Agricultural Land Use Change in Ghana: First Evidence of Cocoa-to-Rubber Conversion Using Remote Sensing and Farmer Surveys

Nana Kwabena Darko
Cocoa Health and Extension Division, Ghana Cocoa Board, P. O. Box 3179 Accra, Ghana
Collins Oduro
prezduro@gmail.com

Department of Geography and Spatial Information Techniques, Ningbo University, Ningbo 315211, China
Emmanuel Yeboah
School of Remote Sensing and Geomatics Engineering, Nanjing University of Information Science and Technology, 210044 Nanjing, Jiangsu, China
Efiba Vidda Senkyire Kwarteng
lynnvid@yahoo.com

Department of Geomatic Engineering, Kwame Nkrumah University of Science and Technology, Ghana

---

Research Article

Keywords: Agricultural land use change, Agricultural Sustainability, Cocoa-to-Rubber Transition, Ghana Cocoa Sector, Remote sensing and GIS, Smallholder Farmers

Posted Date: June 3rd, 2025

DOI: https://doi.org/10.21203/rs.3.rs-6798890/v1

Additional Declarations: The authors declare no competing interests.

Abstract

Cocoa remains Ghana's principal cash crop and a livelihood source for over a million farmers. However, recent declines in yield, price volatility, and land pressure from illegal mining have diminished its economic appeal, leading to a shift toward more profitable alternatives like natural rubber. Here we show for the first time that rubber cultivation has significantly expanded in Ghana's Huni Valley, replacing 23.5% of former cocoa fields between 2008 and 2020. This study integrates remote sensing, GIS analysis, and farmer surveys to assess land use change and the socio-economic drivers of crop transition. Landsat imagery was used to classify land cover changes, while chi-square tests were applied to determine key decision-making factors among 390 farmers. Results reveal a 4.3% decline in cocoa coverage and a 4.8% increase in rubber plantations. The shift is significantly associated with farmer age, years of cocoa experience, and perceived profitability ($p < 0.05$). Farmers cited rubber's lower labor demands and higher, stable returns as critical incentives. The Huni Valley's agricultural landscape is undergoing structural change, driven by economic rationality and systemic challenges within the cocoa sector. This is the first comprehensive study combining spatial and social data to explain cocoa-to-rubber conversion in Ghana, offering new insights for land use policy and agricultural extension services. We recommend targeted interventions such as price stabilization, improved cocoa varieties, and land tenure reforms to counter the accelerating decline in cocoa production and ensure sustainable land use in Ghana's cocoa belt.

Introduction

Agriculture plays a pivotal role in Ghana's economy, contributing significantly to employment, food security, and export earnings. Cocoa (Theobroma cacao) remains the most critical cash crop, generating $2 billion annually in foreign exchange (USDA, 2025) and supporting the livelihoods of 800,000 farm families across 10 of Ghana's 16 regions. As of 2024, cocoa is the country's third-largest export commodity after gold and crude oil, highlighting its fiscal importance (USDA, 2025). Ghana ranks as the second-largest global cocoa producer after Côte d'Ivoire, and the crop is a major source of foreign exchange and fiscal stability. However, the sector faces existential threats from climate shocks (Wongnaa & Babu, 2020), disease outbreaks (Wessel & Quist-Wessel, 2015), and competition with illicit mining (galamsey) (Siaw et al., 2023). These challenges are exacerbated by declining yields. Ghana's cocoa production plummeted to 530,873 MT in 2023/2024, its lowest level in 15 years, due to erratic weather, disease, and labor shortages (USDA, 2025).

Declining yields, aging plantations, and increasing vulnerability to diseases such as the Cocoa Swollen Shoot Virus Disease (CSSVD) have significantly undermined the profitability of cocoa farming in Ghana (Amon-Armah et al., 2021). These biological constraints are further exacerbated by severe soil degradation (Doe et al., 2022). Recent studies estimate that Ghanaian cocoa soils achieve only 30% of their potential yield capacity (Amponsah-Doku et al., 2022). Environmental stressors are also compounding the problem; Oduro et al. (2025), highlight rising land surface temperatures as a critical factor in Ghana's climate variability, which poses growing threats to the stability of agricultural production. Simultaneously, external pressures such as illegal mining and land dispossession accelerate cocoa farm abandonment (Hirons et al., 2018). Siaw et al. (2023), describes coercive land acquisition tactics by miners, including deliberate flooding of adjacent farms and offering large one-time payments to force land sales. Similarly, Eberhard et al. (2022), report that repeated crop failures, coupled with delayed disbursement of subsidies from COCOBOD, are driving farmers to liquidate land assets or convert to more immediately lucrative alternatives such as mining or rubber cultivation. The cumulative impact of these ecological, economic, and institutional pressures is evident in the 2021/2022 cocoa season, which recorded a dramatic output decline of over 30%, primarily due to unfavorable weather conditions and intensified disease burden.

Concurrently, alternative crops, especially natural rubber (Hevea brasiliensis), have gained traction among Ghanaian farmers as cocoa yields decline due to climate stressors, soil degradation, and economic pressures. This mirror findings from Afele et al. (2024), where farmers adopted alternative strategies (e.g., agroforestry or crop switching) in response to climate-driven yield declines, with 17.5% resorting to non-agronomic interventions (e.g., selling land) as soils became unproductive. Rubber's appeal is compounded by its longer productive lifespan (25–30 years) contrasting with full-sun cocoa systems that degrade soils within 10–15 years (Amponsah-Doku et al., 2022) and its lower labor demands. Moreover, rubber benefits from structured market linkages (e.g., contract farming with GREL), while cocoa farmers face systemic challenges such as mismatched fertilizers (94% of Ghana's cocoa soils receive inappropriate inputs) and limited composting of cocoa waste to restore fertility (Amponsah-Doku et al., 2022). These dynamics have accelerated land-use shifts, particularly in the Western Region, where rubber plantations increasingly replace degraded cocoa farms.

The Huni Valley landscape within Ghana's Western Region exemplifies this shift. Historically, this area has been characterized by forest cover and cocoa cultivation but is undergoing rapid transformation due to agricultural diversification, mining, and urban expansion. The cutting down of cocoa trees and reallocation of land and labor resources to rubber cultivation by smallholder farmers has sparked concerns among policymakers and researchers regarding the long-term impacts on cocoa sustainability, national export earnings, and ecological balance. Thus, it is critical to understand the socio-economic motivations behind this shift.

This study addresses critical gaps in understanding farmers' crop diversification decisions, specifically the cocoa-to-rubber transition, by combining geospatial analysis with socioeconomic drivers, an approach lacking in previous research in Ghana. While studies like Eberhard et al. (2022), have documented land-use changes, and others (Acheampong et al., 2018; Hashmiu et al., 2022) have raised awareness about plantation conversions, our work advances the field in these key ways: First, this study applies remote sensing and GIS methodologies to quantify the spatial extent of conversion in Huni Valley, enabling targeted interventions. In addition to the biophysical mapping, the study also investigates the socio-economic drivers behind this trend. By integrating geospatial analysis with farmer perspectives, the research aims to provide a holistic understanding of land use transitions and offer practical recommendations for sustaining agricultural productivity and land resource management in

Ghana's cocoa belt. By aligning geospatial data with farmer perspectives, we seek to bridge the gap between "where" and "why" these transitions happen. In doing so, this research contributes directly to Sustainable Development Goal (SDG) 2.3, which aims to enhance the productivity and incomes of small-scale producers, and SDG 12.2, which promotes sustainable management and efficient use of natural resources. Gaining insights into these decision-making processes can help shape more responsive agricultural policies and extension services that align with farmers' needs and priorities.

Methods

2.1 Study area

The study was conducted in the Huni Valley Cocoa District, located in Ghana's Western Region (latitudes 5°09'–5°46' N, longitudes 1°39'–1°59' W). This district spans 1,453 km^2 and is part of the Prestea-Huni Valley Municipality, which covers 7% of the Western Region's land area (Prestea Huni-Valley Municipal Assembly, 2018). It borders Tarkwa to the west, Wassa Akropong to the northwest, and Daboase to the southeast (Fig. 1). As one of 15 cocoa districts under Ghana Cocobod's Cocoa Health and Extension Division (CHED), the region is a hub for cash crop production, including cocoa, rubber, oil palm, and citrus (Doe et al., 2022). Small-scale mining (legal and illegal) also contributes to local livelihoods but poses environmental challenges.

The area lies within Ghana's wet equatorial rainforest zone, characterized by bimodal rainfall: a major season (March–July) and a minor season (September–November), with mean annual precipitation of 1,878 mm like the rest of the South-Western Ghana (Oduro et al., 2022). Temperatures average 26–30°C year-round (Oduro et al., 2024), with 70–80% relative humidity. The climate supports dense tropical forests with canopy heights of 15–40 m, dominated by species such as Khaya (mahogany), Triplochiton scleroxylon (wawa), and Milicia excelsa (odum). However, forest reserves like Bonsa (160.6 km^2), Ben West (26 km^2), and Nkotoben (50 km^2) face threats from logging and mining.

The terrain is undulating, with elevations ranging from 150–300 m above sea level. Soils are acidic ($pH < 6.0$) due to leaching under high rainfall, limiting phosphorus and calcium availability but remaining suitable for cocoa, rubber, and staple crops like cassava and maize (Doe et al., 2022). The region is drained by perennial rivers (e.g., Ankobra) and seasonal streams (e.g., Peme, Opong), which support fishing and irrigation but are increasingly polluted by mining runoff. Agriculture dominates land use, with cocoa and rubber plantations expanding into formerly forested areas. The coexistence of these cash crops with smallholder food farms creates a fragmented landscape ideal for studying land-use transitions.

2.2 Materials and data sources

This study used both primary and secondary sources of data. Primary data were collected through interviews with key respondents (cocoa farmers who had fully or partially shifted their resources to rubber farming) and spatially referenced farm measurements (Ahmed, 2024) from Huni Valley Cocoa district office. The secondary data includes existing datasets from the United States Geological Survey website, the methodological framework designed for this study is illustrated in Fig. 2.

2. 3 Landsat images

The research used data listed in Table 1 and referenced data. Additionally, it shows the details of the data type and other materials used for the project with their respective sources. As Table 3.2 indicates, a Landsat 7 Thematic Mapper (TM) for 2008, and Landsat 8 Operational Land Imager and Thermal Infrared Sensor (OLI/TIRS) for 2020 with Path 194 and Row 56 were acquired from the United States Geological Survey (USGS) Earth Explorer website for classification and analysis. The images obtained had cloud cover of less than ten percent, with similar spatial resolution of 30m x 30m. Landsat images were employed because they covered the intended study periods and their spatial resolution is also good for land use classification (Sarfo, et al., 2022; Agarwal & Lambin, 2024). Also, to prevent seasonal differences in reflected radiation due to vegetation, Landsat images were obtained by considering the acceptable cloud cover, seasonality, and phenological effects (Dalu et al., 2025).

Table 1
The data type and source of data for the research work

S/N	Data Type	Source of Data
1	Landsat 7 (C2L1) and 8 (C2L2)	USGS Earth Explorer
2	Administrative boundary shape file	CHED
3	Cocoa Points (Training samples)	Ground Truthing (CHED)
4	Rubber Points (Training samples)	Ground Truthing (CHED)
5	Structured Questionnaire	Self-administered using KoboCollect

2.4 Reference data and interview questionnaire

Primary data were gathered through a structured interview questionnaire (refer to Supplementary material Appendix 1) using the Kobocollect Android app (https://kobotoolbox.org/nanached) and spatial data (ground truthing) from the Huni Valley cocoa district office. Collecting primary data allowed the researcher to tailor the data collection process to the specific needs of the study, ensuring the reliability and accuracy of findings (Sarfo et al., 2022). It also facilitated the integration of local ecological knowledge and community understanding into the decision-making process (Elves-Powell et al., 2024).

2.5.1 Clipping, geometric corrections, sub-setting and enhancements

The Landsat 7 and 8 images were imported into QGIS software, which is an open source for the preprocessing to take place. To extract the study area from the large scene/tile, image subsets or clipping were done in QGIS for all the images. This was done by using a vector shapefile of Huni Valley to extract or clip the region of interest which is the study area from the entire scene.

Radiometric corrections were done to aid the conversion of raw digital numbers (DN) to reflectance values, which involved atmospheric correction to remove the effects of the atmosphere on the sensor readings using absolute radiometric correction calibration and Simplified Atmospheric correction (SAC) model. Geometric correction was performed to align the images to a geographic coordinate system to ensure high accuracy. The images downloaded were almost cloud-free; especially the clipped area of interest, and therefore required no cloud masking processes.

After clipping the study area, individual bands were combined to form multispectral images, which can be viewed in different colour combinations (RGB combination). Upon careful examination, false colour composite was used to show all the land cover classes distinguishable on the images. For the purposes of visual legibility and interpretability of the images, subsetted images needed to be subjected to enhancements.

Subsequently, there was a need to improve the quality for image enhancement. The contrast stretching technique was used to improve the visual quality of the images. The band selection plays a major role in the LULC. The best band selection for Landsat 7 was Band 4 (Near-Infrared, NIR), Band 3 (Red), and Band 5 (Shortwave Infrared 1, SWIR) and that of Landsat 8 was Band 5 (Near-Infrared, NIR), Band 4 (Red), and Band 6 (Shortwave Infrared 1, SWIR).

2.5.2 Training Samples

Training samples were selected for classification from Hand-held GPS (Trimble Juno 3D and Stonex S4II) acquired survey data collected by the Cocoa Health and Extension Division of Ghana Cocobod (in its 2nd and 3rd Country-Wide Survey) and used to augment the crop classification further. High-resolution reference samples were obtained from Google satellite basemap in QGIS (Quick Map Service plug-in), with an equal number of 200 samples chosen for each class, based on successful outcomes from previous studies (Li et al., 2021).

Using the Semi-Automatic Classification Plug-in Dock (SPD) menu and tools in QGis 3.24.1, training samples were pinpointed using the ground reference points as a guide to mark specific areas involving either cocoa or rubber. The area of interest (study area) was extracted from the ESRI satellite basemap in QGIS (Quick Map Service) using the raster tool's "convert map to raster". The output raster map was then exported and given the required Coordinate Reference System (WGS 84/UTM zone 30N) to match all other datasets. The number of ground reference points for cocoa and rubber were 7,990 and 234 respectively, were gathered for research, covering classes such as Cocoa, Rubber, Forest and Bare land/Settlement. These classes were organized into Land Use Classes (Table 2).

Table 2
Land use classification scheme

Land Use Classes	Description of Land Use Classes
Cocoa Vegetation	Areas covered with cocoa
Rubber Vegetation	Areas with tree canopies of rubber plantation.
Forest	Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ
Built-ups and bare land	Includes physical structures such as residential, commercial areas industrial, roads, bare lands, etc.

2.6 Accuracy assessment

The last stage of the supervised classification process represents the final output stage. The final output of the classification process may either be produced as a thematic or classification map, with each map representing each class of interest. Land-use/cover classification relies on assessing the accuracy of classified data or output maps. Results may not accurately represent original data and may contain errors. Analysts must characterize these errors before use. Ground truthing, a widely recognized approach, involves collecting training data from sample sites through field reconnaissance.

This comparison uses an error matrix to quantify the accuracy of each categorized map, as well as the total map accuracy (overall accuracy), which combines all classes. Accuracy assessment signifies the reliability and replication of the thematic classification generated by the analyst's methods. In land-use/cover-related projects, an error matrix is generated to assess class accuracies based on the category of classes classified (Sarfo et al., 2023).

Accuracy was assessed quantitatively by calculating the overall accuracy (the ratio of correctly classified pixels to the total number of sampled pixels) and the kappa coefficient. The interpretation of the kappa values is as follows: a kappa value of less than 0 indicates no agreement; 0-0.2 indicates slight agreement; 0.2–0.41 indicates fair agreement; 0.41–0.6 indicates moderate agreement; 0.6–0.8 indicates substantial agreement, and 0.81-1.0 indicates almost perfect agreement. A kappa value of 1 indicates perfect agreement, whereas a kappa value of 0 indicates no agreement. The kappa coefficient was determined using Eq. 1.

$$\mathrm{k} = \frac{N\sum_{i=1}^{n} mi,i - \sum_{i=1}^{n}(GiCi)}{N^2 - \sum_{i=1}^{n}(GiCi)} \tag{1}$$

where i = the class number; n = the total number of classified pixels compared to the reference pixels;, i = the number of values belonging to the reference class i that have also been classified as class I (pixels found in both the reference and classified maps); Ci = the total number of predicted pixels belonging to class i; and Gi = the total number of reference pixels belonging to class i.

2.8 Assessment of change

The area for each land cover class was calculated from the pixel counts for each distinct class, and the corresponding percentages were determined. These values were then used to calculate the rate of change, the annual rate of change, and their respective percentages. The results were visually presented in graphs illustrating the rate of change. Equations 2 and 3 were used to calculate the annual rate of change and the percentage rate of change.

$$Annual\ Rate\ (A) = \frac{Area_{x+1}\ - Area\ x}{Tyears}$$

2

$$Percentage\ Rate = \frac{Annual\ rate\ of\ change}{\sum_{k=1}^{n} Area_x * Tyears} * 100$$

3

where $Area_x$ = Area of each class, $Area_{x+1}$= Area of the corresponding class in the preceding year, T_{years} = Difference in years, $\sum_{k=1}^{n} Area\mathrm{x}$ = Total area corresponding to each year.

2.9 Data analysis

This study analyzed the quantitative data using IBM SPSS version 27.0 for statistical analysis. The statistical results are presented in tables and charts. The data analysis involved statistical methods such as descriptive statistics and chi-square test to explore the level of statistical significance of some selected factors that influence farmers' decision-making to shift farm enterprise (Adnan et al., 2017). Supervised classification results of cocoa, rubber, forest and bareland/settlement areas are presented in maps and analysed using content analysis and visual interpretations as most aspects were qualitative, techniques similar to those applied by Eberhard et al. (2022) in Ghanaian agricultural landscapes.

2.10 Hypotheses and Chi-Square Test of Association

A chi-square test was used to examine the strength of association between certain factors (like demographic, economic, agro-economic, risk of production, farm characteristics) and a farmer's decision to switch resources from cocoa to rubber cultivation (Mchugh, 2013). The variables in this research were mostly categorical with nominal scale values.

A Chi-square test of association with Phi and Cramer's V results was used to determine the statistical significance of the association between a farmer's decision to switch from cocoa to rubber cultivation (the dependent variable) and each factor (the independent variable) that can influence that decision. The dependent variable (decision to switch or invest resources into rubber cultivation) was measured using the binary outcome, YES or NO. All the independent variables (the factors) were measured using either a four or five-point Likert scale of varying values, except gender and crop. Adnan et al. (2017), used a similar approach to analyze factors influencing Malaysian farmers' adoption of sustainable practices. The chi-square test for association was conducted under the following hypotheses:

$\varvec{H}_0$

Factors like individual, household and demographic characteristics, economic, agronomic, risk of production, farm characteristics and others have no association with farmers’ decision to change from cocoa to rubber.

$\varvec{H}_1$

Factors like individual, household and demographic characteristics, economic, agronomic, risk of production, farm characteristics and others have significant association with farmers’ decision to change from cocoa to rubber.

3.12 Sample Size and Sampling Technique

Yamane’s (1967) proposed a formula for determining the sample size in finite populations. The formula takes the form:

n = $\frac{N}{1+N(e)^2}$ Yamane (1967)

where: n is the sample size, N is the population size (19,000), e is the margin of error (often set to 5%). The sample size calculation was:

n = $\frac{19000}{1+19000(0.05)^2}$

n = 391.75

Therefore, the sample size for the study was 390 respondents. With respect to sampling technique, firstly, farmers within four selected communities were identified using either purposive or snowball sampling/referrals and chief farmers’ assistance.

Results

3.1 Land Use Classification and Change Detection

3.1.1 Land use maps and classification for 2008 and 2020

Land use land cover patterns of Huni Valley for the year 2008, and 2020 are depicted in Figs. 3a and 3b respectively. The supervised classification of Huni Valley for 2008 and 2020 revealed four distinct land use categories: cocoa, rubber, forest vegetation, and bareland/settlement. In 2008, cocoa cultivation covered 39.57% (57,493.35 ha) of the study area, while rubber accounted for 8.96% (13,015.53 ha). By 2020, Cocoa cultivation had declined to 35.26% (51,227.37 ha), whereas Rubber cultivation increased to 13.71% (19,917.81 ha). Forest Vegetation showed a slight increase from 45.81% (66,564.90 ha) in 2008 to 46.83% (68,047.92 ha) in 2020, while Bareland/Settlement decreased from 5.66% (8,225.82 ha) to 4.20% (6,109.29 ha) over the same period (Fig. 3). The classification accuracy was assessed using confusion matrices, yielding overall accuracies of 92.80% (Kappa = 0.88) for 2008 and 92.40% (Kappa = 0.88) for 2020, indicating high reliability in the classification results.

3.2 Land use change detection (2008–2020)

The transition analysis revealed significant shifts in land use between 2008 and 2020. Cocoa cultivation decreased by 4.31% (– 6,265.98 ha), while rubber cultivation increased by 4.75% (+ 6,902.28 ha). Forest vegetation experienced a marginal increase of 1.02% (+ 1,483.02 ha), and bareland/settlement declined by 1.46% (– 2,116.53 ha).

A notable finding was the conversion of 23.54% of cocoa areas to rubber, highlighting a trend of farmers replacing cocoa with rubber plantations (Fig. 4). This shift suggests economic and agronomic motivations driving land use changes in the region.

3.3 Land use classification accuracy assessment

The accuracy of the supervised classification technique employed in this study was evaluated for both 2008 and 2020. In 2008, the overall classification accuracy was 92.80%, with a Kappa Statistic of 0.88. By 2020, the overall accuracy was 92.40%, maintaining a Kappa Statistic of 0.88 (Tables 3). These results demonstrate a high level of agreement between the thematic maps generated from satellite images and the reference data. A Kappa Statistic of 0.88 indicates a substantial level of agreement, suggesting that the classification results are reliable and can be used confidently to analyze land use changes in the study area.

Table 3
Comparison of land use classification accuracy assessment for 2008 and 2020

Category	Year	Cocoa	Rubber	Forest	Bareland/ settlement	Total	User Accuracy %	Kappa
Cocoa	2008	184	4	6	4	198	92.93	0
	2020	156	8	6	6	176	88.64	0
Rubber	2008	3	37	4	1	45	82.22	0
	2020	3	59	0	7	69	85.51	0
Forest	2008	2	3	224	0	229	97.82	0
	2020	2	0	232	0	234	99.15	0
Bareland/ settlement	2008	3	5	1	19	28	67.86	0
	2020	2	2	2	15	21	71.43	0
Total	2008	192	49	235	24	500	0.00	0
	2020	163	69	240	28	500	0.00	0
Producer Accuracy %	2008	0.96	0.76	0.95	0.79	0.00	92.80	0.00
	2020	0.96	0.86	0.97	0.54	0	92.40	0
Kappa		0	0	0	0	0	0	0.88

3.4 Change detection of areas converted from cocoa to rubber

The spatiotemporal analysis of land use changes between 2008 and 2020 (Fig. 3a and 3b) revealed a substantial directional conversion of agricultural land from cocoa to rubber cultivation in the Huni Valley. Quantitatively, an estimated 13,532.04 hectares, representing 23.54% of the cocoa-covered area in 2008, had been transitioned into rubber plantations by 2020 (Fig. 5). In contrast, only 6,783.46 hectares of land previously used for rubber were converted back into cocoa during the same period. This net gain of 6,748.58 hectares for rubber cultivation highlights a marked shift in land use preference.

3.5 Factors influencing farmers' decisions to shift from cocoa to rubber

To investigate the drivers behind the transition from cocoa to rubber cultivation, structured interviews were conducted with 390 farmers in Huni Valley. The survey revealed a striking trend: all respondents had adopted rubber farming, with 22.3% (87 farmers) abandoning cocoa entirely for rubber monocropping, while the majority (77.7%, 303 farmers) opted for mixed cocoa-rubber systems (Fig. 6).

3.6 Drivers of cocoa farm decline

The transition from cocoa to rubber cultivation was strongly influenced by the distribution of farm sizes (Fig. 7a). First, the predominance of smallholder operations created inherent disadvantages, over half (52.06%) of respondents cultivated cocoa on plots smaller than 2.5 acres, significantly below the West African average of 7–10 acres. These suboptimal farm sizes limit economies of scale while requiring intensive labor inputs. Second, land tenure arrangements played a dual role in shaping investment behavior and crop transition dynamics. Inherited landholders (28.2% of respondents) typically had more flexibility to convert farms, while those operating under sharecropping and contract-based agreements faced significant disincentives to invest in long-term cocoa rejuvenation, such as replanting or soil fertility improvement. In total, 52.3% of cocoa farms were cultivated under such temporary or insecure arrangements, severely constraining farmer autonomy.

To further explore this complexity, we cross-tabulated land tenure type with ownership arrangements (Table 4). The data reveal that insecure tenure arrangements cut across all forms of land acquisition. For instance, even among farmers who had purchased land outright, 47 out of 93 (over 50%) reported farming under sharecropping or contract conditions. Similarly, 54 out of 110 inherited landholders operated without full ownership control. These findings highlight how layered and fragmented tenure systems not only undermine security but also restrict land use flexibility and investment. Factors that make the transition to rubber, with its lower maintenance requirements and higher returns, are more appealing. Most critically, profitability concerns emerged as the decisive factor driving farm abandonment or conversion (Fig. 7b). Only 7.9% of farmers considered cocoa farming very profitable, while 81.1% reported marginal or negative returns.

Table 4
Cross-tabulation of Cocoa Land Tenure Type by Ownership Arrangement

Cross-tabulation of ownership type by tenancy status					
Land tenancy type	**Self-owned**	**Family-owned**	**Share-cropping with landowners**	**Contract**	**Total**
Inherited	26	30	22	32	**110**
Family land	14	22	26	30	**92**
Lease	25	23	21	26	**95**
Purchased	23	23	28	19	**93**
Total	**88**	**98**	**97**	**107**	**390**

3.7 Economic appeal of rubber cultivation

The large-scale adoption of rubber farming reflected its compelling advantages as an alternative cash crop. Unlike cocoa's labor-intensive daily, daily harvesting, and post-processing requirements, rubber's latex extraction needed only intermittent labor (2–3 days weekly), making it particularly attractive to the region's aging farmer population (mean age: 57.3 years). The crop's scalability was evidenced by 76% of respondents cultivating more than 1 acre of rubber, with many leveraging its lower maintenance needs to expand operations. Critically, rubber offered superior and more stable returns – 68.7% of farmers rated it very profitable compared to just 7.9% for cocoa (Fig. 8ab), reflecting both higher yields per acre and guaranteed buy-back agreements through Ghana Rubber Estates Ltd. This price stability proved decisive, with World Bank data showing rubber prices grew steadily at 4.2% annually (2015–2022) while cocoa prices fluctuated wildly (± 12%). The transition was further facilitated by farmers' ability to transfer existing land tenure arrangements from cocoa to rubber, with 23.8% eventually purchasing land outright for rubber cultivation compared to 22.6% for cocoa.

3.8 Synthesis of transition dynamics

Farmers facing structural constraints in cocoa production (small plots, labor intensity, and declining margins) increasingly viewed rubber as a sustainable alternative offering better labor efficiency, price stability, and income potential. While some maintained cocoa as a risk diversification strategy (77.7% practicing mixed cropping), the clear profitability advantage explains why 22.3% converted entirely to rubber. These findings suggest that without interventions to improve cocoa's competitiveness through better pricing, input subsidies, or yield-enhancing technologies, the transition to rubber will likely accelerate, with significant implications for Ghana's agricultural landscape and cocoa production targets.

3.9 Farmers' decisions to transition from cocoa to rubber cultivation

To identify the socio-economic factors significantly associated with farmers' decisions to transition from cocoa to rubber cultivation, the Pearson chi-square test of independence was employed. The results are summarized in Table 4.13. Among the variables tested, three factors exhibited statistically significant associations at the 5% significance level. These were: age of the farmer ($\chi^2 = 7.57$, $p = 0.04$), years of experience farming cocoa ($\chi^2 = 8.02$, $p = 0.04$). Perceived profitability of cocoa farming investment outcomes ($\chi^2 = 6.02$, $p = 0.03$). These findings suggest that older cocoa farmers, those with longer tenure in cocoa cultivation, and those who perceive cocoa as less profitable are significantly more inclined to shift toward rubber cultivation. This aligns with broader trends in agrarian transition, where seasoned farmers often reassess crop choices based on long-term performance and risk.

In contrast, the analysis revealed no statistically significant associations for other variables, including gender ($\chi^2 = 0.74$, $p = 0.79$), education level ($\chi^2 = 6.54$, $p = 0.26$), household size ($\chi^2 = 0.36$, $p = 0.99$), size of cocoa farms, farm ownership type, and investment requirements for pest and disease control. These non-significant results suggest that such factors may not play a central role in influencing the crop-switching decision in this context.

Although significant p-values were observed, the effect sizes indicated by Phi or Cramér's V statistics were generally small (ranging between 0.03 and 0.04 for significant variables), indicating weak associations. Therefore, while age, farming experience, and profitability perception are important, they are likely part of a broader constellation of factors influencing farmer behavior.

Table 5
Chi-square test results – association between selected factors and farmers' decision to switch from cocoa to rubber

Factor	χ^2 (Chi-square)	df	p-value	Phi/Cramér's V
Gender	0.74	1	0.79	0.88
Age	7.57	3	0.04 **	0.03
Education	6.54	5	0.26	0.23
Size of household	0.36	4	0.99	0.99
Years of farming	8.02	3	0.04 **	0.04
Size of farm	1.58	3	0.66	0.67
Ownership type	4.92	3	0.18	0.18
Profitability	6.02	3	0.03 **	0.03
Investment demand/farm maintenance	0.055	1	0.81	1
**** = statistical significance at $p < 0.05$.**				

Discussion

This study examined agricultural land use change in the Huni Valley area of Ghana, focusing on the shift from cocoa to rubber cultivation among smallholder farmers. The findings reveal a complex interaction of land use trends, economic motivations, and farmer demographics driving this transition. Remote sensing analysis, survey data, and statistical testing provide a multi-dimensional view of this evolving agricultural landscape.

4.1 Land use transitions and spatial patterns

The land use classification and change detection between 2008 and 2020 highlight a clear trend of agricultural conversion, with cocoa land decreasing by 4.31% and rubber land expanding by 4.75%. The conversion of 23.54% of former cocoa areas into rubber plantations is particularly noteworthy, indicating not only a shift in crop preference but a reconfiguration of the region's agronomic profile. These findings are consistent with regional and global trends where smallholder farmers pivot toward more profitable or lower-risk cash crops in response to economic and environmental pressures (Fox, 2014; Wessel & Quist-Wessel, 2015).

The classification accuracy (Kappa = 0.88 for both years) confirms the reliability of these observations and validates the application of supervised classification techniques in agricultural land monitoring. The observed increase in forest cover, although modest, may suggest either natural regeneration or strategic reforestation, potentially linked to fallowing or sustainability programs. The decline in bareland/settlement could reflect increasing land productivity or shifting spatial patterns of rural habitation.

4.2 Cocoa-to-rubber transition: economic drivers and farmer behavior

The switch from cocoa to rubber cultivation is rooted in economic rationality but also reflects systemic vulnerabilities in Ghana’s cocoa sector. Rubber farming was perceived as significantly more profitable by 68.7% of respondents (vs. 7.9% for cocoa), with lower labor demands and stable market prices appealing to aging farmers (Koffi et al., 2024). This mirrors regional trends, such as the 31.97% rubber expansion in Côte d’Ivoire (2016–2024), highlighting structural shifts in West African agro-economies. However, these transitions are not purely voluntary. As Siaw et al. (2023) demonstrate, cocoa farmers facing "agricultural poverty" due to inflation, low yields, and insecure tenure are often forced into distress-driven decisions, whether selling land to miners (galamsey) or pivoting to rubber. Eberhard et al. (2022) corroborate this, showing how crop failures (e.g., fungal outbreaks) and COCOBOD’s delayed input subsidies push farmers toward immediate cash alternatives (mining or rubber), even if long-term outcomes are precarious.

These profitability concerns are compounded by structural challenges in cocoa farming (Teye et al., 2024). Over half of the farmers surveyed cultivated on less than 2.5 acres, far below the regional average, limiting their ability to achieve economies of scale. Insecure land tenure further exacerbated the problem; the majority of cocoa farms were operated under tenancy or sharecropping arrangements, which disincentivize long-term investment in farm maintenance or replanting (Addaney et al., 2022). In contrast, rubber cultivation was often facilitated by more secure or transferable tenure arrangements, with many farmers eventually purchasing land outright for rubber expansion.

These results resonate with literature on livelihood adaptation strategies under agrarian stress. Farmers in West Africa and Southeast Asia have increasingly adopted rubber as a resilient crop choice in response to declining returns in traditional crops like cocoa or coffee (Bymolt et al., 2018). The ability of rubber to offer consistent income, reduced input costs, and established market linkages (e.g., Ghana Rubber Estates Ltd.) enhances its appeal among smallholders seeking financial stability (Fox et al., 2014).

4.3 Sociodemographic correlates with switching behavior

Chi-square tests of association revealed that age, years of cocoa farming, and perceived profitability of cocoa farming were significantly associated with the decision to switch to rubber cultivation. Older farmers and those with longer experience in cocoa farming were more likely to shift, potentially due to accumulated knowledge of cocoa’s declining profitability and a desire for less labor-intensive alternatives. The preference for rubber among older farmers (mean age: 57.3 years) mirrors Teye et al.’s (2025) observation that aging cocoa farmers resist labor-intensive innovations (e.g., pruning, fertilizing).

Rubber’s lower maintenance requirements thus offer a pragmatic alternative. Farmers perceiving cocoa as less profitable were also significantly more inclined to convert to rubber.

These findings align with prior studies showing that farm-level decision-making is influenced not only by market forces (Vigneri, 2018) but also personal and experiential factors, including risk perception, opportunity cost, and physical capacity (Kolavalli & Vigneri, 2011). However, effect sizes (Phi/Cramér’s V) were low, suggesting that while these variables are statistically significant, their influence may be modest and mediated by other unmeasured factors (Vigneri & Kolavalli, 2018).

Notably, factors such as gender, education level, household size, farm size, and investment costs for pest control showed no significant association with switching behavior. This indicates that demographic or resource-based variables alone may not sufficiently explain the transition, underscoring the need to consider a broader constellation of motivations, including access to credit, market contracts, extension services, and peer influence (Kongor et al., 2018; Quaye et al., 2021).

4.4 Broader implications for policy and land use planning

The shift from cocoa to rubber presents both opportunities and challenges for Ghana's agricultural sector. While rubber offers short-to-medium-term economic benefits for individual farmers (Fox et al., 2014), widespread adoption raises critical questions about cocoa sustainability, export diversification, and land use planning (Vigneri & Kolavalli, 2018). Given cocoa's importance to Ghana’s economy and foreign exchange earnings, continued conversion could threaten national production targets unless counterbalanced by policies that enhance cocoa's profitability and resilience (Kongor et al., 2018). Like Côte d’Ivoire, where rubber adoption followed cocoa market volatility (Koffi et al., 2024), Ghana’s farmers prioritize crops with stable returns. National interventions such as cocoa price stabilization or rubber-agroforestry incentives could mitigate unsustainable transitions (Teye et al., 2024).

Policymakers and agricultural extension services must consider targeted interventions to sustain cocoa cultivation, including input subsidies, yield-boosting technologies, and tenure reforms (Gyan & Bajan, 2022). This aligns with farmers in Huni Valley citing low cocoa profitability (7.9% ‘very profitable’) as a key reason for shifting to rubber, a crop less dependent on state-supported inputs. In parallel, a more integrated land use policy is needed to balance economic development with ecological sustainability, particularly as rubber expansion may influence biodiversity, water cycles, and carbon storage differently than cocoa-based agroforestry systems.

The decline of cocoa in Huni Valley reflects not only farmer preferences for rubber’s profitability and lower labor demands but also external pressures from artisanal mining. Siaw et al. (2023) document how “galamsey” operators coerce landowners into selling cocoa farms, degrading fertile lands and displacing smallholders. This parallels our findings of cocoa’s diminishing appeal, suggesting Ghana’s cocoa sector faces a crisis of both economic viability and physical encroachment (Wongnaa & Babu, 2020). While rubber’s market stability attracts farmers, cocoa’s decline could be reversed through targeted subsidies, as seen in Côte d’Ivoire (Koffi et al., 2024). However, such measures must also address competition from ASM. Siaw et al. (2023) propose that Ghana Cocoa Board's village loan programs could deter land sales to miners by improving short-term liquidity for farmers. Coupled with cocoa price stabilization, this would make cocoa competitive with rubber and mining economies (Jung et al., 2020).

Conclusion

This study provides the first integrated spatial and social evidence of cocoa-to-rubber land use transitions in Ghana's Huni Valley. Between 2008 and 2020, 23.5% of cocoa farms were converted to rubber, driven primarily by declining cocoa profitability, aging farmer populations, and rubber's market appeal. Here we show that structural limitations in cocoa farming such as small plots, insecure tenure, and low returns are triggering a rational and economically motivated shift toward rubber. The statistically significant associations between transition behavior and factors like age and experience highlight the importance of farmer perception and long-term viability in shaping land use decisions. Without targeted interventions price stabilization, input support, and secure tenure the shift away from cocoa will likely intensify. These findings offer crucial policy insights for securing Ghana's cocoa economy and promoting sustainable land use strategies.

Declarations

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

Ethical Approval

Informed consent was obtained from all individual participants included in the study.

References

1. Acheampong, P. P., Owusu, V., & Nurah, G. (2018). How does Farmer Preference matter in Crop variety Adoption? the case of Improved Cassava varieties' Adoption in Ghana. *Open Agriculture*, *3*(1), 466–477. https://doi.org/10.1515/opag-2018-0052
2. Addaney, M., Akugudu, J. A., Asibey, M. O., Akaateba, M. A., & Kuusaana, E. D. (2022). Changing land tenure regimes and women's access to secure land for cocoa cultivation in rural Ghana. *Land Use Policy*, *120*(January 2021), 106292. https://doi.org/10.1016/j.landusepol.2022.106292
3. Adnan, N., Md Nordin, S., Rahman, I., & Noor, A. (2017). Adoption of green fertilizer technology among paddy farmers: A possible solution for Malaysian food security. *Land Use Policy*, *63*, 38–52.

https://doi.org/10.1016/j.landusepol.2017.01.022

4. Agarwal, S., & Lambin, E. F. (2024). Interventions to control forest loss in a swidden cultivation landscape in Nan Province, Thailand. *Regional Environmental Change*, *24*(3), 1–15. https://doi.org/10.1007/s10113-024-02286-5
5. Agrawal, T., Hirons, M., & Gathorne-Hardy, A. (2021). Understanding farmers' cropping decisions and implications for crop diversity conservation: Insights from Central India. *Current Research in Environmental Sustainability*, *3*, 100068. https://doi.org/10.1016/j.crsust.2021.100068
6. Ahmed, A. (2024). Land abandonment after land grabbing: exploring the implications for local climate change adaptation and ecological restoration in Ghana. *Regional Environmental Change*, *24*(2), 1–13. https://doi.org/10.1007/s10113-024-02232-5
7. Amon-Armah, F., Domfeh, O., Baah, F., & Owusu-Ansah, F. (2021). Farmers' adoption of preventive and treatment measures of cocoa swollen shoot virus disease in Ghana. *Journal of Agriculture and Food Research*, *3*(January), 100112. https://doi.org/10.1016/j.jafr.2021.100112
8. Amponsah-Doku, B., Daymond, A., Robinson, S., Atuah, L., & Sizmur, T. (2022). Improving soil health and closing the yield gap of cocoa production in Ghana – A review. *Scientific African*, *15*, e01075. https://doi.org/10.1016/j.sciaf.2021.e01075
9. Bymolt, R., Laven, A., & Tyszler, M. (2018). Demystifying the cocoa sector in Ghana and Côte d'Ivoire. Chapter 8, Cocoa Cocoa production practices. *Gender and Cocoa*, 145–175. Retrieved from https://www.kit.nl/wp-content/uploads/2019/09/Demystifying-cocoa-sector-chapter14-gender-and-cocoa.pdf
10. Dalu, T., Oduro, C., Matsimela, R. M., Munyai, L. F., Wu, N., Moyo, S., & Cuthbert, R. N. (2025). Macroplastic distribution patterns and accumulation in an urbanised Austral subtropical river system. *Scientific Reports*, *15*(1), 1–15. https://doi.org/10.1038/s41598-025-94282-w
11. Doe, E. K., Attua, E. M., Dogbatse, J. A., & Fosu-Mensah, B. Y. (2022). Assessing the condition and capability of soils in cocoa districts of Ghana using geovisualization. *Soil Security*, *7*(February), 100058. https://doi.org/10.1016/j.soisec.2022.100058
12. Eberhard, E. K., Hicks, J., Simon, A. C., & Arbic, B. K. (2022). Livelihood considerations in land-use decision-making: Cocoa and mining in Ghana. *World Development Perspectives*, *26*(May 2020), 100417. https://doi.org/10.1016/j.wdp.2022.100417
13. Elves-Powell, J., Dolan, J., Durant, S. M., Lee, H., Linnell, J. D. C., Turvey, S. T., & Axmacher, J. C. (2024). Integrating local ecological knowledge and remote sensing reveals patterns and drivers of forest cover change: North Korea as a case study. *Regional Environmental Change*, *24*(3), 1–14. https://doi.org/10.1007/s10113-024-02254-z
14. Fox, J. (2014). Through the technology lens: The expansion of rubber and its implications in Montane Mainland Southeast Asia. *Conservation and Society*, *12*(4), 418–424. https://doi.org/10.4103/0972-4923.155587
15. Fox, J., Castella, J.-C., Ziegler, A. D., & Westley, S. B. (2014). Expansion of rubber mono-cropping and its implications for the resilience of ecosystems in the face of climate change in montane mainland

Southeast Asia. *Global Environmental Research*, *18*(2), 145–150.

16. Gyan, J. K., & Bajan, B. (2022). Market analysis on cocoa beans export: The case of Ghana and Cote d'Ivoire in West Africa. *Journal of Agribusiness and Rural Development*, *66*(4), 375–384. https://doi.org/10.17306/j.jard.2022.01646
17. Hashmiu, I., Agbenyega, O., & Dawoe, E. (2022). Determinants of crop choice decisions under risk: A case study on the revival of cocoa farming in the Forest-Savannah transition zone of Ghana. *Land Use Policy*, *114*(December 2021), 105958. https://doi.org/10.1016/j.landusepol.2021.105958
18. Hirons, M., McDermott, C., Asare, R., Morel, A., Robinson, E., Mason, J., et al. (2018). Illegality and inequity in Ghana's cocoa-forest landscape: How formalization can undermine farmers control and benefits from trees on their farms. *Land Use Policy*, *76*(February), 405–413. https://doi.org/10.1016/j.landusepol.2018.02.014
19. Jung, J. M., Byeon, D. hyeon, Kim, S. H., Sunghoon-Jung, & Lee, W. H. (2020). Estimating economic damage to cocoa bean production with changes in the spatial distribution of Tribolium castaneum (Herbst) (Coleoptera: Tenebrionidae) in response to climate change. *Journal of Stored Products Research*, *89*, 101681. https://doi.org/10.1016/j.jspr.2020.101681
20. Kolavalli, S., & Vigneri, M. (2011). Cocoa in Ghana : Shaping the Success of an Economy. *Yes Africa Can*, (January 2011), 201–217. Retrieved from http://books.google.dk/books?id=4LlaYqIyAWAC&pg=PA201&a mp;lpg=PA201&dq=chapter+12+cocoa+in+ghana&source=bl&ots=DTCx H1iE9x&sig=fFiYp0zRfJvjDsliB1yXIW x8UfA&hl=no&sa=X&ei=C4_vU7OxE4PuyQPG2YLoDw&ved=0CCwQ6AEwAQ#v=onepage&q=chapter 12 cocoa in ghana&f=false
21. Kongor, J. E., De Steur, H., Van de Walle, D., Gellynck, X., Afoakwa, E. O., Boeckx, P., & Dewettinck, K. (2018). Constraints for future cocoa production in Ghana. *Agroforestry Systems*, *92*(5), 1373–1385. https://doi.org/10.1007/s10457-017-0082-9
22. Li, C., Ma, Z., Wang, L., Yu, W., Tan, D., Gao, B., et al. (2021). Improving the accuracy of land cover mapping by distributing training samples. *Remote Sensing*, *13*(22). https://doi.org/10.3390/rs13224594
23. Mchugh, M. L. (2013). The Chi-square test of independence Lessons in biostatistics. *Biochemia Medica*, *23*(2), 143–9. Retrieved from http://dx.doi.org/10.11613/BM.2013.018
24. Oduro, C., Shuoben, B., Ayugi, B., Beibei, L., Babaousmail, H., Sarfo, I., et al. (2022). Observed and Coupled Model Intercomparison Project 6 multimodel simulated changes in near-surface temperature properties over Ghana during the 20th century. *International Journal of Climatology*, *42*(7), 3681–3701. https://doi.org/10.1002/joc.7439
25. Oduro, C., Bi, S., Wu, N., Agyemang, S., Baidu, M., Babaousmail, H., et al. (2024). Estimating surface air temperature from multiple gridded observations and reanalysis datasets over Ghana. *Advances in Space Research*, *73*(1), 537–552. https://doi.org/10.1016/j.asr.2023.10.029
26. Oduro, C., Thiam, K., Lim, C., Sian, K., Fiifı, D., Hagan, T., et al. (2025). The influence of land surface temperature on Ghana ' s climate variability and implications for sustainable development, 1–17.

27. Quaye, A. K., Doe, E. K., Amon-Armah, F., Arthur, A., Dogbatse, J. A., & Konlan, S. (2021). Predictors of integrated soil fertility management practice among cocoa farmers in Ghana. *Journal of Agriculture and Food Research*, *5*, 100174. https://doi.org/10.1016/j.jafr.2021.100174
28. Sarfo, I., Shuoben, B., Otchwemah, H. B., Darko, G., Kedjanyi, E. A. G., Oduro, C., et al. (2022). *Validating local drivers influencing land use cover change in Southwestern Ghana: a mixed-method approach*. *Environmental Earth Sciences* (Vol. 81). https://doi.org/10.1007/s12665-022-10481-y
29. Sarfo, I., Shuoben, B., Darko, G., Adu, E., Kedjanyi, G., Oduro, C., et al. (2022). Validating Local Drivers Inuencing Land Use Cover Change (LUCC) in Southwestern Ghana: A Mixed-Method Approach (MMA) Analysis, (April), 8–10. https://doi.org/10.22541/au.161895382.21171659/v1
30. Sarfo, I., Bi, S., Kwang, C., Yeboah, E., Addai, F. K., Nkunzimana, A., et al. (2023). Class dynamics and relationship between land-use systems and surface temperature in south-eastern Ghana. *Environmental Earth Sciences*, *82*(4), 1–21. https://doi.org/10.1007/s12665-023-10755-z
31. Siaw, D., Ofosu, G., & Sarpong, D. (2023). Cocoa production, farmlands, and the galamsey: Examining current and emerging trends in the ASM-agriculture nexus. *Journal of Rural Studies*, *101*(October 2022). https://doi.org/10.1016/j.jrurstud.2023.103044
32. Teye, J. K., Yaro, J. A., & Wiggins, S. (2024). Modernizing cocoa production in Ghana: successes, constraints, and future possibilities of innovation diffusion in the cocoa sector. *African Geographical Review*, *44*(2), 135–148. https://doi.org/10.1080/19376812.2024.2357622
33. Vigneri, M. (2018). The Board-Managed Cocoa Sector in Ghana, (February). Retrieved from https://www.researchgate.net/publication/322978798
34. Vigneri, M., & Kolavalli, S. (2018). Growth through pricing policy: The case of cocoa in Ghana. Food and Agriculture Organization of the United Nations. *Background Paper for UNCTAD-FAO Commodities …*, (January), 1–21. Retrieved from https://www.fao.org/3/i8329en/I8329EN.pdf
35. Wessel, M., & Quist-Wessel, P. M. F. (2015). Cocoa production in West Africa, a review and analysis of recent developments. *NJAS - Wageningen Journal of Life Sciences*, *74–75*, 1–7. https://doi.org/10.1016/j.njas.2015.09.001
36. Wongnaa, C. A., & Babu, S. (2020). Building resilience to shocks of climate change in Ghana's cocoa production and its effect on productivity and incomes. *Technology in Society*, *62*(December 2019), 101288. https://doi.org/10.1016/j.techsoc.2020.101288
37. United States Department of Agriculture. (2025). Ghana cocoa sector overview – 2025 (Report No. GH2025-0008). Foreign Agricultural Service. https://fas.usda.gov/

Supplementary material Appendix 1

Supplementary material Appendix 1 is not available with this version

Figures

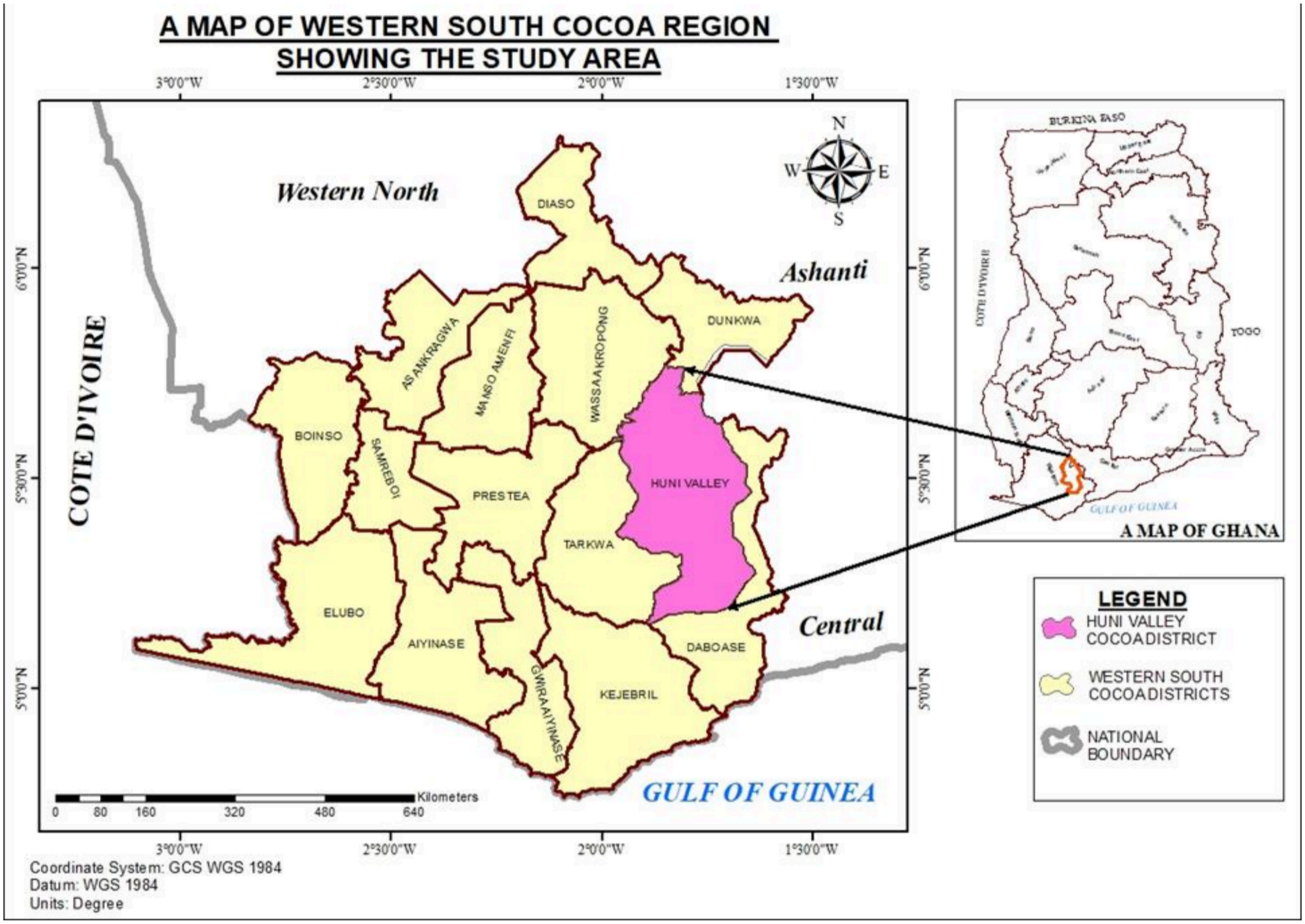

Figure 1

Map Showing the Location of the Study Area.

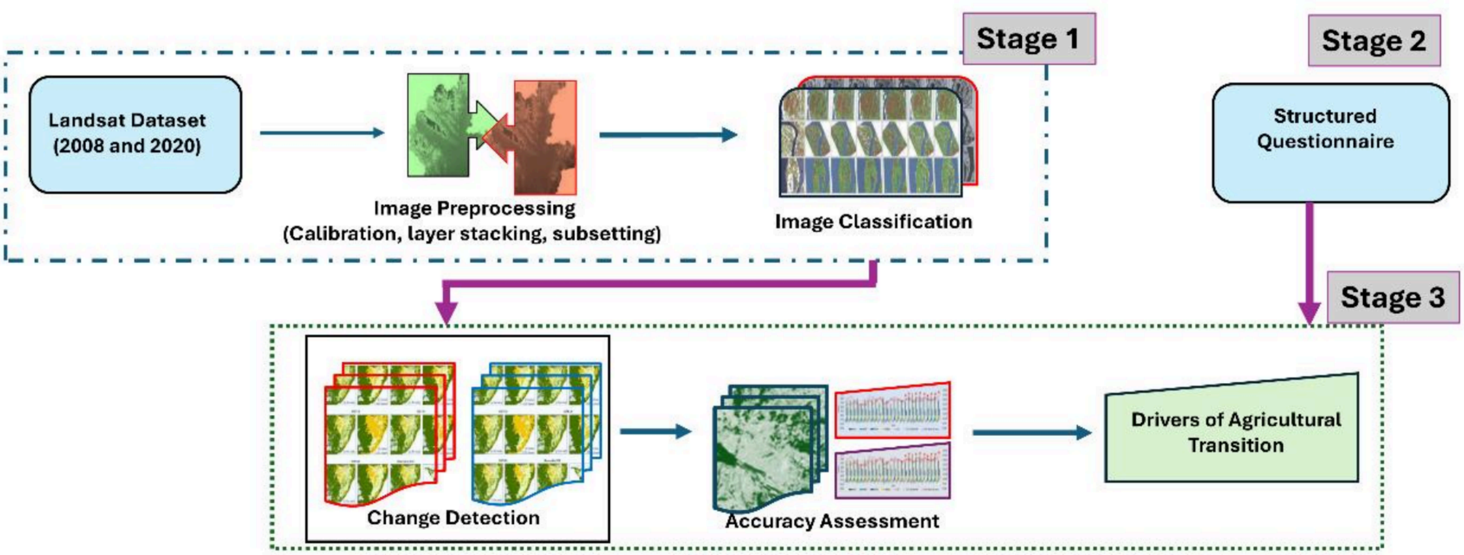

Figure 2

Methodological framework designed for this study

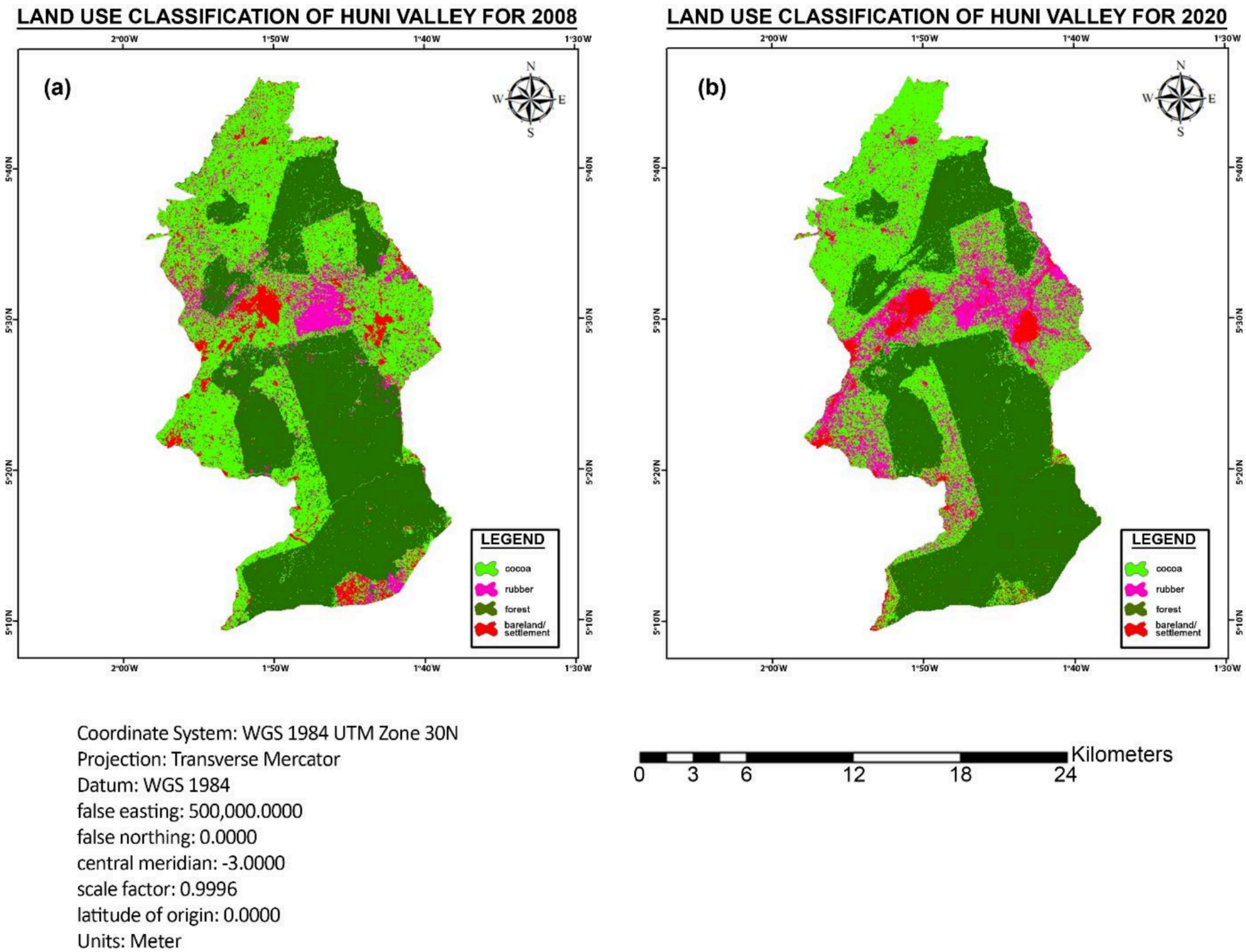

Figure 3

Land use maps of the year 2008 (a) and the land use map of the year 2020 (b) in the Huni Valley.

Land Use/Land Cover Change: Huni Valley (2008–2020)

Shifts in area and percentage by land use category

Land Use/Land Cover	2008 (Ha)	2008 (%)	2020 (Ha)	2020 (%)	Change (Ha)	Change (%)	Remark
Cocoa	57,493.35	39.57	51,227.37	35.26	−6,265.98	−4.31	**Decrease**
Rubber	13,015.53	8.96	19,917.81	13.71	6,902.28	4.75	**Increase**
Forest	66,564.90	45.81	68,047.92	46.83	1,483.02	1.02	**Increase**
Bareland/Settlement	8,225.82	5.66	6,109.29	4.20	−2,116.53	−1.46	**Decrease**

Figure 4

Shifts in area and percentage by land use category in Huni Valley for the years 2008 and 2020

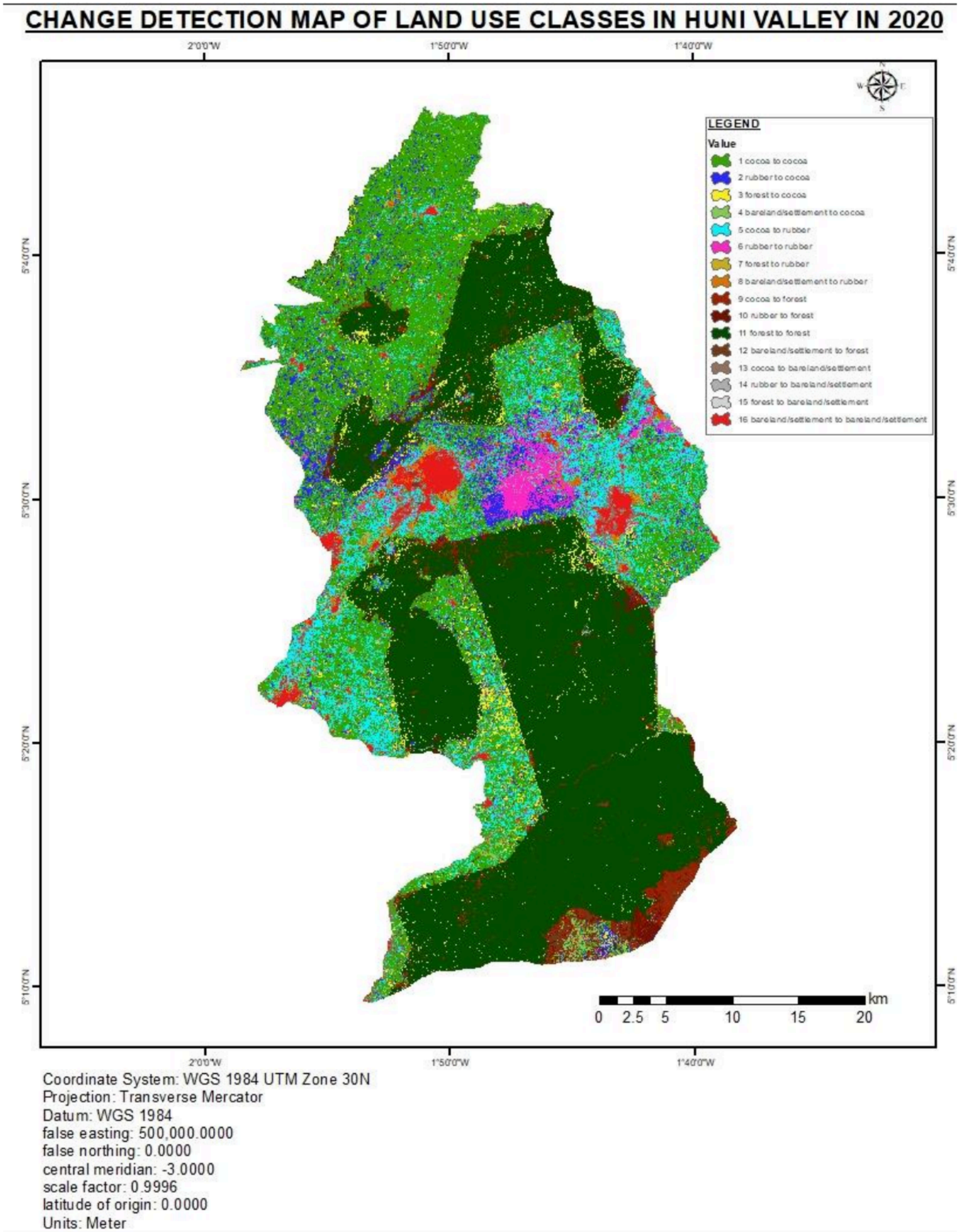

Figure 5

Change Detection Map of Land Use Classes in Huni Valley in 2020

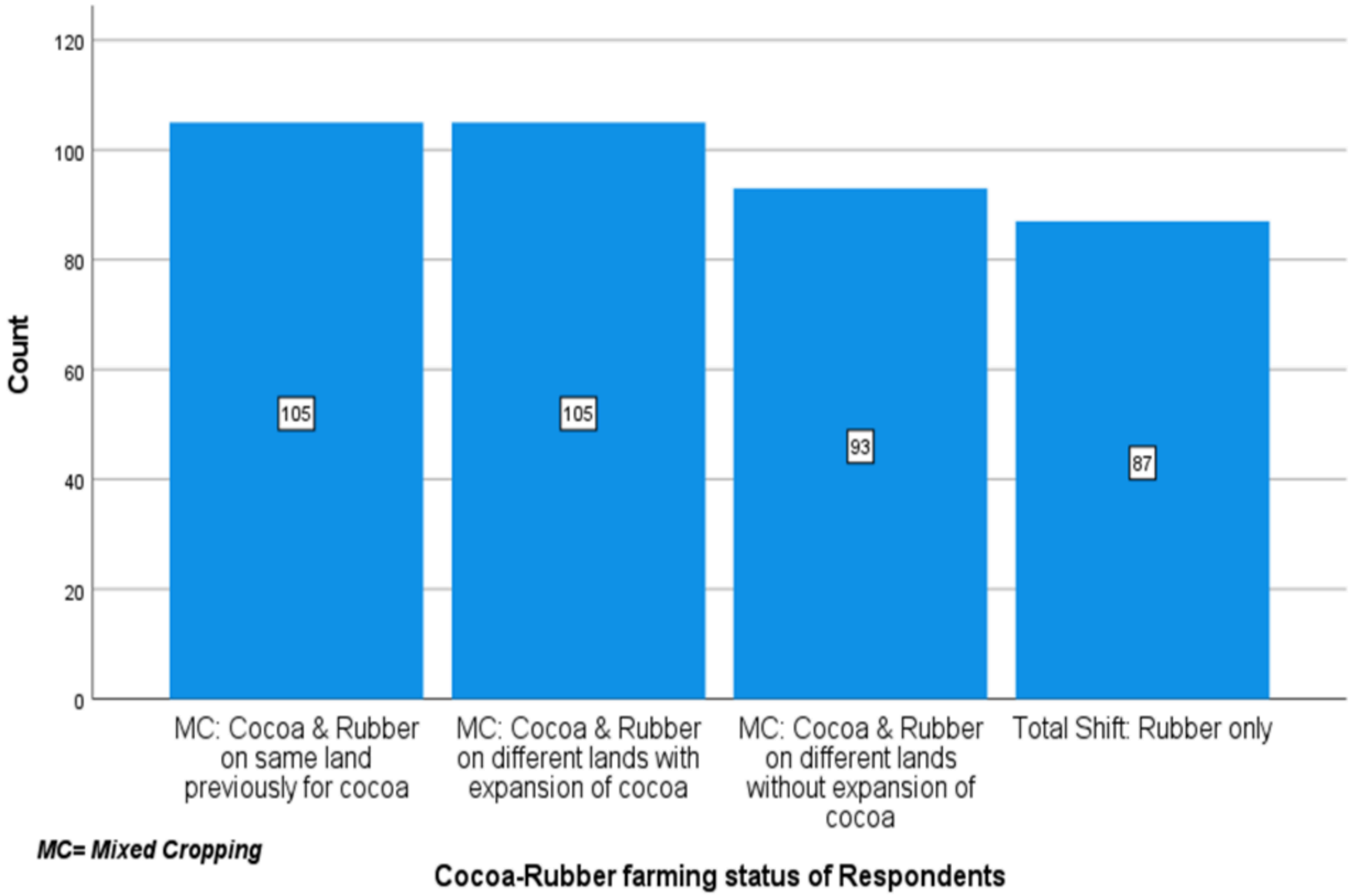

Figure 6

The distribution of enterprise shift among respondents

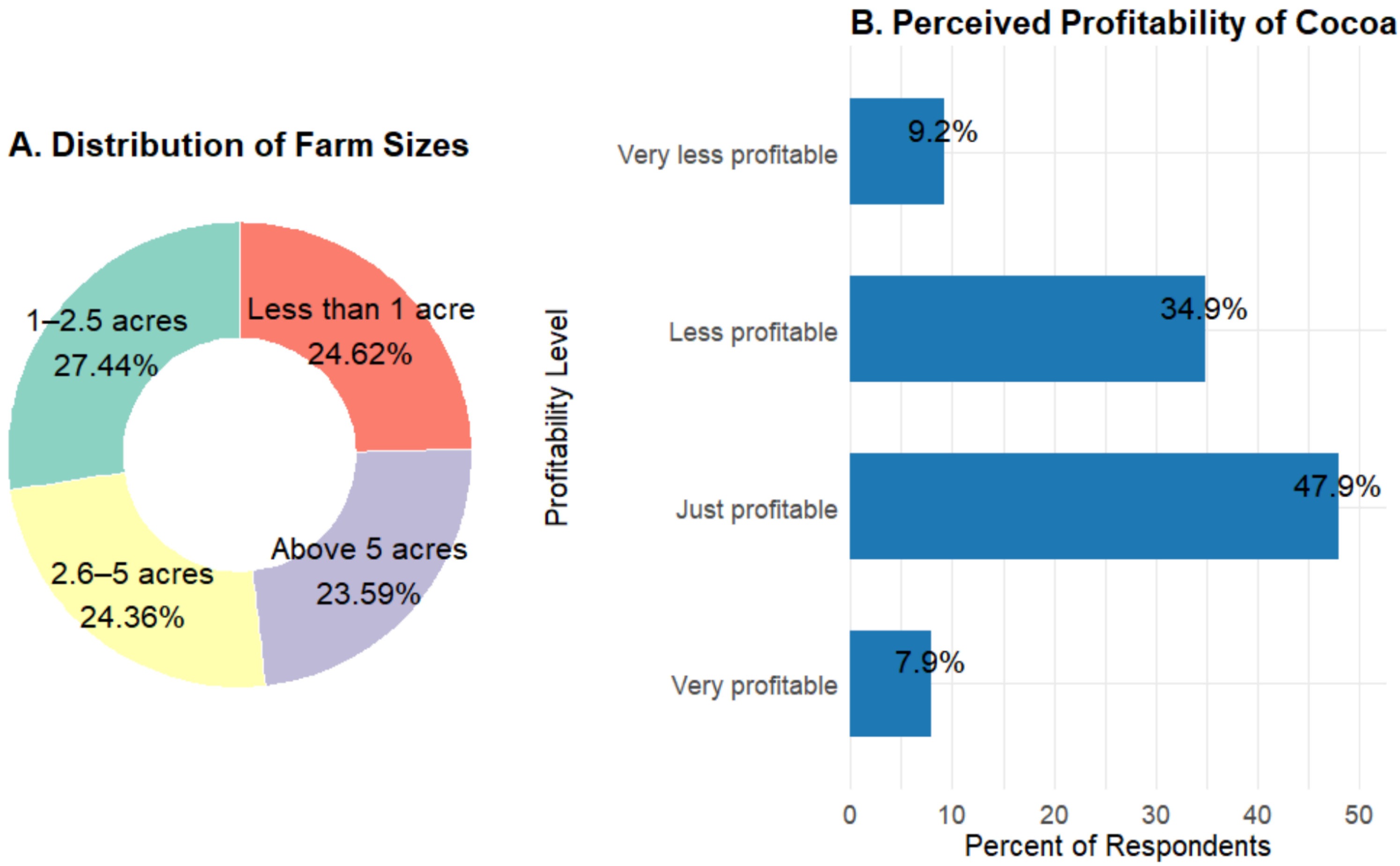

Figure 7

Key constraints driving the transition from cocoa to rubber farming in Huni Valley. (a) distribution of farm sizes (b) perceived profitability.

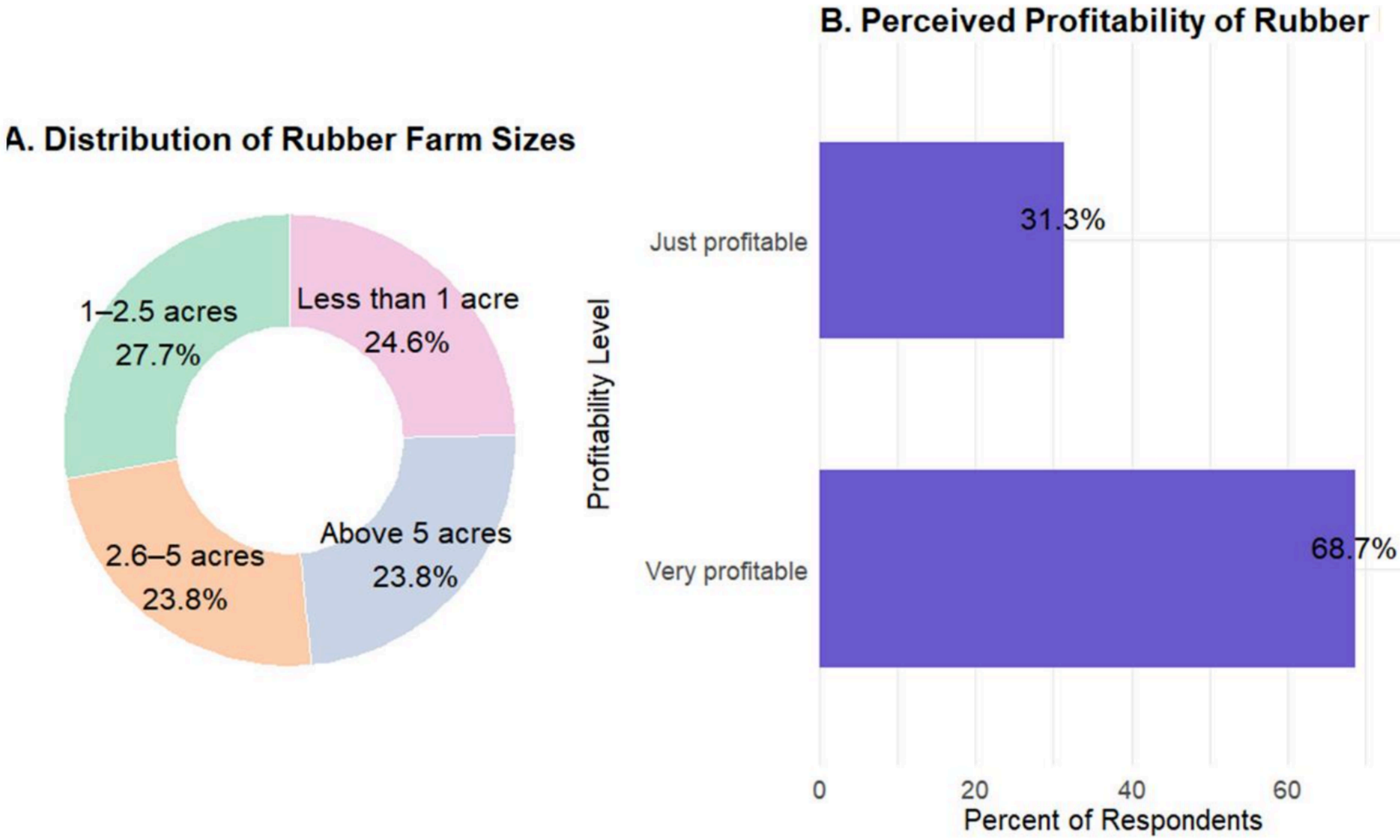

Figure 8

Key constraints driving the transition to rubber farming in Huni Valley. (a) distribution of farm sizes (b) perceived profitability.