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Contribution of soil macro-fauna diversity and abundance to soil fertility enhancement in cocoa-based (*Theobroma cacao*) agroforestry systems in the Littoral Region of Cameroon: An appraisal of cocoa farmers' local knowledge

Azembouh Roshinus Tsufac^{1*}, Bernard Palmer Kfuban Yerima,² Roger Kogge Enang² and Nyong Princely Awazi¹

¹Department of Forestry, Faculty of Agronomy and Agricultural Sciences, University of Dschang, P. O. Box 222, Dschang, Cameroon.

²Department of Soil Sciences, Faculty of Agronomy and Agricultural Sciences, University of Dschang, P. O. Box 222, Dschang, Cameroon.

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Soil macro-fauna diversity and abundance greatly influence soil fertility. However, little has been done to confirm this hypothesis in cocoa-based agroforestry systems. It was in this light that this research work was undertaken in order to fill the knowledge gap. Through the use of a mixed research method for data collection and appropriate data analysis procedures, findings showed that diverse soil macro-fauna were identified by cocoa farmers in cocoa-based agroforestry systems with the main being earth worms (100%), ants (100%), termites (70%), millipedes (50%), centipedes (50%), and snails (60%). Most cocoa farmers perceived that soil macro-fauna diversity in cocoa-based agroforestry systems was high (58.3%) and very high (17%) respectively. Earth worms, ants, millipedes, centipedes, spiders, harvestmen and scorpions were perceived by most cocoa farmers (44%, 38.3%, 43.3%, 41.3%, 55.6%, 53.3% and 48% respectively) to have a high level of abundance in cocoa-based agroforestry systems. A statistically significant direct non-causal and causal relationship ($p < 0.05$) existed between soil macro-fauna diversity and soil fertility enhancement in cocoa-based agroforestry systems, implying that the higher the diversity, the higher the level of soil fertility and the lower the diversity, the lower the level of soil fertility enhancement. Concerning soil macro-fauna abundance, a statistically significant direct non-causal and causal relationship ($p < 0.05$) existed between soil macro-fauna abundance (i.e. for earth worms, ants, termites, beetles, crickets, woodlice, snails and slugs) and soil fertility enhancement in cocoa-based agroforestry systems, implying that the greater the abundance of these soil macro-fauna, the greater the fertility of the soil. It is recommended that measures be taken to ensure soil macro-fauna diversity and abundance in order to enhance the fertility of the soil in cocoa-based agroforestry systems.

Key words: Cocoa, cocoa farmers, agroforestry, cocoa-based agroforestry systems, soil macro-fauna, macro-fauna, soil fertility, Cameroon.

INTRODUCTION

Agroforestry systems are climate-smart, environmentally friendly, agro-ecological and sustainable farming systems

wherein trees/shrubs are integrated in crop and pasturelands in order to obtain socio-economic and environmental/ecosystem benefits (Jose, 2012; Amare et al., 2018; Leakey, 2019; Quandt et al., 2018; Awazi et al., 2020; Awazi and Avana, 2020). Agroforestry systems are broadly classified into three major groups, that is, agrosilvicultural, silvopastoral and agrosilvopastoral (Awazi et al., 2019). These three main categories are characterized by practices like home gardens, trees on croplands, home gardens with livestock, life fences, windbreaks, coffee-based agroforestry, cocoa-based agroforestry, rubber-based agroforestry, trees on grazing lands, aquaforestry, entomoforestry and many others (Tsufac et al., 2019; Awazi et al., 2020). Although the term “systems” is often used interchangeably with the term “practices”, systems generally refer to the three broad categories, while practices refer to the sub-categories.

Agroforestry systems provide different ecological services one of which is soil fertility enhancement (Nair, 2011; Asaah et al., 2011; Noordwijk et al., 2019; Tsufac et al., 2019). This is done through nutrient cycling between the above-ground and below-ground components of the system (Cardinael et al., 2020). The above-ground components are trees/shrubs as well as crops while the below-ground components are tree roots and soil organisms. The close interaction of these two components contributes towards soil fertility enhancement in the agroforestry system (Jose, 2009, 2012; Leakey, 2017; Amare et al., 2018).

In Cameroon, cocoa-based agroforestry systems constitute one of the main types of agroforestry systems (Sonwa et al., 2007; Laird et al., 2007; Jagoret et al., 2011, 2014; Tankou, 2015). It is a system where mostly smallholder farmers integrate and/or maintain trees/shrubs in cocoa farms to act as shade for the cocoa plant. Both local and exotic tree species are integrated in the system, and farmers make sure that the trees integrated have multiple uses, thus the term “multipurpose trees” in agroforestry systems (Sonwa et al., 2007). The trees act as shade, wood, building materials, biofertilizers, fodder, windbreaks, food, medicines and many other uses (Tankou, 2015).

Cocoa production in Cameroon which is dominated by smallholder farmers as mentioned earlier, is cultivated under the cocoa-based agroforestry system (Jagoret et al., 2012). It contributes enormously to the Gross Domestic Product (GDP) of the country (Nfinn, 2005; Mukete et al., 2018). However, most of the smallholder farmers engaged in the cocoa production, reap very little benefits from their hard work because the price of cocoa is dictated by middlemen who seek to make as much commission as possible from their middleman role

(Tankou, 2015; Mukete et al., 2018). This situation has made many farmers to abandon their cocoa farms and take to other alternative activities such as market gardening, food crop cultivation and even bike riding (Tankou, 2015).

With soil fertility in cocoa-based agroforestry systems declining and cocoa farmers' inability to purchase fertilizers to replenish the lost fertility, it becomes imperative to promote organic farming methods. For this to be feasible, the soil needs to be treated with care so as not to destroy soil organisms in general and soil macro-organisms in particular which are the engineers working every day to ensure that the soil remains naturally fertile. Thus, looking at the grim picture of soil infertility across cocoa-based agroforestry systems in Cameroon in general and littoral region of Cameroon in particular, this study sought to assess the contribution of soil macro-fauna diversity and abundance to soil fertility enhancement in cocoa-based agroforestry systems. More precisely, the study sought to: (1) identify soil macro-fauna in cocoa-based agroforestry systems; (2) assess the degree of soil macro-fauna diversity in cocoa-based agroforestry systems; (3) examine the level of soil macro-fauna abundance in cocoa-based agroforestry systems; and (4) assess the relationship between soil macro-fauna diversity and abundance and soil fertility in cocoa-based agroforestry systems.

MATERIALS AND METHODS

Description of the study area

The study was carried out in the administrative district of Melong, found in the Mungo division, Littoral region of Cameroon. It lies between longitude 9°17' to 10°52' E and latitude 4°22' to 6°20' N. The study area falls within the Western Highlands of Cameroon, a major agro-ecological and relief region in Cameroon. The Western Highlands covers four administrative regions in Cameroon (part of the littoral, part of the south west, and the entire west and north-west regions) and has a surface area of roughly 50,000 km². A vast majority of the population (over 80%) is engaged in agricultural activities and livestock rearing. Due to the predominance of agricultural activities, the Western Highlands of Cameroon (Mungo division in general and Melong sub-division in particular) is considered one of the major breadbaskets of Cameroon and the Central African sub-region (Tankou et al., 2017). The climate of the Melong sub-division is humid tropical and the vegetation type is degraded forest interspersed with patches of savannah grassland. The soils are mostly feralitic, volcanic, as well as andosols.

Melong administrative district was created in 1962 by Decree No. 62/17 of 26/12/1962 (Plan Communal de Developpement - PCD Melong, 2012). It covers an area of 497 km² and has a population of about 102,000 persons living in both rural and urban settings (Plan Communal de Developpement - PCD Melong, 2012). The municipality of Melong shares boundaries with the municipality of Santchou to the north; the municipality of Nguti to the north-west;

*Corresponding author. E-mail: azembouh1990@gmail.com

the municipality of Bangem to the west; the municipality of Nkongsamba to the south-west; the municipality of Baré to the south-east; the Nkam River and the municipality of Kékem to the east.

Data collection procedure

To achieve the goals of this study, secondary and primary data were collected. For primary data a plethora of sampling techniques were used.

Sampling procedure

The multi-phase sampling procedure was used as reported in previous studies undertaken by some authors in Cameroon (Awazi and Tchamba, 2018; Awazi et al., 2019, 2020). At the first phase, the study area (Mungo division in general and Melong sub-division in particular) was purposively chosen owing to the predominance of cocoa-based (*Theobroma cacao*) agroforestry systems in the area. At the second stage, focus group discussions and key informant interviews were conducted with cocoa farmers and resource persons, respectively in order to obtain relevant information on macro-fauna diversity/abundance and its role in soil fertility enhancement in cocoa-based agroforestry systems in the study area. The focus group discussants were mainly farmers who had great indigenous knowledge about the cocoa-based agroforestry system. Cocoa farmers selected to participate in focus group discussions were done with the help of agricultural/environmental extension agents who had a better mastery of the study area. The key informants who were resource persons living in the different villages in the municipality of Melong included agricultural and environmental extension agents, chiefs, quarter heads, heads of cocoa farming groups, sub-divisional delegates in the ministries of agriculture and rural development; forestry and wildlife; environment, nature protection and sustainable development. At the third phase, household surveys were conducted with farmers involved in cocoa-based agroforestry systems. This was done with the help of agricultural extension agents working on the field. The tool used to conduct the household survey was semi-structured questionnaires. The questionnaires were structured to get information on the types of soil macro-fauna in cocoa-based agroforestry systems; the degree of soil macro-fauna diversity in cocoa-based agroforestry systems; the level of soil macro-fauna abundance in cocoa-based agroforestry systems; and the relationship between soil macro-fauna diversity and abundance and soil fertility in cocoa-based agroforestry systems. The fourth and last stages involved direct field surveys on the farm plots of cocoa farmers. In these phases, both soil macro-fauna diversity/abundance and soil fertility parameters were measured. This was done through inventories of soil macro-fauna and collection of soil samples for laboratory testing.

Secondary data

To realize the objectives of this work, secondary data was collected from the following sources:

- (1) The Regional, Divisional and Sub-Divisional Delegations of Agriculture and Rural Development; Forestry and Wildlife, Environment and Nature Protection; and Economy and Regional Planning, and Municipal councils found in the Mungo division in general and Melong sub-division in particular;
- (2) Libraries in the Faculty of Agronomy and Agricultural Sciences of the University of Dschang;
- (3) Scientific publications or articles, books and book chapters both

- online and offline;
 (4) Different websites on the internet.

Secondary data enabled the verification and comparison of the contribution of soil macro-fauna to soil fertility in cocoa-based agroforestry systems in Melong administrative district to that of other areas in Cameroon, Africa and the world.

Primary data collection

Primary data was collected through household surveys, direct field surveys as well as direct field observations.

Household surveys: Household surveys were conducted with farmers practicing cocoa-based agroforestry systems in order to ascertain their perceptions pertaining to the contribution of soil macro-fauna to soil fertility improvement. Semi-structured questionnaires were administered to 300 cocoa-based agroforestry practitioners. The questionnaires were structured to capture information with respect to the types of soil macro-fauna in cocoa-based agroforestry systems; the degree of soil macro-fauna diversity in cocoa-based agroforestry systems; the level of soil macro-fauna abundance in cocoa-based agroforestry systems; and the relationship between soil macro-fauna diversity and abundance and soil fertility in cocoa-based agroforestry systems. The selection of these farmers was done with the aid of agricultural/environmental extension officials working on the field in the study area. The household survey of 300 farmers was complemented with focus group discussions, and key informant interviews in order to ascertain the truthfulness of farmers' perceptions.

Data analysis

Microsoft Excel 2007 and SPSS 17.0 software packages were used for descriptive and analytical statistical analysis. The main descriptive statistics were charts, graphs, tables as well as percentage indices, while analytical statistics included Spearman's correlation coefficient, Chi-square test statistic, and logistic regression analysis. The analytical statistics were used based on the normality of the data obtained as well as the type of variables, that is, qualitative or quantitative. Analytical statistics indicated the causal and non-causal relationship existing between soil macro-fauna diversity/abundance and soil fertility status in the cocoa-based agroforestry systems in Melong Municipality, littoral region of Cameroon.

RESULTS

Identified soil macro-fauna in cocoa-based agroforestry systems

Diverse soil macro-fauna were identified by cocoa farmers in cocoa-based agroforestry systems in the Littoral region of Cameroon (Table 1).

Table 1 shows that earth worms (100%), ants (100%), termites (70%), millipedes (50%), centipedes (50%), and snails (60%) were identified by cocoa farmers as the main soil macro-fauna in cocoa-based agroforestry systems. As per cocoa farmers' perceptions, beetles, harvestmen, scorpions and slugs were the least identified soil macro-fauna in cocoa-based agroforestry systems.

Cocoa farmers' perceptions of different soil macro-

Table 1. Soil macro-fauna in cocoa-based agroforestry systems.

Soil macro-fauna	Frequency (n)	Percentage (%)	χ^2	p-level
Earth worms	300	100		
Ants	300	100		
Termites	210	70		
Beetles	105	35		
Crickets	120	40		
Woodlice	120	40		
Millipedes	150	50	127.4*	0.000
Centipedes	150	50		
Snails	180	60		
Harvestmen	60	20		
Spiders	135	45		
Scorpions	75	25		
Slugs	90	30		
Others	15	5		

*Significant at 5% probability level.

Table 2. Soil macro-fauna diversity in cocoa-based agroforestry systems.

System	Soil macro-fauna diversity										χ^2	p-level
	Frequency (n)					Percentage						
	VH	H	Av.	L	VL	VH	H	Av.	L	VL		
Cocoa-based agroforestry system	51	175	32	22	20	17	58.3	10.7	7.3	6.7	75.8*	0.000

*Significant at 5% probability level; VH = very high; H = high; Av.= average; L = low; VL = very low.

fauna in cocoa-based agroforestry systems differed significantly ($\chi^2 = 127.4$, $p < 0.05$).

Degree of soil macro-fauna diversity in cocoa-based agroforestry systems

Cocoa farmers perceived the level of soil macro-fauna diversity in cocoa-based agroforestry systems differently (Table 2).

From Table 2, it is noticed that most cocoa farmers perceived that soil macro-fauna diversity in cocoa-based agroforestry systems was high (58.3%) and very high (17%), respectively, with few cocoa farmers (6.7%) perceiving that soil macro-fauna diversity in cocoa-based agroforestry systems was very low.

Cocoa farmers' perceptions of the level of soil macro-fauna diversity in cocoa-based agroforestry systems differed significantly ($\chi^2 = 75.8$, $p < 0.05$).

Level of soil macro-fauna abundance in cocoa-based agroforestry systems

Cocoa farmers perceived the level of soil macro-fauna abundance in cocoa-based agroforestry systems in

a diverse fashion (Table 3).

As shown in Table 3, earth worms, ants, millipedes, centipedes, spiders, harvestmen and scorpions were perceived by most cocoa farmers (44, 38.3, 43.3, 41.3, 55.6, 53.3 and 48%, respectively) to have a high level of abundance in cocoa-based agroforestry systems. Crickets, woodlice, snails and slugs were perceived by most farmers (58.3, 62.5, 53.3 and 55.6%, respectively) to have an average abundance in cocoa-based agroforestry systems. Termites and beetles were perceived by most cocoa farmers (58.6 and 48.6%, respectively) to have a low abundance in cocoa-based agroforestry systems.

As shown in Table 3, a statistically significant difference ($\chi^2 > 40$, $p < 0.05$) existed between farmers' perceptions of abundance of soil macro-fauna in cocoa-based agroforestry systems.

Influence of soil macro-fauna diversity on soil fertility in cocoa-based agroforestry systems

Spearman rank correlation and logistic regression analyses showed the existence of a direct non-causal and causal relationship between soil macro-fauna diversity and soil fertility enhancement in cocoa-based

Table 3. Soil macro-fauna abundance in cocoa-based agroforestry systems.

Soil macro-fauna	Soil macro-fauna abundance										χ^2	p-level
	Frequency (n)					Percentage (%)						
	VH	H	Av.	L	VL	VH	H	Av.	L	VL		
Earth worms	11	132	97	40	20	3.7	44	32.3	13.3	6.7	72.5*	0.000
Ants	15	115	100	35	25	5	38.3	33.3	11.7	8.3	64.8*	0.000
Termites	5	10	15	123	57	2.4	4.8	7.2	58.6	27.2	93.1*	0.000
Beetles	4	4	24	51	22	3.8	3.8	22.9	48.6	21	49.4*	0.000
Crickets	6	8	70	22	14	5	6.7	58.3	18.3	11.7	70.6*	0.000
Woodlice	5	9	75	20	11	4.2	7.5	62.5	16.7	9.2	123.7*	0.000
Millipedes	7	65	54	14	10	4.7	43.3	36	9.3	6.7	141.2*	0.000
Centipedes	9	62	58	12	9	6	41.3	38.7	8	6	59.8*	0.000
Snails	16	35	80	40	9	8.9	19.4	53.3	22.2	6	71.5*	0.000
Harvestmen	10	32	12	4	2	16.7	53.3	20	6.7	3.3	85.3*	0.000
Spiders	44	75	8	5	3	32.6	55.6	5.9	3.7	2.2	92.1*	0.000
Scorpions	23	36	9	5	2	30.7	48	12	6.7	2.7	68.9*	0.000
Slugs	4	7	50	23	6	4.4	7.8	55.6	25.6	6.7	40.3*	0.000

*Significant at 5% probability level; VL = very low; Av. = average; H = high; VH = very high.

Table 4. Role of soil macro-fauna diversity in soil fertility in cocoa-based agroforestry systems.

Soil macro-fauna diversity	Correlation coefficient (r)	p-level	Logistic regression coefficient (B)	p-level
Very high	0.97*	0.000	3.61*	0.000
High	0.88*	0.000	3.09*	0.000
Average	0.71*	0.000	1.37*	0.008
Low	0.65*	0.000	0.98*	0.015
Very low	0.58*	0.000	0.85*	0.024
Likelihood Ratio χ^2	-	-	127.48	0.000
Pseudo R^2	-	-	0.395	-
Number of observations	-	-	300	-

*Significant at 5% probability level.

agroforestry systems (Table 4).

As shown in Table 4, a statistically significant ($p < 0.05$) direct non-causal and causal relationship was found to exist between different levels of soil macro-fauna diversity (very high soil macro-fauna diversity, high soil macro-fauna diversity, average soil macro-fauna diversity, low soil macro-fauna diversity, and very low soil macro-fauna diversity) and soil fertility enhancement in cocoa-based agroforestry systems.

Influence of soil macro-fauna abundance on soil fertility in cocoa-based agroforestry systems

Spearman rank correlation and logistic regression analyses revealed the existence of a direct non-causal and causal relationship between soil macro-fauna abundance and soil fertility enhancement in cocoa-based agroforestry systems (Table 5).

As shown in Table 5, there was a statistically significant

($p < 0.05$) difference between the abundance of some soil macro-fauna (earth worms, ants, termites, beetles, crickets, woodlice, snails and slugs) and soil fertility enhancement in cocoa-based agroforestry systems. Although, there was a direct non-causal and causal relationship between the abundance of some soil macro-fauna (millipedes, centipedes, harvestmen, spiders and scorpions) and soil fertility improvement in cocoa-based agroforestry systems; there was no statistical significance ($p > 0.05$).

DISCUSSION

Soil macro-fauna identified by cocoa farmers in cocoa-based agroforestry systems

Diverse soil macro-fauna were identified by cocoa farmers in cocoa-based agroforestry systems in the Littoral region of Cameroon. Earth worms, ants, termites,

Table 5. Role played by soil macro-fauna abundance in soil fertility in cocoa-based agroforestry systems.

Soil macro-fauna	Correlation coefficient (r)	p-level	Logistic regression coefficient (B)	p-level
Earth worms	0.75*	0.000	2.14*	0.000
Ants	0.71*	0.000	2.06*	0.000
Termites	0.82*	0.000	3.41*	0.000
Beetles	0.73*	0.000	2.08*	0.000
Crickets	0.55*	0.000	1.47*	0.005
Woodlice	0.52*	0.000	1.35*	0.008
Millipedes	0.14	0.459	0.02	0.691
Centipedes	0.20	0.361	0.06	0.536
Snails	0.69*	0.000	1.79*	0.002
Harvestmen	0.12	0.174	0.006	0.724
Spiders	0.11	0.508	0.002	0.837
Scorpions	0.19	0.335	0.04	0.572
Slugs	0.65*	0.000	1.53*	0.002
Likelihood Ratio χ^2	-	-	171.558*	0.000
Pseudo R^2	-	-	0.296	-
Number of observations	-	-	300	-

*Significant at 5% probability level.

millipedes, centipedes, and snails were the major soil macro-fauna identified by cocoa farmers in their cocoa-based agroforestry systems. Beetles, harvestmen, scorpions and slugs were the least identified soil macro-fauna in cocoa-based agroforestry systems. Cocoa farmers' perceptions of different soil macro-fauna in cocoa-based agroforestry systems differed significantly. Differences in cocoa farmers' perceptions of the different soil macro-fauna could be attributed to differences in age, farm experience, educational level, farm size and many others. Cocoa farmers' identification of earth worms, ants, termites, millipedes, centipedes, and snails as major soil macro-fauna in cocoa-based agroforestry systems could be attributed to the easily identifiable nature of these soil macro-fauna when compared to others such as harvestmen and scorpions which are very much elusive. Mostly, biophysical studies have been carried out to identify soil macro-fauna in agricultural systems (Harvey et al., 2006; Moco et al., 2009, 2010; Huerta et al., 2009; Rahman et al., 2012; Deheuvelds et al., 2014; Suarez et al., 2018; Mortimer et al., 2018; Suarez et al., 2019; Villanueva-Lopez et al., 2019; Prayogo et al., 2019; Dahlsjo et al., 2020). However, very limited research has been done on farmers' indigenous knowledge of soil macro-fauna diversity and abundance and their contribution to soil fertility enhancement in cocoa-based agroforestry systems. This study is therefore timely and fills a knowledge vacuum.

Degree of soil macro-fauna diversity and abundance in cocoa-based agroforestry systems

Cocoa farmers perceived the level of soil macro-fauna

diversity in cocoa-based agroforestry systems differently. Most cocoa farmers perceived that soil macro-fauna diversity in cocoa-based agroforestry systems was high, with few cocoa farmers perceiving that soil macro-fauna diversity in cocoa-based agroforestry systems was very low. Cocoa farmers' perceptions of the level of soil macro-fauna diversity in cocoa-based agroforestry systems differed significantly. Biophysical studies have shown that soil macro-fauna diversity is high in different organic/agro-ecological farming systems (Rousseau et al., 2014; Jagoret et al., 2014; Vanhove et al., 2016; Wartenberg et al., 2017; Tongkaemkaew et al., 2018; Suarez et al., 2018; Oliveira et al., 2018; Suarez et al., 2019; Marsden et al., 2020). This could be attributed to the presence of trees and the limited use of toxic agro-chemicals which are harmful to soil macro-fauna.

Cocoa farmers perceived the level of soil macro-fauna abundance in cocoa-based agroforestry systems in a diverse fashion. Earth worms, ants, millipedes, centipedes, spiders, harvestmen and scorpions were perceived by most cocoa farmers to have a high level of abundance in cocoa-based agroforestry systems. Crickets, woodlice, snails and slugs were perceived by most farmers to have an average abundance in cocoa-based agroforestry systems. Termites and beetles were perceived by most cocoa farmers to have a low abundance in cocoa-based agroforestry systems. A statistically significant difference existed between farmers' perceptions of abundance of soil macro-fauna in cocoa-based agroforestry systems. Cocoa farmers' perceptions of the abundance of earth worms, ants, millipedes, centipedes, spiders, harvestmen and scorpions could be attributed to the fact that these soil macro-fauna are frequently seen by the farmers during

their daily farming activities. Meanwhile, soil macro-fauna such as crickets, woodlice, snails, slugs, termites and beetles, which were perceived by cocoa farmers to have average to low abundance, could be attributed to the fact that these soil macro-fauna are not frequently seen by the farmers during their daily activities on the farm. Significant differences in cocoa farmers' perceptions of the abundance of soil macro-fauna could be attributed to farm experience, age, farm size, and educational level. Mainly biophysical studies have been undertaken to assess soil macro-fauna abundance in different agricultural systems (agroforestry inclusive). Most of these studies (Jose, 2009; Oke and Odebiyi, Nair, 2011; Jose, 2012; Asare et al., 2014; Carsan et al., 2014; Rousseau et al., 2014; Dumont et al., 2014; Mortimer et al., 2018; Niether et al., 2019; Wartenberg et al., 2020), have found varying degrees of abundance of soil macro-fauna in different agricultural systems. This study by focusing on cocoa-based agroforestry systems and making use of cocoa farmers' local knowledge breaks away from the norm, which accounts for its originality.

Influence of soil macro-fauna diversity and abundance on soil fertility in cocoa-based agroforestry systems

Correlation and regression analyses showed the existence of a direct non-causal and causal relationship between soil macro-fauna diversity and soil fertility enhancement in cocoa-based agroforestry systems. A statistically significant direct non-causal and causal relationship was found to exist between different levels of soil macro-fauna diversity (very high soil macro-fauna diversity, high soil macro-fauna diversity, average soil macro-fauna diversity, low soil macro-fauna diversity, and very low soil macro-fauna diversity) and soil fertility enhancement in cocoa-based agroforestry systems. Thus, the higher the level of soil macro-fauna diversity in the cocoa-based agroforestry system, the higher the level of soil fertility; and the lower the level of soil macro-fauna diversity in the cocoa-based agroforestry system, the lower the level of soil fertility. As shown by most biophysical studies (Rousseau et al., 2014; Jagoret et al., 2014; Vanhove et al., 2016; Wartenberg et al., 2017; Tongkaemkaew et al., 2018; Suarez et al., 2018; Suarez et al., 2019; Marsden et al., 2020), soil macro-fauna diversity contributes enormously towards enhancing soil fertility in different agricultural systems owing to engineering role (aid in the decomposition of dead organic matter) played by soil macro-fauna. By laying emphasis on the cocoa-based agroforestry system and making use of cocoa farmers' local knowledge, this study brings forth some originality.

A statistically significant direct relationship existed between the abundance of some soil macro-fauna (earth worms, ants, termites, beetles, crickets, woodlice, snails and slugs) and soil fertility enhancement in cocoa-based

agroforestry systems. Although, there was a direct non-causal and causal relationship between the abundance of some soil macro-fauna (millipedes, centipedes, harvestmen, spiders and scorpions) and soil fertility improvement in cocoa-based agroforestry systems, there was no statistical significance. These findings imply that, as the abundance of earth worms, ants, termites, beetles, crickets, woodlice, snails and slugs increases in cocoa-based agroforestry systems, their contribution to soil fertility also increases. The relative abundance of millipedes, centipedes, harvestmen, spiders and scorpions also contributed towards increasing soil fertility in cocoa-based agroforestry systems (although not very significantly). Studies (mostly biophysical) have shown that the abundance of soil fauna in general and soil macro-fauna in particular, in different agricultural systems contribute towards enhancing soil fertility (Jose, 2009, 2012; Oke and Odebiyi, 2007; Nair, 2011; Asare et al., 2014; Carsan et al., 2014; Rousseau et al., 2014; Dumont et al., 2014; Mortimer et al., 2018; Niether et al., 2019; Wartenberg et al., 2020). This could be attributed to the role played by these soil macro-fauna as decomposers of dead organic matter. With focus on cocoa-based agroforestry systems and cocoa farmers' local knowledge, this study has produced some novel findings.

Conclusion

The findings of this study have proven that soil fertility is greatly influenced by soil macro-fauna diversity and abundance in cocoa-based agroforestry systems. From these findings, different soil macro-fauna were identified by cocoa farmers in cocoa-based agroforestry systems with the main being earth worms, ants, termites, millipedes, centipedes, and snails. Most cocoa farmers perceived that soil macro-fauna diversity in cocoa-based agroforestry systems was high and very high respectively, with few cocoa farmers perceiving that soil macro-fauna diversity in cocoa-based agroforestry systems was very low. Earth worms, ants, millipedes, centipedes, spiders, harvestmen and scorpions were perceived by most cocoa farmers to have a high level of abundance in cocoa-based agroforestry systems. Crickets, woodlice, snails and slugs were perceived by most farmers to have an average abundance in cocoa-based agroforestry systems. Termites and beetles were perceived by most cocoa farmers to have a low abundance in cocoa-based agroforestry systems. Correlation and regression analyses showed the existence of a statistically significant direct non-causal and causal relationship between soil macro-fauna diversity and soil fertility enhancement in cocoa-based agroforestry systems, implying that the higher the diversity, the higher the level of soil fertility and the lower the diversity, the lower the level of soil fertility.

Concerning soil macro-fauna abundance, correlation

and regression analyses revealed the existence of a statistically significant direct non-causal and causal relationship between soil macro-fauna abundance (that is, for earth worms, ants, termites, beetles, crickets, woodlice, snails and slugs) and soil fertility enhancement in cocoa-based agroforestry systems, implying that the greater the abundance of these soil macro-fauna, the greater the fertility of the soil. It is therefore recommended that measures be taken to ensure soil macro-fauna diversity and abundance in order to enhance the fertility of the soil in cocoa-based agroforestry systems.

POLICY RECOMMENDATIONS

Four policy recommendations arise from the findings of this study.

First, most cocoa farmers perceived that soil macro-fauna diversity in cocoa-based agroforestry systems was high, with few cocoa farmers perceiving that soil macro-fauna diversity in cocoa-based agroforestry systems was very low. Thus, policies geared towards the sustainability of cocoa-based agroforestry systems should look into this and seek for ways to maintain this for as long as possible.

Secondly, earth worms, ants, millipedes, centipedes, spiders, harvestmen and scorpions were perceived by most cocoa farmers to have a high level of abundance in cocoa-based agroforestry systems. Crickets, woodlice, snails and slugs were perceived by most farmers to have an average abundance in cocoa-based agroforestry systems. Termites and beetles were perceived by most cocoa farmers to have a low abundance in cocoa-based agroforestry systems. Policy makers should take a keen look at this to see which soil macro-organisms deserve much care less they go extinct.

Correlation and regression analyses showed the existence of a statistically significant direct non-causal and causal relationship between soil macro-fauna diversity and soil fertility enhancement in cocoa-based agroforestry systems, implying that the higher the diversity, the higher the level of soil fertility and the lower the diversity, the lower the level of soil fertility. Policy makers should craft policies that seek to ensure more diversity of these soil macro-fauna in cocoa-based agroforestry systems which could be through measures that ban the use of harmful agro-chemicals.

Concerning soil macro-fauna abundance, correlation and regression analyses revealed the existence of a statistically significant direct non-causal and causal relationship between the level of soil macro-fauna abundance (that is, for earth worms, ants, termites, beetles, crickets, woodlice, snails and slugs) and soil fertility enhancement in cocoa-based agroforestry systems, implying that the greater the abundance of these soil macro-fauna, the greater the fertility of the soil.

Policy makers should seek to ensure the abundance of

these soil macro-fauna in cocoa-based agroforestry systems through actions like the banning of harmful agro-chemical use on farms.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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