The Role of Soil Organisms and Functions in different Coconut based Multiple Cropping Systems

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Abstract*—Sampling was done in wet and intermediate zones represented by the Walpita and Makandura research centers, respectively. Eleven land use systems were considered for the study; coconut mono culture (CM), bare land (BL) and coconut multiple cropping. Under coconut multiple cropping, nine different intercrops were selected separately for each zones. The treatments were arranged in a randomized complete block design (RCBD) with three replicates (n = 3). The experiment was conducted under mature baring coconut (>20 years) plantation. Soil Macrofauna was sampled using one transect with three replicates at each land use type using quadrate size (30×30cm) from 0-30 cm depth and visible organisms were handpicked and preserved in 75% alcohol. Dilute plate technique and Spread plate technique was used to determine the soil micro organisms' density. Those techniques were used to cultivate the fungi and bacteria under* 10^{-2} *and* 10^{-5} *dilution level respectively.*

Research identified 12 classes (Crusteacea, Oligochaeta, Hirudinea, Gastropoda, Acarina, Araneida, Scopionida, Chilapoda, Diplopoda, Amphibia, Reptelia) and 14 orders (Hemiptera, Diptera, Coleoptera, Thysanura, Hymenoptera, Lepidotera, Orthoptera, Blattaria, Mantodea, Phasmida, Dermaptera, Isoptera, Siphonaptera, Thysanoptera) of soil organisms. Class insecta shows the high diversity with 14 orders. Colony forming unit (CFU) value of bacteria was higher than that of the fungi value. Findings of intermediate and wet zones' studies suggested that coconut multiple cropping systems may have high diversity, abundance and functional role of soil organisms. Both zones studies suggested that coconut multiple cropping systems may increase soil moisture factor, respiration rate, biomass carbon content, organic carbon percentage, total nitrogen content, organic matter content and C:N ratio in 0-30cm depth other than the coconut monoculture systems. Overall data of two different zones indicated a significant positive correlation of soil organism diversity, abundance and their functional role with cropping systems. Those data can be used as a reliable basic bio indicator for payments for ecosystem services (PES). It supports to valorize the economic value of the ecological services returned by soil organisms.

***Keywords*—Soil organisms, diversity, abundance, multiple cropping systems, eco system services, payments for ecosystem services, soil ecology.**

I. INTRODUCTION

Coconut (*Cocos nucifera* L.) is one the most important crops grown in the humid tropics (Adkins *et al.,* 2005). Extent of lands under coconut cultivation in Sri Lanka which is the fourth of world's coconut cultivation is about 394,836 hectares and it is about 20% out of the total cultivated extent of land in the country (CDA, 2006).

Soil organisms are an integral part of agricultural ecosystems (Nuria *et al*, 2008). These organisms may range from large animals and plants to microscopic bacteria (Davari *et al.,* 2010). Presence of diverse community of soil organisms is essential for the maintenance of fertile soils and productive lands for agriculture and forestry. Soil organisms are responsible for a range of ecological functions and ecosystem services including: nutrient cycling and nitrogen fixation, control of pest and diseases, organic matter decomposition and carbon sequestration, maintenance of a good soil structure for plant growth, rainwater infiltration, and detoxification of contaminants (Nuria *et. al*., 2008).

Ecosystem services are the services provided by the natural environment to benefit both people and other organisms. Payments for ecosystem services (PES) can be essentially defined in terms of payments to land managers or owners to undertake actions that increase the levels of desired ecosystem services (Helen, 2011). More formal definition is ''A PES scheme, simply stated, is a voluntary, conditional agreement between at least one 'seller' and one 'buyer' over a well defined environmental service or a land use presumed to produce that service" (Wunder, 2005).

However, one of the main gaps in agricultural management systems is the lack of awareness and understanding and hence inadequate management of soil biological processes to maintain and improve soil productivity. A major focus is placed on soil macrofauna, the visible part of the surprisingly rich soil life, and its activities in agricultural soils, as this is, firstly, reasonably representative of soil biodiversity as a whole (including micro and meso-organisms and populations) and, secondly, is the part of soil life that can be readily observed and monitored in terms of effects of various management practices (Nuria *et al,* 2008).

The organisms (or biota) are a major factor in soil formation and their effects determine many differences between soils. The various soil organisms affect certain soil processes in different ways (Nuria et al., 2008). Soil organisms play a vital role in soil ecosystems and their presence to sustain a healthy soil (Darwin, 1881).

Soil organisms are an integral part of agricultural ecosystems. The presence of a range of a diverse community of soil organisms is essential for the maintenance of productive soils. Soil organisms are responsible for a range of ecological functions and ecosystem services including: nutrient cycling and nitrogen fixation, control of pest and diseases, organic matter decomposition and carbon sequestration, maintenance of a good soil structure for plant growth and rainwater infiltration, detoxification of contaminants. An excessive reduction in soil biodiversity, especially the loss of species with key functions, may result in severe effects including the long term degradation of soil and the loss of agricultural productive capacity (Nuria et al, 2008). Presence of soil organisms is beneficial to agro ecosystems (Edwards and Fletcher, 1988; Lavelle, 1988; Lavelle et al, 1997; Edwards, 1998; Eriksen and Whalen, 2007).

Soil ecologists are still completing the taxonomy and systematic of soil organisms, revealing life history strategies, and just beginning to understand relationships between organisms and their contribution to ecosystem function (Crossley et al., 1992). One exception is that of earthworms and nitrogen fixing bacteria whose relationship to ecosystem function has been known for decades. This apparent lack of knowledge does not, however, diminish the importance of soil organisms (Neher, 1999).

Mesofauna occupy all trophic levels within the soil food web and affect primary production directly by root feeding and indirectly through their contribution to decomposition and nutrient mineralisation (Crossley et al., 1992).

Bio diversity, soil quality and sustainability are considered to be the factors in ecosystem payment. Diversity and abundance of soil organisms that contribute to the bio diversity and their functions are contributed to the soil quality.

The ecosystem assessment will be based on the information diversity and abundance of the soil organisms. Ecosystem assessment can be used to select the most suitable cropping system for particular micro climatic conditions and it is essential for ecosystem payment. In Sri Lanka basic studies have not been done to exploit the ecosystem payment schemes. Therefore this is important to ecosystem assessment and the payment.

II. MATERIALS AND METHODS

2.1 Experimental Location and Duration

The study was conducted in 2015 at Agronomy Division, Coconut Research Institute, Lunuwila. Experiments were carried out separately in a Randomized Complete Block Design (RCBD) at wet and intermediate zones. Walpita and Makandura research centers represent the wet and intermediate zones, respectively. Eleven land use systems were considered for the study; coconut mono culture (CM), bare land (BL) and nine different multiple cropping systems were selected separately.

Makandura Research Center area belongs to AER IL 1a agro ecological region ,major soil group is red yellow podzolic soil with strongly mottled subsoil and mean annual rainfall >1400 mm(Punyawardena et al., 2003).

Walpita Research Center area belonged to the agro ecological region of WL3, major soil group is red yellow podzolic soil with soft and hard laterite and mean annual rainfall >1700 mm (Punyawardena *et al*., 2003).

2.2 Selection of Intercrops

Mango -*Mangiferaindica*, banana -*Musaparadisiaca*, cocoa -*Theobroma cacao*, pepper -*Piper nigrum*, rambutan -*Nepheliumlappaceum*, manioc- *Manihotesculenta*, pine apple(P.Apple)-*Ananascomosus*, dragon fruit (DF) -*Hylocereusundatus* and sweet potato(SP) -*Ipomoea batatas*were selected intercrops for intermediate zone.

To represent the wet zone, mango -*Mangiferaindica*, banana -*Musaparadisiaca*, cocoa- *Theobroma cacao*, pepper -*Piper nigrum*, rambutan -*Nepheliumlappaceum*, manioc-*Manihotesculenta*, cinnamon -*Cinnamomumceylanicum*,Gliricidia -*Gliricidiasepium* and vanila -*Vanilla planifolia* were selected.

2.3 Experimental Design

Experiments were carried out separately in a RCBD at wet and intermediate zones. Each climatic zone had three treatments and three replicates. They were bare land, mono cropping land and inter cropping lands.

2.4 Soil Sampling and preparation

Soil samples were randomly collected from each experimental site. An undisturbed soil samples were collected using monolith and core sampler, from 0-30 cm depth. Fresh soil was used to determine the diversity and abundance of soil macrofauna, colony forming units of soil microorganism and soil microbial biomass carbon.

Soil samples were air dried at room temperature for 48-72 hours without any contaminations to determine the soil microbial respiration rate, total oxidizable organic carbon, total nitrogen and organic matter content. Those samples were grind and sieved. The mesh size was varied according to the test. 2mm mesh size was used to determine the soil microbial respiration rate and 0.2 mm mesh size was used to determine the total oxidizable organic carbon, total nitrogen and organic matter content.Soil samples were analyzed at both Agronomy and Soil Divisions of Coconut Research Institute.

2.5 Determination of Soil Macrofauna Diversity and Abundance

Key was developed to identify the macrofauna diversity and abundance. Table 1 show the developed key which was used to identify the soil macro organisms.

TABLE 1
MACROFAUNA IDENTIFICATION KEY

Phylum	Subphylum	Class	Order
Platyhelminthes		Turbellaria	
Annelida		Clitellata	
		Oligochaeta	
		Hirudinea	
Mollusca		Gastropoda	
Athropoda	Chelicerata	Arachnida	Acari
			Amblypygi
			Araneae
			Opiliones
			Palpigradi
			Pseudoscorpiones
			Scorpiones
			Solifugae
	Myriapoda	Chilapoda	
		Diplopoda	
		Pauropoda	
		Symphyla	
	Crustacea	Malacostraca	
	Hexapoda	Insecta	Hemiptera
			Diptera
			Coleoptera
			Thysanura
			Hymenoptera
			Lepidotera
			Orthoptera
			Blattaria
			Mantodea
			Phasmida
			Dermaptera
			Isoptera
			Siphonaptera
			Thysanoptera
		Entognatha	Collembola
			Diplura
			Protura
Chordata	Vertebrata	Amphibia	
		Reptelia	

Two different sampling methods were employed for measuring macro fauna diversity and abundance. They are Pitfall method and Monolith sampling method.

2.6 Pitfall Method

The above ground moving soil organisms were collected using pitfall traps. These traps consisted of plastic container (8 x 12 cm) buried in the soil to a depth of 12 cm, with the leaked extremity leveled with the surface of soil (Aquino et al., 2006).

Alongside each transect laid, three unbaited pitfall traps were laid and checked for macrofauna after 24 hours. Samples were trapped in 70% Alcohol. All the macrofauna samples collected were placed in McCartney bottles containing 70% ethanol and taken to the Agronomy Division of the Coconut Research Institute, Sri Lanka for enumeration and taxonomic identification. Biological assessment included macrofauna populations, numbers or abundance, diversity at genus and species level richness.

2.7 Monolith Sampling Method

At each of the benchmark sites (Walpita and Makandura), survey of soil biota (macrofauna) was done in sampling points located using a grid system, but according to the standard TSBF method using randomly dug monoliths of size 25 x 25 x 30 cm. Sampling was done depth wise from 0-30 cm and surface layer and then brought to the sampling base for sorting.

The various groups representing the soil macrofauna were hand-sorted from 25 x 25 cm square soil monoliths, divided into several layers of 15 cm down to a total depth of 30 cm. This method has been employed worldwide by a large number of researchers of the Macrofauna Network (Lavelle, 1997).

2.8 Determination of Soil Moisture Factor (MF)

Moisture Factor was determined by oven dry method. Fresh soil was weighted and it was oven dried under 80 °C for 8 hours. Then dried sample was weighted.

$$\text{Moisture Ratio (MR)} = \frac{(W_2 - W_3)}{(W_3 - W_1)}$$

W_1 – Empty can weight

W_2 - Fresh soil with empty can weight

W_3 – Dry soil with empty can weight

$$\text{Moisture Factor} = 1 + \frac{(W_2 - W_3)}{(W_3 - W_1)}$$

2.9 Enumeration of Microorganisms

Different microbial populations were determined by dilute plate technique and spread plate. 10 g of soil samples were used to prepare the 10-fold dilution series up to 10^{-7}dilution level. Selective growth media and selective dilution levels were used for the cultivation of fungi and bacteria. To cultivate fungi 10^{-2} Dilution level and Potato Dextrose Agar (PDA) was used and 10^{-5} dilution level and Nutrient Agar (NA) was used for bacteria cultivate. After inoculated plates were incubated for about a week in an incubator colonies were counted.

$$\text{CFU} = \frac{n \times c}{v.m/MF}$$

n – Number of colonies

c – for fungi 10^2 and bacteria 10^5

v – Pour volume (ml)

m – Soil weight

MF – moisture factor

2.10 Determination of Soil Microbial Biomass Carbon Content

This was determined according to the Chloroform Fumigation Incubation Technique. 25 gram of fresh soil was measured in a beaker and it was exposed to chloroform vapor for a period of 24 hours. Then the chloroform treated and untreated samples were placed in separate bottles. 2 ml of 0.5 M NaOH containing vial was placed in each bottle and sealed using Para film. Those bottles were kept in a dark place for a week. NaOH was titrated against 0.1 M HCl to determine the absorbed carbon dioxide (CO_2) which was released by the microorganisms from fumigated and unfumigated samples.

$$\text{Bio mass carbon} = \frac{\text{F}}{\text{K}_\text{c}}$$

F- (Volume of 0.1M HCl needed for the blank) – (Volume of 0.1 M HCl needed for the soil)

K_c – Portion of biomass C mineralized to CO_2 = 0.45 (Jenkison and Powlson, 1976)

2.11 Determination of Soil Microbial Respiration Rate

Microbial respiration rate was determined according to the carbon dioxide evolution technique. 10 g of fresh, 2 mm sieved, soil was weighed in to a jam bottle and it was moisten by using pre-determined amount of distilled water. After that 3 ml of 0.2 M NaOH containing beaker was placed in each bottle and sealed using vaslline. Those bottles were kept in a dark place for a week.

Then, 2 ml of barium chloride ($BaCl_2$) solution and few drops of phenolphthalein were added to the NaOH beaker and it was titrated against 0.1 M HCl to determine the absorbedCO_2 from fumigated and unfumigated samples which was released by the microorganisms.

$$\text{Respiration Rate} = \frac{\text{CO}_2\ \text{Weight}}{\text{Soil Weight}/_{\text{MF}} \times \text{Number of Days}}$$

2.12 Determination of Total Oxidizable Soil Organic Carbon Percentage (OC %)

Organic carbon content of soil was estimated according to the Walkley Black method (Nelson and Sommers 1982). 1 gram of 0.2 mm air dried soil sample was measured accurately in to a 500 ml Erlenmeyer flask. 10 ml of 0.1667M$K_2Cr_2O_7$solution was pipette into the flask and 20 ml of conc. H_2SO_4 was added rapidly as possible. It was mixed thoroughly and allowed reaction to complete 30 minutes. Mixture was diluted with 200 ml of distilled water and 10 ml of orthoposphoric acid (85%). Then, 1 ml of diphenylamine indicator was added and solution was titrated with ferrous ammonium sulphate until the color changes from greenish brown to a turbid blue.

$$\text{OC\%} = \frac{(\text{B} - \text{T})}{\text{B}} \times \frac{\text{M}}{1000} \times \text{V} \times \frac{3}{2} \times \frac{1}{0.75} \times \frac{12}{\text{W}} \times 100$$

M – Molarity of $K_2Cr_2O_7$ solution

B – Volume of ferrous ammonium sulphate required for blank (ml)

T - Volume of ferrous ammonium sulphate required for sample (ml)

V - Volume of $K_2Cr_2O_7$ used

W – Weight of the soil sample

0.75 – The recovery factor

M - 0.1667

2.13 Determination of Total Oxidizable Soil Organic Matter Percentage (OM %)

$$\text{OM\%} = \text{OC\%} \times 1.72$$

1.72 – Factor for the conversion of organic carbon to organic matter.

2.14 Determination of Total Soil Nitrogen Content

Total nitrogen content of soil was measured by Micro Kjeldhal method (Jackson, 1973). 0.5 g of finely powdered soil was weighted accurately into a digestion tube and it was moistened by using two drops of distilled water. 1 g of Na_2SO_4 kjeldahal tablets and 3 ml of conc. H_2SO_4 were added. Digestion was undertaken for 5 hours. 10 ml of distilled water was added and dissolved as much of the residue as possible using a whirling mixture and it was diluted up to 75 ml. It was kept overnight and reading was taken.

2.15 Determination of Carbon Nitrogen Ratio

$$\text{C , N } Ratio = \frac{\text{Total C}}{\text{Total N}}$$

2.16 Total SurfaceLitter Content

25 x 25 cm^2square soil monolithswas kept in the selected area and within that surface layer litter was taken. The weight was measured using analytical balance. Surface liter content was calculated using the following equation (De Moraes *et al.*, 2007).

$$\text{Total Surface Litter Content} = \frac{\text{Total litter mass (kg)}}{\text{Litter by area (m}^2\text{)}}$$

2.17 Total Root Biomass Content

Soil was sampled in a volume of 25 x 25 x 30cm^3.Plant roots were collected by hand and those roots were washed and sun dried for 48 hours. After that, sample was oven dried under 65°C for 48 hours (Pregitzer *et al.*, 2008).

$$\text{Total Root Biomass} = \frac{\text{Total Root mass (kg)}}{\text{Root by area (m}^2\text{)}}$$

2.18 Data Analysis

The statistical difference between the treatments in the study was conducted using an Analysis of Variance (ANOVA) with computer software, SAS 9.1 (Faraway, 2002). Mean separation was undertaken by Duncan Multiple Range Test.

III. RESULTS AND DISCUSSION

3.1 Moisture Factor (MF)

Figures 1 and 2 illustrate the changes observed in the moisture factor of soil in Makandura and Walpita Estates with different cropping systems. Water contained in soil is called soil moisture. Soil water is the major component of the soil in relation to plant growth and it increase the soil metabolic rates (Yuste, 2007).The analysis showed that there was statistically significant difference ($p<0.05$) between crop type and this parameter. In both estates banana + coconut intercropping systems represent the highest MF and bare land (BL) represent the lowest one. Because of the high water retention capacity and accumulation of organic matter content in banana+coconut lands; and shade under bare land was reduced than coconut multiple cropping systems therefore evaporative demand is very high and it is not allows a better retention of moisture in soil for a longer period.

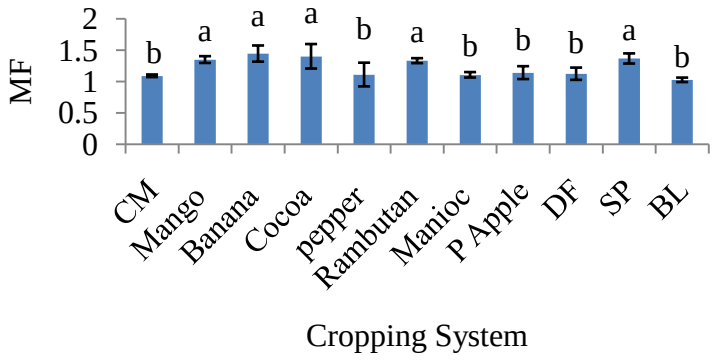

FIGURE 1 MOISTURE FACTOR (MF) MARKANDURA RESEARCH CENTER

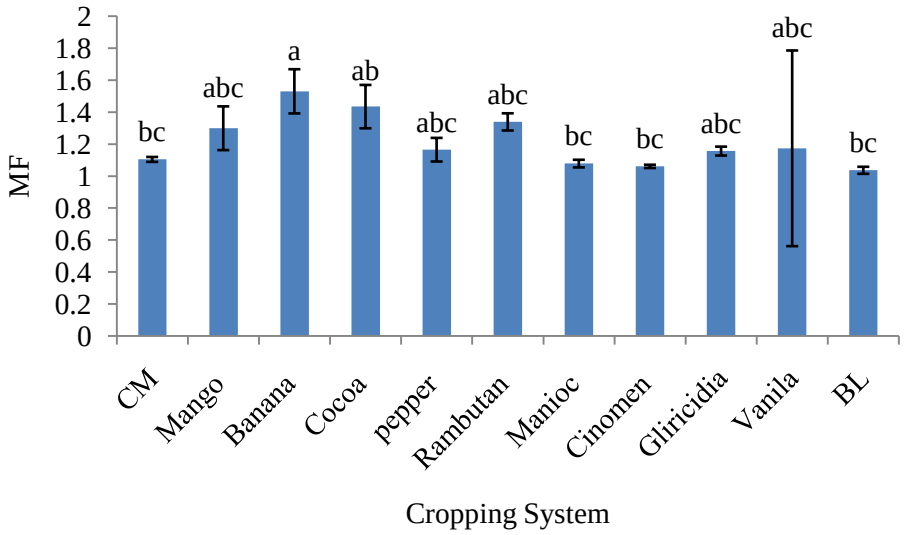

FIGURE 2 MOISTURE FACTOR (MF) WALPITA RESEARCH CENTER

3.2 Total Surface Litter and Root Biomass Content

Figures 3 and 4 illustrate the changes observed in the total litter content of soil in Markandura research center with different cropping systems. The analysis showed that there was statistically significant difference ($p<0.05$) between crop type and this parameter.

Crop density was high in multiple cropping systems than coconut monoculture and bare land. Therefore multiple cropping systems result higher amount of leaf fall and root biomass content. But in pine apple + coconut, dragon fruit+ coconut and vanilla + coconut systems' leaf fall rate was low. Further, above ground was totally cleaned to prevent from diseases. Therefore those multiple cropping systems result the low values. Thick leaf layer under cocoa+ coconut intercropping systems in both zones represent the highest value of both surface and root biomass.

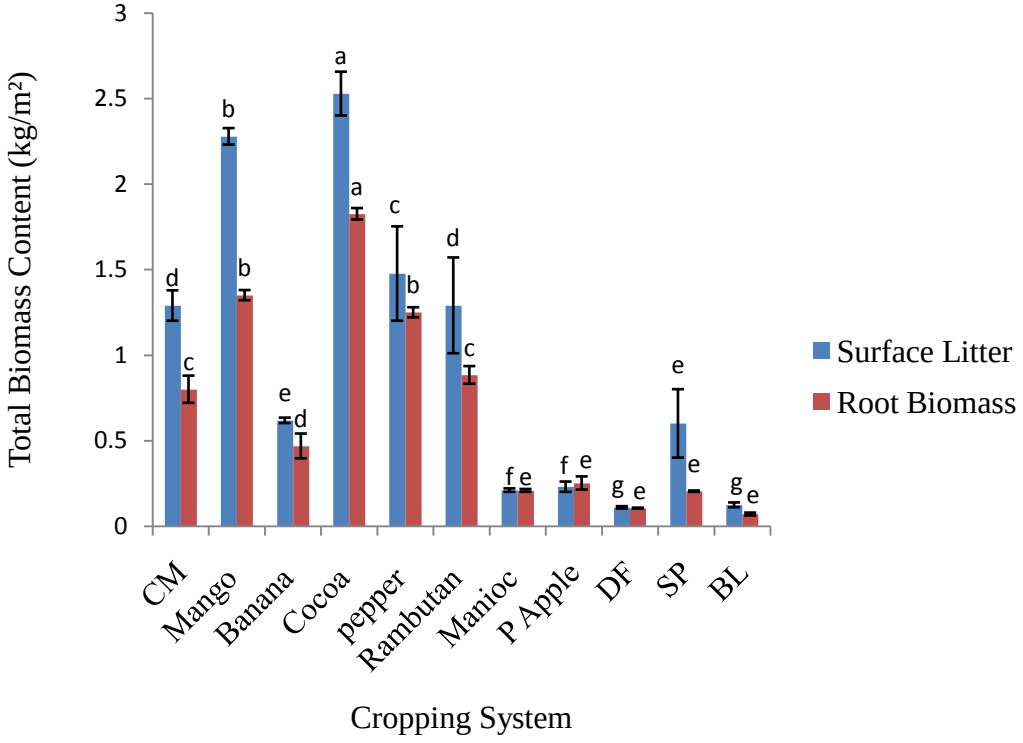

FIGURE 3 TOTAL LITTER CONTENT OF MARKANDURA RESEARCH CENTER

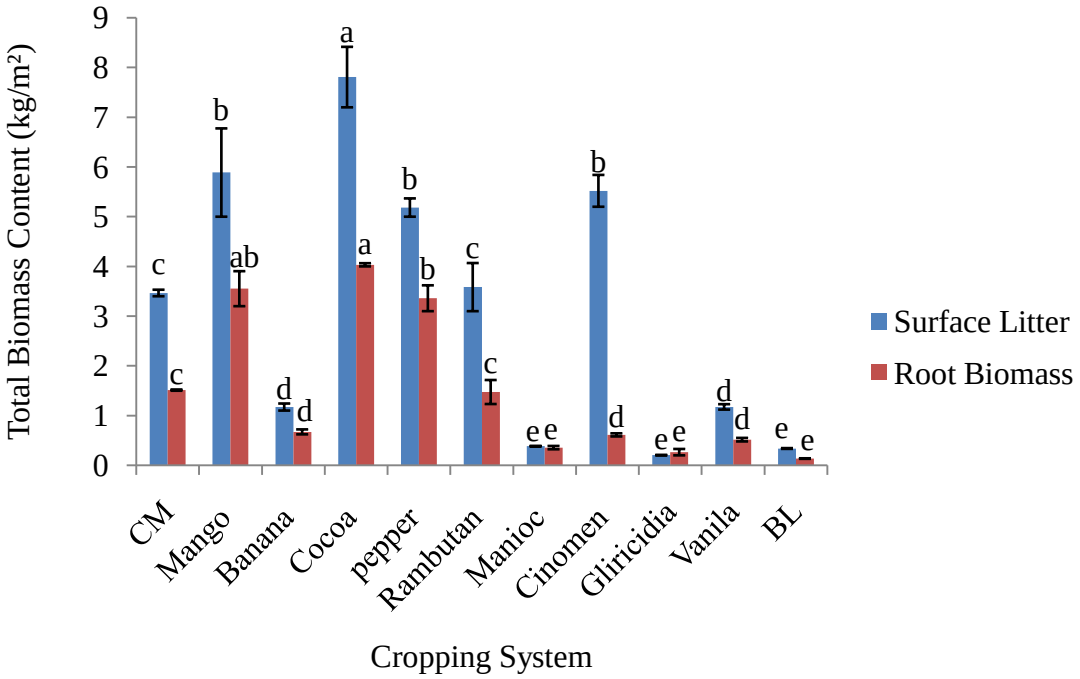

FIGURE 4 TOTAL LITTER CONTENT OF WALPITA RESEARCH CENTER

3.3 Soil Organic Matter (SOM)

Figures 5and 6 illustrate the changes observed in the organic carbon percentage of soil in selected research centers with different cropping systems. The analysis showed that there was statistically significant difference ($p<0.05$) between crop type and this parameter. SOM is a critical component of soil-plant ecosystem and it changes with land use or agricultural management practices (Ghani *et al.*, 2003) and this is the foundation of the productive soil. It promotes the healthy crops, supplies resources for microbes and other soil organisms, and regulates the supply of water, air and nutrients to plants. Cocoa + coconut intercropping system represents the highest organic matter percentage, most probable reason might be cocoa has high ground litter content and bare land represents the lowest one. Soils with organic matter levels above 3.4% are not considered to be vulnerable. SOM can deliver over half of the nitrogen and a quarter of the phosphorous require, thus strongly influencing fertilizer requirements.

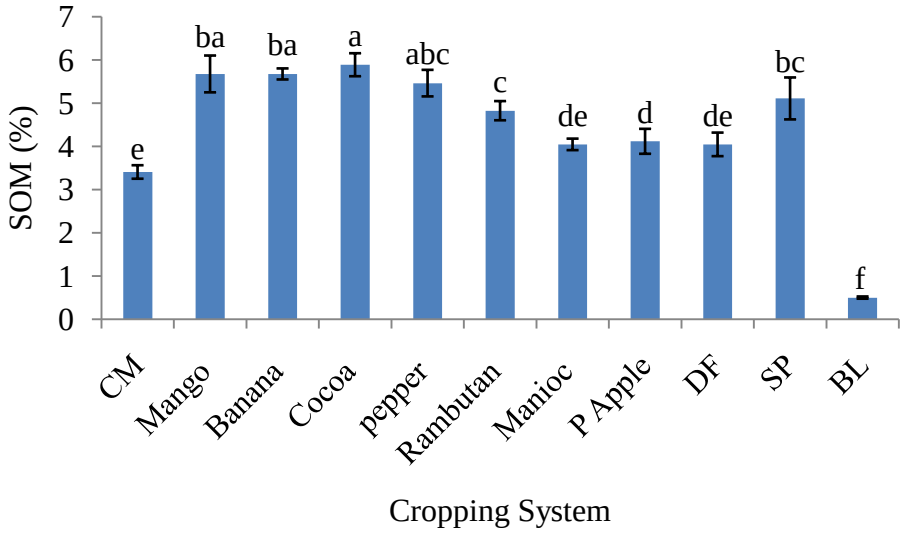

FIGURE 5 SOIL ORGANIC MATTER PERCENTAGE OF MARKANDURA RESEARCH CENTER

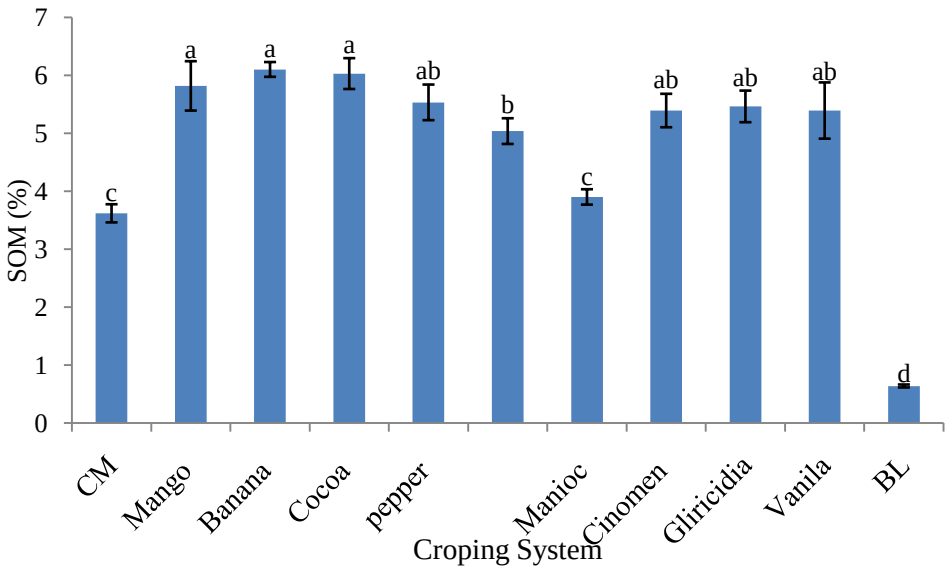

FIGURE 6 SOIL ORGANIC MATTER PERCENTAGE OF WALPITA RESEARCH CENTER

3.4 Soil Organic Carbon (SOC)

Figures 7 and 8 illustrate the changes observed in the organic carbon percentage of soil with different multiple cropping systems. Soil carbon is part of the soil organic matter which is composed of decaying plant and animal matter. The analysis showed that there was statistically significant difference ($p<0.05$) between crop type and organic carbon percentage. SOC is one of the most important constituents of the soil due to its capacity to affect plant growth as both a source of energy and a trigger for nutrient availability through mineralization and this is the main source of energy and nutrients for soil microorganisms. Humus participates in aggregate stability, and nutrient and water holding capacity.SOC structure making soil resistant to erosion, but porous enough to allow air, water and plant roots to move through the soil. An increase in SOM, and therefore SOC, leads to greater biological diversity in the soil (Edwards *et al*., 1999).

The highest SOC percentage was observed in cocoa + coconut multiple cropping systems in both zones. Because of the SOM content in these systems is high. Systems that increase SOC are also more productive, more profitable and more sustainable. Bare land represents the lowest SOC percentage. The probable reason might be soil erosion, compaction and low SOM content. A direct effect of poor SOC is reduced microbial biomass, activity, and nutrient mineralization due to a shortage of energy sources. In non-calcareous soils, aggregate stability, infiltration, drainage, and airflow are reduced. Scarce SOC results in less diversity in soil biota with a risk of the food chain equilibrium being disrupted, which can cause disturbance in the soil environment (Chan, 2008).

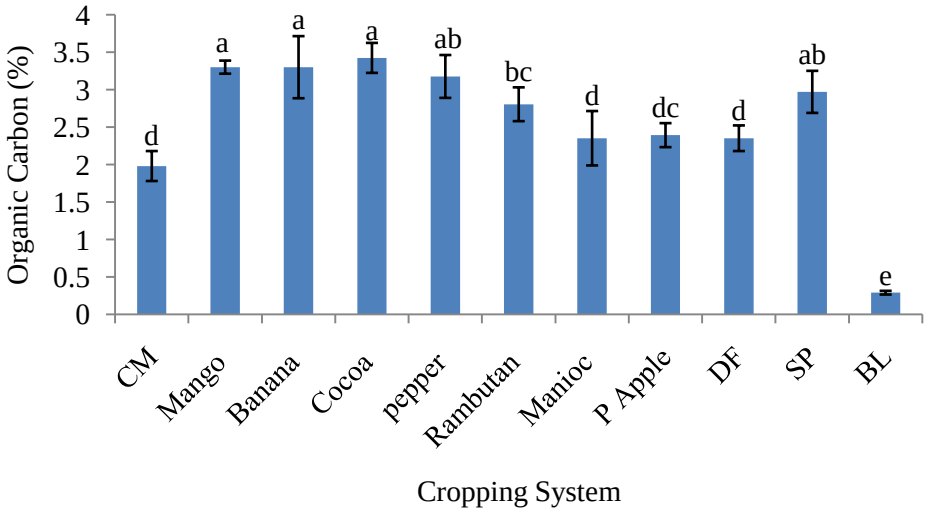

FIGURE 7 ORGANIC CARBON PERCENTAGE OF MARKANDURA RESEARCH CENTER

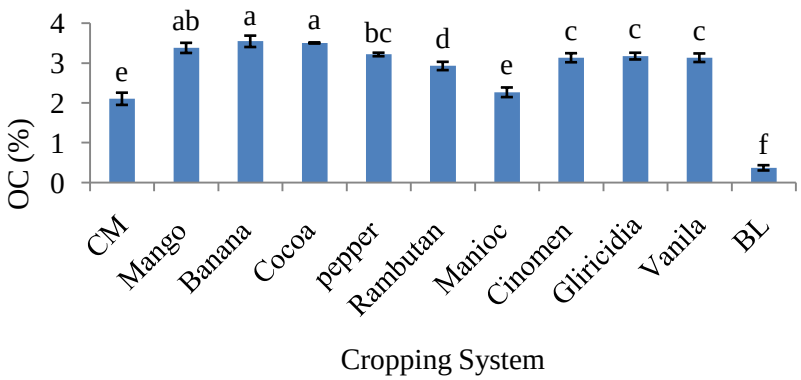

FIGURE 8 ORGANIC CARBON PERCENTAGE OF WALPITA RESEARCH CENTER

3.5 Soil Microbial Biomass Carbon(C)

Figures 9 and 10 illustrate the changes observed in the microbial biomass carbon of soil in Markandura and Walpita research centers with different cropping systems. Soil microbial biomass is the main driving force in the decomposition of organic matter and is frequently used as an early indicator of changes in soil properties resulting from soil management and environment stresses in agricultural ecosystems. The analysis showed that there was statistically significant difference ($p<0.05$) for this parameter. Both research centers' cocoa + coconut intercropping systems were recorded highest biomass carbon value due to the high decomposition rate of SOM. Walpita and Markandura bare lands represent the lowest value because of less microbial activity.

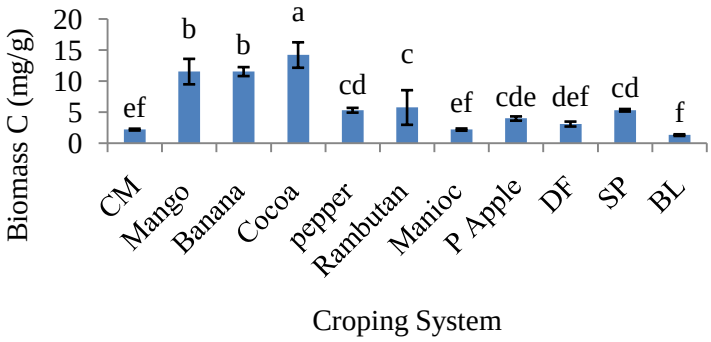

FIGURE 9 MICROBIAL BIOMASS CARBON MARKANDURA RESEARCH CENTER

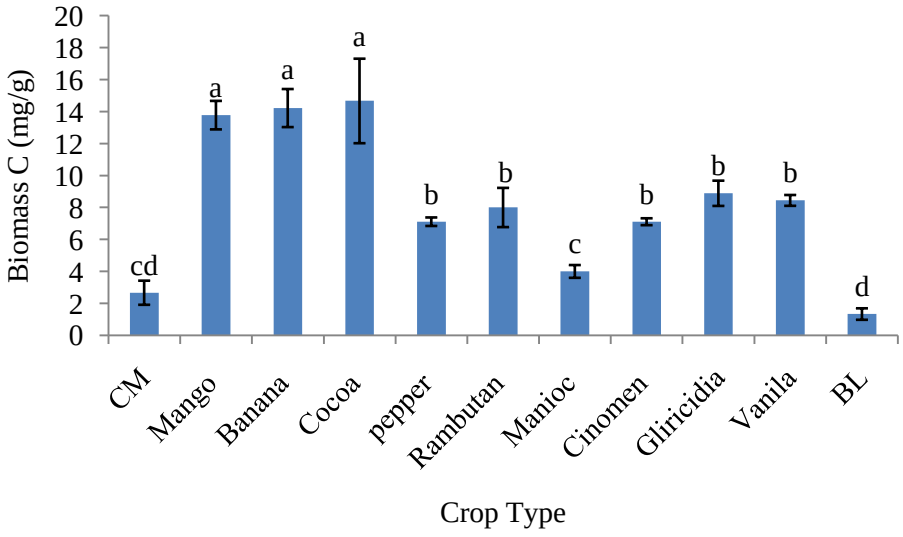

FIGURE 10 MICROBIAL BIOMASS CARBON WALPITA RESEARCH CENTER

3.6 Total Nitrogen (TN) Content

Figures 11and 12 illustrate the changes observed in the total nitrogen content of soil in intermediate and wet zones with different cropping systems. The analysis showed that there was statistically significant difference ($p<0.05$) between crop type and this parameter. Nitrogen in the soil is the most important element for plant development. It is a major part of chlorophyll and the green color of plants. TN can be enriched soil (Paustian et al., 2000; Follett, 2001).

Markandura dragon fruit + coconut intercropping system represent the highest TN content and Walpita it was banana+ coconut, it because of the commercial fertilizers. Nitrogen fixing species can increase soil TN content (Lindemann et al., 2003). Therefore gliricidia + coconut represent the 2^{nd} highest value in Walpita estate.

Markandura lowest TN value was observed in bare land. Nitrogen is lost from the soil system in several ways such as; leaching, denitrification, volatilization, crop removal, soil erosion and runoff in here most probable reason might be soil erosion and runoff. Cinnamon was recorded the lowest value in wet zone, most probable reason might be improper management practices.

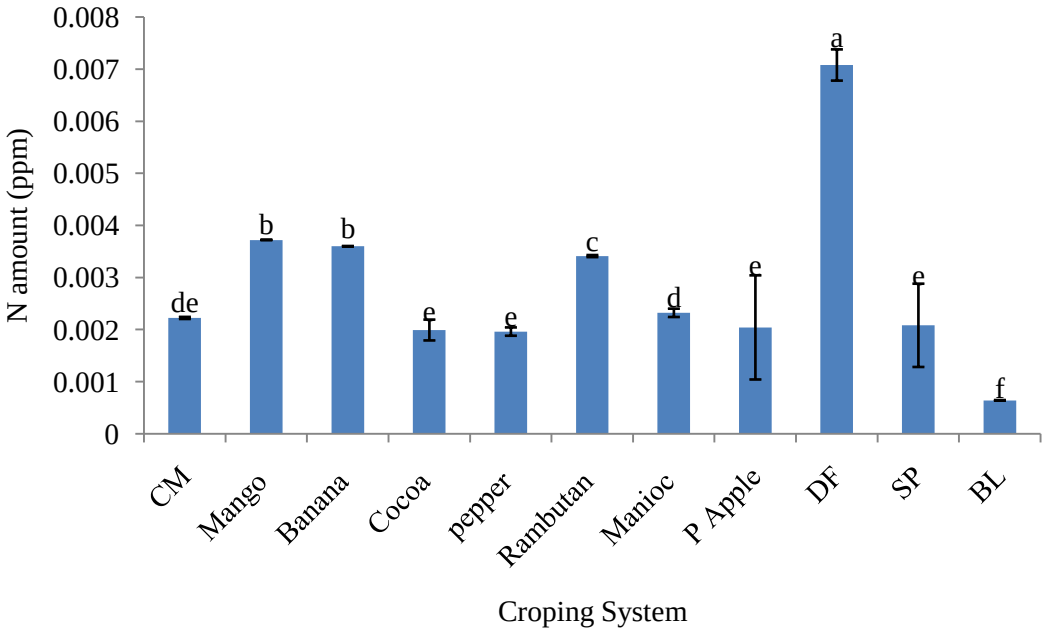

FIGURE 11TOTAL NITROGEN CONTENT OF MARKANDURA RESEARCH CENTER SOIL

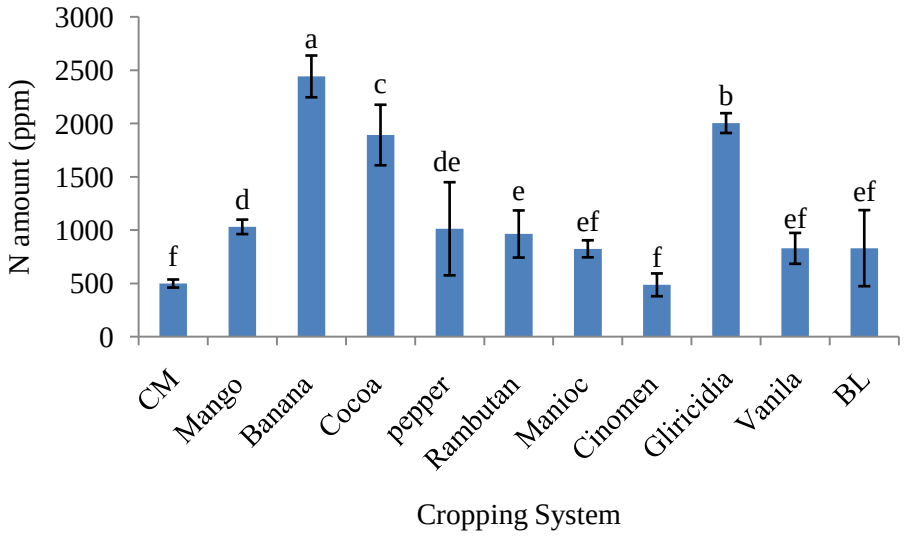

FIGURE 12 TOTAL NITROGEN CONTENT OF WALPITA RESEARCH CENTER SOIL

3.7 Carbon Nitrogen Ratio (C: N)

Figures 13 and 14 illustrate the changes observed in the C: N of soil in Markandura and Walpita research centers with different cropping systems. The analysis showed that there was statistically significant difference ($p<0.05$) between crop type and this parameter. Since the C:N ratio of everything in and on the soil can have a significant effect on crop residue decomposition, particularly residue cover on the soil and crop nutrient cycling (predominantly nitrogen), it is important to understand these ratios when planning crop rotations and the use of cover crops in agricultural systems (Brandy,2002).

Markandura bare land (42) and Walpita cinnamon + coconut intercropping system (64) represent the highest C: N ratios. Most probable reason for this might be low nitrogen content in the soil. The lowest ratio of Markandura was recorded in dragon fruit intercropping system (16) and Walpita it was banana (15). This because of the commercial fertilizers which contain high level of nitrogen. Nitrogen fixing glliricida (15.8) was represented the 2^{nd} lowest ratio of Walpita estate. Researchers report optimum values C: N ratio from 20 to 31. A majority of investigators believe that for C: N ratios above 30 there will be little loss of nitrogen (Brady *et al*., 2002).

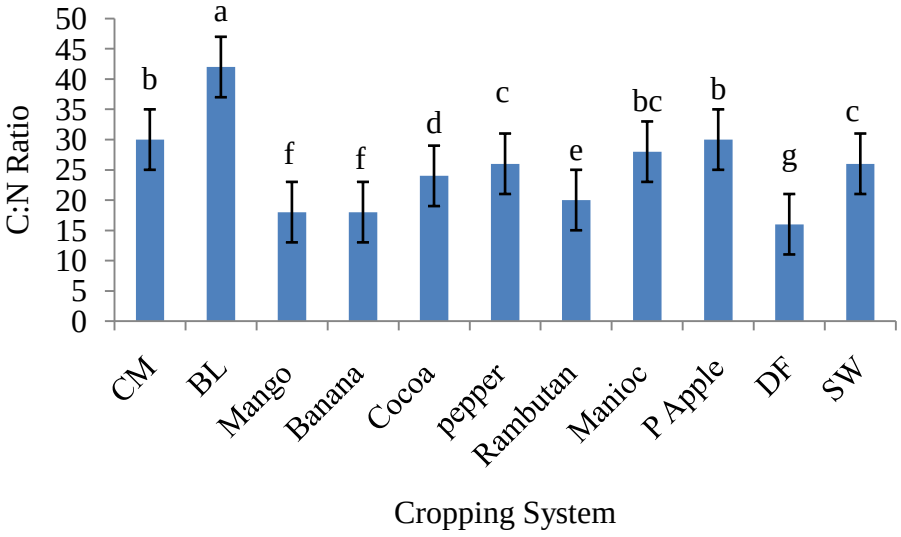

FIGURE 13 C: N OF MARKANDURA RESEARCH CENTER SOIL

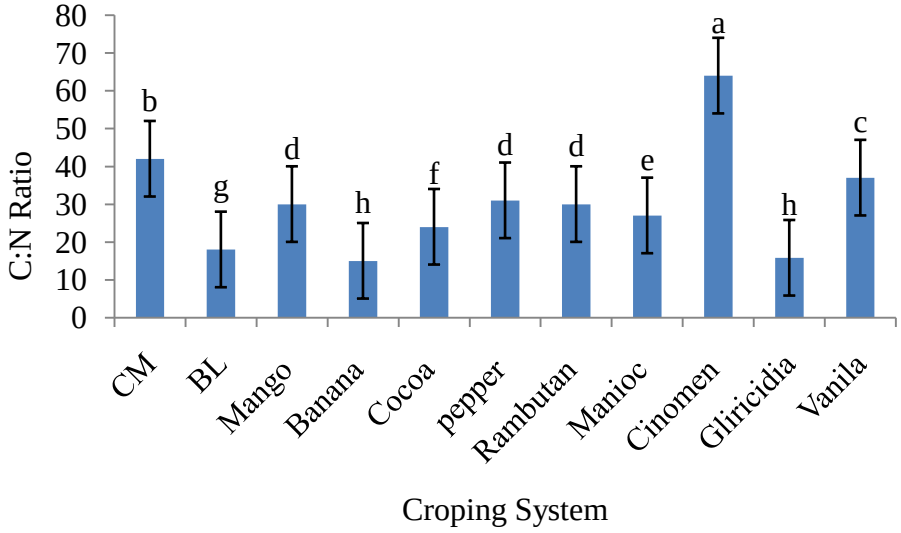

FIGURE 14 C: N TOTAL NITROGEN CONTENT OF WALPITA RESEARCH CENTER SOIL

3.8 Microbial Respiration Rate

Figures 15 and 16 illustrate the changes observed in the respiration rate of soil microbes in intermediate and wet zones with different cropping systems. The analysis showed that there was statistically significant difference ($p<0.05$) for this parameter. Soil respiration reflects the capacity of soil to support soil life including crops, soil animals, and microorganisms. It describes the level of microbial activity, soil organic matter (SOM) content and its decomposition. In the laboratory, soil respiration can be used to estimate soil microbial biomass and make some inference about nutrient cycling in the soil. Soil respiration also provides an indication of the soil's ability to sustain plant growth. Excessive respiration and SOM decomposition usually occurs after tillage due to destruction of soil aggregates that previously protected SOM and increased soil aeration. Depleted SOM, reduced soil aggregation, and limited nutrient availability for plants and microorganisms can result in reduced crop production in the absence of additional inputs.

Both Markandura and Walpita cocoa intercropping systems represent the highest respiration rate and bare land represents the lowest one reason may be due to multiple cropping lands having high SOM content than monoculture and bare land. Microbial respiration rate is higher under active trees than bare lands (Yuste, 2007).

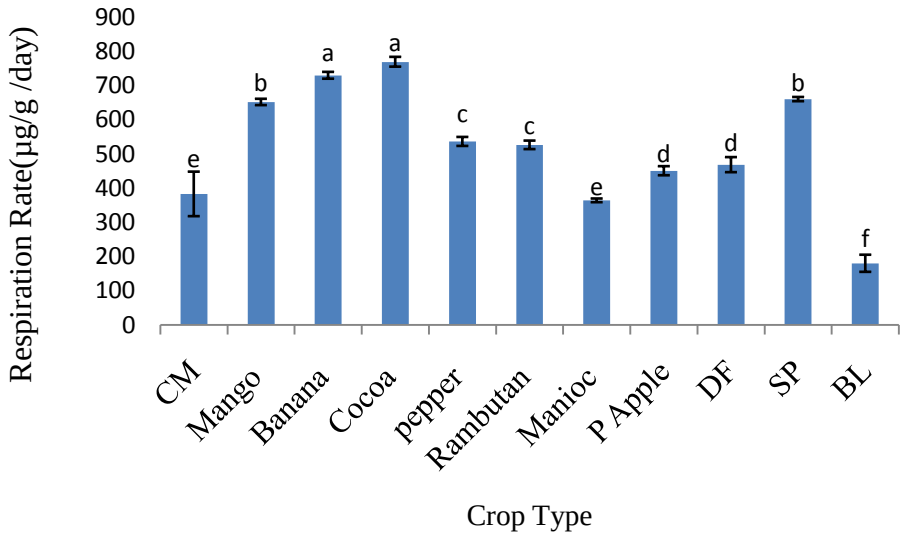

FIGURE 15 MICROBIAL RESPIRATION RATESMARKANDURA RESEARCH CENTER

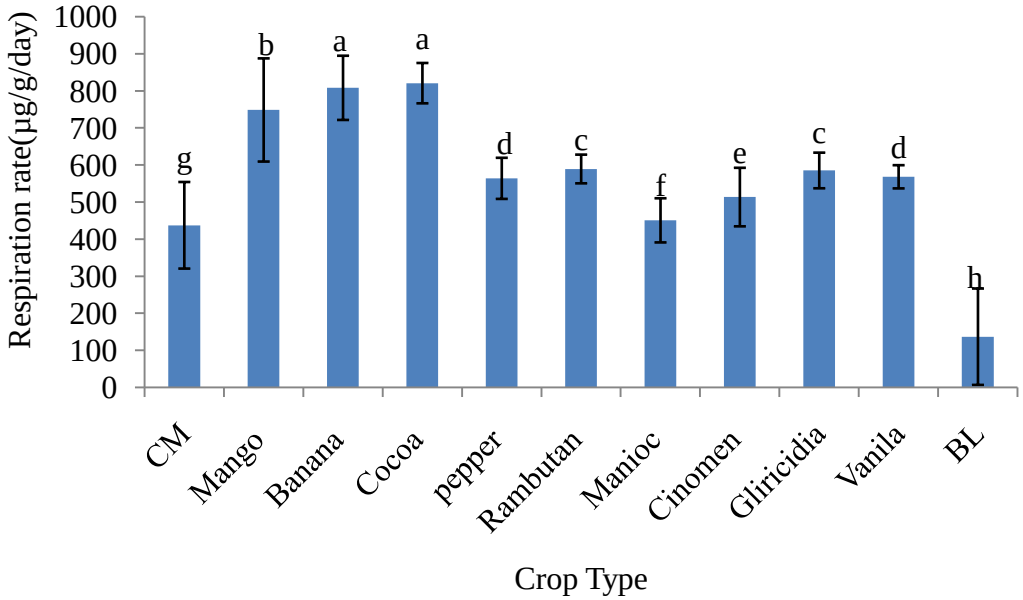

FIGURE 16 MICROBIAL RESPIRATION RATES WALPITA RESEARCH CENTER

3.9 Colony Forming Units (CFU)

Figures 17 and 18 illustrate the Colony forming units (CFU) of fungi in Makandura and Walpita research centers with different cropping systems. The analysis showed that there was statistically significant difference ($p<0.05$) between crop type and CFU of fugi. Preferred range for total CFU/plate is between 30 to 300 colonies/plate for both fungi and bacteria (Raj, 2010). Whole plate values were within that range

Fungal population in relation to soil properties may provide useful information on soil fungal diversity management of the areas (Pongsatorn, 2010). Soil fungal population and diversity are higher in the evergreen forests (Wongseenin, 1971) which have good quality soil. Cocoa intercropping system showed the highest fungi CFU value in both zones because of cocoa has high litter content, OM content, SOC percentage and respiration rate. On the other hand, available food content and favorable environmental conditions for soil microorganisms were supplied by these systems.

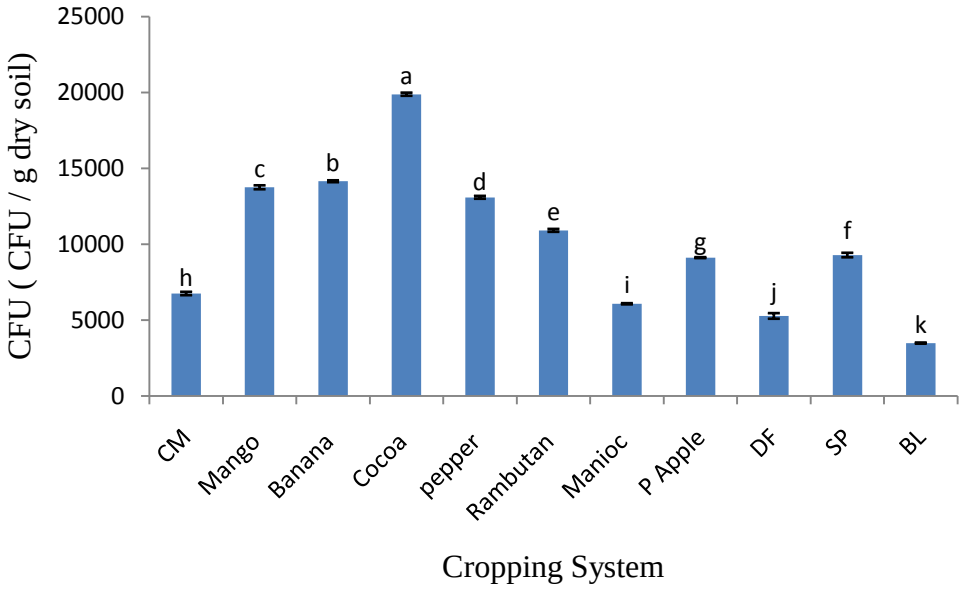

FIGURE 17 COLONY FORMING UNITS (CFU) OF FUNGI IN MAKANDURA RESEARCH CENTER

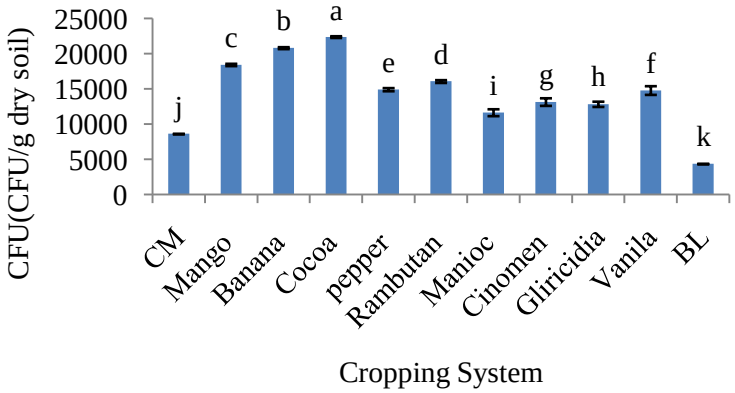

FIGURE 18 COLONY FORMING UNITS (CFU) OF FUNGI IN WALPITA RESEARCH CENTER

Figures 19 and 20 illustrate the Colony forming units (CFU) of bacteria in Makandura and Walpita research center with different cropping systems. The increased bacterial CFU is enhanced the soil mixing and release of nutrients and organic matter (Winding, 1994) therefore high bacterial CFU represents the fertile soil. However the CFU of bacteria in Makandura estate and Walpita estate at 30 cm depth with the different land use systems the analysis showed that there was not statistically significant interaction effect between the cropping system ($p>0.05$) for CFU of bacteria.

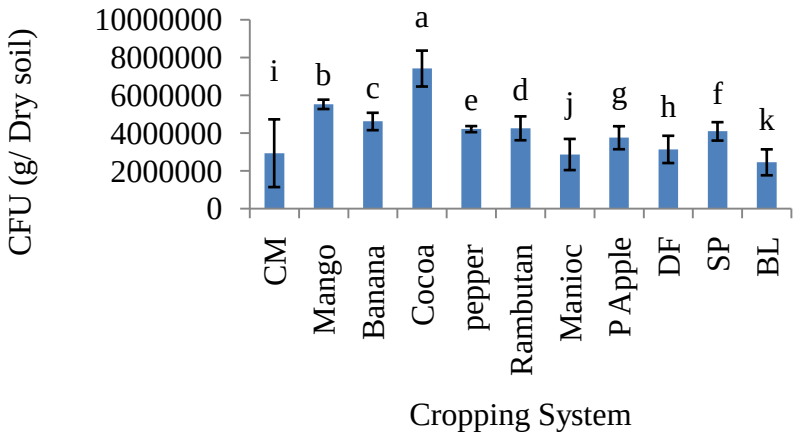

FIGURE 19 COLONY FORMING UNITS (CFU) OF BACTERIA IN MAKANDURA RESEARCH CENTER

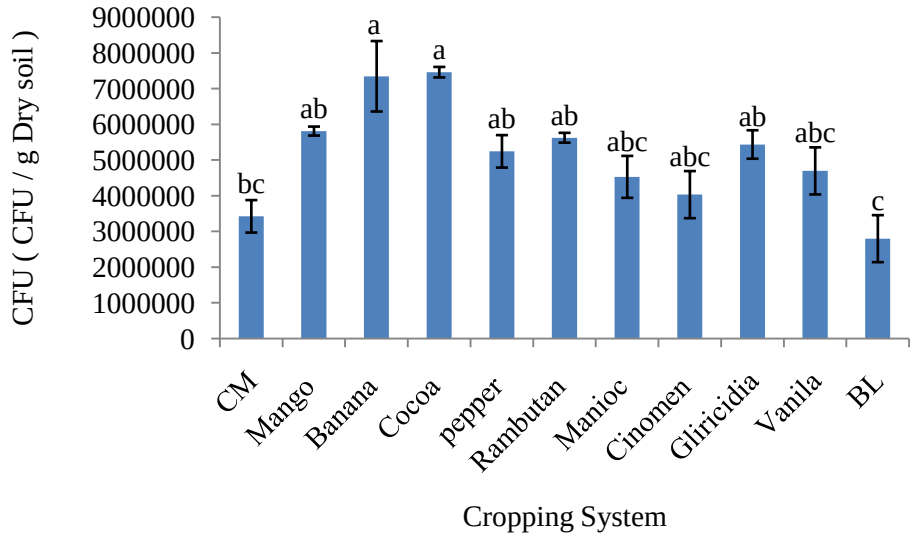

FIGURE 20 COLONY FORMING UNITS (CFU) OF BACTERIA IN WALPITA RESEARCH CENTER

3.10 Diversity and Abundance of Soil Macrofauna

Figures 21, 22, illustrate the abundance of soil macrofauna and 23 and 24 illustrate the diversity of soil macrofauna in Makandura and walpita research centers with different cropping systems. Presence of soil fauna is increased supply of nutrients to plants and enhanced the soil fertility (Alphei et al., 1996).

Analysis showed that there was a statistically significant difference ($p<0.05$) between crop type and the diversity and abundance of soil organisms. In Makandura cocoa + coconut and Walpita vanilla + coconut cropping systems showed the highest abundance value and both zones cocoa+ coconut intercropping system showed the highest diversity value of soil macrofauna.

Cocoa+ coconut intercropping system supplied most favorable ecosystem conditions to the organisms. Therefore it result the high diversity and abundance .There was a grass layer with Walpita vanilla inter cropping system, because of that it represented the high abundance of organisms. Snail density was high in that cropping system.

The lowest diversity and abundance values were recorded in bare lands of both Markandura and Walpita bare lands respectively. That could be the infertile soil in that area.

24 different types of soil organisms were identified and all of them were present in Walpita cocoa + coconut intercropping system.

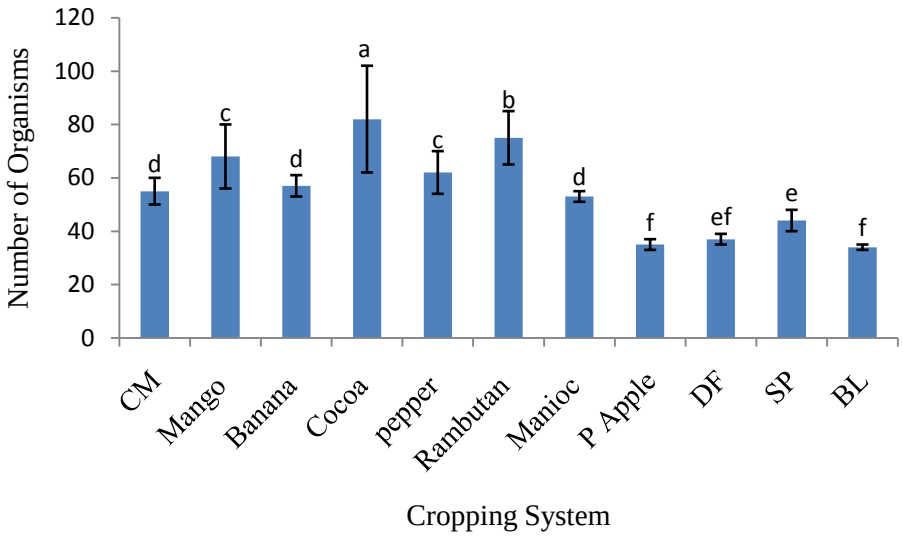

FIGURE 21 ABUNDANCE OF SOIL MACROFAUNA AT MARKANDURA RESEARCH CENTER

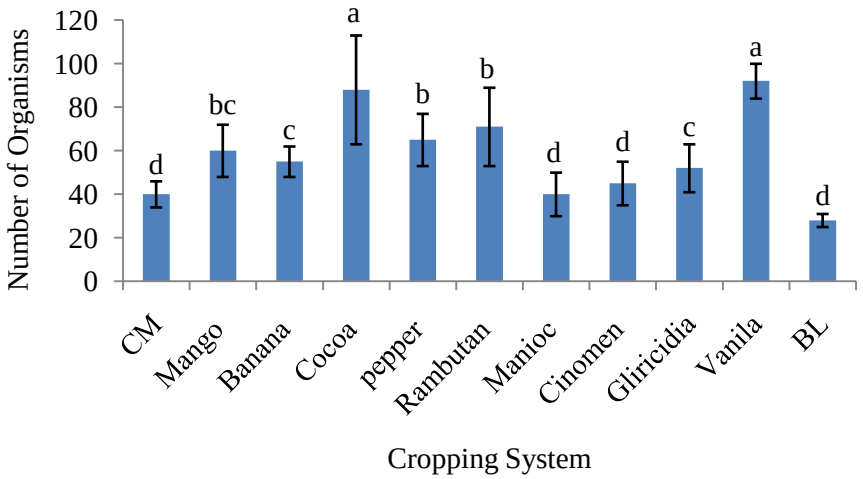

FIGURE 22 ABUNDANCE OF SOIL MACROFAUNA AT WALPITA RESEARCH CENTER

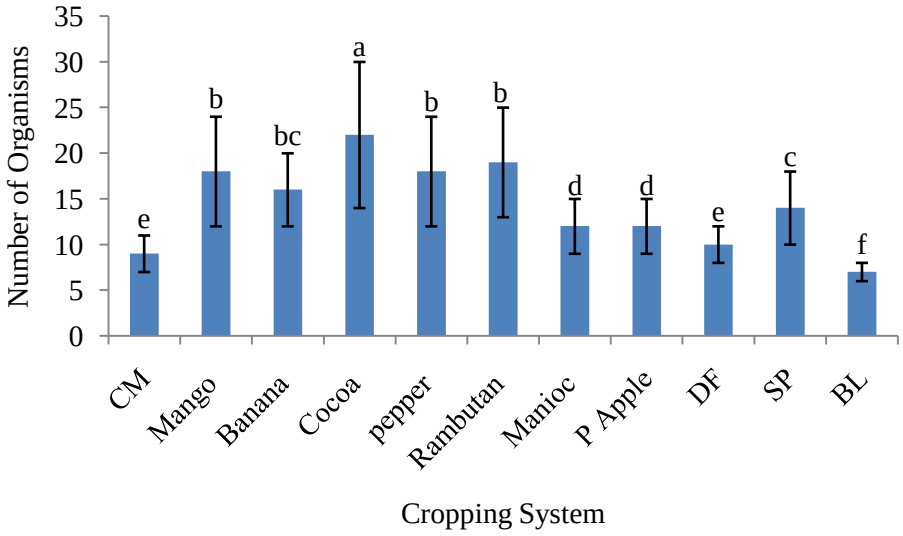

FIGURE 23 DIVERSITY OF SOIL MACROFAUNA AT MARKANDURA RESEARCH CENTER

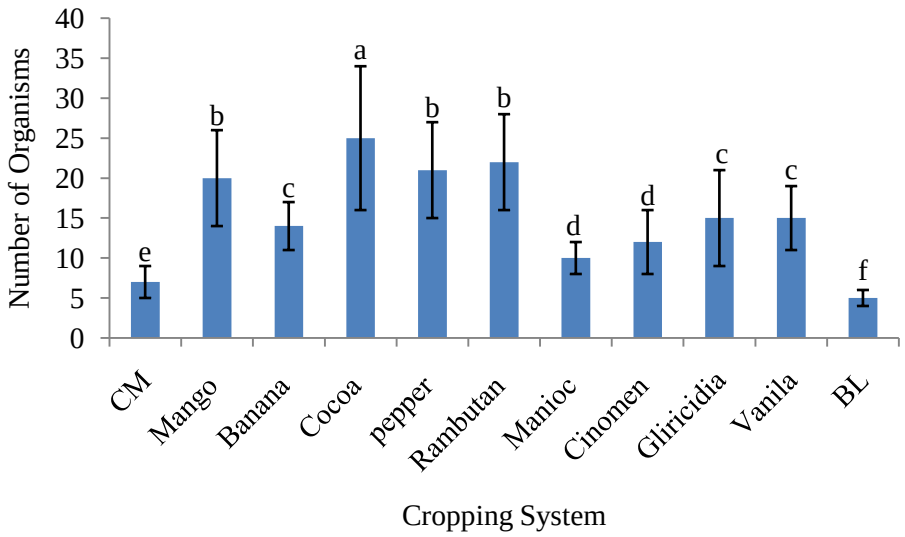

FIGURE 24 DIVERSITY OF SOIL MACROFAUNAAT WALPITA RESEARCH CENTER

IV. CONCLUSIONS

Cropping systems have significant impact on soil organism diversity and abundance due to variability of soil quality. Soil organisms diversity, abundance and functional role was > multiple cropping system > coconut monoculture land and lowest at bare land. Multiple cropping system soil was more productive in term of soil organisms' density and diversity due to high bio mass carbon, SOC, SOM, TN, C: N ratio, litter, and root bio mass content. So multiple cropping systems having the rich ecosystems than coconut monocropping system and bare land. According to this study cocoa + coconut multiple cropping systems represent the richest eco system because it has thick cocoa leaf layer under the crops. Those data can be used as a reliable basic bio indicator for payments for ecosystem services (PES).

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