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Farmers' Perceptions as a Driver of Agricultural Practices: Understanding Soil Fertility Management Practices in Cocoa Agroforestry Systems in Cameroon

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Abstract

In Africa, cocoa yields are low, partly due to soil fertility constraints and poor management. While peoples' knowledge, aspirations, and abilities are key factors explaining their behaviour, little is known about the rationales that underpin soil fertility management practices (SFMPs) of cocoa farmers. To address this gap, we conducted an exploratory survey in two contrasting regions in Cameroon where cocoa is an important crop: the humid forest and the forest-savannah transition zone. Some 30% of farmers in the transition zone as opposed to 13% in the humid forest expressed concerns about soil fertility. The most relevant soil fertility indicators for farmers were high cocoa yield, dark soil colour, ease of tillage, and floral composition. To enhance and maintain soil fertility, farmers used residues from weeding (100%), planting of trees (42%), mineral fertilisers (33%), compost (16%), and manure (13%). More farmers in the transition zone than the humid forest implemented SFMPs. Our findings suggest that soil fertility perceptions, access to inputs, local practices, and experience influence farmers' use of SFMPs. The limited use of mineral fertilisers was explained by poor access whereas the use of organic fertilisers and tree planting were mostly constrained by lack of labour and knowledge. Farmers prioritised practices to increase yield and viewed SFMPs to be the least important management practices, although they believe high cocoa yield is an important indicator of soil fertility. To foster sustainable cocoa intensification, it is necessary to enhance farmers' knowledge on SFMPs, increase access to inputs, and ensure returns on investment while considering farmers' priorities and practices.

Keywords Smallholder farmers · Soil fertility management practices · Pest and disease management · Agroforestry · Post-harvest · Perceptions · Cocoa · Cameroon

Introduction

Cocoa plays a key role in the socio-economic development of West African countries (Alemagi *et al.* 2015; Eyenga *et al.* 2017; Wilson *et al.* 2019) which supply 76% of the world's cocoa (Fountain and Huetz-Adams 2018). Therefore, policy makers pay particular attention to increasing productivity, especially yield (Eyenga *et al.* 2017). Low levels of adoption of good cocoa farming practices, pest and disease attacks, ageing plantations, and poor and decreasing soil fertility contribute to poor average yields (Wessel and Quist-Wessel 2015). Whereas reported yields at farm level vary from 300–400 kg ha^{-1} (Beg *et al.* 2017; Wessel and Quist-Wessel 2015) to 700–900 kg ha^{-1} (Jagoret *et al.* 2017; Jagoret *et al.* 2018), cocoa yields can reach >3000 kg ha^{-1}(van Vliet and Giller 2017; Yin 2004) in on-station trials. Crop simulation models suggest that the potential yield of cocoa exceeds 4000 kg ha^{-1} (Zuidema *et al.* 2005). Poor soil fertility is considered to be an important cause of the prevailing cocoa yield

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gap in Africa (van Vliet and Giller 2017). Soil fertility refers to the degree to which soils support plant growth.

When forests are initially cleared for cocoa plantations, the soils are fertile and can sustain cocoa production for several years, referred to by Ruf and Zadi (1998) as the 'forest rent.' Continuous harvesting of cocoa with no additional fertilisers leads to a decline in soil fertility (Appiah *et al.* 2000; van Vliet and Giller 2017). The decline of cocoa yields (WCF 2018) contributes to deforestation due to expansion of cocoa farming (Ruf and Zadi 1998). Maintenance and enhancement of soil fertility are essential to increase cocoa production with minimum negative environmental impact (Liniger *et al.* 2011; Vanlauwe *et al.* 2010; Vanlauwe *et al.* 2015). Several scholars cited by van Vliet and Giller (2017) have reported increased cocoa yields in response to fertilisation. For instance, in Ghana, the gross yield of fertilised plots was 61% to 116% higher compared with unfertilised plots (Appiah *et al.* 2000). During fertiliser experiments, yield response was stronger when cocoa was cultivated without shade (ibid.; van Vliet and Giller 2017). Besides mineral fertilisation, soil fertility enhancement can be achieved through the application of organic fertilisers or lime, and inclusion of legumes in the cropping system, or a combination of these (Hartemink 2006; MINADER 2018; Vos *et al.* 2003). The implementation of these practices requires farmers' recognition that declining soil fertility is a problem. Understanding the logic and rationale that underpin current farmers' management of soil fertility is essential for designing interventions to enhance yields, but these issues have received little attention in Cameroon.

Individual intrinsic perceptions play a key role in farmers' rationales and are thus a key factor to explain farmers' practices (Aubert *et al.* 2012; Leeuwis and Van de Ban 2004; Mathé and Rey-Valette 2015; Meijer *et al.* 2015). These perceptions are socially constructed, shaped by a combination of cultural, economic, biophysical, and spatial factors (Glover *et al.* 2019; Leeuwis and Van de Ban 2004). Farmers' knowledge and beliefs constitute an important perceptual category that pertains to farmers' awareness of phenomena such as 'soil fertility' and their understanding of cause and effect relations between phenomena and practices. Thus, knowledge and beliefs underpin the perceived consequences of adopting a particular technology or management practice. Whether such consequences are evaluated as advantageous or disadvantageous is determined by the aspirations and values of farmers (Glover *et al.* 2019; Leeuwis and Aarts 2021), which constitute a second perceptual category. Farmers are likely to have different aspirations, e.g., financial gain, peace of mind, independence, productivity, which they regard as more or less important depending on the given context. A third set of perceptions relates to an individual's ability and capacity to adopt new behaviour given available resources and existing biophysical and societal conditions (Leeuwis and Aarts 2021; Leeuwis and Van de Ban 2004). Glover *et al.* (2019) equally stress the relevance of the alignment between farmers' capabilities and proposed farming practices for their implementation. Furthermore, there is a dynamic in the construction of farmer practices that are reshaped over time and involve multiple actors (Leeuwis and Van de Ban 2004). Indeed, the successful implementation of new practices includes factors such as input supply, marketing, community support, transport, and processing (Leeuwis and Van de Ban 2004). In addition, existing institutions (rules and arrangements) and interdependencies are likely to influence the uptake of new technologies (see Leeuwis and Aarts 2021). These interdependencies among practices can be vertical (when adoption depends on the behaviour of other value chain actors), horizontal (when adoption requires the adoption by other farmers), temporal (when adoption depends on decisions made in the past or anticipated for the future) and intra-individual (when adoption requires the acceptance of complementary behaviours) (Leeuwis and Aarts 2021). For instance, for complex technologies with multiple components such as integrated soil fertility management or integrated pest management, the adoption of one component without the other can result in negative outcomes (Glover *et al.* 2019). Finally, farmers' socioeconomic characteristics (Leeuwis and Van de Ban 2004; Meijer *et al.* 2015) also contribute to shaping their perceptions, and thus their practices. In this research, we investigate soil fertility management practices of cocoa farmers and the role of three perceptual categories in shaping these practices: (a) knowledge and beliefs; (b) aspirations and priorities; and (c) abilities and capacities. More specifically, our research contributes to a deeper understanding of how cocoa farmers understand, view, and manage soil fertility, whether they consider SFMPs important for yields as compared to other cocoa farming practices, and which factors constrain the implementation of specific SFMPs.

The Study Area

Located in Central Africa, Cameroon is divided into five agro-ecological zones (AEZs): 1) Sudano-Sahelian; 2) High Guinea Savannah; 3) Western Highlands; 4) Humid Forest with monomodal rainfall pattern; and 5) the Humid Forest with bimodal rainfall pattern (Fig. 1). There are three administrative level in Cameroon: region, division, and subdivisions. We conducted the study in two contrasting areas where cocoa is an important crop: the Mvila division at the heart of the humid forest zone with bimodal rainfall pattern (hereafter referred to as humid forest), and the Mbam-and-Inoubou (M&I) division in a forest-savannah transition zone (hereafter referred to as transition zone; Jagoret *et al.* 2012) (Figs. 1 and 2). We purposively chose these two areas because, although they belong to the same broad AEZ, they differ in terms of dominant soils, vegetation, and rainfall pattern (Jagoret *et al.* 2012; Jiofack *et al.* 2013), biophysical characteristics that influence farmers' practices in general and soil fertility management in particular. Soils in the

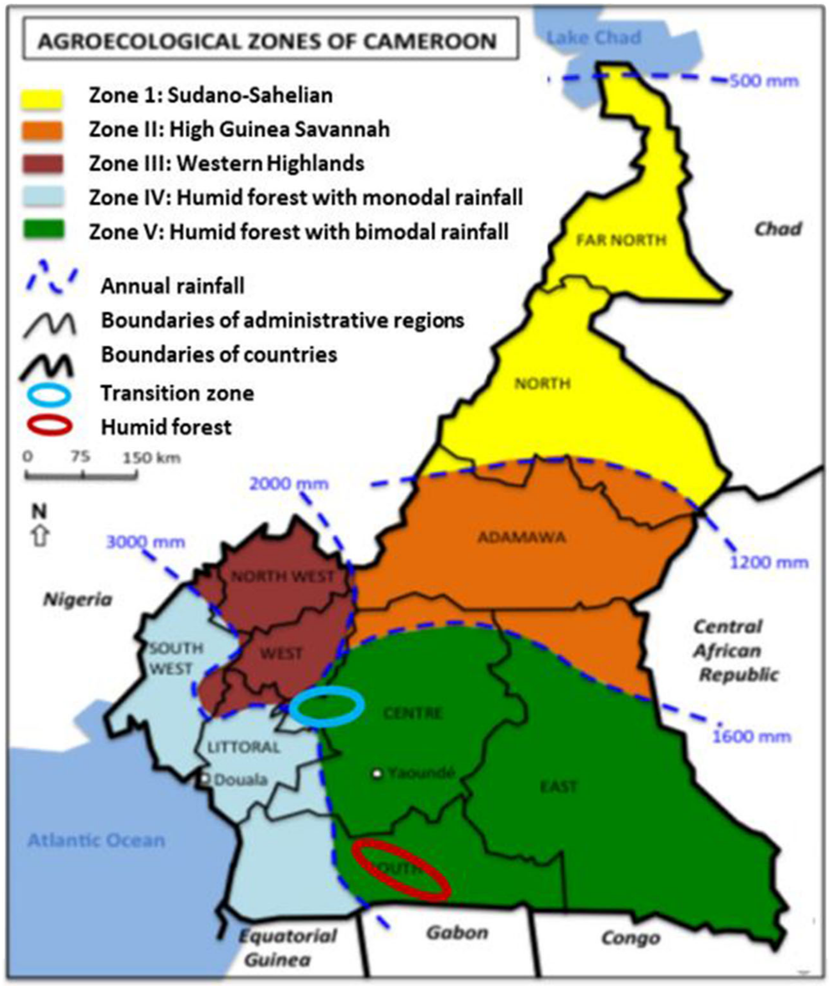


Fig. 1 Map of Cameroon showing the different regions and agro-ecological zones (adapted from Okolle *et al.* 2016; 12)

transition zone are dominated by Haplic ferralsols and Ferralic cambisols, while Acric Ferralsols are dominant in the humid forest (Fig. 2). The vegetation in the transition zone is dominated by low shrub savannah rich in *Imperata cylindrica* with some gallery forest. In the humid forest, dense forest is dominant. The annual rainfall in the transition zone is about 1300 mm, representing a mean deficit of 200 mm relative to the minimum ideal cocoa requirement (Diby *et al.* 2017; Jagoret *et al.* 2012), while annual rainfall in the humid forest ranges between 1650 to 1860 mm (Ayuk *et al.* 1999; Ebela 2017).

Methodology

Respondent Selection

We used purposive sampling to select 120 cocoa farmers (60 per production basin). A farmer registry was not available, and we had no time to establish one for the purpose of random sampling. Consequently, we relied on five local referees with knowledge of the cocoa farming population to identify and recruit respondents. We informed the referees about the study purpose and the average interview length and asked them to invite at least 15 farmers per village; only one farmer per household; ensure gender representativeness; select members and non-members of producers' organisations (PO); not select their own direct family; and, where applicable, ensure the representativeness of both certified and non-certified farmers. Because we were looking at cocoa farming practices, we chose to limit our sample to farmers with at least five years of experience in managing a cocoa farm. Before actually conducting the surveys, we crosschecked the farmers invited by the referees against the minimum criteria of experience in cocoa farming and verified the sample representativeness. In case of uneven distribution, we looked for replacement farmers on the day of the survey. For this purpose, we used snowball sampling with the assistance of farmers and referees present because it was impossible to reschedule the appointments.

Data Collection

We used a semi-structured questionnaire to collect data (see supplementary material), held informal discussions with referees and extension agents, and made field observations to collect data on

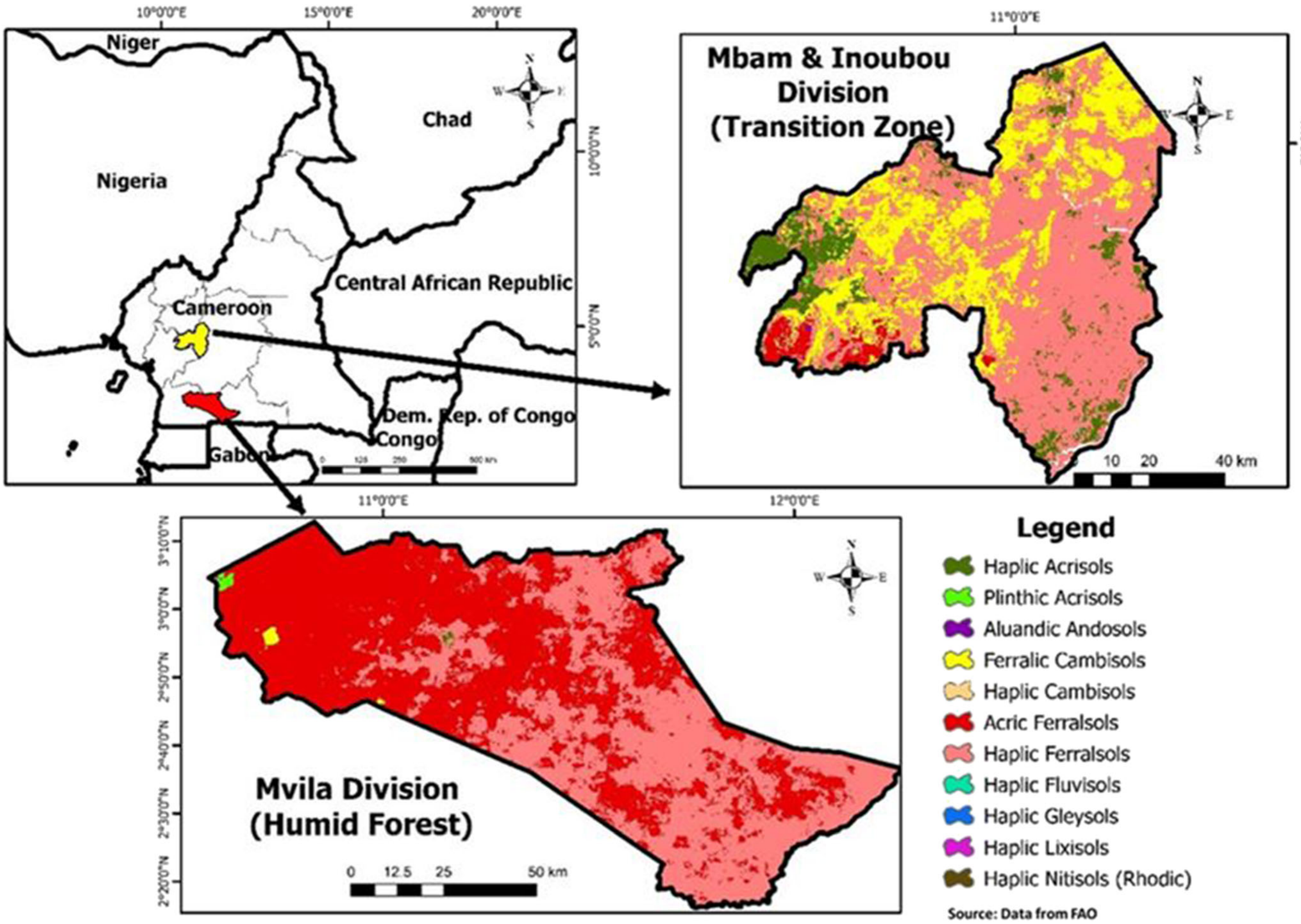


Fig. 2 Field locations and soil typology

farmers' socioeconomic characteristics, perceptions of soil fertility status, viewpoints on its indicators, constraints to and actual use of SFMPs, and viewpoints on the importance of different cocoa farming practices to obtain high yields. We investigated 14 cocoa farming practices recommended by the Cameroonian Ministry of Agriculture and Rural Development (MINADER): the use of improved cocoa varieties, pruning, suckering, shade management, insecticide use, fungicide use, manure and compost application, mineral fertiliser application, sanitary harvesting, harvesting of ripe pods, appropriate fermentation, appropriate drying, appropriate storing, and agroforestry using specific trees to improve soil fertility (MINADER 2018). Farmers scored these practices from zero to five (most important) to indicate their perceived importance to obtain high cocoa yields. We also investigated farmers' experiences with and implementation of four specific SFMPs: the use of manure, compost, and chemical fertilisers, and tree planting (see Table A1). To assess which soil fertility indicators farmers considered important, we designed statements about the relevance of each indicator, using indicators previously reported in the literature, such as soil texture, yields, and flora and fauna composition (e.g. Desbiez *et al.* 2004; Lima *et al.* 2011; Ndaka *et al.* 2015; Wartenberg *et al.* 2018; Fig. 4), and asked farmers to respond using a 5-Point Likert-Scale (strongly disagree to strongly agree). Finally, we asked farmers their reasons for not implementing certain SFMPs.

Data Processing and Analysis

We used descriptive and inferential statistical analyses for our data. We used the Pearson Chi-Square test of interdependencies to make comparisons for categorical variables and the independent t-test for continuous variables. To study the influence of cocoa tree age on SFMPs implementation we used three bins: young cocoa farms (0–10 years), mature cocoa farms (11–20 years), and old cocoa farms (40+ years). We used a significance level of 5% for statistical conclusions. We did the analyses with the Statistical Package for Social Sciences.

Results

We first present the respondents' socioeconomic characteristics followed by a discussion of the extent to which SFMPs are implemented and practised in the different production basins and the perceived barriers to the implementation of SFMPs in terms of capabilities, knowledge, and aspirations related to the practices. Thirdly, we present farmers' perceptions of soil fertility status and viewpoints on its indicators. Lastly, we investigate the importance and priority that cocoa farmers attach to SFMPs compared to other cocoa farming practices.

Socioeconomic Characteristics of the Respondents

Farmers in both study areas did not differ in terms of socioeconomic characteristics, apart from the number of yearly contacts with extension agents, which was significantly higher in the transition zone than in the humid forest ($p = 0.029$) (Table 1). Most farmers were men, and on average they had managed a cocoa farm for 17 years. They cropped 3.2 ha of cocoa in the transition zone and 4.5 ha in the humid forest on average, on one to four plots. The cocoa was planted less than 21 years ago in 43% and 49% of the plots in the humid forest and the transition zone, respectively. Overall, 44% of farmers received at least one training session in the last five years. Farmers in the transition zone had an average total yearly production of 792 kg per farm compared to 979 kg per farm in the humid forest. Finally, 27% of the farmers in the transition zone kept some livestock compared with 16% in the humid forest.

Soil Fertility Management Practices Implemented by Cocoa Farmers

Across the study population, all farmers considered the decay of weeds and cocoa litter as a nutrient source for the crops. Thus, these residues were not removed after manual or chemical weeding. More farmers in the transition zone (42%) than in the humid forest (15%) used herbicides ($p = 0.001$). To enhance soil fertility, some farmers (42%) purposefully associated cocoa with other trees. These were wild trees left during cocoa farm establishment, or domesticated trees (e.g., *Gliricidia sepium*, *Inga edulis*) introduced following recommendations of extension agents and peers or chosen based on local knowledge of various trees utility. In the humid forest, tree planting depended on i) main plot age (67% of farmers with plots aged 21–40 years planted trees compared to less than 34% for remaining class ages; $p = 0.04$,), and ii) training (50% of trained farmers compared to 24% of untrained farmers planted trees; $p = 0.04$). In the transition zone, tree planting correlated with soil fertility perceptions: 80%, 47%, and 22% of farmers who planted trees perceived the soil fertility status as high, moderate, or low, respectively ($p = 0.012$).

In terms of inputs to enhance soil fertility, 33% of farmers used mineral fertilisers, 16% compost, and 13% manure (Table 2). More farmers in the transition zone than in the humid forest used manure (20% and 7%, $p = 0.032$) and mineral fertilisers (47% and 20%, $p = 0.002$). Similarly, 43% of farmers with some training compared with 25% with no training used mineral fertilisers ($p = 0.038$) and manure (21% and 8% $p = 0.033$). In the humid forest,

Table 1 Summary of respondents' socioeconomics characteristics

		Humid forest					Transition zone					t-test
		n	Mean	Median	Min	Max	*n*	Mean	Median	Min	Max	***p* value**
Age (years)		59	50	50	23	78	60	52.3	53	24	85	**0.306**
Gender (count)	Male	43					51					
	Female	17					9					
Experience in cocoa farming (years)		60	17.6	15	5	58	60	17.2	15	5	49	**0.823**
Total size cocoa farm (ha)		60	4.5	3.5	0.5	45	59	3.2	2.5	0.5	25	**0.133**
Number of cocoa plots (count)		60	1.7	1	1	4	60	1.5	1	1	4	**0.172**
Age cocoa plots (count)	0–10	28					25					
	11–20	21					18					
	21–40	15					24					
	41+	24					28					
Annual cocoa production (kg)		59	979	640	100	5950	60	792	555	80	3000	**0.256**
Household members working in cocoa farm (count)		60	3.5	3	1	10	60	3.4	3	1	14	**0.673**
Yearly contact with extension agents (count)		60	1.6	1	0	12	60	3.8	1	0	48	**0.029**
Farmers trained (%)		45					43					
Trainings received the past five years (count)		27	1.3	1	1	9	26	1.7	1	1	5	**0.874**
Credit access (%)		13					13					
Livestock rearing (%)		16					27					

Table 2 Farmers' distribution according to SFMPs implemented and experience

SFMPs	Number of users (*n*)			User average years of experience implementing SFMPs	
	Transition zone	Humid forest	Total	Transition zone	Humid forest
Residues from weeding	60	60	120	17	17.7
Manure	12	4	16	9.9	6.3
Compost	12	7	19	8.2	9
Mineral fertiliser	28	12	40	7.2	6.5
Planting of other trees	29	21	50	15.3	7.7

the use of fertilisers was associated with training (p = 0,000), with trained farmers applying fertilisers more often (41%) than untrained farmers (3%). In the transition zone, compost use was associated with training ($p = 0.013$) and more trained (35%) than untrained (9%) farmers used it. The use of organic and inorganic fertiliser was a recent development, on average (Table 2).

Compost was made from cocoa husks, household waste, and crop residues. Respondents said that manure and compost were generally applied to young farms, especially to those close to homesteads. Although a third of farmers applied mineral fertilisers, further questioning revealed that these were foliar fertilisers applied in small quantities, i.e., less than one kg per hectare. Liquid fertilisers were often mixed with fungicides and insecticides during application.

Perceived Barriers to SFMPs Implementation

Farmers who did not implement SFMPs gave the following reasons: the inability to access inputs (mineral fertiliser, manure, compost, and planting material); financial constraints; limited knowledge and limited previous experience; high labour requirements; and perceptions of the current soil fertility status as 'sufficient' (Table 3). But there were differences among technologies. For example, farmers did not use mineral

Table 3 Number of times that farmers ($n = 120$) stated reasons why they did not use technologies to improve soil fertility

Reasons stated*	Technologies**				
	Mineral fertilisers	Manure	Compost	Trees planting	Total for all technologies
1. Inability due to affordability/availability (%)	**56**	**26**	**21**	**4**	**30**
Lack of money	44	1	4	2	51
Unavailability of the technology	28	35	26	1	90
2. Inability due to labour requirements (%)	**2**	**27**	**22**	**3**	**15**
Lack of labour/time	3	12	16	2	33
Arduousness	0	25	15	0	40
3. Perception of soil fertility status (%)	**16**	**10**	**9**	**19**	**13**
Soil fertility already good	21	14	13	13	61
4. Knowledge/experience (%)	**14**	**36**	**48**	**73**	**39**
Lack of knowledge on how to use	10	13	7	1	31
No previous experience	8	30	36	7	81
Unawareness of utility for cocoa	0	7	7	0	14
Not mastered production techniques	0	0	17	0	17
Lack of knowledge on fertilising trees	0	0	0	41	41
5. Others (%)	**11**	**0**	**0**	**0**	**3**
Destroys the soil	6	0	0	0	6
Fear of dependency	4	0	0	0	4
Promotion of organic agriculture	4	0	0	0	4
Total number occurrence	128	137	141	67	473

* More than one reason may be given per farmer

** The relative frequency with which the different categories were mentioned is given in bold fertilisers mainly because they were unable to access them (56% of the answers), while 'lack of knowledge and previous experience' was the main barrier to tree planting (73%), use of compost (48%), and use of manure (36%). Some farmers indicated they had never used compost or manure nor seen other people use them in cocoa. Also, some did not know how to produce compost. Finally, labour constraints were a major barrier to the use of manure (27%) and compost (22%). Some barriers were more pronounced in one location than the other. For instance, the lack of previous experience in using organic fertilisers was mentioned more than twice as often in the transition zone as in the humid forest. On the other hand, 'sufficient' soil fertility was mentioned 44 times in the humid forest compared to 17 times in the transition zone (Table A2).

Farmers' Perceptions of Soil Fertility Status and Viewpoints on its Indicators

Regarding the soil fertility status of their cocoa farms, 54%, 22%, and 24% of cocoa farmers viewed it as moderate, (very) low, and (very) high, respectively. However, more farmers in the transition zone (30%) than in the humid forest (13%) regarded soil fertility as low or very low whereas more farmers in the humid forest (32%) than the transition zone (17%) deemed it high or very high (Fig. 3).

Most farmers either agreed or strongly agreed that high yields (90%), dark soil colour (85%), ease of ploughing (82%), plant indicator species (80%), and flora abundance (79%) were soil fertility indicators. Fewer farmers either agreed or strongly agreed that thick litter layer (48%), abundant soil fauna (58%), high-water retention capacity (64%), and deep soil (64%) indicated fertile soils (Fig. 4). However, farmers' views about the indicators high yields, abundant soil fauna and abundant and diverse vegetation were associated with the location (Fig. 4); significantly more farmers in the transition zone than in the humid forest agreed on these indicators ($p = 0.02$, $p = 0.032$, and $p = 0.05$, respectively).

Farmers' Prioritisation of SFMPs Compared with Other Cocoa Farming Practices

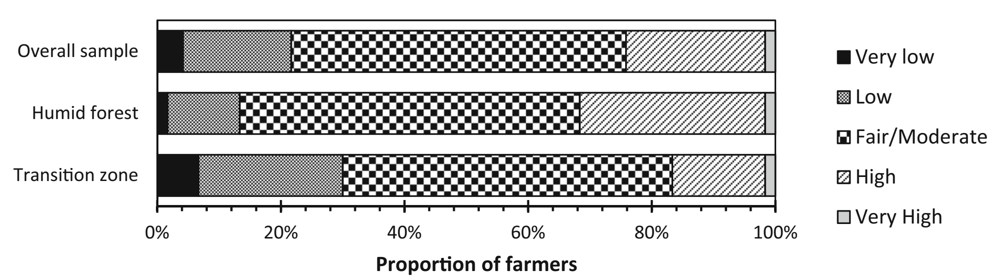
Farmers in both study locations scored cocoa farming practices in terms of their importance to obtain high yields and ranked them in the following decreasing order of importance: harvest and post-harvest management, insecticide application, shade management, fungicide application, pruning and use of improved varieties (Table 4). The scores varied between the locations: mean scores were significantly different for fungicide application and shade management, which both received a higher score in the humid forest than in the transition zone ($p = 0.04$ and $p = 0.03$, respectively). SFMPs were considered by farmers to be the least important management practices to achieve good cocoa yields.

Discussion

Farmers' Perceptions of Soil Fertility Were Consistent with Biophysical Knowledge but Differed between Individuals and Locations

We observed a diversity of perceptions of the present soil fertility status and viewpoints on soil fertility indicators both at the level of individual farmers and between the two production basins. More farmers in the transition zone than in the humid forest showed concern regarding soil fertility and were inclined to take actions towards soil fertility improvement. This might be linked to lower forest rents and less fertile soils in the transition zone. Cocoa farms in the humid forest are established on previously forested lands, whereas in the transition zone they are either established in gallery forests or on savannah land. In addition, due to soil fertility depletion and land pressure, farmers in the transition zone have engaged in savannah afforestation with cocoa (Jagoret *et al.* 2012; Jagoret *et al.* 2018; Nijmeijer *et al.* 2019). However, the differences observed in farmers' perceptions of soil fertility status might be attributable to a different appreciation of what "fertile soil" means for individual farmers.

Fig. 3 Farmers' opinion about soil fertility status, humid forest ($n = 60$) transition zone ($n = 60$), overall sample ($n = 120$)



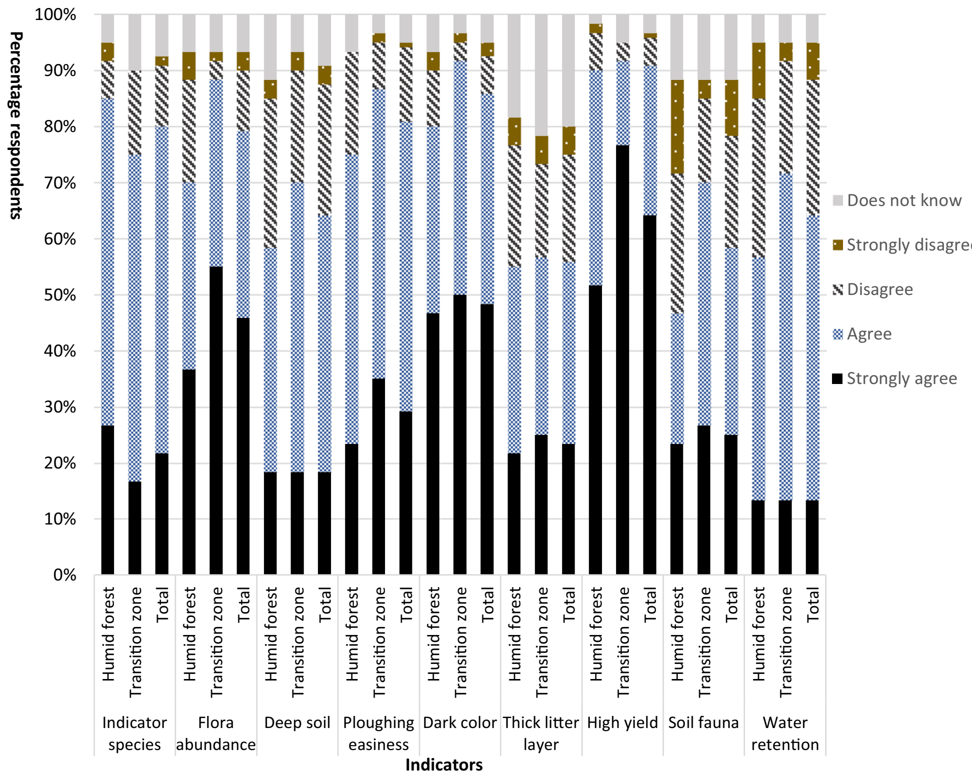


Fig. 4 Farmers' views on soil fertility indicators in the transition zone ($n = 60$), humid forest ($n = 60$), and total studied population ($n = 120$)

Therefore, it is essential to build a common understanding of what soil fertility means among farmers and consider the biophysical characteristics of the farmers' environment when developing strategies to promote the implementation of SFMPs.

Our results indicate that farmers' interpretations of soil fertility indicators are largely consistent with existing biophysical knowledge. The farmers considered high yields, dark soil colour, ease of ploughing, and vegetation diversity as the core indicators of soil fertility. Farmers' view of dark colour as a positive indicator of soil fertility reflects Saïdou *et al.*'s (2004) findings in Benin where most farmers associate dark soil colour with high soil organic matter content. However, six of our

Table 4 Mean score and rank of different cocoa farming practices with respect to their importance to obtain high yields and significance of the means score difference between the two cocoa production basins. The values in brackets represent the rank by decreasing order of importance of each individual practice from 1 (most important) to 14 (least important). Numbers in bold highlight ranking per production basin for practices with significantly different rankings

Farming practices	Production basin			t-test
	Humid Forest (n = 60)	Transition zone ($n = 60$)	Mean	***p value***
Harvest well-ripe pods	4.60 (1)	4.45 (3)	4.53 (1)	**0.256**
Appropriate fermentation	4.45 (5)	4.58 (1)	4.52 (2)	**0.387**
Appropriate drying	4.30 (6)	4.58 (1)	4.44 (3)	**0.106**
Insecticide application	4.50 (3)	4.25 (7)	4.38 (4)	**0.174**
Shade management	4.50 **(3)**	4.17 **(8)**	4.34 (5)	**0.03****
Fungicide application	4.51 **(2)**	4.10 **(9)**	4.31 (6)	**0.041****
Pruning	4.28 (7)	4.25 (5)	4.27 (7)	**0.844**
Use of improved varieties	4.07 (8)	4.37 (4)	4.22 (8)	**0.062**
Sanitary harvest	4.02 (9)	4.32 (6)	4.17 (9)	**0.117**
Sorting cocoa beans	3.95 (10)	3.97 (10)	3.96 (10)	**0.946**
Appropriate storing	3.73 (11)	3.90 (11)	3.82 (11)	**0.568**
Fertiliser application	3.58 (12)	3.07 (12)	3.33 (12)	**0.104**
Planting species that fertilise the soil	3.04 (13)	2.70 (13)	2.87 (13)	**0.279**
Manure/compost application	2.27 (14)	2.86 (14)	2.57 (14)	**0.097**

** Mean differences significant at 5% interval interviewed farmers disagreed with this assessment and claimed that dark soils are less fertile than red ones. We also found that farmers' views of soil fertility indicators differed across the two production basins, which is in line with earlier findings (Ibrahima *et al.* 2017; Kome *et al.* 2018, Ndaka *et al.* 2015). Therefore, we argue that farmers' perceptions of soil fertility are linked to the inherent characteristics of their surrounding environment and how they are understood. For instance, the fact that farmers in the humid forest live in and are surrounded by tropical forest biodiversity might explain why more of them do not associate diversified vegetation and abundant soil fauna with soil fertility, as opposed to farmers in the transition zone. Finally, while visual topsoil characteristics provide some indication of soil fertility status, farmers would have a better assessment of soil fertility status if soil chemical analyses were affordable and more widely available in Cameroon.

Barriers to SFMPs Use: Availability and Costs of Inputs and Farmers' Lack of Knowledge and Experience

Our results show that all farmers rely on weed residues as a source of crop nutrients and some consciously associate cocoa with other trees for fertility purposes. MINADER (2018) reported that leguminous tree planting was not widely used in cocoa farming. It appears that most farmers are not aware of leguminous trees or other tree species that can enhance soil fertility. However, in Cameroon, cocoa cropping is generally based on complex agroforestry systems where cocoa is associated with forest or fruit tree species that farmers preserve and/or plant after partial forest clearing (Jagoret *et al.* 2014; Sonwa *et al.* 2007; Sonwa *et al.* 2014). These trees fulfil several vital functions in cocoa plantations (Asaah *et al.* 2011; Jagoret *et al.* 2014): they reduce pest and disease incidence and enhance soil fertility (Jagoret *et al.* 2018) and they add leaf litter to the soil organic matter pool, which may reduce the need to add fertiliser (Duguma *et al.* 2001; Jagoret *et al.* 2012; Jagoret *et al.* 2018). However, competition for light, water, and nutrients in cocoa-based agroforestry systems can also result in decreasing cocoa yields if the degree of shade and tree density are not properly managed (Jagoret *et al.* 2017). Thus, efforts should continue to encourage the planting of leguminous and other cocoa-friendly tree species at the correct tree density and with proper shade management.

As previously reported (MINADER 2018), we found that few cocoa farmers (33%) used mineral fertilisers, mainly because they could not afford them. Previous findings (Hartemink 2006; Vanlauwe *et al.* 2010) already highlighted the high cost of fertilisers as a barrier to their use. Farmers are often unable to access credit to purchase fertilisers and their cost represents a high share of farmers' income (Wilson *et al.* 2019). Furthermore, farmers are likely to consider investments in fertilisers risky given the large annual and inter-farm variation in cocoa yields (Wilson *et al.* 2019), the sensitivity of cocoa to weather variations, the low and unstable cocoa price, and the lack of land tenure and tree security (O'Sullivan and Norfolk 2017). Rural lands in Cameroon are generally subject to customary law, with only about 3% of them registered because of the complexity and high costs of the process to acquire a formal land ownership certificate (Kenfack and Teguia 2019; USAID 2011). Consequently, there are multiple forms of customary land arrangements with different levels of security. Our results indicated no dependency between types of land 'tenure' (inheritance, purchase, renting, sharecropping) and investment in SFMPs ($p > 0.05$). Further investigations are needed to understand farmers' perceptions of land and tree security and how this affects their decisions to invest in SFMPs. In addition, designing policies that increase fertiliser availability and affordability could boost their use among cocoa farmers.

Besides the cost, farmers said they do not use mineral fertilisers because their parents made a living from cocoa without them. This highlights the role of social learning in behaviour construction (Bandura and Walters 1977). Some farmers claimed that fertiliser use "destroys the soils," leading to leaf yellowing and "burning." Fertiliser application was not mentioned by any farmer as a key topic covered during training. Moreover, as reported by farmers and key informants, there is little supervision or regulation of the fertiliser market and use. Of all the respondents, 33% said they were using mineral fertiliser, but when we probed further, we found that the amounts of nutrients added were almost insignificant (less than one kg per hectare). Many of our respondents reported that they mixed fertilisers with insecticides or fungicides, which may compromise the effectiveness of the plant protection agents (Gandini *et al.* 2020; Griffith 2010). Finally, farmers who claimed to fear dependency on fertilisers indicated that once fertilisers were used, the yield could not be sustained without them. As they were not sure of their capacity to continuously apply fertilisers, they chose not to invest in them. These findings highlight the need to increase farmers' exposure to fertilisers and their knowledge of proper fertiliser use. Organic fertilisers (compost and manure) were generally not used. The absence of livestock on most farms can explain the lack of manure. In the transition zone, more farmers had livestock and more manure was applied compared with the humid forest. Furthermore, the transport and application of manure and compost are laborious. Cocoa farmers are often older and simultaneously involved in other social and income-generating activities.

Our results suggest that the way farmers view soil quality influences their decision to employ SFMPs, as Tittonell *et al.* (2005) also found. In general, more farmers in the transition zone than in the humid forest considered soil fertility to be low and hence took actions to improve it. The differences in the biophysical and the socioeconomic contexts in which the farmers act also explain their behaviour (Leeuwis and Van de Ban 2004; Tittonell *et al.* 2005). In addition, the transition zone has been targeted by several research activities (Bourgoing and Todem 2010; Jagoret *et al.* 2011; Jagoret *et al.* 2012) and farmers have been exposed to improved management practices.

Our findings also suggest that, while credit provision is essential to increase access to, and use of mineral fertiliser, raising farmer awareness and knowledge will be more relevant to increase organic fertiliser use and tree planting for soil fertility.

Farmers' Prioritisation of Cocoa Farming Practices: Implications for SFMP Implementation

Farmers considered SFMPs the least important practices to obtain a high cocoa yield. They pay more attention to harvest, post-harvest, and pest and disease management practices. Farmers stated that cocoa buyers have minimum requirements in terms of quality which, when not met, reduces farmers revenue from cocoa sales. When cocoa is not well dried, buyers apply a 'refraction rate' to account for weight loss during further drying. In addition, pests and diseases contribute greatly to poor cocoa yields (van Vliet and Giller 2017) and are responsible for about 30%–40% of cocoa yield loss worldwide (Diby *et al.* 2017; Ndoumbe-Nkeng *et al.* 2017), which might explain why they are given a higher priority by farmers. Fungicide application and shade management are more important to farmers in the humid forest as a strategy to obtain high cocoa yields. As rainfall and humidity are higher in the humid forest than in the transition zone, plantations in the humid forest are more likely to suffer from black pod disease, which is a significant threat to cocoa production in Cameroon (Ndoumbe-Nkeng *et al.* 2004; Ndoungue *et al.* 2018). Thus, farmers tend to prioritise practices that ensure a minimum yield and income.

The lack of interest in SFMPs suggests that besides farmers' capabilities, knowledge, and experience, which limit the use of soil fertility technologies, the way they prioritise management practices may be key in explaining their behaviour. Farmers do not apply fertilisers because they consider weeding, pruning, or pest and disease management to be more important. The low importance assigned to SFMPs could also result from the lack of attention to soil fertility during farmer training (Table A3). Fertiliser application is more effective in cocoa production when other good agricultural practices are implemented (van Vliet and Giller 2017). Therefore, if the implementation of SFMPs is to be promoted, there is a need to demonstrate the relevance of SFMPs to farmers and determine under what conditions fertiliser application would add value to production. We argue that raising farmers' awareness on the interdependencies among various cocoa farming practices and their combined effect on yield could be a starting point. Moreover, further studies should explore whether extension agents consider soil fertility to be a key issue for cocoa farming in the Cameroonian context and how the topic is discussed with farmers.

Conclusions

We investigated how farmers prioritise cocoa management practices in two contrasting cocoa-producing basins in Cameroon and the role of their knowledge, aspirations, and capabilities in explaining their behaviour. We found that farmers' perceptions of soil fertility are consistent with biophysical knowledge but differ between individuals and locations. Moreover, the availability and costs of inputs, farmers' lack of knowledge and experience with SFMPs, and farmers' perceptions of current soil fertility status constitute the main barriers to SFMPs use. However, these barriers constrain the implementation of individual SFMPs to a different extent. Finally, farmers considered SFMPs as the least important for high cocoa yield, with one-third of farmers using mineral fertilisers and half as many organic fertilisers.

The need for the intensification of cocoa production is widely recognised to limit cocoa-driven deforestation. Management of soil fertility is central to maintaining and enhancing cocoa yields in future as soils become exhausted. To foster the transition towards sustainable cocoa production, measures that improve farmers' awareness of soil fertility problems, increase farmers' knowledge of the interactions among cocoa management practices, increase access to affordable inputs, and improve returns on investment will be key. Our research has highlighted several reasons for whether or not Cameroonian farmers invest in SFMPs. However, future research should pay attention to how farmers' perceptions of trees and land tenure security affect their decisions to invest in SFMPs.

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Compliance with Ethical Standards

Conflict of Interest No potential conflict of interest was reported by the authors.

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