Assessing gender and geospatial factors impacting cocoa productivity in Ghana's organic and conventional agroforestry systems

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Abstract

Understanding geospatial and gender dynamics of farm productivity is crucial for addressing inequities in the development of cocoa (*Theobroma cacao* L.) agroforestry support services. Cocoa agroforestry systems (CAS) play a vital role in mitigating deforestation, soil degradation, and the negative impacts of climate change on sustainable agriculture. However, there is a lack of information on the spatial distribution of cocoa farms and the gender dimensions of land productivity in organic and conventional CAS, which hinders equitable access to development support. This study examines the spatial and gender dynamics of organic cocoa (OC) and conventional cocoa (CC) farm productivity to promote fair distribution of resources and development support within CAS in Ghana. A multi-stage sampling method was employed across three soil types—ferralsols, lixisols, and leptosols in selected agroecological zones. Eleven CC and 11 OC farms were randomly selected for each soil type. Data collected included cocoa farm sizes, farm polygons, yields, gender, and socioeconomic attributes of farmers. The results revealed that OC and CC farms were spatially dispersed. Characterization of the farmers' socioeconomic data showed significant gender disparities, with male dominance in cocoa farm ownership. Despite these disparities, female cocoa farmers who own their lands demonstrated higher soil organic carbon conservation and cocoa productivity than male farmers. These findings suggest that spatial clustering of cocoa farms and gender equity are needed to enhance the delivery of development support, helping to achieve the 2030 Sustainable Development Goals (SDG), particularly women's empowerment (SDG 5) to promote sustainable agriculture (SDG 2). In addition to gender equality, spatial clustering and connectivity of CAS are environmentally sound for conserving life on land (SDG 15), boosting efficient support partnerships (SDG 17) and tackling climate change (SDG 13).

Keywords: agglomeration; crop yield; development support; ecofeminism; connectivity, spatial clustering of farms

Introduction

The spatial distribution of farms and the dynamics of gendered access to resources are increasingly recognized as central determinants of agricultural productivity in both conventional and organic agroforestry systems globally (Self et al., 2024; Popovici et al., 2022; Vroege et al., 2020; Schmidtner et al., 2012). In cocoa (*Theobroma cacao* L.) production systems, especially those practicing agroforestry, these factors shape the capacity of farmers to mobilize innovations, access farm inputs and extension services, and benefit from spillovers arising from proximity to growth poles and resource hubs (Bicksler et al., 2022; Hailu and Deaton, 2016; Martin & Ottaviano, 2001).

International empirical studies affirm that farm spatial clustering, whether by geography, market access, or resource services, positively influences productivity, resource-use efficiency, and knowledge diffusion. For instance, in France, Canada, and Southeast Asia, proximity among farms has been linked to enhanced soil health, policy support, and adoption of sustainable practices (Boncinelli et al., 2016; Schmidtner et al., 2012). This agglomeration effect is well established in spatial economics and development theory, where clustered production fosters economies of scale, learning, and innovation (Vlados & Chatzinikolaou, 2020; Martin & Ottaviano, 2001). However, the extent to which similar agglomeration dynamics manifest within Ghana's cocoa agroforestry landscapes remains poorly understood, particularly gendered access and resource flows.

Cocoa production in Ghana, ranked second globally behind Côte d'Ivoire (FAOSTAT, 2021) is primarily managed through conventional and organic agroforestry systems. These systems, which integrate cocoa trees with diverse timber and shade species, contribute to carbon sequestration, biodiversity conservation, and sustainable land use (Asare et al., 2019; Rajab et al., 2016). Notably, organic cocoa agroforestry systems have gained global recognition as nature-based solutions that not only mitigate land degradation but also address social inequities, including gender disparities in agricultural productivity (Tsikata et al., 2022; Bandanaa et al., 2021; Shiva, 2016). When spatially organized, these systems facilitate access to communal knowledge networks and input delivery systems, strengthening farm resilience and sustainable intensification (Doe et al., 2022; Singh et al., 2022).

Despite this potential, Ghana's average cocoa land productivity (0.55 t/ha) remains lower than in smaller-producing countries such as Togo, Indonesia, and Peru (Asante et al., 2022; FAOSTAT, 2021). Research suggests that gender-based disparities shaped by unequal access to extension services, land, and inputs, partially account for these productivity gaps (Amanor et al., 2020; Djokoto et al., 2017). Okpokiri et al., (2016) have indicated that women may outperform men in cocoa production under certain conditions, while Danso-Abbeam et al.,(2020) suggest otherwise, emphasizing the complex, context-specific nature of gendered performance. However, a significant gap remains in understanding how gender intersects with the spatial organization of farms to affect productivity within organic and conventional cocoa systems.

The theoretical framework for this study draws from spatial development theory, agglomeration economics, and gender-equity frameworks in agricultural development. These frameworks posit that spatial proximity and social organization among farms influence the flow of resources, institutional support, and innovation diffusion (Bicksler et al., 2022; Shiva, 2016; Martin & Ottaviano, 2001). Furthermore, gender-sensitive approaches are critical to achieving the UN's 2030 Sustainable Development Goals (SDGs), particularly SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 5 (Gender Equality), SDG 13 (Climate Action), and SDG 15 (Life on Land). Evidence from Asia and Africa confirms that gender-equitable resource allocation improves women's productivity and resilience, but such interventions must be tailored to the spatial realities and socio-ecological contexts of farmers (Tsikata et al., 2022, Bowyer-Bower and Shiva, 1996).

In Ghana, the lack of spatially explicit and gender-disaggregated data on cocoa farm productivity hinders effective policy design and targeted intervention. Particularly absent is a clear understanding of how gendered spatial clustering within agroecological zones affects access to resources and participation in public-private partnerships (SDG 17). Addressing this gap is essential for the spatial targeting of development programs, including climate-smart agriculture, input subsidies, and inclusive extension models.

This study, therefore, seeks to explore the spatial and gender dynamics of cocoa farm productivity across organic and conventional agroforestry systems in Ghana. By analyzing these dynamics across three distinct soil ecotypes. The research will contribute new insights into how location, gender, and farming system interact to shape agricultural outcomes. The findings are expected to inform spatially precise, gender-equitable, and ecologically resilient policy and development strategies for Ghana's cocoa sector.

Materials and Methods

Study Area

The study was conducted in smallholder cocoa farms located in four patriarchal communities (Figure 1) across three soil ecotypes (SE) in the Western, Eastern, and Oti regions of Ghana. These communities are Old Ankasa Quarters, Mongua, Adimdim and Pampawie (Papase), which are within four cocoa administrative districts of the Cocoa Health and Extension Division (CHED) of Ghana Cocoa Board (COCOBOD). Each community represents a soil ecotype, which refers to an intersection of a given soil type and an agroecological zone (vegetation type). Old Ankasa Quarters within longitude 2°39'47.403 "W and latitude 5°13'54.263"N and Mongua in longitude 2°43'37.088"W and latitude 5°33'2.685"N represent Ferralsols (FR) or Oxisols of Wet Evergreen (WE) soil ecotype (FR.WE) in the Western Region (WR). Adimdim (longitude

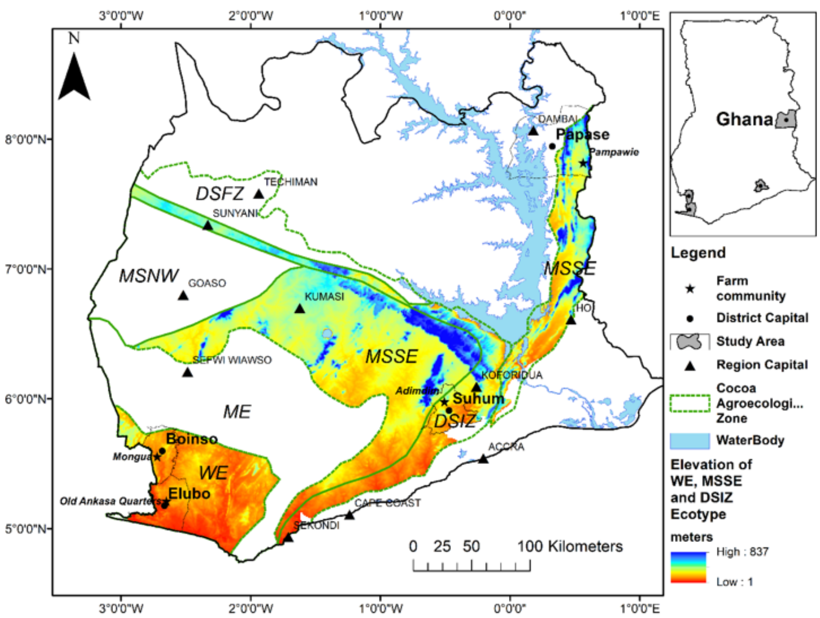


Figure 1 Map of the study area

0°30'43.758"W and latitude 5°58'44.851"N) represents Lixisols (LX) or Alfisols soil type in Dry Semi-deciduous Inner Zone (DSIZ) soil ecotype (LX.DSIZ) in the Suhum Cocoa District of the Eastern Region (ER). Pampawie located on longitude 0°33'15.253"E and latitude 7°49'12.887"N representing Leptosols (LE) or Entisols of the Moist Semi-deciduous South-East (MSSE) soil ecotype (LE.MSSE) in the Papase Cocoa District of the Oti Region (OR). The Oti Region was curved out of the Volta Region. The amount of annual rainfall and cocoa production varies in the sequence of LX.DSIZ < LE.MSSE < FR.WE. Mean daily temperature (25°C) and annual rainfall (1270-1651 mm) of the LX.DSIZ are lower than those of the FR.WE (26°C and 1732 mm) soil ecotype. The mean daily temperature and annual rainfall are about 25°C and 1400-1800 mm, respectively, in the LE.MSSE. The maturity or suitability of these soil ecotypes inclines in the order of LE.MSSE < LX.DSIZ < FR.WE, representing young, mature and very old weathered soils, respectively (Doe et al., 2023; FAO and ITPS, 2015).

Study philosophy, design, sample size, sampling, inclusion and exclusion criteria

The study was premised on spatial ecology and ecofeminist philosophy (Bowyer-Bower and Shiva, 1996; Gaard and Gruen, 1993; Shiva and Mies, 2014). Ecofeminism explores a trilogy of ecology, feminism, and social justice, to mitigate unfair gender disparities in ecosystems. Therefore, the study was designed as a spatial cross-sectional agroecosystem analysis (Conway, 1987) involving 11 organic cocoa (OC) and 11 conventional cocoa (CC) farmers and their farms, within each of the three soil ecotypes, making a total of 66 farms. The sample size was determined based on a previous district-wide cocoa survey (Doe et al., 2022; Quaye et al., 2021).

Equal numbers for both OC and CC cropping systems (CS) were selected to compare the spatial distribution of the farms and their land productivity within each soil ecotype. The selection involved a multi-stage stratified sampling process within the specified cropping systems and soil ecotypes. The first stage involves sampling of CHED Cocoa Districts that have both OC and CC farms while the second stage involved random sampling of the OC and CC farms within each soil ecotype.

To qualify as a farmer for the study, one must own an organic or a conventional cocoa farm. According to the definitions by Doe et al. (2023) and Asigbaase et al. (2020, 2021), CC farms rely on sustainable farm practices with prudent synthetic agrochemical applications aimed at maximizing cocoa yield. Conversely, the OC farms prioritize ecologically friendly practices, using nonsynthetic inputs, and emphasizing natural methods for pest and disease control, as well as soil health.

Both OC and CC cropping systems depict sustainable farming (Sumberg and Giller, 2022 ; Giller et al., 2021) due to the rational resource use and the agroforestry system used by the farmers. Based on the Ghana Cocoa Board (2018) and UTZ/Rainforest Alliance Sustainable Cocoa schemes, farmers with fewer than 18 timber species or permanent shade trees per hectare on their cocoa farm were excluded from the study. Additionally, to qualify, a farmer must have been farming on the same farm site for at least ten years.

Data collection and measurement of variables

Data for the study were collected through one-on-one individual interviews of the sampled farmers using a semi-structured questionnaire.

The questionnaire was pre-tested to ensure reliability and validity (Teye, 2012; Bryman, 2004). The variables include cocoa farm yield, farmer age (*FAge*), number of cocoa trainings attended (*Ext*) in the previous year, female (*FSex*) and male (*MSex*) farmers. Cocoa yield was defined as the weight of dry cocoa beans in metric tonnes per hectare (Doe et al., 2023; Williams et al., 1989). Other variables included whether the farmer was a (Native) or a migrant (Migrant), farmland tenancy (LT), and farm size (ha).

The farm polygons and sizes were measured using a handheld GPS device (GPSMap 64, Garmin Ltd., USA). The soil ecotypes—LX.DSIZ, FR.WE, and LE.MSSE—were determined by intersecting shapefiles of the soil types with the agroecological zones of the sampled farm location. Total annual cocoa farm yield (t ha^{-1}) was calculated using equation 1.1 (Fairtrade International, 2025), by dividing the product of the number of dry cocoa bean bags and the weight of each bag (0.0645 t) by the farm size (ha). As an indicator of soil health and fertility, the amount of soil organic carbon (SOC) (g kg^{-1}) conserved at a depth of 0-30 cm in the farm soil was computed using equation 1.2.

$$Cocoa\ yield = \frac{dry\ cocoa\ beans\ harvested\ in\ tons\ (t)}{size\ of\ cultivated\ farmland\ (ha)} \quad (1.1)$$

$$SOC\ conservation\ Intensity = \frac{dry\ cocoa\ beans\ harvested\ in\ tons}{size\ of\ cultivated\ farmland} \times \frac{1}{SOC} \quad (1.2)$$

The intensity of SOC conservation measures the amount of carbon conserved per cocoa yield. SOC % (g kg^{-1}) was determined using Walkley and Black (1934) (Walkley and Black., 1934).

In addition, binary numbers 1= Yes and 0 = No were used to represent socioeconomic indicator variables like gender (FSex) where female farmer = 1, male farmer = 0, and Nativity, where being a native farmer =1 or a migrant = 0. The same applies to the LT. The LT arrangements were outright and inherited farmland ownership and sharecropping systems such as 'abunu' and 'abusa'. The 'abunu' LT is where half (1/2) of the harvest goes to the landlord and "abusa" is where two-thirds (2/3) of the cocoa harvest belongs to the farmer.

Statistical analysis

Descriptive and inferential statistics were used to analyze the data. Descriptive statistics such as mean (μ), standard deviation (SD = σ) and percentages (%) were computed to describe the attributes of the farmers and their farms. The statistical analyses were done using R version 4.1.3 (R Core Team, 2019) while ArcGIS version 10.7 was used to map the cocoa farm polygons and their spatial distribution.

Due to freedom of farmers to establish farms in any suitable and acceptable location of their choice, an average nearest neighbor (ANN) statistic was used to determine the spatial distribution (clustering, randomness, or dispersion) of the OC and CC farms in each soil ecotype. If the ANN statistic is less than one (<1), near zero (0), and greater than one (>1), the spatial distribution is considered clustered, random, and dispersed, respectively. The ANN statistic was computed by dividing the observed average distance (d_0) and the expected average distance (d_e) between centroids of each farm polygon and the nearest neighbor using equations 2.1-2.3 (Naazie et al., 2024).

$$ANN = \frac{d_0}{d_e} \quad (2.1)$$

$$d_0 = \frac{\sum_{i=1}^{n} d_i}{n} \quad (2.2)$$

$$d_e = \frac{0.5}{\sqrt{n/A}} \quad (2.3)$$

The d_e assumes a random distribution while the d_0 is the actual distribution of the polygons. The d_i represents Euclidean distance (d) between a polygon, centroid (i) and its nearest neighbor, with n being the total number of polygons enclosed in each area (A). The area is the smallest rectangle enclosing the polygons, which implies the ANN statistic, and z-score are sensitive to the size of A. The ANN z-score was calculated as expressed in equation 3.1 (Naazie et al., 2024).

$$z\ Score = \frac{d_0 - d_e}{standard\ error} \qquad (3.1)$$

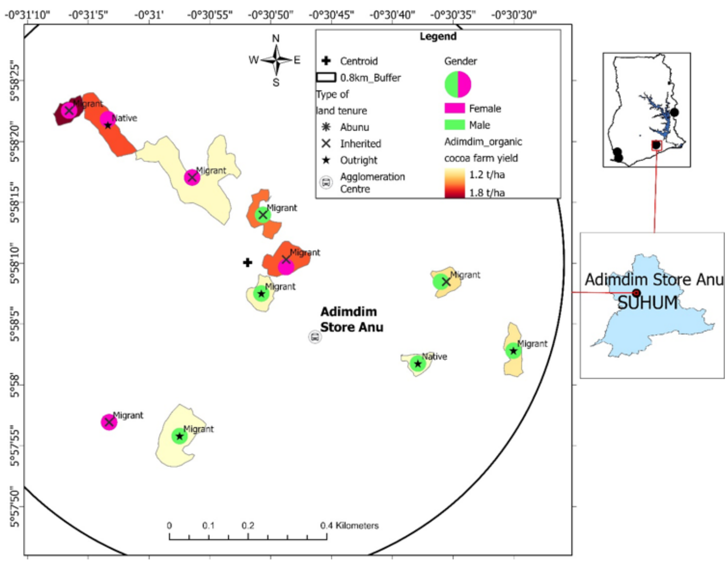
$$standard\ error = \frac{0.26136}{\sqrt{n^2/A}} \qquad (3.2)$$

Furthermore, parametric inferential statistical test of the mean cocoa yield difference was computed and tested using analysis of variance (ANOVA) for significant differences between OC and CC farm productivity. To ascertain gender difference in the cocoa yield (productivity), a non-parametric test of difference using Wilcoxon-Mann-Whitney rank sum test (McGee, 2018; Fagerland and Sandvik, 2009) was performed. This allowed the examination of the differences between male and female OC and CC productivity. The statistical significance of each test was determined at a 5% significance level.

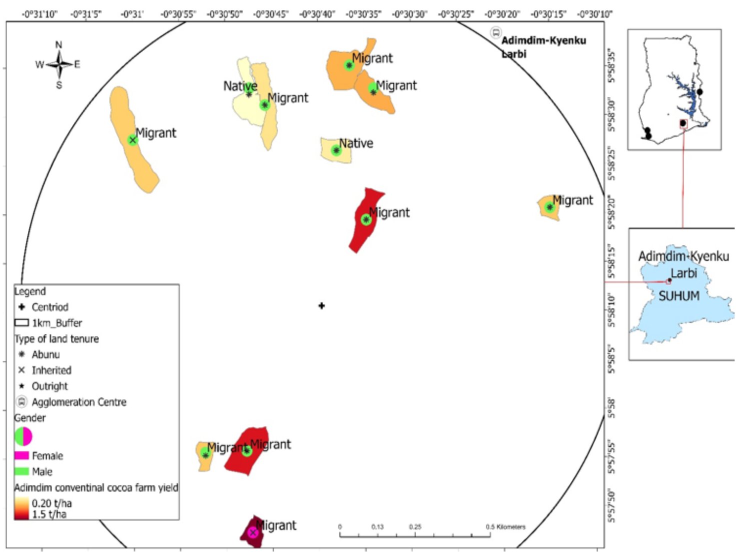
Results and Discussion

Figure 2 presents the spatial distribution of the organic (A1, B1, C1) and conventional (A2, B2) cocoa farms by locations, gender dynamics, and productivity(Figure 2).

(A1)



(B1)



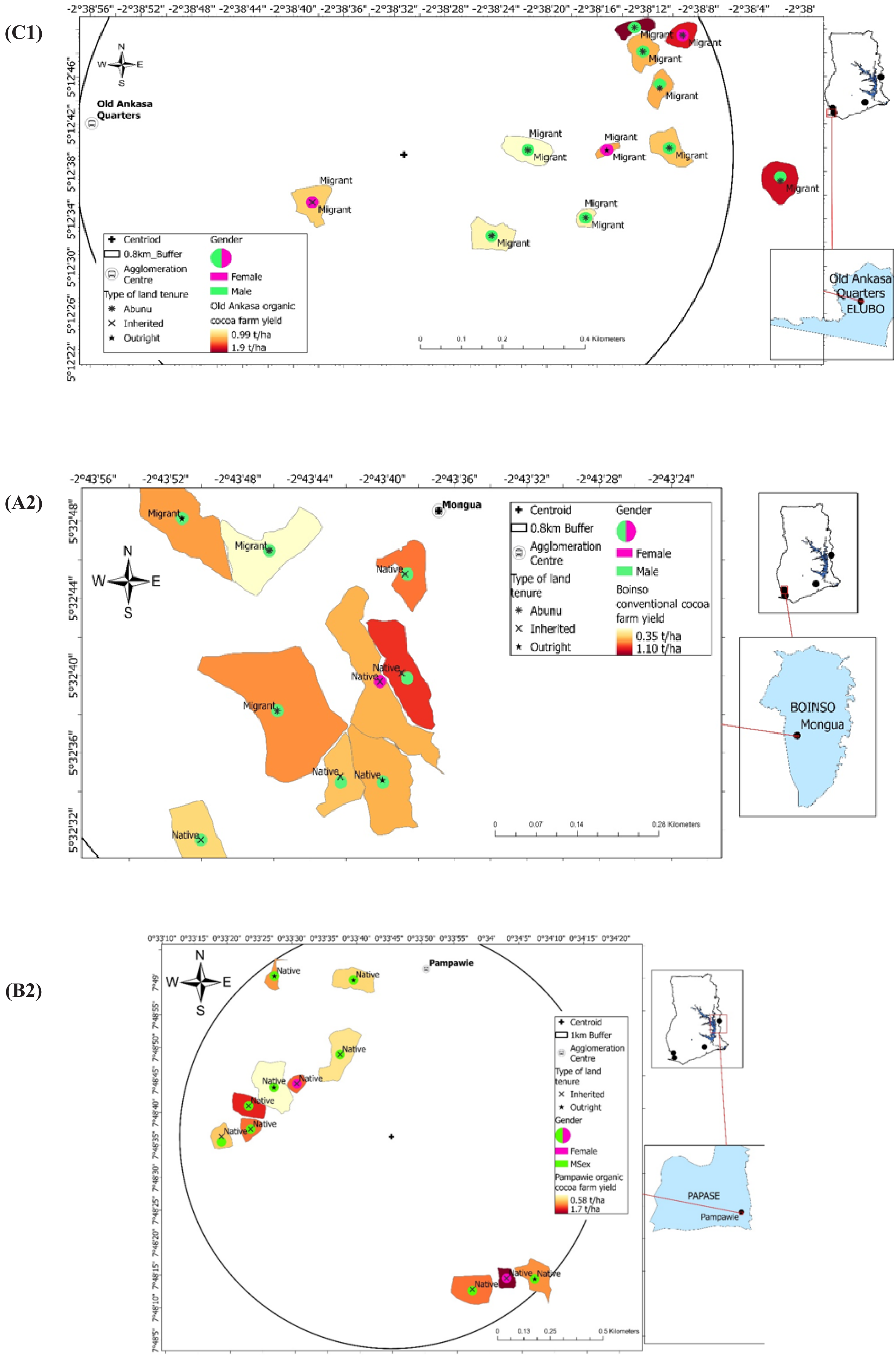


Figure 2 Geospatial and gender dynamics of organic (A1, B1 & C1) and conventional (A2, & B2) cocoa farms, productivity and agglomeration points in selected soil ecotypes. Old Ankasa Quarters and Mongua represent Ferralsols (Oxisols) of Wet Evergreen (WE) soil ecotype (FR.WE); Adimdim represents Lixisols (Alfisols) of Dry Semi-deciduous Inner Zone (DSIZ) soil ecotype (LX.DSIZ); Pampawie represents Leptosols (Entisols) of Moist Semi-deciduous South-East (MSSE) soil ecotype (LE.MSSE) in the Papase Cocoa District of the Oti Region (OR)

The locations of each cluster of farms represent the soil ecotypes while the proximity of between farms and the agglomeration center indicate the extent of dispersion rather than clustering. Some of the farms were in remote places and moribund (old or near-extinct) areas. Such moribund cocoa farming areas are suitable for cocoa rehabilitation and soil conservation. The observed dispersed distribution (Table 1) of the farms implies less agglomeration potential for the study area. The observed dispersed spatial distribution of farm locations is inconsistent with the findings of Popovici et al. (2022) and Schmidtner et al. (2012), who argued that clustering promotes agglomeration and facilitates development support. Although the general spatial distribution of both cropping systems was significantly (p <0.05) dispersed (Table 1), the OC farms exhibited more clustering than the CC farms. Also, female and male-owned farms were dispersed which limits information flow and spillovers to enhance their capacities (Figure 2). However, the proximity of the female cocoa farms depicts less dispersion (Figure 2 A1) within the organic agroforestry systems, which should contribute to information flow and spillovers to enhance their productivity capacities.

Farmers and scientists have always sought better ways to connect with others to harness their shared interests and resources for sustainable farming and development (Brevik et al., 2020). For instance, the connectivity of knowledge from agriculture research and extension services is better harnessed for maximum benefit among neighboring communities with similar socioeconomic

TABLE 1

Average nearest neighbor estimates of organic and conventional cocoa farms

Factors/statistics	**Soil ecotypes**					
	FR.WE		**LX.DSIZ**		**LE.MSSE**	
Point of agglomeration	Quarters Old Ankasa	Agric Boinso	Adimdim Store Anu	Adimdim Kyenku Larbi	Pampawie Sika Hene Fie	Pampawie Chief Farmer
Cropping system	OC	CC	OC	CC	OC	CC
Area covered by farms (m^2)	517981.7	238921.3	864383.0	1895494.9		
Observed Mean Distance (m):	190.6	121.3	160.8	193.1	200.6	170.6
Expected Mean Distance (m):	113.8	77.3	140.2	190.9	113.8	130.1
Average Nearest Neighbor (ANN) ratio	1.675	1.569	1.147	1.012	1.763	1.311
z-score:	4.085	3.445	0.933	0.080	5.015	4.185
p-value:	0.000	0.001	0.351	0.936	0.020	0.025
Distribution	dispersed	dispersed	random	random	dispersed	dispersed
Interpretation	Given the z-score (4.085), there is a less than 1% likelihood that the dispersed pattern could be the result of random chance.	Given the z-score (3.445), there is a less than 1% likelihood that the dispersed pattern could be the result of random chance	Given the z-score (0.933), the random pattern does not appear to be significant. In other words, the distribution is neither dispersed or clustering	Given the z-score (0.080), the random pattern does not appear to be significant. In other words, the distribution is neither dispersed or clustering	Given the z-score (5.015), there is a less than 5% likelihood that the dispersed pattern could be attributed to random chance.	Given the z-score (4.185), there is a less than 5% likelihood that the dispersed pattern could be attributed to random chance.

and gender attributes. The same applies to agricultural equipment and labour services such as cocoa farm spraying and weeding gangs in Ghana. Boosting clustering would be also essential to harness the benefits of collaborative partnerships (SDG17) among cocoa stakeholders in both organic and conventional cocoa agroforestry systems. Although farmers have the liberty to establish farms in acceptable places of their choice, doing so in proximity to other cocoa farms can be encouraged by demarcating cocoa cropping zones to improve the clustering and connectivity of the fragmented cocoa agroforest landscapes. Clustering and connectivity can extend biodiversity corridors for endangered species preservation in fragmented cocoa agroforest landscapes (Asare et al., 2014; Schroth and Harvey, 2007). As demonstrated in Figure 2, this type of biodiversity corridor landscape connectivity can be possible by improving the spatial proximity and clustering of the CAS between and within each soil ecotype. These biodiversity corridor landscapes can also serve as climate change adaptation and mitigation strategies. Furthermore, without reneging on tackling the observed socioeconomic and gender differences, a more all-inclusive and holistic sustainable development could be attained by addressing the observed limited spatial clustering and resource connectivity.

The spatial proximity (clustering or dispersion) of farms impacts socioeconomic factors (Bonfiglio and Arzeni, 2019; Malek et al., 2019). The male and female OC farmers in the LX.DSIZ (Table 1) were closer to each other (Figure 2: A1), but the same cannot be said for CC systems, locations, and soil ecotypes due to the uneven gender distribution. The remaining locations and cropping systems had more male relative to female cocoa farmers. This finding underscores the male dominance and labor-intensive nature of cultivating cocoa. Male-dominant cocoa production can be attributed to their physical strength so tend to cultivate more farmlands than women (Maduka et al., 2023; Aneani and Ofori-Frimpong, 2013).

The characterization of the observed OC and CC agroforestry systems revealed similar male and female socioeconomic attributes and differences (Tables 2 & 3), highlighting the state of gender parity and disparity. Generally, both farmers were approximately 51±15 years old, with a majority (57.0%) attaining college, middle, or junior high school level of formal education (Table 2). While there were no significant differences in the farmers' age,

TABLE 2

Socioeconomic attributes of cocoa farmers in the study area

Socioeconomic factors	Measurement	Organic cocoa (OC)	Conventional cocoa (CC)	Combined average
Female farmer (FSex) ***	1=Yes, 0=No	19%	22%	20%
Male farmer (MSex) ***	1=Yes, 0=No	81%	78%	80%
Farmer age (FAge)	Years	55 (14)	46.4 (13)	50.7 (14.6)
Cocoa training (Ext)	Frequency	4.9 (2.3)	3.22 (1.8)	4.06 (2.24)
Education (Edu)	None (1=Yes, 0=No)	34%	56%	20%
	Primary (1=Yes, 0=No)	43%	10%	23%
	College (1=Yes, 0=No)	23%	34%	57%
Farm size (FSize)	Ha	1.1 (1.1)	1.2 (0.63)	1.1 (0.89)
Cocoa yield***	t ha^{-1}	1.24 (0.39)	0.89 (0.38)	1.07 (0.42)

Figures in parentheses are standard deviations. ** significant at 5%; *** significant at 1%

TABLE 3
Gendered cultivated cocoa farmland productivity by nativity and land tenancy

Nativity/migrant status of farmer	Female (20%, n=13)	Male (80%, n=53)	Total (100%, n=66)
Abunu land tenancy	1.7±0.0 (7.7%)	1.0±0.5 (39.2%)	1.0±0.5 (32.8%)
Inherited land tenancy	1.3±0.3 (76.9%)	1.0±0.4 (33.3%)	1.1±0.4 (42.2%)
Outright land ownership	1.4±0.1 (15.4%)	1.0± 0.3 (27.5%)	1.0 0.3 (25.0%)
Overall cocoa yield	1.4± 0.3 (100%)	1.0± 0.4 (100%)	1.1± 0.4 (100%)
Migrant	1.5±0.2 (61.5 %)	1.1±0.4 (45.1%)	1.2±0.4 (48.4%)
Native	1.2±0.4 (38.5%)	0.9±0.4 (54.9 %)	1.0±0.4 (51.6%)

SD = standard deviation (±) of cocoa farm yield (t ha-1); Pearson Chi2(2) = 8.4064 (p = 0.015)

frequency of extension training (4), and farm size (1.1 ha) between the OC and CC systems, most of the cocoa farms were owned by males (80%) with only 20% female ownership (Table 3). The low percentage of female farm owners is probably because women, compared to men, have relatively lower access to relevant information on their land rights and ways of enforcing such rights. Their usufruct rights to land are usually contingent on inheritance or the continued goodwill of a man (chief, household head, brother, husband, or son) due to gender disparity. Thus, males dominated (4:1 male-female ratio) the cocoa landscape in this study. This 4-to-1 male-to-female gender distribution of cocoa farm ownership evidences a male-dominant cocoa sector, confirming findings by Jamal et al. (2021), Amon-Armah et al. (2021), and Daymond et al. (2017), contrary to the female dominance observed in the food crop subsector (Tsikata et al., 2022; Shiva, 2016). The current finding also aligns with Djokoto et al. (2017), who reiterated that gender differentials in farm ownership deprive women of resources and decision-making power. The situation leads to income disparities and limits the ability of the women to fend for themselves, and their children (Amanor et al., 2020; Djokoto et al., 2017; Aneani and Ofori-Frimpong, 2013; Oluyole and Sanusi, 2009).

Results from the present study also showed that most of the farmers were natives (51.6%) as opposed to migrants (48.4%), and the migrants were mostly females (61.5%). In addition, a significant relationship (Chi-square (2) = 8.406, p-value = 0.015) exist between the dominant male-female (4/1) gender ratio and their farmland tenancy. While a majority (67.2%) of the farmers inherited (42.2%) or outrightly owned (25.0%) the cocoa farmlands (Table 3), there were also 'abunu' sharecroppers (32.8%), indicating varied land tenancy and resource endowments. More male farmers owned cocoa farmland outrightly (27.7%) compared to the females (15.4%), however most (76.9%) of the female farmers inherited farmlands compared to the males (33.3%).

Therefore, recognizing male-dominant cocoa farm ownership is relevant for formulating equitable resource support systems towards reversing the imbalance toward attaining SDG 5.a.1. Women contribute enormously to cocoa farming at various stages, from planting to processing, however, the cocoa money belongs to the men (Adomaa, 2022). The resource endowment of the males enhances their technological and climate change adaptive capacities compared to the females (Jamal et al., 2021; Wrigley-Asante et al., 2019). Gender disparities also persist in other agroecosystems (Tsikata et al., 2022), however gendered support considerations are often overlooked due to the endemicity of patriarchy, disproportionate gender roles, and power, compounding the inequalities. The United Nations' Agenda 2030 SDGs (United Nations, 2015) articulate the relevance of gender equity (SDG 5) for sustainable farming (SDG 2), climate action (SDG 13), life on land (SDG 15), and partnership (SDG 17). Furthermore, promoting gender parity in organic/conventional farm ownership using ecofeminist philosophy is crucial for shaping equitable social development and sustainable agroecosystems in the cocoa sector. This can be achieved through deconstructing and reconstructing obsolete patriarchal cultural practices such as changing the cultural and legal norms that tie land ownership to men. In addition, advocating for policy reforms and legal recognition of women's land rights that allow women to inherit and own more cocoa farmlands.

It was also found that, the productivity of the few cocoa farms inherited (1.3 t ha^{-1}) and outrightly owned (1.4 t ha^{-1}) by the women was similar to male cocoa farmers (Table 3), indicating women's farmland ownership-induced management capability. There was a significant difference (*p-value*<0.05) between the land productivity (yield) of the female 'abunu' sharecroppers (1.7 t ha^{-1}) and the male (1.0 t ha^{-1}) 'abunu' sharecroppers. The average combined (pooled) yield of the OC and CC farms was 1.07 t ha^{-1} (Figure 3). Abbeam et al. (2020) (Danso-Abbeam et al., 2020) reported higher cocoa output among males (1.5t) compared to females (1.0t), but the current study revealed a gender-based cocoa yield difference in favour of women. However, the finding corroborates Okpokiri et al. (2016), who reported that female farmers outperform male farmers. The cocoa yield in farms owned by females surpassed the combined average yield (1.07 t ha^{-1}) of all male farmers, as well as the yields from the OC (1.22 t ha^{-1}) and CC (0.89 t ha^{-1}) systems.

The current study also revealed lower soil organic carbon (SOC) in the conventional cocoa (CC) agroforestry system compared to

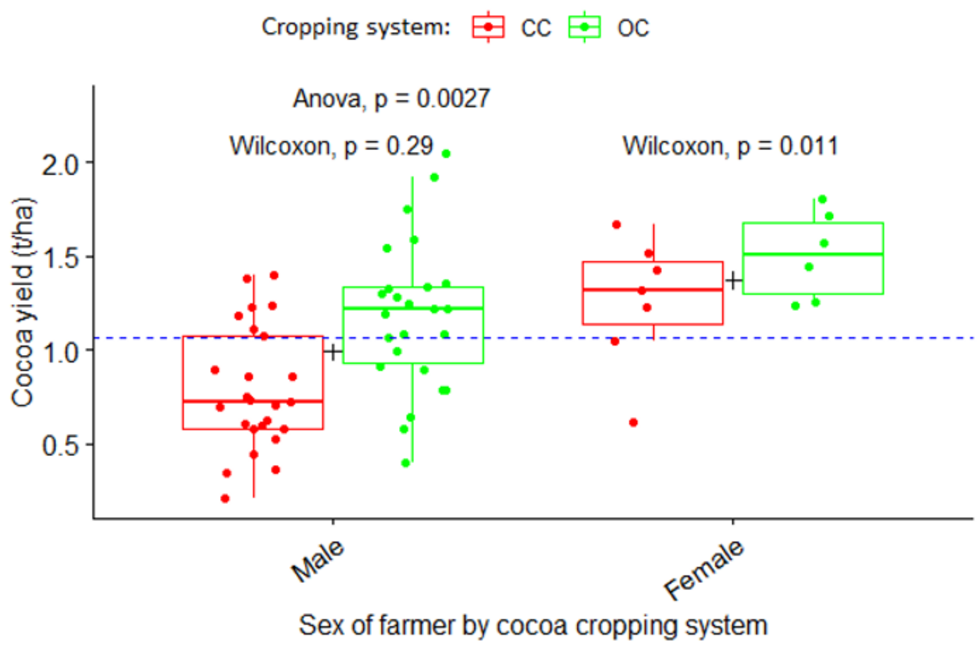


Figure 3 The annual cocoa yield of female and male farmers by cropping systems, dashes representing pooled average with + denoting average organic and conventional yield

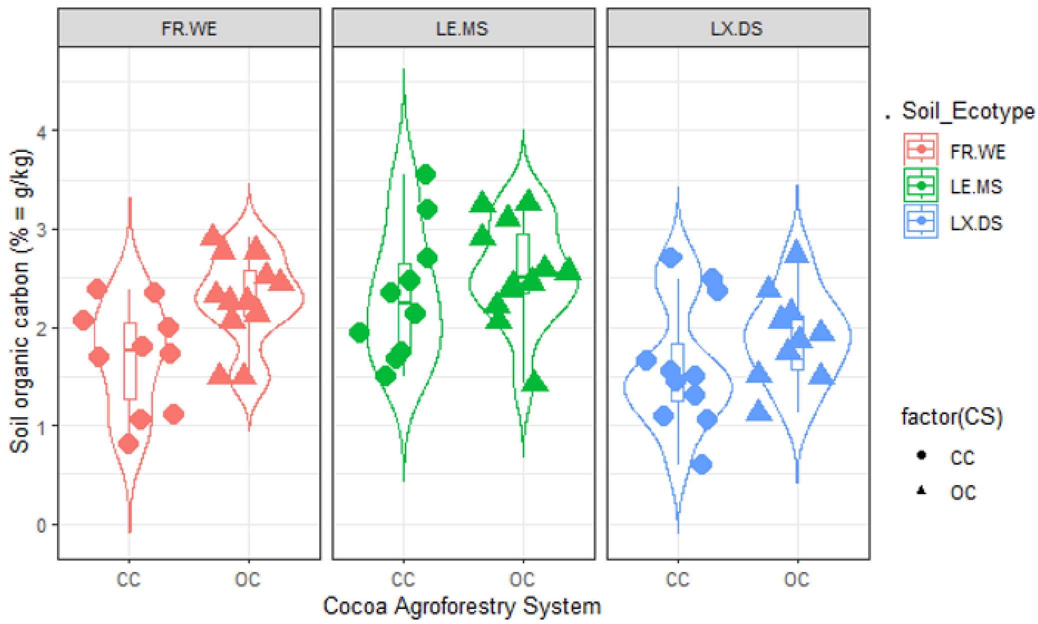


Figure 4 Soil organic carbon content of conventional cocoa (CC) and organic cocoa (OC) agroforestry systems across three soil ecotypes

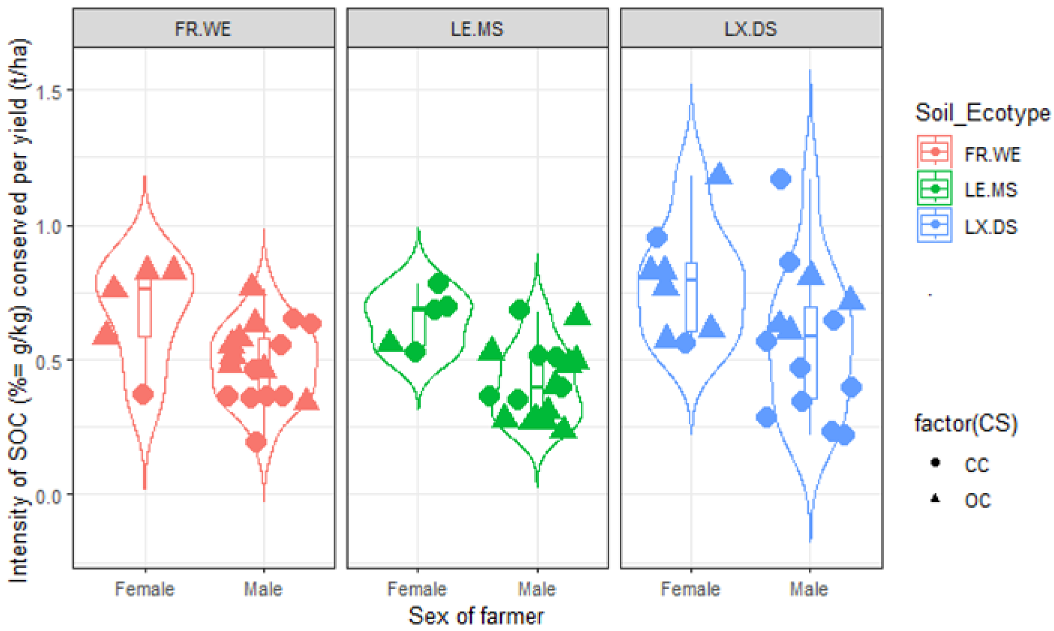


Figure 5 Soil organic carbon conservation intensity per yield by male and female farmers in organic cocoa (OC) and conventional cocoa (CC) agroforestry systems across three soil ecotypes

the organic cocoa (OC) across the three soil ecotypes (Figure 4). The observed dwindling levels of SOC of the soil ecotypes correlate inversely with weathered soil maturity sequence (LE.MSSE < LX.DSIZ < FR.WE) suggested by Doe et al., 2023; FAO and ITPS, (2015). The observed SOC distribution sequence of the soil ecotypes implies the older (FR.WE) soil ecotype had lower SOC compared to the younger one (LE.MSSE). It was also found that the SOC distribution across the soil ecotypes correlates with soil conservation intensity and cocoa productivity of the female farmers (Figure 5). The SOC conservation intensity index per cocoa yield harvested from the female-owned farms was higher than male-owned cocoa farms across the different cropping systems and soil ecotypes (Figure 5). Therefore, the difference in cocoa farm yield or land productivity between the male and female farmers could be attributed to the soil characteristics of the cropping systems (Doe et al., 2023). In addition, some previous studies have attributed higher cocoa yield of female-owned cocoa farms to smaller farm sizes, low-external inputs (Djokoto et al., 2017), and less use of agrochemicals, resulting in a conducive soil ecosystem for SOC and pH mediating soil fertility and productivity (Asigbaase et al., 2021, 2020, 2019). According to Bandanaa et al. (2021), positive social development occurs when women engage in organic cocoa farming. This social development role of women has been linked to their ability to manage nature better (Shiva, 2016; Tsikata et al., 2022), in the current case, soil organic carbon farming using the observed CAS. However, only 23.4% of women usually own their farms or have a secure tenancy for their agricultural lands (FAO, 2023). The higher cocoa farmland productivity of the few female farm owners relative to the males should justify mobilizing resources and intensifying development supports for women toward sustainable cocoa productivity enhancement.

One of the main gender sensitivity constraints to development is women's right to secure farm ownership (SDG5.a.1) to increase the share of female farmland ownership (SDG 5.a.2) in the cocoa subsector of Ghana. Securing farmland ownership and tenancy rights of cocoa farmers would lead to increased investment (Doe, 2013, 2006) and productivity (SDG 2.3) of both organic and conventional cocoa agroforestry systems. It would also be prudent in terms of mitigating the global environmental challenges of climate change (SDG13), ecosystem service (SDG 15), and soil security (Bouma, 2020) and ultimately improve the sustainability of the cocoa agroforestry systems.

Furthermore, cocoa stakeholders, especially Licensed Buying Companies (LBC) and development support partners (The Hershey, SNV, IDH, CARE, Mondelez, Cargill, Mars, etc.), are encouraged to ensure gender equity in development support. Popular support systems include farm input, credit, extension service, mapping, gang pruning, and weeding. The support delivery systems should recognize the random and dispersed spatial distribution of the organic and conventional cocoa farms to reach productive farms and farmers in remote areas. Following Ragasa et al. (2013 and Elias et al. (2012), extension services must not target only resource-rich male farmers.

Conclusions

This study highlights the spatial distribution of organic and conventional cocoa agroecosystems and examines the gender dynamics among women who outperform men in cocoa productivity. The socioeconomic characterization of male and female cocoa farms reveals significant differences, with men dominating the cocoa sector. Although we did not find significant clustering, which limits our ability to demonstrate whether geospatial clustering among cocoa farmers by gender could benefit from agglomeration effects related to proximity to resource service centers and growth poles, we did show that female cocoa farmers achieve higher productivity than their male counterparts. Female-owned cocoa farms yielded more cocoa beans per unit of land in their agroforestry systems, surpassing the combined yield of all farmers and yields from both organic and conventional systems. We conjecture that these disparities stem from variations in social, human, and capital resource endowments, which promote a male-dominated cocoa agroecosystem while perpetuating gender inequalities. Recognizing and supporting the contributions of female farmers to sustainable cocoa production in agroforestry systems is therefore, crucial. Cocoa stakeholders should implement spatially targeted initiatives to address gender disparities in resource endowments. These initiatives should include support for women in accessing farm resources such as inputs, credit, training, and technical knowledge. By doing so, the cocoa sector can benefit from increased productivity among women. We acknowledge that our results should be interpreted with caution, as our sample size is small and may not capture the full extent of disparities in clustering or dispersion among cocoa farms based on the gender of the farmers. Future studies with a larger sample size to further validate our findings are recommended.

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Author contribution

EKD: research idea, design and conceptualization, methodology; data curation; formal analysis, manuscript writing; EMA and PBO: academic supervision and scientific review, FA-A, MM, DAB, BYFM and FB: scientific review. BYFM is the corresponding author.

Conflict of interest statement

The authors declare that they have no conflict of interest.

Ethics statement

This study was reviewed and approved (ECH 231/21-22) by the Ethics Committee for Humanities, University of Ghana. The participants provided their written informed content to participate in the study.

Consent

Before the study commenced, permission was sought from the chiefs and elders of the communities as well as participants. No one was exposed to any psychological or physical risk.

Data Availability

Data is available upon request.

Consent for publication

All authors have read and approved the publication of this manuscript.

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