air-dried soil was weighed into a 500-ml conical flask. A reference sample and a blank were included. Ten millilitres of 0.1667M Potassium dichromate ($K_2Cr_2O_7$) solution was added to each weighed soil sample and two empty flasks (blanks), followed by the addition of 20 ml concentrated Sulphuric acid (H_2SO_4). Each sample was swirled and allowed to stand for 30 min for the reaction to complete. The reaction mixtures were then diluted with 200 ml distilled water and 10 ml concentrated Orthophosphoric acid (H_3PO_4). Ten millilitres of Sodium fluoride (NaF) solution and 2 ml diphenylamine indicator were added to the reaction

and titrated with standard 0.5M Ferrous sulphate ($FeSO_4$) solution to a brilliant green colour. The two reactions without soil samples (blanks) were run simultaneously.

The percentage of organic carbon (%OC) was calculated as:

$$\frac{10(S - T) \times 0.003}{S} \times \frac{100}{\text{Wt. of soil(g)}} \times 1.3$$

$$= \frac{3 \times (S - T)}{S} \times 1.3 \qquad \text{(As 1 g of soil is used)}$$

Per cent OM was calculated as: %OC x 1.724

Where:

S = millilitres of $FeSO_4$ solution required for blank;
T = millilitres of $FeSO_4$ solution required for soil sample;
0.003 = weight of C (Thus, 1 ml 0.1667 M K_2Cr_2O7 = 0.003 g C);
1.3 = Percentage value of organic carbon obtained;
1.724 = Van Bemmelen factor.

3.3.6 Determination of total nitrogen

Total soil nitrogen was determined by the Kjeldahl digestive and distillation protocol (Soils Laboratory Staff. Royal Tropical Institute., 1984; Motsara and Roy, 2008). One gramme of air-dried soil sample was weighed into a Kjeldahl digestion flask. To this, 0.7 g Copper sulphate, 1.5 g Potassium sulphate and 30 ml of 0.05M Sulphuric acid were added. The sample was then digested for 3 h until a clear digest was obtained. The digest was diluted with 50 ml distilled water and mixed by swirling until no more sediment dissolved and allowed to cool and transferred into a distilling flask. A 25 ml aliquot of the solution was transferred to the reaction chamber and 10 ml of 40 % NaOH solution added, followed by distillation. The distillate was collected in 2.0 % Boric acid and was titrated with 0.02 *N* HCl using Bromocresol green as indicator. A blank

distillation and titration were also carried out to take care of the traces of nitrogen in the reagents as well as the water used.

The %N in the sample was expressed as:

$$\%N = \frac{n \times (a - b) \times 1.4 \times mcf}{w}$$

Where

n = Concentration of HCl used in titration

a = Volume of HCl used in sample titration (ml)

b = Volume of HCl used in blank titration (ml)

w = Weight of air-dry soil sample (mg)

mcf = moisture correction factor ((100%+%moisture)/100)

$1.4 = 14 \times 0.001 \times 100\%$ ($14 = \text{atomic weight of N}$)

3.3.7 Determination of available phosphorus

The available phosphorus was extracted with Bray's No.1 Extractant (0.03 M NH_4F + 0.025 M HCl) as described by Bray and Kurtz (1945). A 5 g soil sample was weighed into a 50-ml centrifuge tube and 30 ml of Bray's Extractant No.1 added. The mixture was shaken for 5 min on a reciprocating shaker and centrifuged at 3000 rpm for 5 min. A 1ml aliquot, 2 ml of the colouring reagent (ammonium molybdate), 6ml distilled water and 1 ml L-Ascobic acid were pipetted into a test tube and uniformly mixed by shaking. The solution was allowed to stand for 6 min for the blue colour to develop to its maximum. The absorbance was measured on a spectronic 21D spectrophotometer at a wavelength of 660 nm at medium sensitivity. Standard series of 0, 1, 2, 3, 4 and 5 mgP/L were prepared from 20 mg/L phosphorus stock solution.

The stock solution was prepared by dissolving 0.2195 g of pure KH_2PO_4 in 1 litre to obtain 50 µg P/ml stock solution. 10 ml of the stock solution was diluted to 0.5 litres with distilled water to obtain 1 µg P/ml solution.

Available phosphorus was calculated as follows:

$$\text{P (mg/kg soil)} = \frac{(a-b)\times 35\times 15\times \text{mcf}}{w}$$

where,

a = mg/L P in sample extract

b = mg/L P in blank

mcf = moisture correcting factor

35 is volume of extracting solution

15 is volume of final solution

w = sample weight in grammes

3.3.8 Determination of exchangeable cations

Exchangeable basic cations (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0 *M* ammonium acetate extract (Black, 1986) and the exchangeable acidity (hydrogen and aluminium) was determined in 1.0 *M* KCl extract (Page *et al.,* 1982). A 5 g soil sample was weighed into a leaching tube and leached with 100 ml buffered 1.0 *M* ammonium acetate solution at pH 7.

To analyse for calcium and magnesium, a 25 ml aliquot of the extract (leachate) was transferred into an Erlenmeyer flask, and 1 ml portion of hydroxylamine 53 hydrochloride, 1 ml of 2.0 % potassium cyanide, 1 ml of 2.0 % potassium ferrocyanide, 10 ml ethanolamine buffer and 0.2 ml Eriochrome Black T solution were added. The solution was titrated with 0.01 *M* EDTA (ethylene diaminetetraacetic acid) to a pure turquoise blue colour.

3.3.8.1 Determination of calcium only

A 25 ml aliquot of the 1.0 M ammonium acetate extract was transferred into a 250 ml Erlenmeyer flask and the volume made up to 50 ml with distilled water. Following this, 1 ml hydroxylamine, 1 ml of 2.0 % potassium cyanide and 1 ml of 2.0 % potassium ferrocyanide solution were added. After a four minutes, 5 ml of 8.0 *M* potassium hydroxide solution and a spatula of murexide indicator were added. The resultant solution was titrated with 0.01 *M* EDTA solution to a pure blue colour.

The concentrations of calcium + magnesium or calcium were calculated using the equation:

$$\text{Ca + Mg (or Ca) (cmol}_{(+)}\text{/kg soil)} = \frac{0.01\times(Va-Vb)\times 1000}{w}$$

Where,

w = weight (g) of air – dried soil used

Va = ml of 0.01 *M* EDTA used in sample titration

Vb = ml of 0.01 *M* EDTA used in blank titration

0.01 = concentration of EDTA

3.3.8.2 Determination of exchangeable potassium and sodium

Potassium (K) and sodium (Na) in the leachate were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting both 1 g/l K and Na solutions separately to 100 mg/l. 25 ml portion of each solution was transferred into 250 ml volumetric flask and diluted to the 250 ml with distilled water. Portions of 0, 5, 10, 15, 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks. One hundred millilitres of 1.0 *M* NH4OAc solution was added to each flask and diluted to 200 ml with distilled water. This resulted in standard series of 0, 2.5, 5.0, 7.5, 10

mg/l for K and Na. Potassium and sodium were measured directly in the leachate by flame photometry at wavelengths of 766.5 and 589.0 nm, respectively.

The concentrations of Potassium and Sodium were calculated using the following equations:

$$\text{Exchangeable K } (\text{cmol}_{(+)}/\text{kg soil}) = \frac{(a-b) \times 250 \times \text{mcf}}{10 \times 39.1 \times w}$$

$$\text{Exchangeable Na } (\text{cmol}_{(+)}/\text{kg soil}) = \frac{(a-b) \times 250 \times \text{mcf}}{10 \times 23 \times w}$$

where,

a = mg/l K or Na in the diluted sample percolate

b = mg/l K or Na in the diluted blank percolate

w = weight (g) of air- dried soil sample

mcf = moisture correcting factor

3.3.8.3 Determination of effective cation exchange capacity (ECEC)

This was calculated by summation of exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) and exchangeable acidity (Al^{3+} and H^{+}).

3.4 Data analysis

The effects of the agro-ecological zones and landscape (land use) on the soils physicochemical properties and nematode assemblage were observed by a two-way interaction effects on the parameters using Residual Maximum Likelihood (REML) Linear Mixed Models (VSN International, 2011). The **Fixed Model:** Agro-ecological zone*Landscape, and **Random Model:** Farm/Quadrat were used to run soil pH, organic C and N, available nutrients and exchangeable cations. Means were compared with standard error of difference at 5% probability.

Nematode community data were run with the Residual Maximum Likelihood (REML) Linear Mixed Models with **Fixed Model:** Agro-ecological zone *Landscape, and **Random Model:** Community. Parameters run were Genus richness, Hills index (N2), Shannon index, Simpson's index, combined maturity index, maturity index of plant parasitic nematodes, maturity index of free-living nematodes and fertility index. Means were compared with standard error of difference at 5% probability.

The fixed models in the Residual Maximum Likelihood (REML) Linear Mixed Models represent the factors that would influence the differences observed whilst the Random Models represent replication. Farmer socio-economic data were presented as frequencies and percentages in tables and graphs.

CHAPTER FOUR

4.0 RESULTS

4.1 Demographic profile of inhabitants of the research areas

Each agro-ecological zone is inhabited by a multiplicity of tribes, some overlapping between zones. Areas sampled in the Semi-Deciduous Forest zone were extensively inhabited by the Ashantis and Kwahus. These tribes cultivate wide variety of crops; major of which are maize, cassava, cocoyam, plantain, vegetables and cash crops such as cocoa and oil palm.

The Guinea Savannah zone is the driest of the three zones studied, with a grassland vegetation and clusters of drought resistant trees such as baobab (*Adansonia spp*) and shea (*Vitellaria paradoxa*) trees. Maize, millet, sorghum, cowpea, soybean, yam and vegetables such as onion, pepper, and tomato are among the major crops cultivated by the Mamprusis who are the major inhabitants of the selected communities. They also own large herds of cattle and smaller ruminants.

Even though a good number of farmers owned the land on which they farm, farm sizes were mostly two or less acres. Farmers were mostly males across all zones. About 20 and 6.7 % of respondents were females in the Semi-Deciduous Forest and Forest-Savannah Transition zones, respectively. Among the Mamprusis, all randomly selected farmers were males (Appendix 1).

Majority of respondents were over 31 years of age. In the Semi-Deciduous Forest zone, only 6.7 % of farmers were below the age of 31 years. In the Forest-Savannah Transition and Guinea Savannah, 13 and 20 %, respectively, were below age 31 years (Appendix 1). The youth (below age 40 years) are actively involved in crop cultivation

among all tribes encountered. Among the Ashantis/Kwahus, 40 % of farmers were in the youth bracket. Among the Bonos and Mamprusis, 60 and 66.7 %, respectively, were within the youth bracket.

The level of formal education among farmers in all zones was generally low. In the Semi-Deciduous Forest, Forest-Savannah Transition and Guinea Savannah zones, 53.3, 46.7 and 36.7 % of farmers had no formal education; 20, 40 and 16.7 %, respectively, dropped out at the primary education level.

The use of family labour in a number of farm operations was common, especially among the Mamprusis. Farmer household size varied among zones with the Semi-Deciduous Forest zone having the least average of about 5 persons per household, followed by the Forest-Savannah Transition zone with 7 and the highest of 9 in the Guinea Savannah zone. Langbinsi, one of the three selected communities in the Guinea Savannah zone, had the highest value of about 11 persons per farmer household (Fig. 4.1).

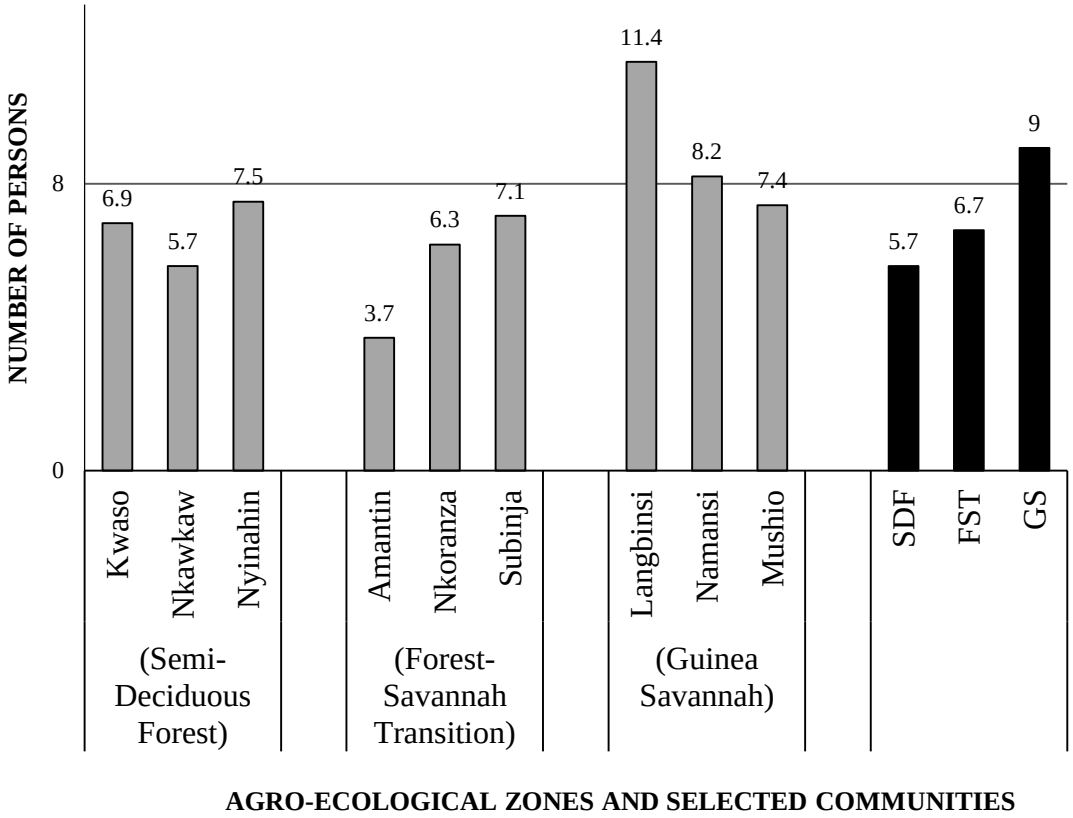


Figure 4.1: Average farm household size of selected communities in the Semi-deciduous Forest, Forest-Savannah and Guinea Savannah agro-ecological zones.

4.2 Dominant crop cultivation practices in the study areas

In the Semi-Deciduous Forest zone, 46.7 % of sampled maize and tomato fields had been continuously cropped for at least three years. Continuous cropping on the same piece of land was more pronounced in the Forest-Savannah Transition and Guinea Savannah with 66.7 and 97.0 % sampled farms continuously cropped over the past three or more years (Table 4.1).

Land clearing for a new season's cropping was done by burning by some farmers. This practice was more common in the Semi-Deciduous Forest zone with 50 % of farmers practicing it. About 40.0 and 23.3 % of farmers in the Forest-Savannah Transition and Guinea Savannah zones, respectively, practiced bush burning. About 37 % of the

farmers practiced burning after slashing or after killing weeds with herbicide. The use of herbicide in the clearing of land and control of weed was also very common in all three zones and was used in both maize and tomato cultivation. About 80.0, 83.3 and 76.7 % of the farmers applies herbicides in the Semi-Deciduous Forest, Forest-Savannah Transition and Guinea Savannah, respectively.

The use of insecticide and fungicide, however, was totally absent in the cultivation of maize. The use of mineral fertilizer was highly patronized in the cultivation of both crops in any of the three zones. Practices such as the application of farm yard manure and compost, cover cropping and intercropping with legumes were not common. No farmer practiced cover cropping in all the three zones. The use of herbicide is common among surveyed farmers. In total, 80% of farmers apply herbicide to their field (Table 4.1).

The rate of application of liquid herbicide ranged from 4.9 – 9.9 L/ha averaging 7.8 L/ha across all the Zones. Table 4.1 shows the percentage of tomato fields to which fungicide and insecticide were applied in the three zones. No maize field was applied with fungicides and insecticides. All tomato farmers interviewed in Semi-Deciduous Forest had applied fungicides to their fields. About 40% of tomato fields in Forest-Savannah Transition and 53% in Guinea Savannah were applied with fungicide.

Table 4.1: Percentage distribution of farmers by selected cultivation practices in the Semi-Deciduous Forest, Forest-Savannah Transition and Guinea Savannah agro-ecological zones.

Practice	Semi-Deciduous Forest		Forest-Savannah Transition		Guinea Savannah	
	Maize	Tomato	Maize	Tomato	Maize	Tomato
Continuous cropping	%	%	%	%	%	%
< 3years	53.3	53.3	20.0	46.7	0.0	6.7
3 – 5	26.7	46.7	6.7	6.7	0.0	20.0
6 – 8	13.3	0.0	6.7	13.3	6.7	13.3
9 – 11	0.0	0.0	6.7	13.3	33.3	20.0
> 11	6.7	0.0	60.0	20.0	80.0	40.0
Insecticide application	0.0	60.0	0.0	40.0	0.0	66.7
Fungicide application	0.0	100.0	0.0	40.0	0.0	53.3

	Semi-Deciduous Forest	Forest-Savannah Transition	Guinea Savannah
Bush burning	50.0	40.0	23.3
Herbicide use	80.0	83.3	76.7
Cover cropping	0.0	0.0	0.0
Legume Intercropping	0.0	3.3	5.6
Crop rotation	13.3	73.3	16.7
Use of mineral fertilizer	63.3	76.7	74.4
Use of farm yard manure	0.0	3.3	5.6
Use of compost	0.0	0.0	1.1

4.3 Nutritional status and physicochemical properties of soil samples from the study areas.

4.3.1 Soil reaction

Maize sites in the Semi-Deciduous Forest zone had an average pH of 5.76, which was not significantly different ($P < 0.05$) from that of the undisturbed sites (5.76), but significantly higher ($P < 0.05$) than what was recorded in tomato sites (5.27). In both the Forest-Savannah Transition and the Guinea Savannah, variations observed were not significantly different ($P < 0.05$). (Fig 4.2A). The Semi-Deciduous Forest zone had a significantly lower average pH of 5.13, than the Forest-Savannah Transition (5.822) and Guinea Savannah zones (6.16) (Fig. 4.2 A).

4.3.2 Organic matter

Organic matter levels were highest in the Semi-Deciduous Forest zone, averaging 1.53 %, followed by Forest-Savannah Transition (1.25 %). Guinea Savannah recorded the lowest value of 0.85 %. Significant difference in organic matter content was observed in the Semi-Deciduous Forest and Guinea Savannah zones, comparing the different land uses within each zone (Fig. 4.2 B). In the Semi-Deciduous Forest zone, maize sites recorded an average of 1.77 % OM content, significantly different ($P < 0.05$) from tomato sites (1.15 %) but not significantly different from that of undisturbed sites (1.68 %).

Variations observed in the Forest-Savannah Transition are no significantly different ($P < 0.05$). In the Guinea Savannah, however, maize sites recorded the highest value of 1.08. Tomato sites recorded 0.93 % OM which is not significantly different ($P < 0.05$) from 0.52 % of the undisturbed sites (Fig. 4.2 B).

4.3.3 Nitrogen

Total nitrogen (%N) was highest in the Semi-Deciduous Forest zone and lowest in the Forest-Savannah Transition zone. The Guinea Savannah zone had significantly lower ($P < 0.05$) total nitrogen than the Semi-Deciduous Forest zone, but higher than that of the Forest-Savannah Transition zone (Fig. 4.2 C). Maize landscapes had the highest total nitrogen in the Semi-Deciduous Forest zone, but had least %N in the Guinea Savannah zone. In the Forest-Savannah Transition, %N in maize and tomato sites were identical but were both lower than %N of undisturbed sites. Available nitrogen (NO_3^- $+NH_4^+$) levels, however, were identical among the zones and landscapes of the Semi-Deciduous Forest zone but highest in undisturbed sites of both Forest-Savannah Transition and Guinea Savannah zones.

4.3.4 Available P, exchangeable K, Ca, Mg and Na

Guinea Savannah had the highest levels of available Phosporus and exchangeable Potassium, but had the least of exchangeable Magnesium as compared to the Semi-Deciduous Forest and the Forest-Savannah Transition which were identical. Available Phosphorus levels varied among landscapes within agro-ecological zones (Fig. 4.3 B). Potassium values were not significantly different ($P < 0.05$) among landscapes in both Semi-Deciduous Forest and Forest-Savannah Transition zones. In the Guinea Savannah, undisturbed sites had the highest level of exchangeable K. Sodium levels were identical across all three agro-ecological zones and landscapes within Forest-Savannah Transition and Guinea Savannah zones (Fig. 4.3 C).

In the Semi-Deciduous Forest, tomato sites had higher exchangeable Na than undisturbed sites but identical to maize; maize sites, however, were similar to tomato and undisturbed landscapes in the Forest-Savannah Transition and Guinea Savannah

zones. Calcium levels were lowest in the Guinea Savannah zone and identical among its landscapes, whilst Semi-Deciduous Forest and Guinea Savannah zones had identical levels with their landscapes showing varying differences among their landscapes. Guinea Savannah had least Mg with its landscapes showing no significant differences. In the Semi-Deciduous Forest and Forest-Savannah Transition Mg levels were significantly different among their landscapes (Fig 4.4 A)

4.3.5 Al, H and Effective cation exchange capacity (ECEC) ($cmol_{(+)}/kg$)

The Guinea Savannah had the highest level of Al + H with its maize landscape recording the least level. Landscapes within the Semi-Deciduous Forest and Forest-Savannah Transition zones showed no significant differences. ECEC, a summation of (K, Ca, Mg, Na, Al and H in $cmol_{(+)}/kg$) showed various variations between and within the agro-ecological zones. The Forest-Savannah Transition zone had the highest average ECEC of 8.923 $cmol_{(+)}/kg$. The average ECEC of the Semi-Deciduous Forest and Guinea Savannah zones were 6.91 and 6.29 $cmol_{(+)}/kg$, respectively, but are not significantly different ($P < 0.05$) (Fig 4.5).

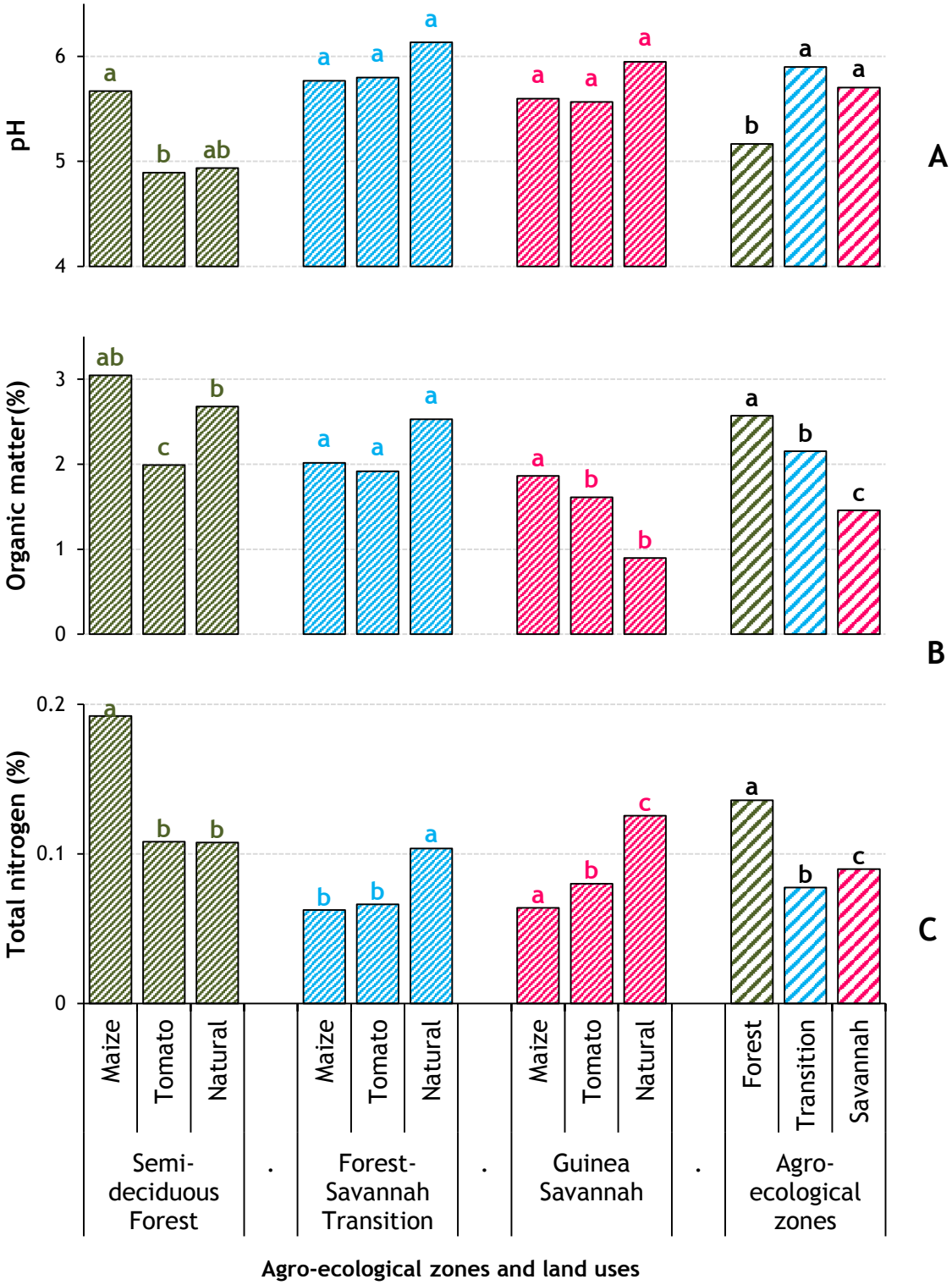


Figure 4.2: A= Soil pH, **B** = OM (%) and **C** = organic nitrogen (%) of Maize, Tomato and Undisturbed sites in the Semi-Deciduous Forest, Forest-Savannah Transition and Guinea Savannah agro-ecological zones.

Data represent analysis of 132 samples in each agro-ecological zone. Bars with different letters within an agro-ecological zone are statistically different ($P < 0.05$)

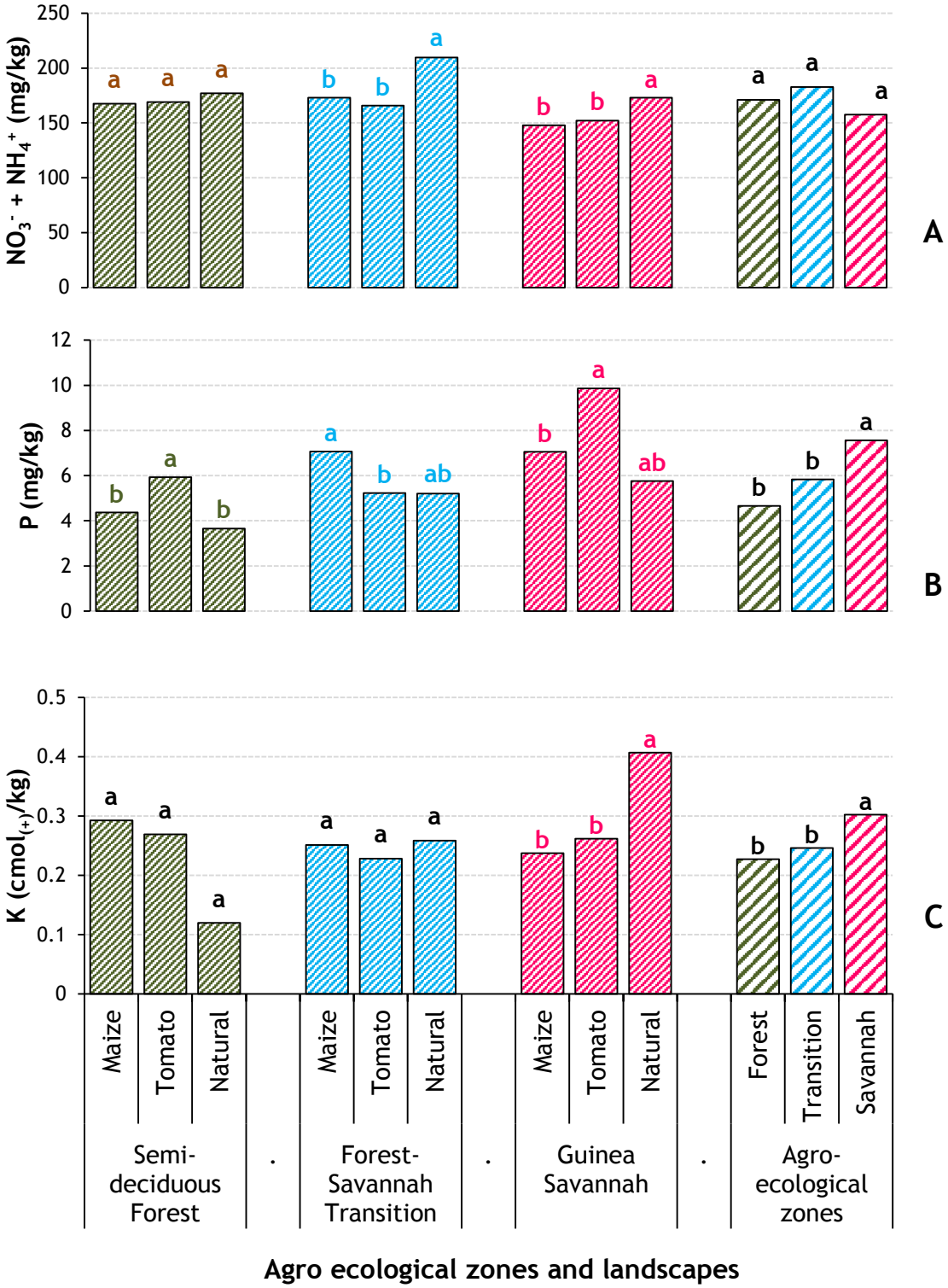


Figure 4.3: A = Soil available nitrogen (NO_3^- + NH_4^+in mg/kg), **B** = P (mg/kg) and **C** = K($cmol_{(+)}$/kg) of Maize, Tomato and Undisturbed landscapes in the Semi-Deciduous Forest, Forest-Savannah Transition and Guinea Savannah agro-ecological zones.

Data represent analysis of 132 samples in each agro-ecological zone. Bars with different letters within an agro-ecological zone are statistically different at P = 0.05.

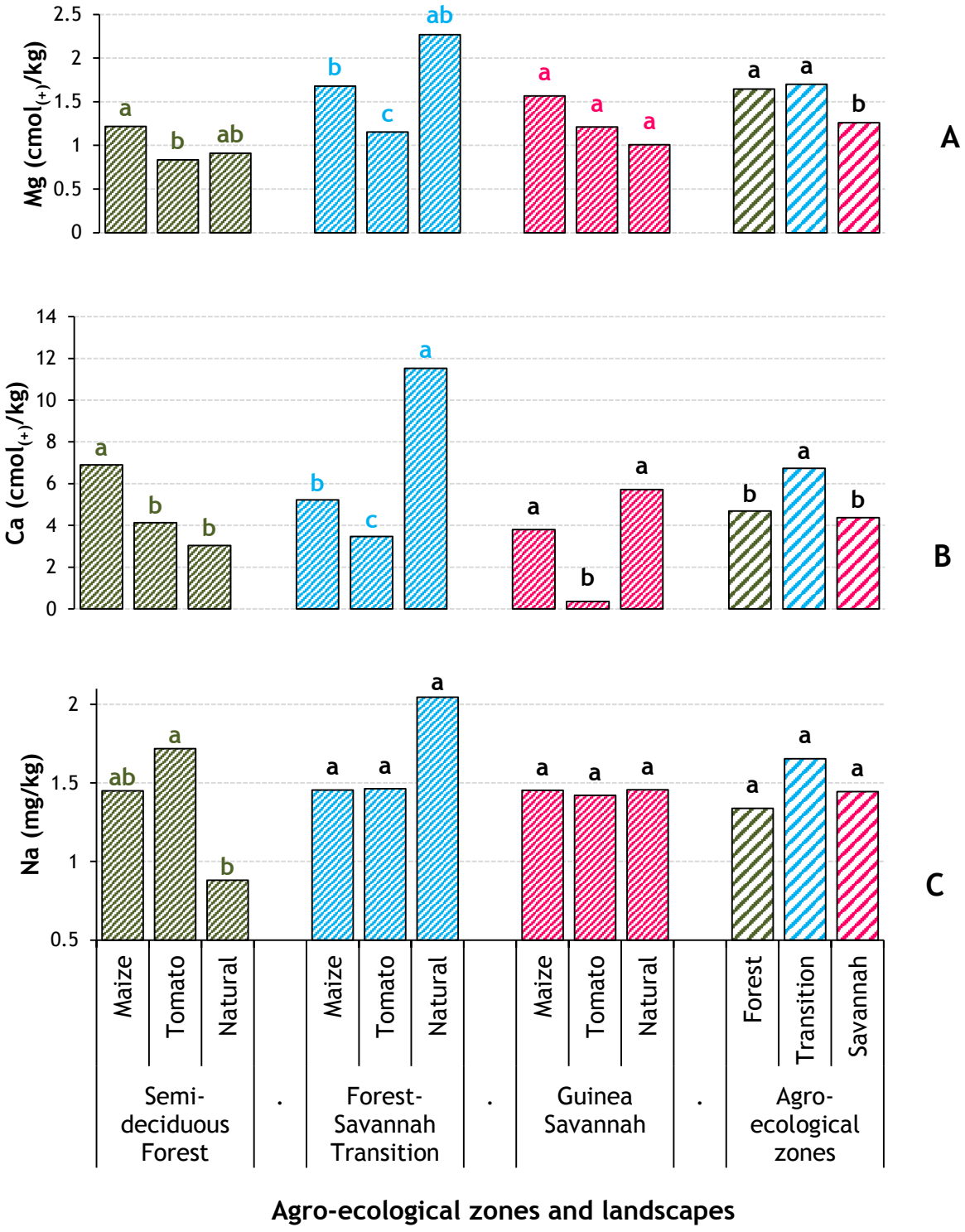


Figure 4.4: A = Soil Ca ($cmol_{(+)}$/kg), **B** = Mg ($cmol_{(+)}$/kg) and **C** = Na (mg/kg) of Maize, Tomato and Undisturbed landscapes in the Semi-Deciduous Forest, Forest-Savannah Transition and Guinea Savannah agro-ecological zones.

Data represent analysis of 132 samples in each agro-ecological zone. Bars with different letters within an agro-ecological zone are statistically different at P = 0.05

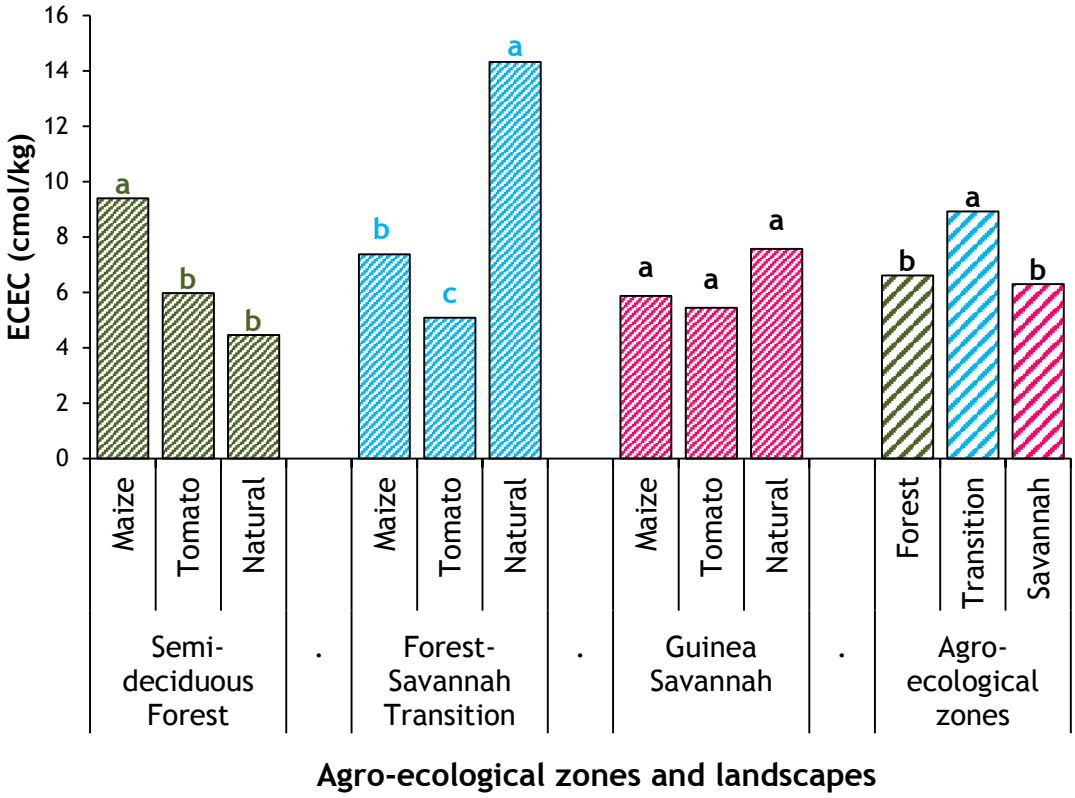


Figure 4.5: Effective cation exchange capacity in $cmol_{(+)}$/kg of Maize, Tomato and Undisturbed landscapes in the Semi-Deciduous Forest, Forest-Savannah Transition and Guinea Savannah agro-ecological zones.

Data represent analysis of 132 samples in each agro-ecological zone. Bars with different letters within an agro-ecological zone are statistically different at P = 0.05

4.4 Nematode community analysis

Nematode community analysis was done to reveal nematode diversity, ecological disturbance and soil food web and nutrient cycling potential.

4.4.1 Nematode diversity

A total of 61 genera of nematodes were identified; 50, 51 and 49 genera were identified in the Semi-Deciduous Forest, Forest-Savannah Transition and Guinea Savannah agrological zones, respectively. Appendices 2, 3 and 5 list nematodes genera identified in the various landscapes of the three agro-ecological zones under study. Majority of the identified genera, in undisturbed landscapes of all three agro-ecological zones, were bacterivorous (Appendices 3,4,5). The relative abundance of the nematode genera varied across agro-ecological zones with some genera totally absent in some the zones.

Plant parasitic genera; *Aglenchus, Anguina, Criconema, Criconemoides, Helicotylenchus Hoplolaimus, Moloidogyne, Pratylenchus, Rotylenchus, Tylenchorhynchus, Paratrichodorus* and *Longidorus* were present in all the three agro-ecological zones. *Malenchus* was absent in the Guinea Savannah zone. *Tylenchus, Radopholus, Globodera, Hirschmenniella, Rotylenchulus* and *Xiphenema* were absent in the Forest Savannah Transition zone.

With bacteria-feeding nematodes, the genera *Panagrolaimus, Protorhabditis, Acrobeles, Chiloplacus, Eucephalobus, Heterocephalobus, Plectus, Pseudacrobeles, Zeldia, Wilsonema* and *Prismatolaimus* were present in all the three agro-ecological zones. *Odontopharynx* was absent in the Forest-Savannah Transition zone. *Ethmolaimus* was absent in the Guinea Savannah zone. *Acrolobus, Microlaimus* and *Mesorhabditis* were present only in the Forest-Savannah Transition.

Fungivorous genera, *Aphelenchoides, Aphelenchus, Ditylenchus* and *Filenchus* were present in all the three agro-ecological zones. *Mononchus*, a predator genus, was identified only in the Semi-Deciduous Forest and Guinea Savannah agro-ecological zones. Omnivorous genera, *Dorylaimus, Tylenchodorus, Nygolaimus* and *Prodorylaimus* were identified in all the zones.

The Semi-Deciduous Forest agro-ecological zone recorded an average Genus richness (N0) of 18.53, 19.33 and 23.00 for maize, tomato and undisturbed landscapes, respectively. Average genus richness for maize, tomato and undisturbed landscapes in the Forest-Savannah Transition zone were 17.53, 15.80 and 24.33 respectively; and 12.93, 10.53, 20.67 for maize, tomato and undisturbed landscapes in the Guinea Savannah zone. Undisturbed landscapes in each agro-ecological recorded higher genus richness, compared to maize and tomato landscapes in the respective zones. Maize and tomato landscapes of the Guinea Savannah had the lowest genus richness (Fig 4.6 **A**).

Hills index (N2), which is a measure of the number of very dominant taxa, was least in tomato landscapes of the Guinea Savannah zone; however was not significantly different ($P < 0.05$) from that of undisturbed sites in the Guinea Savannah zone. In the Semi-deciduous Forest zone, all three landscapes were not significantly different ($p < 5$). Undisturbed sites in the Forest-Savannah Transition zone had significantly higher Hills index (N2) than tomato landscapes but not significantly different from that of maize landscapes (Fig 4.6 **B**).

Shannon index measures nematode diversity by focussing on rare nematode taxa. The more rare nematodes present, the higher the Shannon index. In the Semi-deciduous

Forest zone, maize, tomato and undisturbed sites recorded 2.640, 2.678 and 2.695 respectively, which were not significantly ($P < 0.05$) different from each other. Some significant ($P < 0.05$) variations were observed in both Forest-Savannah Transition and Guinea Savannah zones with undisturbed sites recording highest values of 2.842 and 2.520, respectively. In the Guinea Savannah zone, however, Shannon index of maize (2.423) was not significantly ($P < 0.05$) different from that of the undisturbed sites.

Simpson index, unlike Shannon index, is sensitive to common nematode taxa in measuring nematode diversity. No significant ($P < 0.05$) variations were observed among the various land uses in the Semi-deciduous Forest zone: 0.083, 0.080 and 0.088 for maize, tomato and undisturbed respectively. Tomato fields recorded the highest Simpson's index; 0.11 and 0.15, in the Forest-Savannah Transition and Guinea Savannah zones, respectively, (Fig 4.6 **D**).

4.4.2 Ecological disturbance

Maturity index measures the level of disturbance of the soil ecosystem with lower values indicating more disturbance. Combined maturity index (ΣMI) takes into consideration all nematode trophic groups present a soil sample. Undisturbed sites in all three zones had the highest combined maturity index: 1.57, 1.69 and 1.45 for the Semi-Deciduous Forest, Forest-Savannah Transition and Guinea Savannah zones respectively. (Fig4.7**A**). The most disturbed soils in terms of combined maturity index were maize and tomato sites in the Semi-deciduous Forest (1.13 and 1.01 respectively) and Guinea Savannah zones (0.94 and 1.16 respectively).

Variations in maturity index of plant parasitic nematodes (PPI) differed from what was observed in combined maturity index. In the Semi-deciduous Forest zone, maize recorded the least value of 2.560 which is significantly different ($P < 0.05$) 3.079 and

3.11 of tomato and undisturbed sites. Even though maize sites in the Forest-Savannah had the least value of 2.365, this was not significantly different from that of tomato (2.705) and undisturbed (2.624) sites. Significant difference was also not observed among the various land uses in the Guinea Savannah zone. (Fig4.7**B**).

The variations observed in maturity index of free-living nematodes were slightly similar to what was observed in the combined maturity index. The most disturbed free living nematode (least maturity index of free-living nematodes) was in maize (1.728) sites of the Guinea Savannah zone. The least disturbed free-living population was observed in undisturbed landscapes of the Forest-Savannah Transition zone (2.241), even though this is not significantly different from tomato (2.108) and maize (2.087) sites.

4.4.3 Soil food web

The relationship between Enrichment Index (a measure of opportunistic bacterivorous and fungivorous nematodes), and the Structure Index (indicator of food web state affected by stress or disturbance) was used for a graphic representation (Fig 4.9) which describes the soil community profile in four quadrants according to Ferris *et al.* (2001): *Quadrat A*= enriched but unstructured, *Quadrat B* = enriched and structured, *Quadrat C* = resource-limited and structured, and *Quadrat D* = resource-depleted with minimal structure.

The results across landscapes and agro-ecological zones were concentrated in Quadrat A and Quadrats D. Soil food webs in Semi-Deciduous Forest, in general, had depleted resource with minimal structure. In Forest-Savannah Transition, nearly all soils from maize landscape had highly enriched but unstructured food web with that of undisturbed landscapes being resource-depleted and minimal structure. Majority of

tomato landscapes in the Forest-Savannah Transition also had food webs of minimal structure with depleted resource. In the Guinea Savannah, tomato landscapes had slightly enriched and minimal structured soil food web.

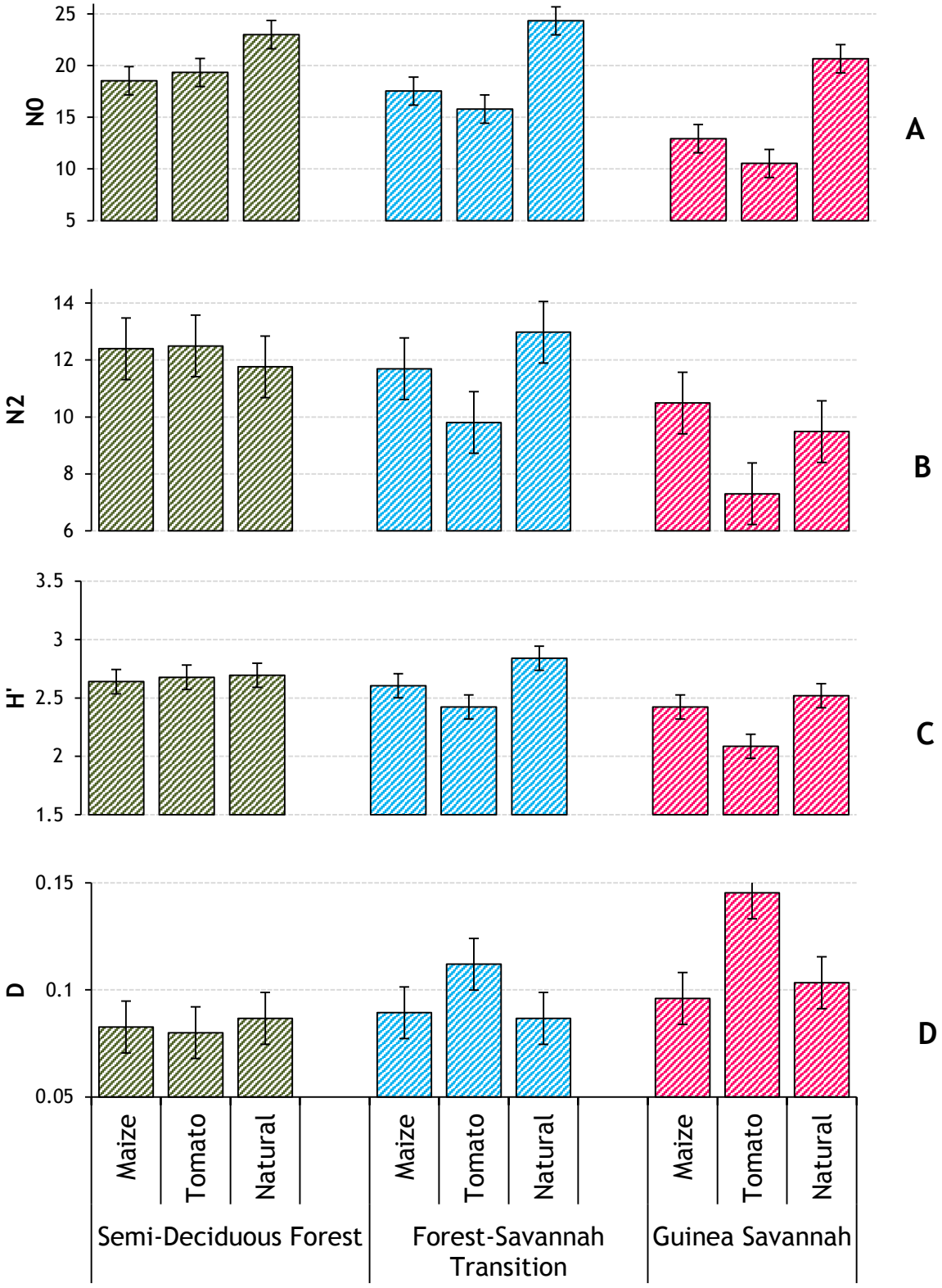


Figure 4.6: **A**= Genus richness **B** = Hills Index (N2), **C** = Shannon Index (H'), **D**= Simpson's Index (D) of Maize, Tomato and Undisturbed landscapes in the SEMI-Deciduous Forest, Forest-Savannah Transition and Guinea Savannah agro-ecological zones.

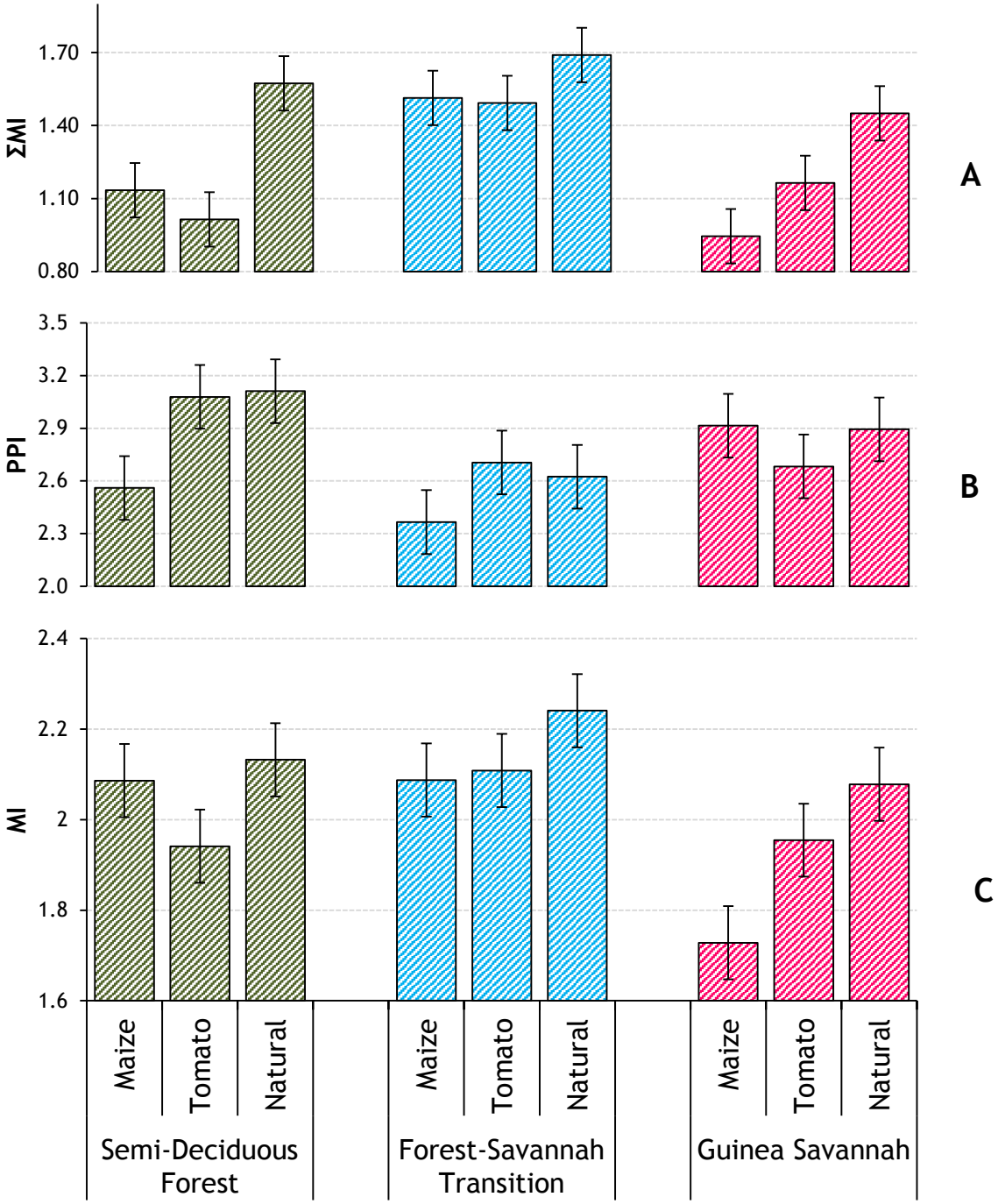


Figure 4.7: A= Combined Maturity Index (**ΣMI**) **B** = Maturity Index of Plant Parasitic Nematodes (PPI), **C** = Maturity Index of Free-living Nematodes (MI) of Maize, Tomato and Undisturbed landscapes in the Semi-Deciduous Forest, Forest-Savannah Transition and Guinea Savannah agro-ecological zones.

Data represent analysis of 33 samples in each agro-ecological zone. Error bars represent standard error of difference ($P < 0.05$).

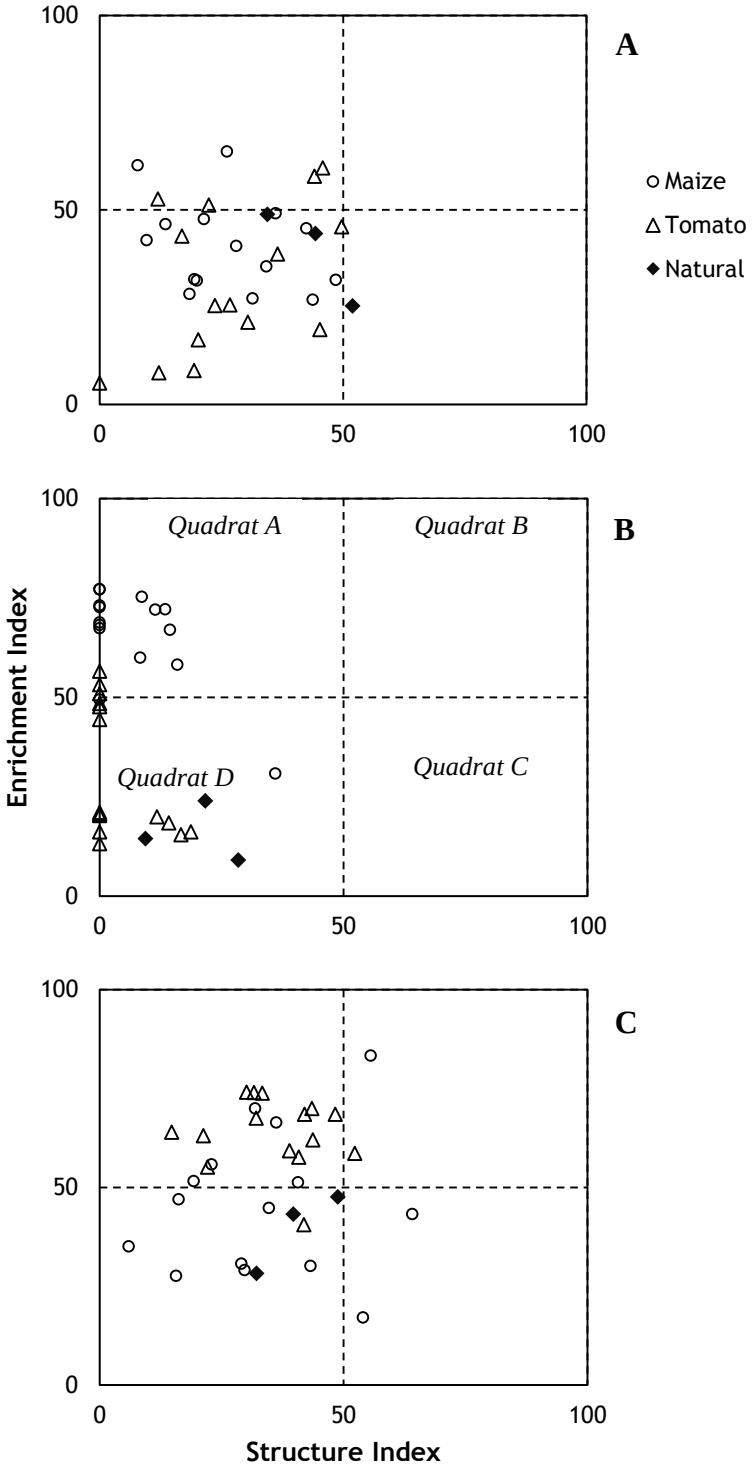


Figure 4.8: The soil food web state of maize, tomato and undisturbed landscapes in Semi-Deciduous Forest (A), Forest-Savannah Transition (B) and Guinea Savannah (C).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Demographics

Ninety-one percent of the heads of farms surveyed were males. Even though women, and, sometimes, children, were encountered actively working on the farms, men are generally regarded head of the household, hence head and owner of the farmland. Despite the important role women play in agriculture, they have much more limited access to land and agricultural extension than their male counterparts (Duncan, 2004). This phenomenon is more prevalent in the northern parts of Ghana. IFAD's (1998) evaluation of the Upper East Region of Ghana (Guinea Savannah zone) established that even though women supply up to 80% of the labour in farm activities such as harvesting, storing, processing and marketing of farm produce, they have limited access to and control of land. At best, a woman can expect to obtain temporary use of a plot of land from her husband, if the latter feels he can spare the woman's labour (IFAD, 1998). The study confirmed this, since all the 33 farmers randomly interviewed in Guinea Savannah zone were males (Table 4.1).

Agriculture offers over 10 million jobs in Ghana (Oppong-Anane, 2006). Sixty percent and 67 % of respondents in the Forest-Savannah Transition and Guinea Savannah, respectively, were below the age of 40 whilst 40% in the Semi-Deciduous Forest zone were below the age of 40 (Table 4.1). This survey revealed that the youth are actively involved in agriculture with respect to maize and tomato cultivation in the three agro-ecological zones. However, majority of them have no form of formal education.

In Ghana, farming is considered as a work for the poor and uneducated. This was clearly evident in the distribution of the farmers by level educational acquired (Appendix 1).

In the Guinea Savannah zone, for example, none of the farmers interviewed attained tertiary education. Some level of education may be necessary for farmers to understand and implement, without supervision, some types of strategies. Some basic skills like record keeping, crop spacing, application of agro inputs at recommended rates, observing withdrawal periods of biocides, composting, are enhanced by education.

5.1.1 Access to land and cultivation practices

The type of cultivation practice chosen by an individual largely depends on his/her culture, level of education, available technology and income level. Many small holder farmers receive weak suport from their government with regard to productive technologies, extension support, health and education, which limits the ablity of small holder farmers to graduate from porvety through agricultural productive growth (Jayne *et al.*, 2005). Most of the farmers, interviewed, revealed that the Ministry of Food and Agriculture have not been consistent in providing them with improved cropping technologies through their extension service.

Statistics, Research and Information Directorate (SRID) of MoFA (2010) reported that about 90 % of farm holdings in Ghana are less than 2 hectares. Access to land plays an important role in sustainable agriculture; farmers with limted land area tend to continously cultivate the same parcel of land for prolonged number of years. Access to land may also influence the area of land at the disposal of farmers; the majority of farmers interviewed had farms of not more that an acre (0.4 ha) (Appendix 1). Owning land, however, does not guarantee farmers' ability to cultivate large areas of land as other factors such as technology and funding are necessary. Out of the 65 farmers who owned the farmland, 59 of them cultivated less than 3 acres of land.

The survey discovered that even though majority of farmers continuously cultivated their lands for over 9 years in the Semi-Deciduous Forest and Forest-Savannah Transition zones (Table 4.1), their cultivation practices, however, were not directed towards maintaining good soil health. Land clearing by burning which was a common practice across all the three agro-ecological zones, destroys soil biota which in turn influences the nutrient cycling ability of the soil ecosystem in a negative way. Different agricultural practices affect soil biota in different ways and the response may be positive or negative (FAO, 2014). Cultivation practices, such as tillage, crop rotation, fertilizer and biocide application, influence soil biota population, diversity and functions (Gupta *et al.*, 2014).

Once a forest is open up for cultivation, the soil gradually loses organic matter and the fertility of the soil declines as land is left bare and exposed to erosion of soil and nutrients (IIRR and ACT, 2005). The debris from clearing of a forest for cultivation is usually burnt to make way for cultivation. Once the soil organic matter content begins to decline without adequate replenishment, the soil gradually losses its fertility and its ability to support the initial soil population. The rate of fertility loss and organic matter loss may increase when farmers make no intentional effort to replenish the soil's reservoir of organic matter. Addition of compost, crop rotation, cover cropping and addition of farm yard manure are among practices that improve organic matter build up and soil fertility replenishment, but were very rarely practiced by the farmers.

The fast physical, nutritional and biological deterioration of soils in Africa and the consequent declines in agriculture productivity are as a result of inappropriate soil preparation and tillage methods adopted by most farmers (FAO, 2000).

5.2 Types and levels of nutritional and physicochemical degradation

The observed variations in soil organic carbon content among agro-ecological zones can be attributed to the differences in vegetation, amount of annual rainfall and human activities. Even though the Guinea Savannah has vegetation which promotes organic matter build-up, levels were comparatively low. The perennial problem of bush fires in Northern Ghana during the long dry season (Gariba, 2011) and high temperatures are major factors which may explain the low levels of soil organic matter, especially in undisturbed sites which are at the mercy of bush fires in the Guinea Savannah zone.

Effect of crop cultivation on soil organic matter content varied among zones. The relatively higher level of percent organic matter in maize landscapes in the Guinea Savannah zone (Fig 4.2B) may be attributed to the superior ability of maize (C4 plants) to accumulate dry matter (Ehlers and Goss, 2003) but these levels were far below those of the Semi-Deciduous Forest zones as, most maize fields in the Semi-Deciduous Forest zone were mostly newly opened forests. In the Forest-Savannah Transition, even though statistical differences were not detected, cultivation reduced soil organic matter content. MoFA (1998) suggested the regular incorporation of manure into soils in the Savannah zones to improve their soil organic matter percentage. This approach is feasible since the Guinea Savannah zone has the major livestock production regions of Ghana (Oppong-Anane, 2006).

Studies in Kenya by Kapkiyai *et al.* (1999) revealed that; addition of high rate of mineral fertilizers and manure and retention of maize stover, individually, did not reverse decline of soil organic matter resulting from continuous cultivation, but a combination of the amendments halved the loss of soil organic matter. However, they concluded that stover and manure are counterbalance because stover is a major component of ruminant diet. Oppong-Anane (2006) confirms that most livestock

farmers practice supplementary feeding, using crop residues, in the dry season. Some households use crop residues such as maize and millet stalks for alternate purposes such as fuel and thatching of roof.

Smallholder farmers' effort alone, if any, in improving soil organic levels in cultivated soils, is inadequate. Their activities rather worsen the deprived levels of soil organic matter.

In order to improve the level soil organic matter content, the study suggests an integrative and interdisciplinary approach. For instance, Ghana Institute of Engineers (2013) estimates that 3 million tons of solid waste is generated every year in Ghana; most of which is generated in the urban areas. The waste can be recycled into organic fertilizer and other products. Organic fertilizer from such a setup is expected to be relatively cheaper than imported mineral fertilizer. Once farmers are educated by the Ministry of Food and Agriculture on the importance of supplementing mineral fertilizer with the organic type, farmers may patronize the low priced but useful organic fertilizer which would enhance soil organic matter percentage and nutrient levels in cultivated soils.

Results from this research, according to soil nutrient ratings by Loganathan (1987) (Appendix 5), indicate that both cultivated and undisturbed landscapes have low levels of plant nutrients such as %N, K, P, Ca and Mg in all three agro-ecological zones. Total nitrogen levels of maize landscapes in the Semi-Deciduous Forest zones were of moderate quantities. In the Forest-Savannah Transition and Guinea Savannah zones, cultivation of maize and tomato had further reduced %N in the soils.

The introduction of a country-wide price subsidy on some types of mineral fertilizers by the government of Ghana in 2008, in attempt to mitigate the effect of rising food

prices (Banful, 2009), may have encouraged more farmers to use fertilizers but still below the recommended rates of application (Ragasa *et al.*, 2013). Farmers, therefore, continue to remove nutrients from the soil when they harvest their crops but do not replace these nutrients with the right rate of mineral fertilizers. This would mean that farmers yield will continue to dwindle over time and likely to make the farm less productive and profitable. In the wake of climate change and its impacts on agriculture, the plight of smallholder farmers may worsen.

5.3 Level of biological degradation

5.3.1 Nematode community diversity

Every soil nematode taxa is specialised in what they feed on. There are bacteria-feeders, fungi-feeders, predators, omnivores and herbivores (plant parasites). For this reason, nematodes play a central role in the soil food web (Neher, 2001). The diversity in nematode community reflects the soil ecosystem status.

The reduced nematode richness (indicated by the number of genera) in maize and tomato landscapes, compared to the undisturbed landscapes in their respective agro-ecological zones, indicates the interference in nematode community by crop cultivation. Nematode diversity (N0, N2, H' and D) varied among the various landscapes in the Forest-Savannah Transition and Guinea Savannah zones, but identical among landscapes of the Semi-Deciduous Forest zone. Most cultivated soils of the Semi-Deciduous Forest were freshly opened forests, hence, even though diversity seems to be slightly higher in undisturbed soils, values were not statistically different from those of maize and tomato landscapes.

The relatively harsh (dry climate and low organic) soil condition and prolonged land cultivation could explain the lower nematode diversity in the Guinea Savannah.

5.3.2 Ecological disturbance

Cultivation practices such as tillage, fertilization, irrigation and pesticide application cause a disturbance of soil ecosystem; if a soil ecosystem receives nutrient input, for example, opportunistic bacterivorous and fungivorous nematodes respond rapidly to the corresponding increase in their resources (Villenave *et al.*, 2013; Bongers *et al.*, 1997). Maturity index is a measure of disturbance of the soil nematode community with smaller values being indicative of more disturbed environment (Neher and Darby, 2006).

The addition of mineral fertilizer and biocides such as herbicides and fungicides to the soil is common in all three agro-ecological zones and this is reflective in the low values of combined maturity index (ΣMI) in maize and tomato landscapes, indicating disturbance of the soil ecosystem by crop cultivation.

5.3.3 Soil food web

The Enrichment Index and the Structure Index, both based on the indicator importance of functional guilds of nematodes, are descriptors of food web condition. Soil food web conditions varied with landscapes and agro-ecological zones, but were generally of minimal structure which is indicative of low prevalence of higher trophic level nematodes which may be a consequence of environmental perturbation or of agricultural practices. (Ferris *et al.*, 2001; Neher and Darby, 2006). In the semi-deciduous forest, soil food web generally are of minimal structure and not very enriched. Food web of Tomato landscapes of the forest-savannah transition were concentrated at the proximal end of the structure trajectory, hence, are considered basal and may indicate stressed environment according to Ferris et al (2001). Overall, the study shows that the soils have structural deficits which is consistent with the soil physiochemical data.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

This study confirms the hypothesis of this research that cultivation practices are not directed towards the maintenance of good soil health. It was also discovered that soils of the study areas are inherently poor in terms of plant nutrients and fragile in terms of soil food web condition, even in undisturbed soils. The warm tropical climatic and unsustainable cultivation practices impede the accumulation of organic matter (OM) which serves as the power house for soil ecosystem and source of plant nutrient.

The severity of low nutrients in the three agro-ecological zones, especially in the Guinea Savannah zone, requires the application of soil amendments in right quantities in addition to strategic management practices to enhance OM build-up and nutrient levels in the soil.

The level of nutritional degradation and soil ecosystem fragility variation among agro-ecological zones and landscapes suggest that the one-size-fits all approach of solving nutrient and biological degradation is not the way to go. However, enhancement of OM levels of soils might, in all cases, be necessary for improving nutrient status and soil food web conditions. The study recommends an interdisciplinary and collaborative research in developing locally applicable technologies which will enhance the productivity of farmers but not at the expense soil health.

The study noticed the widespread use of cell phone among farmers. This could be a useful tool for communicating information such as weather forecast, commodity prices as well as tailored cultivation technologies directly to farmers. This could be a way to bridge the gap between farmers and the Extension Services of Ministry of Food and Agriculture. The study, therefore, recommends that the Ministry of Food and

Agriculture should take advantage of telecommunication technologies in transferring tailored cultivation technologies to farmers.

The quantum of solid waste generated in Ghana especially at the urban centres also offers an opportunity for the manufacture of organic fertilizer which can improve soil health considerably. The study recommends that Government of Ghana should develop policies that would set up recycling plants that would produce organic fertilizer from organic wastes. Organic fertilizer produced in this manner can then be incorporated into the national fertilizer subsidy programme which, at the long run, would improve the level of organic matter content of cultivated soils.

REFERENCES

1. Banful, A.B. (2009). Operational Details of the 2008 Fertilizer Subsidy in Ghana - Preliminary Report. GSSP Background Paper 18. Washingtion D.C.: IFPRI.

2. Black, C.A., ed. (1986). Methods of soil analysis, Part I. Physical and mineralogical properties, including statistics of measurement and sampling. Part II. Chemical and microbiological properties. Madison. Wis. USA: Agronomy series, ASA.

3. Boahen, P., Dartey, B.A., Dogbe, D.P., Boadi, E.A., Triomphe, B., Daamgard-Larsen, and Ashburner, J. (2007). Conservation agriculture as practiced in Ghana. Nairobi: African Conservation Tillage Network, Centre de Coopération Internationale de Recherche Agronomique pour le Développement, Food and Agriculture Organization of the United Nations.

4. Bongers, T. (1999). The Maturity Index, Evolution of Nematode Life History Traits, Adaptive Radiation and cp-scaling. *Plant and Soil*, 212: 13-22.

5. Bongers, T. and Bongers, M. (1998). Functional diversity of nematodes. *Applied Soil Ecolology*, 10: 239-251.

6. Bongers, T. and Ferris, H. (1999). Nematode community structure as a bioindicator in environmental monitoring. *Trends in Ecololgy and Evolution*, 14: 224-228.

7. Bongers, T., van der Meulen, H. and Korthals, G. (1997). Inverse relationship between the nematode maturity index and plant parasite index under enriched nutrient conditions. *Applied Soil Ecology*, 6: 195-199.

8. Bot, A. and Benites, J. (2005). The Importance of Soil Organic Matter; Key to Drought-resitant Soil and Sustained Food and Production. FAO Soils Bulletin. Rome: FAO.

9. Bouyoucos, G.J. (1962). Hydrometer Method for making Particle Size Analysis of Soils. *Agronomy Journal*, 54: 464-465.

10. Bray, R.H. and Kurtz, L.T. (1945). Determination of Total, Organic and Available Forms of Phosphorus in soil. *Soil Science*, 599: 39-45.

11. C.I.H (1900). C.I.H. Description of Plant-parasitic Nematodes, Set 2-8. 103 Peter's Street, S. Albans, Herts., England: Commonwealth Institute of Helminthology.

12. Coyne, D.L., Nicol, J.M. and Claudius-Cole, B. (2007). Practical Plant Nematology; A Field and Laboratory guide. Cotonou, Benin: SP-IPM Secretariat, International Institute of Tropical Agriculture (IITA).

13. Crawsell, E.T. and Lefroy, R.D.B. (2001). The role and function of organic matter in tropical soils. In E.T. Crawsell, ed. Nutrient Cycling in Agroecosystems. Netherlands: Kluwer Academic Publishers. 7-18.

14. Doran, J.W. and Zeiss, M.R. (2000). Soil Health and Sustainability: Managing the Biotic Component of Soil Quality. *Applied Soil Ecology*, 15: 3-11.

15. Duncan, B.A. (2004). Women in Agriculture in Ghana. 2nd ed. Accra: Printright.

16. Ehlers, W. and Goss, M.J. (2003). Water Dynamics in Plant Production. Wallingford: CABI.

17. FAO (2000). Manual on Intergrated Soil Management and conservation Practices. FAO Land and Water Bulletin 8. Rome: FAO.

18. FAO (2001). Soil Fertility Management in Support of Food Security in Sub-Saharan. Rome: Food and Agriculture Organization of the United Nation.

19. FAO (2005). Fertilizer Use by Crops in Ghana. Rome: Food and Agriculture Organization of the United Nations.

20. FAO (2008). An International Technical Workshop Investigating Sustainable Crop Intensification: The Case for Improving Soil Health. Rome: FAO.

21. FAO (2011). Save and Grow, A Policymakers's Guide to the Sustainable Intensification of Smallholder Crop Production. Rome: Food and Agriculture Organization of the United Nations.

22. FAO (2014). FAO. [Online] Available at: http://www.fao.org [Accessed 18 July 2014].

23. Ferris, H., Bongers, T. and de Goede, R.G.M. (2001). A framework for soil food web diagnostics: extention of the nematode faunal analysis concepts. *Applied Soil Ecology*, 18: 13-29.

24. Gariba, C.A. (2011). Bush Fires in Northern Ghana. [Online] Available at: http://www.ghanaweb.com [Accessed 21 January 2014].

25. GhIE (Ghana Institute of Engineers) (2013). Ghana Institute of Engineers. [Online] Available at: http://ghie.org.gh/ [Accessed 10 Sepamber 2014].

26. Good, I.J. (1953). The population frequencies of species and the estimation of population parameters. *Biometrika*, 40: 237-264.

27. Greeland, D.J., Wild, A. and Adams, D. (1992). Organic matter dynamics in soils of the tropics - from myth to reality. In R. Lal & S.P. A., eds. Myths and Science of Soils the Tropics. Madison: Soil Science Society of America. 17-39.

28. Gupta, V.V.S.R., Neate, S.M. and Leonard, E. (2014). Life in the Soil. [Online] Available at: http://www.csiro.au [Accessed 13 January 2014].

29. Hill, M.O. (1973). Diversity and Evenness: A Unifying Notion and its Consequencies. *Journal of Ecology*, 43: 1-11.

30. Hurlbert, S.H. (1971). The nonconcept of species diversity: a critique and alternative parameters. *Ecology*, 52: 557-586.

31. IFAD (1998). IFAD. [Online] Available at: http://www.ifad.org [Accessed 14 July 2014].

32. IIRR and ACT (2005). Conservation Agriculture: A Manual for Farmers and Extension Workers in Africa. Nairobi: International Institute of Rural Re-construction, Nairobi; African Conservation Tillage Network, Harare.

33. Jairajpuri, M.S. and Ahmed, W. (1992). Dorylaimida: Free-Living, Predaceous and Plant-Parasitic Nematodes. Leiden: BRILL.

34. Jayne, T.S., Mather, D. and Mghenyi, E. 2005. Smallholder Farming In Difficult Circumstances: Policy Issues for Africa, draft, Paper presented at the Conference on the future of Small Farms, June 26-29. Michigan, 2005. MSU.

35. Kapkiyai, J.J., Karanja, N.K., Qurenshi, J.N., Smithson, P.C. and Woomer, P.L. (1999). Soil organic matter and nutrient dynamics in a Kenyan nitisol under long-term fertilizer and organic input management. *Soil Biology and Biochemistry*, 31: 1773-1782.

36. Liang, W., Li, Q., Jiang, Y. and Neher, D.A. (2005). Nematode faunal analysis in an aquic brown soil fertilised with slow-release urea, Northeast China. *Applied Soil Ecology*, 29: 185-192.

37. Loganathan, P., (1987). Soil Quality Considerations in the Selection of Sites for Aquaculture. [Online] Available at: http://www.fao.org [Accessed 2 September 2014].

38. Luc, M., Sikora, R.A. and Bridge, J. (c2005). Plant Parasitic Nematodes in Subtripical and Tropical Agriculture. 2nd ed. Wallingford: CABI Publishing.

39. Ludwig, J.A. and Reynolds, J.F. (1988). Statistical Ecology: A Primer on Methods and Computing. New York: John Wiley.

40. McSweeney, C., New, M. and Lizcano, G. (2010). UNDP Climate Change Country Profiles: Ghana. *Bulletin of the American Meteorological Society*, 91:

157-166. Available at: http://country-profiles.geog.ox.ac.uk [Accessed 18 July 2013].

41. Melakeberhan, H. (2010). Assessing Cross-disciplinary Efficiency of Soil Amendments for Agro-biologically, Economically, and Ecologically Integrated Soil Health Management. *Journal of Nematology*, 42: 73-77.

42. Melakeberhan, H. (2013). A Soil health Strategy for Boosting Multi-sector Rural Development in Sub-Saharan Africa: Phase I- What is the Soil Biology Story? Unpublished.

43. Ministry of Food and Agriculture (MoFA) (1998). National Soil Fertility Management Action Plan. Accra: Directtorate of Crop Services.

44. Motsara, M.R. and Roy, R.N. (2008). Guid to Laboratory Establishment for Plant Nutrient Analysis, FAO Fertilizer and Plant Nutrition Bulletin. 19th ed. Rome: Food and Agriculture Organisation of the United Nations.

45. Mwangi, W. (1996). Low Use of Fertilizers and Low Productivity in Sub-Saharan Africa. Mexico: NRG Paper 96-105.

46. Neher, D.A. (2001). Role of Nematodes in Soil Health and their use as Indicators. *Journal of Nematology*, IV(33): 161-168.

47. Neher, D.A. (2010). Ecology of Plant and Free-Living Nematodes in Natural and Agricultural soil. *Annual Review of Phytopathology*, 48: 371-394.

48. Neher, D.A. and Campbell, C.L. (1994). Nematode communities and microbial biomass in soils with annual and perennial crops. *Applied Soil Ecology*, 1: 17-28.

49. Neher, D.A. and Darby, B.J. (2006). Computation and Application of Nematode Community Indices: General Guidelines. In E. Abebe, I. Andrassy & W. Traunspurger, eds. Freshwater Nematodes: Ecology and Taxonomy. Cambridge: CAB Publishing. 211-222.

50. Oppong-Anane, K. (2006). Country Pasture/Forage Resources Profiles. Rome, Italy: FAO.

51. Page, A.L., Miller, R.H. and Keeney, D.R. (1982). Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties, Agronomy series 9. 2nd ed. Madison: ASA,SSSA.

52. Paton, T.R. (1978). The Formation of Soil Material. London: George Allen and Unwin.

53. Ragasa, C., Dankyi, A., Acheampong, P., Wiredu, A.N., Chapoto, A., Asamoah, M. and Tripp, R. (2013). Patterns of Adoption of Improved Maize Technologies in Ghana. Washington D.C.: IFPRI.

54. Ritz, K. and Trudgill, D.L. (1999). Utility of Nematode Community Analysis as an Integrated Measure of the Functional State of Soils: Perspective and Challenges. *Plant and Soil*, (212): 1-11.

55. Sánchez-Moreno, S., Minoshima, H., Ferris, H. and Jackson, L.E. (2006). Linking Soil Properties and Nematode Community Composition: Effects of Soil Management on Soil Food Webs. *Journal of Nematology*, 8(5): 703-715.

56. Shannon, C.E. and Weaver, W. (1949). The Mathematical Theory of Communication. Illinois, USA: University of Illinois, Urbana.

57. Simpsom, E.H. (1949). Measurement of Diversity. *Nature*, 163: 688.

58. Soils Laboratory Staff. Royal Tropical Institute. (1984). Analytical methods of the service laboratory for soil, plant and water analysis. Part 1: Methods for soil analysis. Amsterdam: Royal Tropical Institute.

59. Stanturf, J.A., Warren, J..M.L., Charnley, S., Polasky, S.C., Goodrick, S.L., Armah, F. and Nyako, Y.A. (2011). Ghana Climate Change Vulnerability and Adaptation Assessment. Washington D.C.: USAID.

60. Statistics, Research and Information Directorate (SRID) (2010). Agriculture in Ghana. Facts and Figures. Accra: Ministry of Food and Agriculture.

61. Van Bezooijen, J. (2006). Methods and Techniques for Nematology, Revised Version. Wageningen.

62. Villenave, C., Jimenez, A., Guernion, M., Pérès, G., Cluzeau, D., Mateille, T., Martiny, B., Fargette, M. and Tavoillot, J. (2013). Nematodes for Soil Quality Monitoring: Results from the RMQS BioDiv Programme. *Open Journal of Soil Science*, 3: 30-45.

63. VSN International (2011). GenStat for Windows 14th Edition. VSN International, Hemel Hempstead, UK: GenStat.co.uk.

64. Wikipedia (2014). Wikipedia. [Online] Available at: http://en.wikipedia.org/wiki/Soil_health [Accessed 21 February 2014].

65. Yeates, G.W., Bongers, T., De Goede, R.G.M., Freckman, D.W. and Georgieva, S.S. (1993). Feeding habits in soil nematode families and genera — an outline for soil ecologists. *J. Nematol.*, 25: 316-331.

APPENDICES

Appendix 1: Demographic distribution of respondents in the various communities selected within the Semi-Deciduous Forest, Forest-Savannah Transition and Guinea Savannah agro-ecological zones.

	Semi-Deciduous Forest zone					**Forest-Savannah Transition zone**					**Guinea Savannah zone**				
	No. of respondents			**Total**	%	*No. of respondents*			**Total**	%	*No. of respondents*			**Total**	%
	Kwaso	Nkawkaw	Nyinahin			Amantin	Nkoranza	Subinja			Langbinsi	Namansi	Mushio		
Sex															
Female	1	1	4	**6**	20.0	-	2	-	**2**	6.7				**-**	0.0
Male	9	9	6	**24**	80.0	10	8	10	**28**	93.3	10	10	10	**30**	100.0
Age															
≤ 30	1	1	-	**2**	6.7	1	1	2	**4**	13.3	2	2	2	**6**	20.0
31 - 40	3	4	3	**10**	33.3	6	4	4	**14**	46.7	5	4	5	**14**	46.7
41 - 50	6	4	4	**14**	46.7	2	3	3	**8**	26.7	3	2	2	**7**	23.3
50 <	-	1	3	**4**	13.3	1	2	1	**4**	13.3	-	2	1	**3**	10.0
Education															
None	3	8	5	**16**	53.3	4	5	5	**14**	46.7	3	6	2	**11**	36.7
Islamic	-	-	-	**-**	0.0	-	-		**-**	0.0	5	1	3	**9**	30.0
Primary	4	1	1	**6**	20.0	5	3	4	**12**	40.0	1	2	2	**5**	16.7
Secondary	2	1	4	**7**	23.3	-	2	-	**2**	6.7	1	1	3	**6**	16.7
Tertiary	1	-	-	**1**	3.3	-	-	1	**1**	3.3	-	-	-	**0**	0.0
Landownership															
Owned	6	8	6	**20**	66.7	6	9	4	**19**	63.3	9	8	9	**26**	86.7
Leased	3	2	2	**7**	23.3	4	1	6	**11**	36.7	1	1	1	**3**	10.0
Share Gain	1	-	2	**3**	10.0	-	-	-	**0**	0.0	-	1	-	**1**	3.3
Farm Size (ac)															
≤ 2	**10**	**10**	**9**	**29**	96.7	**10**	**10**	**7**	**27**	90.0	**7**	**9**	**10**	26	86.7
> 2	**-**	-	1	**1**	3.3	-	-	3	**3**	10.0	3	1	-	4	13.3

Appendix 2: Nematodes identified in maize, tomato, and undisturbed landscapes of the Semi-Deciduous Forest zone

Trophic Group	Genus	Cp-value	Maize %	Tomato %	Undisturbed %
Plant parasitic	Aglenchus	2	1.5	0.0	0.0
	Anguina	2	4.2	0.0	0.0
	Malenchus	2	2.3	0.0	0.0
	Tylenchus	2	0.5	0.8	0.0
	Radopholus	3	3.9	4.2	0.0
	Criconema	3	0.0	0.0	4.0
	Criconemoides	3	0.7	1.5	0.0
	Globodera	3	0.5	0.0	0.0
	Helicotylenchus	3	4.9	7.1	1.7
	Hirschmenniella	3	1.5	0.5	0.0
	Hoplolaimus	3	3.3	0.0	2.3
	Meloidogyne (J2)	3	8.0	10.8	10.0
	Pratylenchus	3	5.8	5.6	2.3
	Rotylenchulus	3	0.0	8.7	0.0
	Rotylenchus	3	2.6	0.0	0.3
	Tylenchorhynchus	3	1.4	4.3	2.3
	Paratrichodorus	4	2.1	0.9	0.3
	Longidorus	5	0.9	1.2	0.0
	Xiphinema	5	1.5	2.1	2.7
Bacterivores	Panagrolaimus	1	2.2	3.6	2.0
	Protorhabditis	1	3.7	8.8	5.0
	Acrobeles	2	2.9	1.6	7.0
	Acrobeloides	2	2.6	0.4	3.3
	Chiloplacus	2	10.2	9.5	15.3
	Eucephalobus	2	4.3	2.7	4.7
	Heterocephalobus	2	0.6	0.3	1.0
	Monhysteridae	2	1.1	0.0	1.3
	Plectus	2	1.7	1.5	0.3
	Pseudacrobeles	2	0.3	0.0	11.7
	Zeldia	2	0.2	3.7	1.7
	Wilsonema	2	1.4	1.1	1.3
	Prismatolaimus	3	1.1	2.6	2.7
	Odontopharynx	3	0.3	0.1	0.7
	Ethmolaimus	3	0.1	0.0	0.0
Fungivores	Aphelenchoides	2	4.8	4.5	0.7
	Aphelenchus	2	4.7	4.5	1.0
	Ditylenchus	2	4.3	4.7	2.0
	Filenchus	2	3.7	0.0	6.3
	Diphtherophoridae	3	0.1	0.0	0.0
Predators	Mononchus	4	0.7	0.2	0.7
Omnivores	Dorylaimus	4	0.2	0.1	0.7
	Eudorylaimus	4	0.2	0.3	1.0
	Thornenema	4	0.1	0.2	0.0
	Tylenchodorus	4	0.5	0.5	0.7
	Aporcelaimellus	5	0.4	0.7	0.3
	Aporcelaimus	5	0.2	0.2	1.7
	Discolaimidae	5	0.5	0.1	0.0
	Nygolaimus	5	0.2	0.0	0.0
	Prodorylaimus	5	0.6	0.4	1.0

Appendix 3: Nematodes identified in maize, tomato, and undisturbed landscapes of the Forest-Savannah Transition zone

Trophic Group	Genus	Cp-value	Maize %	Tomato %	Undisturbed %
Plant parasitic	Aglenchus	2	1.9	1.7	6.3
	Anguina	2	5.9	0.4	0.0
	Malenchus	2	0.2	0.7	0.3
	Paratylenchus	2	0.0	0.0	2.7
	Criconema	3	0.1	0.2	1.7
	Criconemoides	3	0.1	0.0	0.0
	Helicotylenchus	3	4.1	6.7	0.3
	Hoplolaimus	3	0.7	0.0	1.0
	Meloidogyne (J2)	3	4.8	10.7	6.7
	Pratylenchus	3	7.3	7.3	1.0
	Rotylenchus	3	0.3	0.0	0.0
	Tylenchorhynchus	3	2.1	0.9	3.0
	Paratrichodorus	4	0.1	0.8	0.3
	Longidorus	5	0.0	0.0	0.7
Bacterivores	Panagrolaimus	1	1.7	1.7	1.3
	Protorhabditis	1	3.9	3.7	5.0
	Acrobeles	2	5.3	4.4	2.0
	Acrobeloides	2	7.7	7.7	2.3
	Cephalobus	2	1.5	0.3	0.0
	Cervidellus	2	0.0	0.6	0.0
	Chiloplacus	2	9.1	12.9	15.3
	Acrolobus	2	0.9	0.0	0.0
	Eucephalobus	2	5.7	7.1	5.7
	Heterocephalobus	2	1.5	1.2	1.7
	Monhysteridae	2	0.0	0.7	0.3
	Plectus	2	0.5	0.1	1.3
	Pseudacrobeles	2	6.3	8.1	7.3
	Microlaimus	2	0.1	0.0	0.0
	Zeldia	2	0.4	0.9	4.0
	Wilsonema	2	0.5	0.9	1.7
	Prismatolaimus	3	0.5	0.3	2.7
	Mesorhabditis	3	1.4	0.3	0.0
	Ethmolaimus	3	0.1	0.0	0.3
Fungivores	Aphelenchoides	2	3.3	2.5	6.3
	Aphelenchus	2	8.5	3.7	4.3
	Ditylenchus	2	4.7	4.0	1.0
	Filenchus	2	4.5	4.1	5.7
	Diphtherophoridae	3	0.0	0.5	0.0
Omnivores	Dorylaimus	4	0.5	0.7	1.0
	Eudorylaimus	4	1.3	0.6	1.0
	Microdorylaimu	4	0.1	0.0	0.0
	Thornenema	4	0.1	0.0	1.0
	Tylenchodorus	4	0.4	0.5	0.7
	Tylencholaimus	4	0.3	1.6	0.0
	Aporcelaimellus	5	0.5	0.3	0.0
	Aporcelaimus	5	0.3	0.3	1.7
	Discolaimoides	5	0.1	0.0	0.0
	Discolaimidae	5	0.0	0.0	0.7
	Discolaimus	5	0.7	0.9	0.0
	Nygolaimus	5	0.0	0.1	0.3
	Prodorylaimus	5	0.1	0.2	1.3

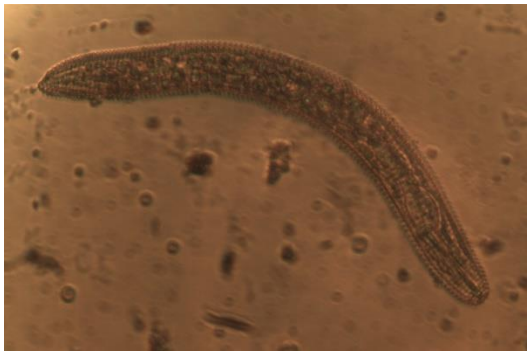
Appendix 4: Nematodes identified in maize, tomato, and undisturbed landscapes of the Guinea Savannah zone

Trophic Group	Genus	Cp-value	Maize %	Tomato %	Undisturbed %
Plant parasitic	Aglenchus	2	0.9	0.9	0.0
	Anguina	2	0.0	3.6	0.0
	Tylenchus	2	0.9	0.9	0.0
	Radopholus	3	7.1	0.4	0.0
	Criconema	3	0.0	0.5	1.3
	Criconemoides	3	0.2	0.0	0.0
	Globodera	3	1.1	0.0	1.3
	Helicotylenchus	3	6.3	10.1	3.3
	Hirschmenniella	3	1.5	0.0	0.0
	Hoplolaimus	3	1.4	0.0	1.0
	Meloidogyne (J2)	3	10.1	17.9	11.7
	Pratylenchus	3	9.7	5.2	5.7
	Rotylenchulus	3	2.1	0.0	0.0
	Rotylenchus	3	1.9	0.0	3.3
	Tylenchorhynchus	3	2.1	0.3	1.0
	Paratrichodorus	4	0.0	0.3	0.3
	Trichodorus	4	0.0	0.2	0.0
	Longidorus	5	0.0	0.1	0.0
	Xiphinema	5	0.5	0.0	1.3
Bacterivores	Panagrolaimus	1	7.1	0.0	0.0
	Protorhabditis	1	9.0	4.1	0.0
	Acrobeles	2	2.7	0.0	6.7
	Acrobeloides	2	8.0	2.0	1.0
	Chiloplacus	2	5.8	21.9	17.3
	Eucephalobus	2	3.9	1.1	2.3
	Heterocephalobus	2	0.0	3.1	3.0
	Monhysteridae	2	0.3	0.0	0.0
	Plectus	2	0.0	0.0	0.3
	Pseudacrobeles	2	1.7	14.5	14.7
	Zeldia	2	1.0	0.0	0.3
	Wilsonema	2	1.3	0.7	6.3
	Prismatolaimus	3	1.1	0.1	4.0
	Odontopharynx*	3	0.0	0.0	0.7
Fungivores	Aphelenchoides	2	2.1	1.7	1.7
	Aphelenchus	2	6.7	3.5	1.3
	Ditylenchus	2	2.0	3.2	5.3
	Filenchus	2	1.5	3.0	3.7
Predators	Mononchus	4	0.1	0.0	0.0
Omnivores	Dorylaimus	4	0.1	0.7	0.0
	Tylenchodorus	4	0.1	0.0	0.0
	Nygolaimus	5	0.0	0.0	1.0
	Prodorylaimus	5	0.1	0.0	0.0

Appendix 5: Ratings of soil nutrient in agricultural soils (Logathan, 1987).

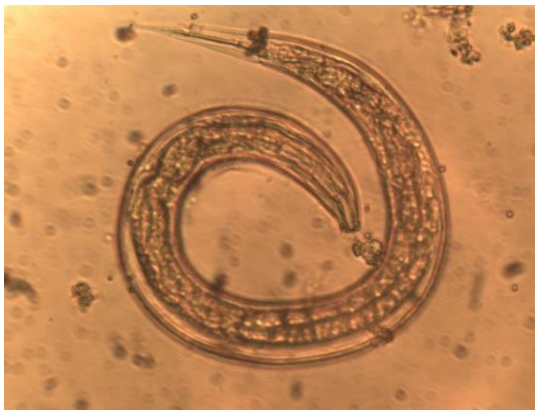
	Very low	**Low**	**Moderate**	**High**	**Very High**
N%	< 0.05	0.05 - 0.15	0.15 - 0.20	0.20 - 0.30	< 0.03
P(ppm)	< 3	3-10	10-20	20-30	< 30
K (meq/100g)	< 0.2	0.2-0.3	0.3-0.6	0.6-1.0	< 1.0
Ca (meq/100g)	< 2	2-5	5-10	10-20	< 20
Mg (meq/100g)	< 0.3	0.3-1.0	1.0-3.0	3.0-8.0	< 8.0

Appendix 6: Nematode genera image gallery from the study

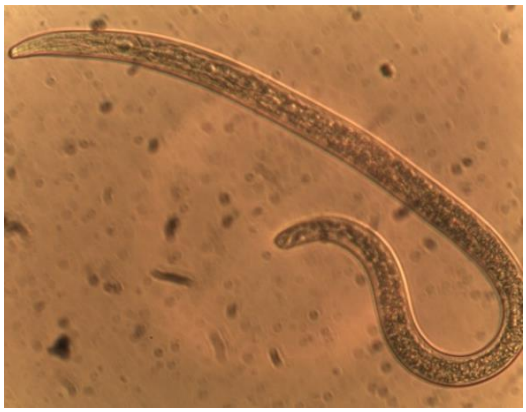


Criconemoides

Eucephalobus



Heterocephalobus



Aphelenchoides

Helicotylenchus

Mononchus