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Contribution of soil macro-fauna to soil fertility improvement in cocoa-based (*Theobroma cacao*) agroforestry systems in the Littoral Region of Cameroon: Examining cocoa farmers' indigenous knowledge

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Soil macro-fauna play an important role in soil fertility improvement in different agricultural systems. However, limited research has been done to assess the role played by soil macro-fauna to soil fertility enhancement in cocoa-based agroforestry systems. This study was therefore initiated to fill this knowledge void. A mixed research approach was used during data collection, and data analysis was done using descriptive and analytical statistics. Findings showed that the main indicators of soil fertility perceived by cocoa farmers in cocoa-based agroforestry systems were cocoa yield (100%), soil colour (90%) and presence of soil macro-organisms (80%). Cocoa farmers identified earth worms (100%), ants (100%), termites (70%), millipedes (50%), and centipedes (50%) as the main soil macro-fauna found in cocoa-based agroforestry systems. With respect to the contribution of soil macro-fauna to soil fertility improvement, cocoa farmers perceived that earth worms, ants, and termites (62, 47.7, 57.6, and 52.4, respectively) contributed highly to soil fertility improvement in cocoa-based agroforestry systems while crickets, woodlice, snails and slugs were perceived by cocoa farmers (61.7, 60, 45.6, and 58.9%, respectively) to contribute only averagely to soil fertility improvement in cocoa-based agroforestry systems. Through correlation and regression analysis, it was found that the main soil macro-fauna contributing significantly ($p<0.05$), to soil fertility improvement in cocoa-based agroforestry systems were earth worms, ants, termites, beetles, snails and slugs. On the basis of these findings, it is recommended that appropriate measures be taken to ensure the sustainability of soil macro-fauna in cocoa-based agroforestry systems owing to the great role they play role in soil fertility improvement.

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

INTRODUCTION

Cocoa (*Theobroma cacao*) production is dominated by countries found in the tropics (Duguma et al., 2001; Oke and Odebiyi, 2007; Vaast and Somarriba, 2014). These are countries characterized by humid conditions (high temperatures and large amounts of rainfall) which suit the cocoa plant perfectly (Rice and Greenberg, 2000; Tankou, 2015). Most of the cocoa (over 95%) is produced by smallholder farmers whose farm sizes scarcely go beyond 5 ha (International Cocoa Organization – ICCO, 2007). Although cocoa remains a major cash crop for countries in the tropics, and contributes enormously to the Gross Domestic Product (GDP) of these countries, the GDP per capita continues to be low, and poor infrastructural and communication facilities are major stumbling blocks to economic growth (Utomo et al., 2016).

In Cameroon, cocoa yields have been dwindling in recent years and smallholder cocoa farmers are bearing the brunt of these dwindling yields (Kimengsi and Azibo, 2013; Kimengsi and Tosam, 2013). Dwindling yields in smallholder cocoa farms have generally been attributed to soil fertility exhaustion, inadequate maintenance of cocoa farms, ageing farmers and farms, poor and unsustainable agricultural practices that destroy soil organisms, major players in soil fertility enhancement in agricultural systems and many other factors. It is thus imperative to promote agro-ecological practices that are sustainable, protect soil organisms and foster natural decomposition of organic materials (Nfinn, 2005; Jagoret et al., 2011, 2012; Alemagi et al., 2015; Mukete et al., 2018; Jagoret et al., 2018).

Agroforestry is one of the agro-ecological farming systems which is climate-smart, environmentally friendly and sustainable (Asaah et al., 2011; Nair, 2011; Jose, 2012; Atangana et al., 2013; Asare et al., 2014; Kiptot et al., 2014; Utomo et al., 2016; Leakey, 2017; Amare et al., 2018; Leakey, 2019; Noordwijk et al., 2019; Tsufac et al., 2019; Awazi and Tchamba, 2019; Awazi et al., 2019, 2020; Awazi and Avana, 2020). Cocoa-based agroforestry systems have been identified as an agro-ecological system par excellence which allows the combination of production targets with environmentally friendly management practices, protecting both soil and biodiversity, enhancing soil macro-fauna activity and improving soil fertility (Schroth et al., 2001; Sonwa et al., 2007; Jose, 2009; Jagoret et al., 2011, 2014; Vanhove et al., 2016; Montagnini, 2017; Jagoret et al., 2018). Soil macro-fauna have been identified as major contributors to soil fertility enhancement in different agricultural systems owing to their capacity to decompose organic matter (Rousseau et al., 2012; Marsden et al., 2020).

Although studies have been carried out in different agroforestry systems (mainly biophysical), demonstrating the role of soil organisms in general to soil fertility improvement (Laird et al., 2007; Moco et al., 2009; Rousseau et al., 2012; Jagoret et al., 2014; Marsden et al., 2020; Suarez et al., 2018, 2019; Mortimer et al., 2018; Dahlsjo et al., 2020), little or nothing has been done across the tropics in general and Cameroon in particular to assess the important role soil macro-fauna in particular play in enhancing soil fertility in cocoa-based agroforestry systems. It was within this framework that this study sought to examine the contribution of soil macro-fauna to soil fertility improvement in cocoa-based agroforestry systems. More specifically, the study sought to: (1) identify the indicators of soil fertility perceived by farmers in cocoa-based agroforestry systems; (2) identify the different soil macro-fauna species perceived by farmers in cocoa-based agroforestry systems; (3) assess the role played by soil macro-fauna to soil fertility in cocoa-based agroforestry systems; and (4) examine the influence of soil macro-fauna on soil fertility in cocoa-based agroforestry systems.

MATERIALS AND METHODS

Study area

The study was undertaken in Melong sub-division, Mungo division, littoral region of Cameroon (Figure 1). Longitudinally, it lies between 9°17’ to 10°52’ E and latitudinally between 4°22’ to 6°20’ N. Melong sub-division is part and parcel of the Western Highlands of Cameroon – one of the five agro-ecological and relief regions of Cameroon. The Western Highlands of Cameroon stretches across four administrative regions (that is, the entire west and north-west regions, part of the littoral region, and part of the south west region). It covers a surface area of about 50,000 km^2. Agriculture is the main livelihood activity carried out by the population. The Western Highlands of Cameroon (Melong sub-division inclusive) is considered one of the major breadbaskets of Cameroon and the Central African sub-region due to the large quantity of agricultural products produced in this agro-ecological zone (Tankou et al., 2017).

Melong sub-division was created in 1962 by Decree No. 62/17 of 26/12/1962 (Plan Communal de Developpement – PCD Melong, 2012). It has a surface area of 497 km^2 and has a population of about 102,000 inhabitants living rural and urban areas (PCD Melong, 2012). Melong sub-division shares boundaries with Santchou sub-division to the north; Nguti sub-division to the north-west; Bangem sub-division to the west; Nkongsamba sub-division to the south-west; Baré sub-division to the south-east; the Nkam river and Kékem sub-division to the east.

Melong sub-division has an equatorial climate of the Guinean type. Rainfall is abundant with an average annual rainfall of 2350 mm. The climate is marked by two rainy seasons - a long rainy season from June 20 to November 15 and a short rainy season from March 20 to April 15, and two dry seasons from November 20 to March 15 for the long dry season and from April 20 to May 15 for the short dry season. The months of August and September experience the largest amounts of rainfall. Atmospheric humidity is high. The average annual temperature is about 20°C and can drop to as low as 10°C at the top of mountains (PCD Melong, 2012).

The soils here are black and essentially clayey-lateritic, but sandy-clayey soils can be found in some areas. Hydromorphic soils are generally found in swampy areas. From the north to the south

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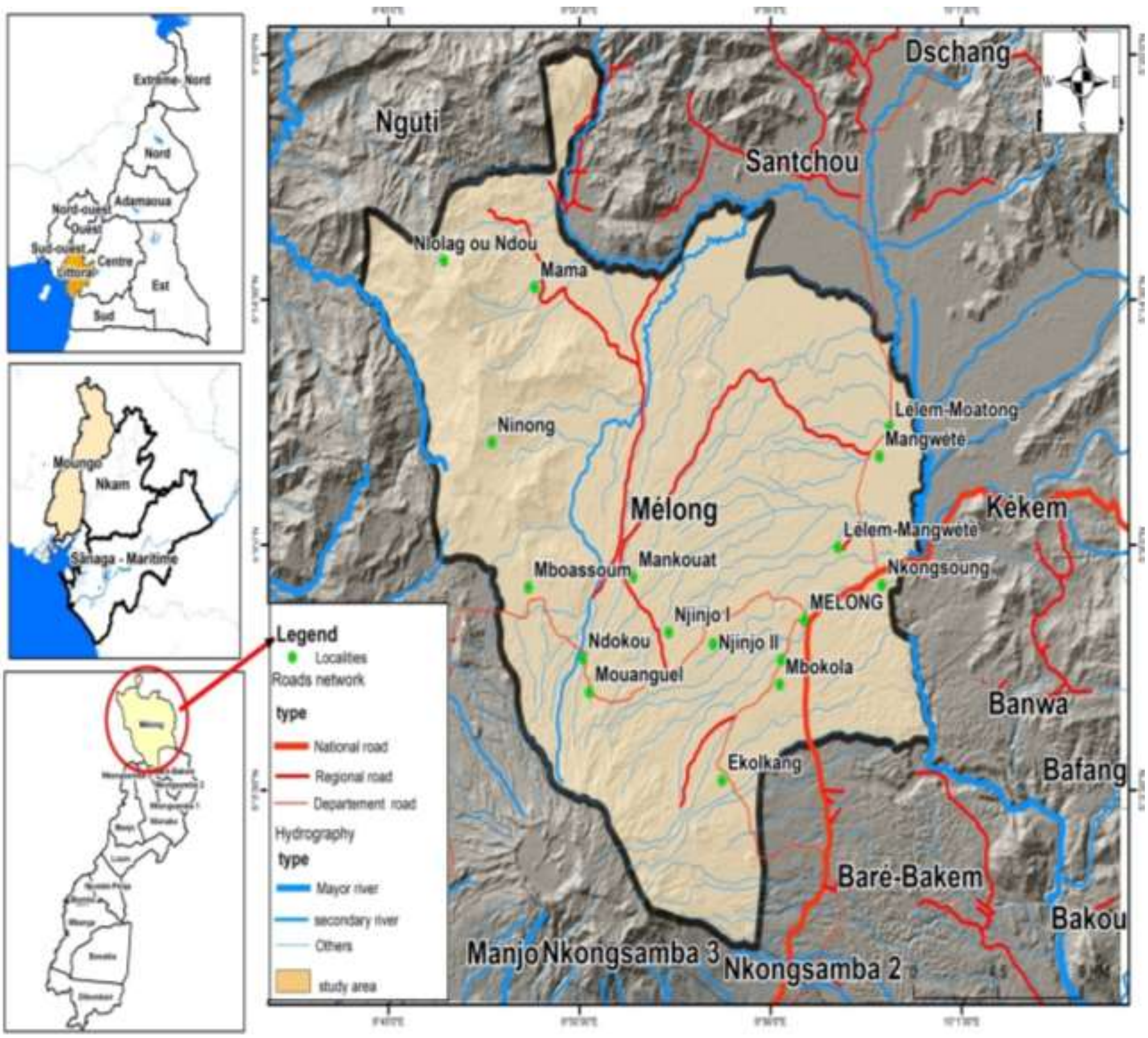

Figure 1. Map showing the study area.

of Melong sub-division, the soils are largely made up of solidified volcanic lava coming from Mount Manengouba. There are four types of soils: Ferralitic soils or basic soils (These are the soils derived from basalt, they are clayey-sandy, generally not deep and rejuvenated by erosion); Ferralitic humus soils (They are clayey with an acid PH with a high organic matter content, that is, 13%); Typical ferralitic soils (These are averagely deep soils, less than 2 m, contain clay and silt with a pH between 5.5 and 6.5. They are sensitive to erosion. They are found west of Melong sub-division; Hydromorphic soils (They are characterized by ferruginous concretions and have a sandy-clay texture, their pH is acidic) (PCD Melong, 2012).

The relief of Melong sub-division is rolling. It can be sub-divided into two zones: the highlands made up of hills and mountains, and the lowlands made up of vast plains. The altitude ranges from 740 m (Mbo plain) to 2,268 m (Mount Manengouba). The central town of Melong is characterized by a rugged relief made of plateaus, valleys and hills (Plan Communal de Developpement – PCD Melong, 2012).

The hydrography of Melong sub-division is quite rich and varied. There are several rivers and streams including the Nkam, Mboussé, Edibwang, Mouandjong, Mbe, Mounhe, Mbiang, Nkudi, Hué, Editebeng, Mébondé, Aboho, Mbel, Meneh, Mê, Kousso, Ngoedi, Ebanouel, Mbong, Mebang, Edjel, Moukang, Medo, Mwediboum, Mandi, Ngang, Black water, Ma'a, Njoh, Mpouandang, Nkonkele, Mvou, Mwetibi, Otieu and Edikum. These rivers and streams criss-cross the different villages found in Melong sub-division and are characterized by some waterfalls in the localities of Ndikambo (40 m) and Schuio (37 m). The rivers and streams are full of fish, sand and rocks. They are exploited by farmers for domestic needs (drinking, washing, cooking, bathing, and irrigation), fishing and construction projects. The most recurrent fish are carp and catfish (Plan Communal de Developpement – PCD Melong, 2012).

The vegetation is mainly made up of degraded forest characterized by forest and savannah grassland. Secondary and gallery forests are equally dominant. The main floral species found in Melong sub-division are Bilinga, Iroko, Azobe, Baobab, Padou, Landa, Mokingui, etc. The forests abound in non-timber forest products (NTFPs) such as Njansang, hazelnuts, "bitter Kola", rattan, bamboo, and raffia, and various medicinal plants. The disappearance of the forest in some localities is a consequence of wanton cutting of trees (PCD Melong, 2012).

Many fauna species have disappeared from what was once savannah and forest. We have for example the chimpanzee and the gorilla in Ediengo, Nzakon, Mama, Mbokem, and the elephant. Nevertheless, we have wild birds (the raven, raven, sparrow-hawk, toucan, partridge, wild pigeons), and wild animals (monkeys, antelopes, hares, porcupines, tiger, wild cats, palm rats and other small rodents, not forgetting the reptiles found in the wetlands). The aquatic fauna includes carp, snake catfish, crabs, and tilapias. This fauna diversity is also threatened considerably by the disappearance of certain species, either due to unregulated hunting or bush fires, and especially, by continued deforestation (PCD Melong, 2012).

Data collection

To attain the study's objectives, socioeconomic data were collected through household surveys, focus group discussions and key informant interviews. Different sampling techniques were used.

Sampling procedure

The multi-stage sampling procedure was followed as used by other studies carried out in Cameroon (Awazi and Tchamba, 2018; Awazi et al., 2019). At the first stage, Mungo division in general and Melong sub-division in particular was purposively chosen owing to the widespread practice of cocoa-based agroforestry systems by cocoa farmers. The second phase involved focus group discussions and key informant interviews with farmers and resource persons respectively. Focus group discussions and key informant interviews were conducted in order to get a general overview of soil fertility and the contribution of soil macro-fauna to soil fertility improvement in cocoa-based agroforestry systems in the study area. Focus group discussions and key informant interviews were also conducted in order to know the types of cocoa farmers to be sampled during household surveys. At the third stage, household surveys were undertaken with farmers involved in cocoa-based agroforestry systems. This was done through the use of semi-structured questionnaires. The questionnaires were structured to get information on the indicators of soil fertility in cocoa-based agroforestry systems; the different soil macro-fauna species in cocoa-based agroforestry systems; the role played by soil macro-fauna to soil fertility in cocoa-based agroforestry systems; and the influence of soil macro-fauna on soil fertility in cocoa-based agroforestry systems. The assistance of agricultural/environmental extension agents working on the field was indispensable during all the stages of the sampling process.

Primary data collection

Primary data were collected through household surveys, focus group discussions and key informant interviews.

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 tailored to capture information with respect to the indicators of soil fertility in cocoa-based agroforestry systems; the different soil macro-fauna species in cocoa-based agroforestry systems; the role played by soil macro-fauna to soil fertility in cocoa-based agroforestry systems; and the influence of soil macro-fauna to soil fertility in cocoa-based agroforestry systems. The simple random sampling technique was used during the administration of questionnaires to cocoa-based agroforestry practitioners. This gave the cocoa farmers an equal opportunity of being selected during the survey. Information gotten from household surveys was complemented with that obtained through key informant interviews and household surveys. The truthfulness of farmers' perceptions was ascertained by key informants and focus group discussants. Agricultural/Environmental extension officials working on the field in Melong sub-division provided vital assistance during the primary data collection process.

Secondary data collection

To attain objectives of the study, secondary data were equally collected from the following sources: the regional, divisional and sub-divisional delegations of Agriculture and Rural Development; Forestry and Wildlife, Environment and Nature Protection; Economy and Regional Planning; as well as Municipal Councils found in the Mungo division in general and Melong sub-division in particular; Libraries in the Faculty of Agronomy and Agricultural Sciences (especially the library of the faculty, the library of the department of forestry and the library of the department of soil science); scientific publications or articles, books and book chapters both online and offline; and different websites/academic platforms on the internet especially Scopus, ResearchGate, Academia and Google Scholar. Secondary data allowed for the verification and comparison of the contribution of soil macro-fauna to soil fertility in cocoa-based agroforestry systems in Melong sub-division to that of other areas in Cameroon, Africa and the world.

Data analysis

Data collected on the field was analyzed using Microsoft Excel 2007 and SPSS 17.0. Descriptive and analytical statistics were computed. The main descriptive statistics computed were charts, graphs, tables as well as percentage indices, while analytical/ inferential statistics computed were Spearman's correlation coefficient, Chi-square test statistic, and logistic regression. The analytical/inferential statistics were computed on the basis of the normality of the collected data as well as the type of variables (qualitative or quantitative). Analytical/Inferential statistics were computed in order to show the causal and non-causal relationship existing between soil macro-fauna and soil fertility in cocoa-based agroforestry systems in Melong sub-division, Mungo division, littoral region of Cameroon.

RESULTS

Indicators of soil fertility perceived by farmers in cocoa-based agroforestry systems

Cocoa farmers perceived diverse indicators of soil fertility in cocoa-based agroforestry systems (Figure 2). From Figure 2, the main indicators of soil fertility perceived by farmers in cocoa-based agroforestry systems were cocoa yield (100%), soil colour (90%), presence of soil organisms (80%), indicator plant species (75%), growth rate/vigour of the cocoa plant (70%), indicator weed species (65%) and soil compaction (50%). The least

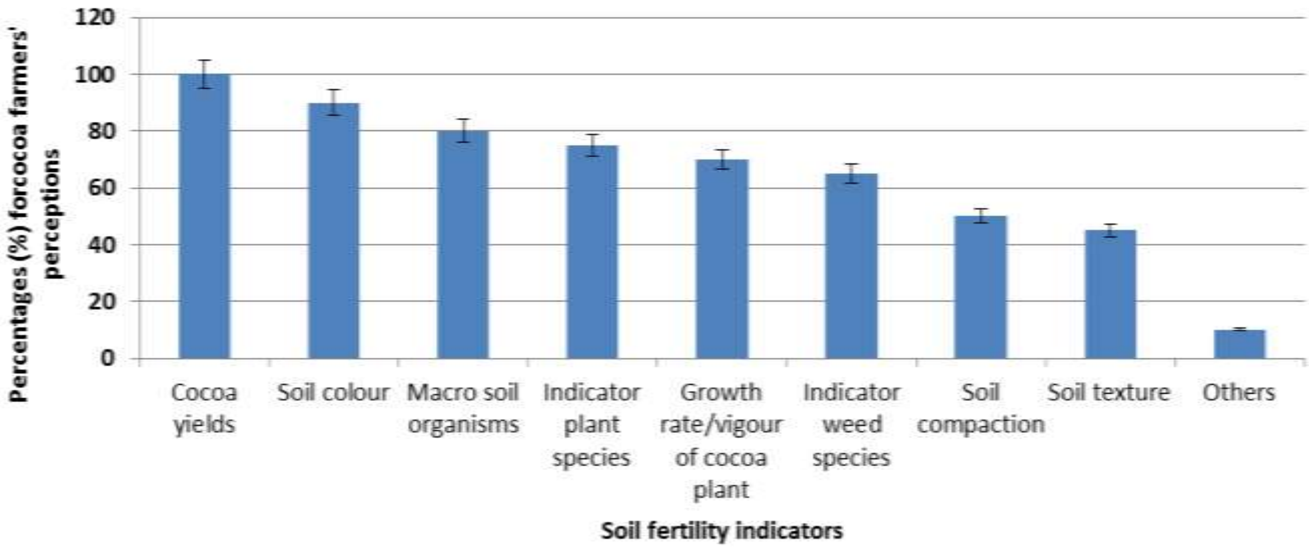

Figure 2. Soil fertility indicators perceived by cocoa farmers.

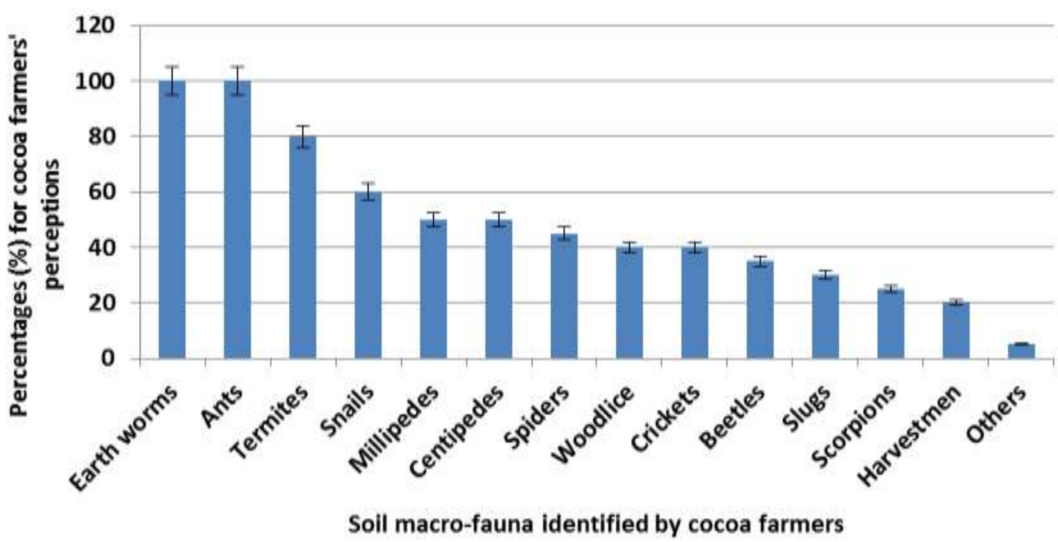

Figure 3. Soil macro-fauna species identified by farmers.

perceived indicators of soil fertility in cocoa-based agroforestry systems were soil texture (40%) and others like humus (10%).

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

Cocoa farmers identified diverse soil macro-fauna in cocoa-based agroforestry systems in the littoral region (Figure 3).

Figure 3 shows that the major soil macro-fauna identified by cocoa farmers in cocoa-based agroforestry systems were earth worms (100%), ants (100%), termites (70%), millipedes (50%), and Centipedes (50%). Soil macro-fauna least identified by cocoa farmers in cocoa-based agroforestry systems were scorpions (25%), beetles (35%), slugs (30%), and harvestmen (20%).

Farmers' perceptions of the role played by soil macro-fauna to soil fertility improvement in cocoa-based agroforestry systems

Cocoa farmers' perceptions of the contribution of soil macro-fauna to soil fertility enhancement differed

Table 1. Contribution of soil macro-fauna to soil fertility enhancement in cocoa-based agroforestry systems.

Soil macro-fauna	Contribution to soil fertility enhancement										χ^2	p-level
	Frequency					Percentage						
	VL/N	L	Av.	H	VH	VL/N	L	Av.	H	VH		
Earth worms	4	9	37	186	64	1.3	3	12.3	62	21.3	92.6*	0.000
Ants	10	18	71	143	58	3.3	6	23.7	47.7	19.3	72.4*	0.000
Termites	4	11	14	121	60	1.9	5.2	6.7	57.6	28.6	61.3*	0.000
Beetles	3	7	20	55	20	2.9	6.7	19.1	52.4	19.1	46.7*	0.000
Crickets	4	5	74	25	12	3.3	4.2	61.7	20.8	10	121.1*	0.000
Woodlice	5	6	72	24	13	4.2	5	60	20	10.8	144.3*	0.000
Millipedes	8	64	52	16	10	5.3	42.7	34.7	10.7	6.7	44.9*	0.000
Centipedes	10	62	56	14	8	6.7	41.3	37.3	9.3	5.3	62.3*	0.000
Snails	13	34	82	41	7	7.2	18.9	45.6	22.8	3.9	73.8*	0.000
Harvestmen	11	33	12	3	1	18.3	55	20	5	1.7	40.7*	0.000
Spiders	43	77	7	5	3	31.9	57.1	5.2	3.7	2.2	49.7*	0.000
Scorpions	21	38	11	3	2	28	50.7	14.7	4	2.7	92.9*	0.000
Slugs	4	6	53	22	5	4.4	6.7	58.9	24.4	5.6	81.3*	0.000

*Significant at 5% probability level; VL/N = very low/nothing; Av. = average; H = high; VH = very high.

significantly for the different soil macro-fauna (Table 1).

From Table 1, it is found that most cocoa farmers perceived that earth worms, ants, termites (62, 47.7, 57.6, and 52.4%, respectively) contributed highly to soil fertility improvement in cocoa-based agroforestry systems. For crickets, woodlice, snails and slugs, most cocoa farmers (61.7, 60, 45.6, and 58.9%, respectively) perceived that these soil macro-fauna's contribution to soil fertility improvement in cocoa-based agroforestry systems was average. For millipedes, centipedes, harvestmen, spiders and scorpions, most cocoa farmers (42.7, 41.3, 55, 57.1 and 50.7%, respectively) perceived that the contribution of these soil macro-fauna to soil fertility improvement was low.

Cocoa farmers' perceptions of the contribution of soil macro-fauna to soil fertility improvement in cocoa-based agroforestry systems differed significantly across the different soil macro-fauna (χ^2 > 40, p<0.05).

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

Through the use of correlation (Spearman rank correlation) and regression (logistic regression) analyses, it was found that a direct non-causal and causal relationship respectively exists between different soil macro-fauna and soil fertility in cocoa-based agroforestry systems (Table 2).

From Table 2, earth worms, ants termites, beetles, snails and slugs were the main soil macro-fauna having a statistically significant direct non-causal and causal relationship (p<0.05) with soil fertility improvement in cocoa-based agroforestry systems. Although soil macro-fauna like crickets, woodlice, millipedes, harvestmen, spiders and scorpions had a direct relationship with soil fertility improvement in cocoa-based agroforestry systems, there was no statistical significance (p>0.05).

DISCUSSION

Varied indicators of soil fertility were perceived by cocoa farmers in cocoa-based agroforestry systems. These indicators were cocoa yield, soil colour, presence of soil macro-organisms, indicator plant species, growth rate/vigour of the cocoa plant, indicator weed species, soil compaction, soil texture and others like humus. This could be attributed to the fact that yield is generally seen as an indicator of soil fertility because the higher the yield, the greater the fertility of the soil and vice versa; for colour, the darker the soil, the greater the fertility, the more reddish the soil, the lesser the fertility; for soil macro-organisms, the more diverse and abundant the soil macro-organisms, the greater the fertility, and vice versa; while for indicator plant species, the presence of some indicator plant species like the sun flower (*Tithonia diversifolia*) implies the soil is fertile, while the presence of other plant species like ferns indicates soil infertility; for growth rate/vigour of the cocoa plant, the greater the growth rate/vigor of the cocoa plant, the more fertile the soil and vice versa; equally indicator weed species show the level of soil fertility, that is, the greater the presence of some weed species like fern, the less fertile the soil, while the presence of less ferns indicates that the soil is fertile; for soil compaction, the more compact and harder

Table 2. Role played by soil macro-fauna in soil fertility enhancement in cocoa-based agroforestry systems.

Soil macro-fauna	Correlation coefficient (r)	p-level	Logistic regression coefficient (B)	p-level
Earth worms	0.85*	0.000	3.69*	0.000
Ants	0.67*	0.000	2.05*	0.000
Termites	0.79*	0.000	3.04*	0.000
Beetles	0.63*	0.000	2.01*	0.000
Crickets	0.11	0.526	0.006	0.651
Woodlice	0.16	0.513	0.004	0.628
Millipedes	0.18	0.504	0.002	0.619
Centipedes	0.20	0.324	0.01	0.472
Snails	0.54*	0.000	1.18*	0.028
Harvestmen	0.29	0.173	0.03	0.247
Spiders	0.10	0.686	0.008	0.859
Scorpions	0.14	0.589	0.005	0.698
Slugs	0.58*	0.000	1.36*	0.012
Likelihood Ratio χ^2	-	-	153.26*	0.000
Pseudo R^2	-	-	0.435	-
Number of observations	-	-	300	-

*Significant at 5% probability level.

the soil, the less fertile it is and vice versa; for texture, the more loamy the soil, the more fertile it is, while being too coarse or fine makes the soil infertile; while for humus, the more the humus content, the more fertile and vice versa.

Thus, cocoa farmers' indigenous knowledge allows them to identify different indicators of soil fertility. Studies carried out by Dawoe et al. (2012), Rousseau et al. (2013), Jagoret et al. (2014), Bezabih et al. (2016), Omari et al. (2018), and Essougong et al. (2020), have shown that farmers identify different indicators of soil fertility based on the local knowledge of their environment. However, most of these studies were not carried out in Cameroon, and most were done in other agricultural systems and not within cocoa-based agroforestry systems.

Species of soil macro-fauna identified by farmers in cocoa-based agroforestry systems

Different soil macro-fauna were identified by cocoa farmers in cocoa-based agroforestry systems in the littoral region of Cameroon. The major soil macro-fauna identified by cocoa farmers in cocoa-based agroforestry systems were earth worms, ants, termites, millipedes, and centipedes. Meanwhile, soil macro-fauna least identified by cocoa farmers in cocoa-based agroforestry systems were scorpions, beetles, slugs, and harvestmen. Cocoa farmers' identification of earth worms, ants, termites, millipedes, and centipedes, as the main soil macro-fauna found in cocoa-based agroforestry systems could be attributed to the recurrent nature of these soil macro-fauna across the tropics in general. These are common soil macro-fauna seen on a daily basis by cocoa farmers while carrying out farming activities in their cocoa farms. On the other hand, soil macro-fauna such as scorpions, beetles, slugs and harvestmen which were least identified by cocoa farmers in cocoa-based agroforestry systems could be attributed to the elusive nature of some of these soil macro-fauna, which makes it difficult for cocoa farmers to see them during their daily farm activities.

Most studies carried out to identify soil macro-fauna in different agricultural systems (agroforestry inclusive) have mainly used the biophysical approach (Deheuvels et al., 2014; Suarez et al., 2018; Tongkaemkaew et al., 2018; Oliveira et al., 2018; Mortimer et al., 2018; Suarez et al., 2019; Villanueva-Lopez et al., 2019; Prayogo et al., 2019; Marsden et al., 2020; Dahlsjo et al., 2020). Equally, the aforementioned studies were undertaken across different parts of the tropics, mostly in South America, with little or nothing done across Africa in general and Cameroon in particular. Thus, this study has filled a knowledge void, firstly by trying to identify the different soil macro-organisms in cocoa-based agroforestry systems, and secondly, by making use of the socio-economic approach which has scarcely been used to identify soil macro-organisms in agricultural systems.

Famers' local knowledge of the importance of soil macro-fauna to soil fertility improvement in cocoa-based agroforestry systems

There were different perceptions among cocoa farmers pertaining to the contribution of soil macro-fauna to soil fertility enhancement in cocoa-based agroforestry systems. Most cocoa farmers perceived that earth worms, ants, termites contributed highly to soil fertility improvement in cocoa-based agroforestry systems, while crickets, woodlice, snails and slugs, were perceived by cocoa farmers to contribute only averagely to soil fertility improvement in cocoa-based agroforestry systems. Millipedes, centipedes, harvestmen, spiders and scorpions on their part, were perceived by cocoa farmers to contribute only minutely to soil fertility improvement in cocoa-based agroforestry systems.

The significant difference in cocoa farmers' perceptions of the contribution of soil macro-fauna to soil fertility improvement in cocoa-based agroforestry systems could be attributed to the fact that most farmers already had a deeply rooted belief that soil macro-fauna such as earth worms, ants and termites contribute to soil fertility improvement more than other types of soil macro-fauna. And again, cocoa-farmers' perceptions of earth worms, ants and termites as contributing highly to soil fertility improvement could be due to the fact that cocoa farmers see these soil macro-fauna daily on their farms while they carry out their daily farm activities, which makes them to have the firm belief that these soil macro-fauna play a significant role in improving soil fertility. While for the other soil macro-fauna such as crickets, woodlice, snails, slugs, millipedes, centipedes, harvestmen, spiders, and scorpions which were perceived by most cocoa farmers to enhance soil fertility in an average or minute way, this could be explained by the fact that most of these soil macro-fauna are elusive, making farmers to believe that they play little or no role in soil fertility improvement.

Studies undertaken across different parts of the tropics (mainly biophysical) on agroforestry and non-agroforestry systems have shown that soil organisms in general and soil macro-fauna in particular play a great role in influencing soil fertility (Laird et al., 2007; Moco et al., 2009, 2010; Suarez et al., 2018, 2019; Mortimer et al., 2018; Cardinael et al., 2020). In Cameroon, very limited research has been done in this direction. This study being carried out in Cameroon in the first place and secondly, making use of socio-economic data has therefore broke from the norm, which accounts for its originality.

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

Correlation and regression analyses indicated that a direct non-causal and causal relationship respectively exists between different soil macro-fauna and soil fertility in cocoa-based agroforestry systems. Earth worms, ants, termites, beetles, snails and slugs were the main soil macro-fauna having a statistically significant direct non-causal and causal relationship with soil fertility improvement in cocoa-based agroforestry systems. Although soil macro-fauna like crickets, woodlice, millipedes, harvestmen, spiders and scorpions had a direct relationship with soil fertility improvement in cocoa-based agroforestry systems, there was no statistical significance. Thus, the greater the earth worms, ants, termites, snails and slugs in cocoa-based agroforestry systems, the more fertile the soils. As reported by other studies (Huerta et al., 2009; Rahman et al., 2012; Pinho et al., 2012; Vasconcellos et al., 2013; Dollinger and Jose, 2018; Sileshi et al., 2020; Tongkaemkaew et al., 2018; Oliveira et al., 2018; Dahlsjo et al., 2020), soil organisms in general play a great role in soil fertility improvement in agricultural systems. This study however focused on the contribution of soil macro-fauna to soil fertility improvement in cocoa-based agroforestry systems which accounts for the originality of the work.

Conclusion

As shown by the findings of this study, the important role played by soil macro-fauna in soil fertility improvement in cocoa-based agroforestry systems cannot be over emphasized. Major soil fertility indicators perceived by cocoa farmers in cocoa-based agroforestry systems were cocoa yield, soil colour and presence of soil macro-organisms. Cocoa farmers identified earth worms, ants, termites, millipedes, and centipedes as the main soil macro-fauna found in cocoa-based agroforestry systems. With respect to the contribution of soil macro-fauna to soil fertility improvement, cocoa farmers perceived that earth worms, ants, termites and termites contributed highly to soil fertility improvement in cocoa-based agroforestry systems while crickets, woodlice, snails and slugs were perceived by cocoa farmers to contribute only averagely to soil fertility improvement in cocoa-based agroforestry systems. Through correlation and regression analysis, it was found that the main soil macro-fauna contributing significantly, to soil fertility improvement in cocoa-based agroforestry systems were earth worms, ants, termites, beetles, snails and slugs. Based on these findings, it is recommended that appropriate measures be taken to ensure the sustainability of soil macro-fauna in cocoa-based agroforestry systems owing to the great role they play in soil fertility improvement.

Policy ramifications

Two main policy ramifications emerge from this study. With respect to the contribution of soil macro-fauna to soil fertility improvement, cocoa farmers perceived that earth worms, ants, and termites contributed highly to soil fertility improvement in cocoa-based agroforestry systems while crickets, woodlice, snails and slugs were perceived by cocoa farmers to contribute only averagely to soil fertility improvement in cocoa-based agroforestry systems. This calls for policies that will go a long way to protect these soil macro-fauna which can play a significant role in soil fertility improvement in cocoa-based agroforestry systems.

Through correlation and regression analysis, it was found that the main soil macro-fauna contributing significantly to soil fertility improvement in cocoa-based agroforestry systems were earth worms, ants, termites, beetles, snails and slugs. Although policies need to lay special emphasis on these soil macro-fauna, all the different soil macro-fauna should be part of the policy framework in order to enhance the role played by these organisms in soil fertility.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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