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Optimal land resource allocation for tree crop enterprises among farmers in the eastern region of Ghana: A target MOTAD linear programming analysis

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Abstract

This paper examines the optimal land resource allocation for tree crop enterprises in the Eastern region of Ghana based on data collected from sampled cocoa, oil palm and rubber farmers. The estimated net present value (NPV) and benefit-cost ratio (BCR) revealed that cocoa production was the most profitable and rubber production the least profitable. The target MOTAD linear programming (LP) profit-maximising enterprise combination allocated 73.9% and 26.1% of the average land to cocoa and oil palm production, respectively, and nothing to rubber, with an NPV of USD 262.70/ha. However, sensitivity analysis revealed that highly risk-averse farmers would cultivate more oil palm and rubber and less cocoa. In a high production-risk environment, efforts to sustain cocoa production would require more deliberate policy initiatives to support cocoa farmers. Alternative policies to promote and expand other tree crops, particularly rubber, should also tackle the associated risk factors.

Key words: discounting technique, farmland allocation, linear programming technique; risk-sensitivity analysis, tree crop enterprises

1. Introduction

Agriculture remains a major contributor to Ghana's economic development, accounting for a major portion of livelihoods in rural communities and employing about 33.0% of the workforce (Ghana

Statistical Service [GSS] 2021). The sector also contributed on average of about 20% of the country's gross domestic product (GDP) over the period 2013 to 2023 (Ghana Statistical Service 2024). Cocoa (*Theobroma cacao*) and oil palm (*Elaeis guineensis*) are among the major tree crops cultivated in Ghana and contribute significantly to foreign exchange earnings, employment, raw material for industries and poverty reduction (World Bank 2018). In most households involved in cocoa production, about 67% of the household income comes from cocoa production (Denkyirah *et al*. 2017). Smallholder farmers dominate Ghana's cocoa production, with an average farm size of two hectares per household (Wessel & Quist-Wessel 2015). Oil palm is the second most significant tree crop in Ghana after cocoa, and small-scale producers and processors dominate the industry (Khatun *et al*. 2020). Although rubber (*Hevea brasiliensis*) is not cultivated on as large a scale as cocoa and oil palm, Ghana has 19 000 hectares of rubber plantations, including 12 000 hectares of industrial plantations. Of the 7 000 hectares of village plantations, 3 600 hectares are recently planted plantations (Ministry of Economy and Industry 2020). Village plantations are usually established with the support of industry actors like Ghana Rubber Estate Limited (GREL).

Unlike food crops cultivated purposely to meet household nutritional needs in addition to earning a cash income, farmers go into tree crop production to generate cash income. Tree crop farmers therefore will endeavour to maximise their gains from their tree crop production decisions, bearing in mind that such decisions are long-term ones with associated long-term effects. In particular, the decision-making regarding what combination of crops to produce, and what quantity to produce, are important in determining the level of profit a farmer receives from his/her farm produce. These decisions are influenced by the availability of resources such as land, labour and capital, as well as the availability of markets and the prevailing market prices of the commodities, along with their embedded risk-taking. Over the decades, and unlike the case with other tree crops, there are guaranteed licensed buying companies that are allowed to purchase dried cocoa beans on behalf of a cocoa-marketing company, and the producer price is reviewed at least annually at the opening of the cocoa season. This is done under the oversight responsibility of Ghana Cocobod, the state-owned agency involved in the regulation of the cocoa sector.

Ghana Cocobod also provides research and development through its Cocoa Research Institute of Ghana (CRIG), extension through the Cocoa Health and Extension Division (CHED), and seed/ seedlings through the Seed Production Division, among other services. The other commercial tree crops cultivated in Ghana did not have an agency with direct oversight responsibility for the research and development, production and marketing of their produce as in the case of cocoa, until the recent establishment of the Tree Crops Development Authority (TCDA). It is important to note that the Council for Scientific and Industrial Research (CSIR)–Oil Palm Research Institute, which was initially established as a division under the CSIR–Crop Research Institute in 1964, was upgraded to a centre in 1979 and became a fully-fledged institute in 1988. It had the mandate to conduct demand-driven research aimed at providing scientific and technological support for the development of the oil palm industry in Ghana (Oil Palm Research Institute (2022). In 1992, the institute was given the additional mandate to carry out research on coconut.

The Tree Crops Development Authority (TCDA) was established in 2019 by the Ghanaian government through an Act of Parliament, the Tree Crops Development Authority Act, 2019 (Act 1010), to regulate and develop, in a sustainable environment, the production, processing and trading of six tree crops in Ghana, namely cashew, shea, mango, coconut, rubber and oil palm (Tree Crops Development Authority [TCDA] 2024). In Ghana, cocoa marketing and pricing is regulated by the Ghana Cocoa Board. The TCDA has developed a formula for determining the minimum producer price for raw rubber and oil palm fresh fruit bunch monthly (TCDA 2024). Hitherto, oil palm and most other crops have been sold on the open market with price uncertainties (Choudhary *et al*. 2016), while GREL, the main purchaser in Ghana, sets and adjusts the price of rubber following the world price for internationally traded commodities (Ghana Rubber Estate Limited [GREL] 2024).

It is expected that the functioning of TCDA will generate better opportunities for farmers of the selected tree crops, similar to cocoa under Cocobod. The opportunity could entail allocating more productive resources to these tree crops, or changing their production mix. This paper explores farmers' land allocation decisions and production mix for the tree crop sector. It examines whether, given the opportunity, farmers would be likely to shift land from the cocoa sector to the other tree crops. The paper discusses the profitability of cocoa, oil palm and rubber production and the optimal land allocation to cocoa, oil palm and rubber enterprises that will maximise the farmers' profit. Oil palm and rubber provide income for the whole year (Khatun *et al*. 2020), while cocoa yield and income reduce to insignificant levels in the dry season. This is why combining these crop enterprises might be more beneficial in providing stable income than the production of only one of them.

The optimal allocation of resources, such as capital, land and labour, among various enterprises in which a farmer is engaged is a major challenge, but crucial for profit maximisation. Operations research approaches like the linear programming (LP) models have been used as decision-making tools in resource allocation for food crop enterprise studies elsewhere (Majeke 2013; Muzhinji & Ndou 2022), and also in Ghana (Ofori *et al*. 2015). For example, in Zimbabwe and South Africa, Majeke (2013) and Muzhinji and Ndou (2022) employed the LP model to examine the optimum crop farm enterprise combination for small-scale Marondera and Vhembe farms as case studies, respectively. The optimal results from the production plans derived from LP were superior to the traditional farm plans (the original farm plans or enterprise mix). The LP technique was used by Ofori *et al*. (2015) to examine the allocation of irrigated water for rice production at the Kpong irrigation scheme. These authors concluded that the optimal allocation of irrigated water would increase the total net returns by about 101.50%. However, little literature exists on its use in resource allocation for tree crops in Ghana.

This study uses the target MOTAD LP modelling framework to establish optimal land allocations for various enterprises. The findings add to the existing literature on land allocation decisions among competing crop enterprises from the tree crop perspective. The target MOTAD LP model developed by Tauer (1983), is one of the techniques that address risk in modelling decision-making. It estimates the returns and the associated risks for various enterprise combinations (Tauer 1983), working on the principle that the farmer, notwithstanding the risks he/she faces in production, has a minimum expected target return that he/she aims to achieve in a production season or year. Consequently, examining the appropriate allocation of land resources among enterprises is important in identifying and optimising land allocation strategies for inclusion in the development agenda, like those provided under Ghana's TCDA. Many farmers, notably smallholders, are risk-averse (Anaman 1988; De Pinto *et al*. 2013). Therefore, risk must be incorporated into agricultural planning models to generate empirical results, which are important in farm decision-making and policy analysis.

Ayinde *et al*. (2010) used target MOTAD LP to study sensitivity and uncertainty in small-land scale agricultural systems in Nigeria, using rice, soybeans, cassava, maize, yam, guinea-corn and millet enterprises. Using a target income of N10 000, the profit-maximising plan was to cultivate 0.4263 ha of yam and 0.7096 ha of rice, while at the lowest risk level, the plan was to cultivate 0.4828 ha of yam. Their sensitivity analysis concluded that the relationship between risk level and target income was positive, indicating that the probability of achieving a higher target income was lower than the probability of achieving a lower target income. Fathelrahman *et al*. (2017) studied the optimisation of net returns from greenhouse vegetable production in the UAE using the target MOTAD LP model. Their model included three vegetables, and the optimal solution was to produce 8 511 kg of tomato, 8 057 kg of pepper and 1 039 kg of cucumber. As the risk level was reduced, tomato production decreased, pepper production remained almost the same, while cucumber production increased. However, these studies are based on annual crops and provide the basis for the analysis of resource allocation and the profitability of smallholder tree crop enterprises in Ghana considered in this paper.

2. Methodology

2.1 The study area

The study was conducted in the Eastern region of Ghana, within the Atiwa landscape, where Kwaebibirem and Atiwa West districts were purposely selected (Figure 1). The districts have semi-deciduous forest vegetation and double maxima rainfall regimes, with an annual rainfall of about 1 500 mm and two distinct seasons = one dry and one wet (Adjei-Nsiah *et al*. 2012). The districts experience minimum and maximum temperatures of 26 and 30 degrees Celsius respectively, and their land areas are estimated to be about 803.47 km² and 262.5 km^2 respectively (Kwaebibirem Municipal Assembly 2018; Republic of Ghana 2019), of which 80% is suitable for agriculture. The dominant soil types are silty and silty-clay loams, mainly forest ochrosols (Adjei-Nsiah *et al*. 2012). The districts are noted for cultivating tree crops (viz. cocoa, oil palm and citrus), vegetables (viz. pepper, garden eggs and okra) and food crops (viz. cassava, plantain, rice, maize and cocoyam).

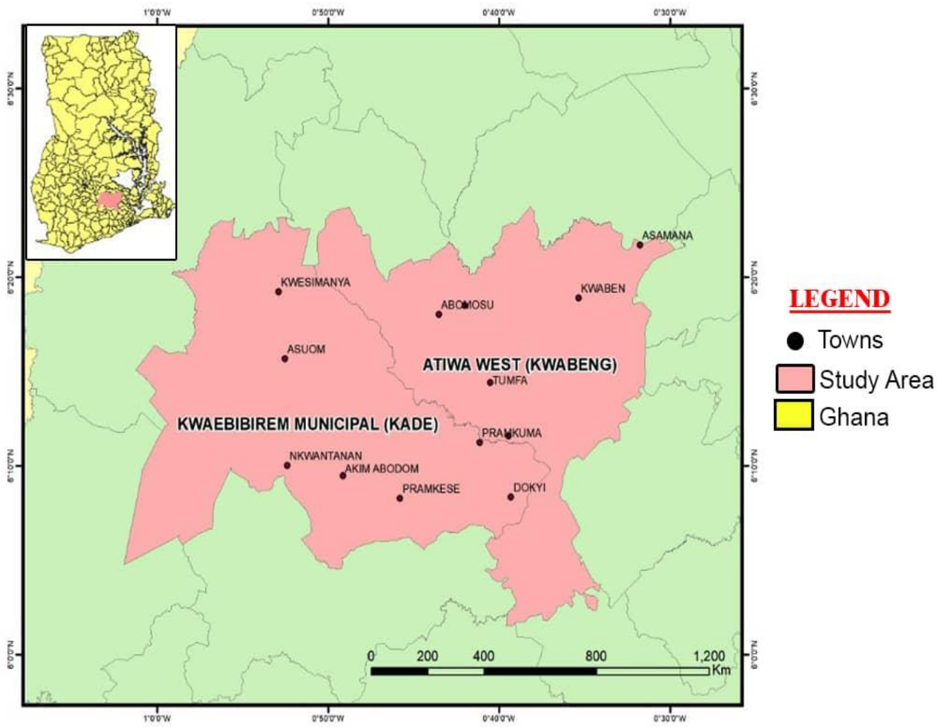

Figure 1: Study area, showing selected communities

Source: Extracted by the Department of Geography and Resource Development, University of Ghana, Legon, 2020

2.2 Sampling and data collection

The sampling and data collection were done within the framework of the project, "Governing multifunctional landscapes in sub-Saharan Africa: Managing trade-offs between social and ecological impacts", which was implemented by the Centre for International Forestry Research (CiFOR) in collaboration with the Forest and Horticultural Crops Research Centre, School of Agriculture, University of Ghana, Legon. Based on agricultural land-use maps produced following the national protocol, the average number of farming households engaged in oil palm and cocoa production was approximated and used to estimate the sample size. The national average farm size of 2.5 ha for cocoa (Asamoah & Owusu-Ansah 2017), and the Eastern region average farm size of 5.7 ha for oil palm, were used (MASDAR 2011). Cochran's formula, adjusted with the finite population correction (Equation 1), was used to calculate the samples needed to achieve statistical significance:

$$n = \frac{\frac{z^2 p(1-p)}{e^2}}{1+\left(\frac{z^2 p(1-p)}{e^2 N}\right)} \tag{1}$$

Using a 5% margin of error (e) and 95% confidence interval (z = 1.96) resulted in sample sizes of 379 cocoa farmers and 339 oil palm farmers. N is the approximate number (population) of households cultivating cocoa and oil palm in the study area, at 36 897 and 2 904, respectively, and p is the assumed proportion of individuals in the population (0.5) with the characteristic of interest.

Stratified random spatial sampling based on crop density zones was used to identify the target communities, and random sampling from farmer lists was used to identify the survey respondents. Four zones, namely cocoa high (oil palm low), cocoa medium (oil palm low), oil palm high (cocoa low) and oil palm medium (cocoa low), were identified based on the clear differences in the density of cultivation areas. Three communities were selected in each density zone. The number of households sampled within each community was determined based on the respective density of the crop, which provides an estimate of the area covered by each crop in that zone and, using the stated average farm size, an approximate number of farmers cultivating each crop in that zone. Within each community, a list of farmers was compiled whose target crop was in production, together with the names of the community leaders, and the sample was taken randomly from the list.

The number of farmers engaged in rubber cultivation was relatively small and their adoption of rubber farming was relatively recent in the target geographies. The number of farmers whose rubber farms were in production was significantly small. Experts who were consulted suggested that a realistic number of surveys that can be collected would likely be 50. Snowball sampling was therefore used to interview fifty (50) rubber farmers. After data cleaning, observations of 334 cocoa farmers, 336 oil palm farmers and 50 rubber farmers were used for the analysis.

Data on production cost (excluding family labour cost), output, revenue, plot size, age of the farm or age of the crop and demographic characteristics was collected from the sampled farmers using a structured questionnaire. The questionnaire was pre-tested with 12 respondents from the Kwaebibirem and Denkyembour districts, and then finalised for the survey.

2.3 Methods of analysis

2.3.1 Estimating profitability of cocoa, oil palm and rubber production

The profitability of cocoa, oil palm and rubber production was estimated using the net present value (NPV) and benefit-cost ratio (BCR) analyses. The NPV was calculated on a per-hectare basis using Equation (2).

$$NPV_i = \sum_{t=1}^{t=n} \frac{B_{it}}{(1+r)^t} - \sum_{t=1}^{t=n} \frac{C_{it}}{(1+r)^t}, \tag{2}$$

where NPV_i is the NPV from the production of a hectare of crop i for 25 years (assumed as the ultimate age of the tree crops, because beyond age 25 the yield of the crops reduces to insignificant levels, and also the discount factor reduces to nearly zero/negligible);
B_{it} is the total return generated from cultivating a hectare of crop i in year t;
C_{it} is the total cost of cultivating a hectare of crop i in year t;
r is the interest rate reflecting the opportunity cost of capital; and
n is the total number of years.

The interest rate charged by the Agricultural Development Bank on agricultural loans in Ghana in 2020, 22%, was used to discount the future costs and benefits to their present values. The investment was profitable if the estimated NPV was positive. The NPV calculation (with reference to the 2020 cropping season) involved the following: revenue per ha per year; cost of production (variable cost) per ha per year; cost of establishment and maintenance cost before maturity per ha per year; and cost of assets. Shade should be provided when seedlings of most tree crops are transplanted under/during establishment. Otherwise, most of the transplanted seedlings would be lost (die). For uniformity, only plantain, normally grown to provide shade for young cocoa trees, was considered as an intercrop in this analysis. The cost/benefit of the intercrop (plantain) was part of the cost/benefit build-up for the analysis.

The BCR was used to estimate the viability of an investment decision. It is calculated, in Equation (3), as the ratio of the present value of benefits of cultivating a hectare of crop i to the present value of the total cost of cultivating a hectare of crop i.

$$\boldsymbol{BCR} = \frac{\sum_{t=1}^{t=n} \frac{B_{it}}{(1+r)^t}}{\sum_{t=1}^{t=n} \frac{C_{it}}{(1+r)^t}} \quad (3)$$

A BCR estimate greater than one for a tree crop investment is considered profitable. In establishing the cash inflow and outflow for each production year, each crop's data was categorised into age groups (Table 1). Within an age group, yield was not expected to differ significantly. The starting age is the age at which harvesting of the crop begins. For each age group, the average cost of production and the average revenue were estimated and used for the calculation of NPV and BCR. Family labour was not considered in the production costs. Hence, the estimated viability measures are referred to as returns to land and management (Karlen *et al*. 2007). Items included in the cost of production include costs of fertiliser and fertiliser application, chemicals and their application, repair or maintenance, harvesting, weed control, pruning, watering, planting material, planting, plantain suckers, tools and equipment. The unit costs of these items, and the undiscounted production costs and revenue, are presented in Appendix 1 and Appendix 2, respectively. Microsoft Excel software was used to estimate the NPV and BCR. The estimated NPV and BCR values are discussed. The NPV was further used in the linear programming to examine the optimal land allocation.

Table 1: Age groups of the tree crops

Tree crops	Age groups of trees (years)			
Oil palm[a]	4–7	8–14	15–20	21–25
Cocoa[b]	4–9	10–15	16–20	21–25
Rubber[c]	7–10	11–14	15–18	19–25

Sources: [a] Rhebergen *et al*. (2018); [b] Mahrizal *et al*. (2014); [c] Mekong Strategic Partners (2020).

2.3.2 Examining the optimal land allocation to cocoa, oil palm and rubber enterprises for maximum profit

A target MOTAD (minimisation of total absolute deviation) LP model was employed to examine the optimal enterprise combination (Tauer 1983; Hazell & Norton 1986). The model has three main components: an objective function, competitive enterprises, and three sets of constraints to realise the set objective. The objective function was specified in terms of maximising the estimated NPV from the production of the crops. The first set of constraints imposes resource constraints (land and labour). The second set of constraints expresses five weather scenarios (very bad, bad, normal, good and very good weather). The third constraint sums the negative deviations from the target income, multiplied by the probability of their occurrence, and is represented by λ. Then, there is the non-negativity constraint. The target MOTAD model applied can be mathematically expressed as:

$$Max.\ E(z) = \sum_{i=1}^{n} c_i x_i , \tag{4}$$

subject to the following constraints:

$$\sum_{i=1}^{n} a_{ik} x_i \leq b_k \tag{5}$$

$$\sum_{i=1}^{n} f_{ih} x_i + Y_h \geq T_h \tag{6}$$

$$\sum_{h=1}^{s} P_h Y_h = \lambda \tag{7}$$

$$X_i;\ Y_h \geq 0 \text{ (non-negativity constraint)}, \tag{8}$$

where E(z) is the expected NPV of the optimal plan; c_i is the estimated NPV per hectare from the i-th enterprise; X_i is the size in hectares of the i-th enterprise; n is the total number of enterprises; a_{ik} is the per-hectare requirement of the k-th resource (land and labour) by the i-th enterprise; b_k is the level of the k-th resource available; f_{ih} is the return of enterprise i under the weather scenario h (i.e. the state of nature); T_h is the total target income under weather scenario h; Y_h is the negative deviation from the target income under weather scenario h; s is the total number of weather scenarios considered; P_h is the probability that weather scenario h will occur; λ is the parameter to be varied from zero to a large number.

Equation (4) maximises the expected return. Equation (5) imposes the usual resource constraints faced by the farmer. Equation (6) measures the enterprise's return under the different states of nature related to the type of weather scenario (h). If the overall return is less than the target T, then the difference is transferred to Equation (7) through Y_h. Equation (7) sums the negative income deviations after weighting them by their probabilities of occurrence. In summary, the target MOTAD principle attempts to mimic the behaviour of farmers concerned with ensuring the achievement of a minimum target income during the production year or season (Tauer 1983; Hazell & Norton 1986).

The target MOTAD model was solved with a linear programming algorithm because it has a linear objective function and linear constraints, and the target MOTAD production plans are second-degree stochastic dominance efficient (Tauer 1983). For a_{ik}, one hectare was assumed to be the land requirement for each crop. The labour quantities, i.e. the number of man days, required to cultivate a hectare of cocoa, oil palm and rubber were obtained from Assuming-Brempong *et al*. (2007), Mensah-Bonsu *et al*. (2009) and Goswami and Challa (2007), respectively. b_k was obtained by estimating the average quantities of land and labour available to a farm household from the data collected. T_h, the total target income, is assumed to be Ghana's extreme or food poverty line per adult equivalence per year for the year 2020. The 2020 food poverty line was estimated based on the 2016/2017 food poverty line of GH¢ 982.2 (GSS 2018). Using the 2020 inflation rate of 10% (GSS 2020), it translates into 1.331*982.2, giving GH¢ 1 307.31 per adult equivalent per year for 2020. The total adult equivalence is given as household size raised to the power of 0.725. The average household size from the primary data was 5.9 persons per household. Hence, the adult equivalence was 3.6 adults per household. The target level of income used for the analysis was therefore calculated as 1 307.31*3.6, which is equal to GH¢ 4 707.00 ($822.90).

The constraints presented in Equation (6) were used to represent five different weather conditions (scenarios) that the crops could be exposed to that would affect their yields. The first and second standard deviations below and above the mean (NPV) represent the five weather scenarios: first and second standard deviations below the mean represent bad weather and very bad weather, respectively; the mean represents normal weather; first and second standard deviations above the mean represent good weather and very good weather, respectively. The average net cash flow per year for each NPV under the five weather scenarios was estimated to match the farmers' annual income to the annual target income in the model. The equivalence annual annuity (EAA) for each of the five NPV estimates was hence estimated. EAA is a budgeting technique used to determine the annual NPV for a long-term project (Donis *et al*. 2020). It generates an average net cash flow per year under each weather scenario. The EAAs represent the five weather conditions/scenarios for the target MOTAD analysis. These were used as the constraints 3, 4, 5, 6 and 7 in Table 2, and are estimated as:

$$EAA = \frac{r\ x\ \mathbb{N}PV}{1-(1+r)^{-n}}, \tag{9}$$

where n is the number of years the project will last.

2.3.3 Estimation of the target MOTAD LP model

Small-scale farmers are mostly concerned about getting an income that will enable them to meet, at the very least, their basic needs, and therefore do not want their income to fall below a certain target income level. To generate a crop-mix production plan consistent with this rationale, the specified target MOTAD LP model shown in Table 2 was designed and estimated for the optimal production plan for cocoa, oil palm and rubber. The coefficients of the objective equation are the estimated NPVs. Constraint 1 is the allocation of one hectare of land each from the average land size of 4.6 hectares. The constraint 2 coefficients are the annual labour requirement per hectare for each crop obtained from the literature, while the amount of labour a farmer needs to cultivate 4.6 ha of land is 615, assuming he/she wants to farm the three tree crops. The coefficients of constraints 3 to 7 are the estimated EAAs (USD equivalent of Ghana cedis), with a target income of $822.90. The coefficients for the slack variables in constraint 8 are the assumed probabilities of the occurrence of the five weather scenarios.

The target MOTAD model was solved by varying λ from zero to a very large number (Tauer 1983). The deviation below the target income, controlled by the parameter λ, was initially set at a large value (≥ $515.38). The large number is such that any number above it produces the same result in the model. It was generated during the analysis. This makes the target MOTAD model comparable to a deterministic linear programming profit-maximising model. As λ was gradually reduced, solutions that differ from the deterministic linear programming profit-maximising model were obtained. When λ = 0, no negative income deviations are allowed. This is equivalent to the (maximum) safety-first decision rule, as the farmer tolerates no deviation from the target income during the production season.

Table 2: Target MOTAD table for tree crop production

Row	Crop activities (ha)			Negative deviations from the target						RHS
	X1	X2	X3	X4	X5	X6	X7	X8		
Objective	271.24	238.21	112.49						≥	MAX
Constraint 1	1.00	1.00	1.00						≤	4.60
Constraint 2	143.00	107.00	151.00						≤	615.00
Constraint 3	13.99	27.97	41.96	1					≥	822.90
Constraint 4	31.47	45.45	55.94		1				≥	822.90
Constraint 5	69.93	68.18	62.94			1			≥	822.90
Constraint 6	92.66	87.41	69.93				1		≥	822.90
Constraint 7	148.60	139.86	117.13					1	≥	822.90
Constraint 8				0.15	0.20	0.35	0.20	0.10	=	λ

Notes: X1 = cocoa, X2 = oil palm, X3 = rubber, X4 to X8 are slack variables; exchange rate: GHS 5.72 = USD 1.

The target MOTAD LP analysis was done using LiPS software version 1.9.4. Farm plans were altered as λ was reduced, while target income was kept at the same level. The values of λ and the corresponding optimal solutions (optimal enterprise mix and the net returns) are presented in Table 3 and discussed.

3. Results and discussion

3.1 Socio-economic characteristics of respondents

Table 3 presents the sex, educational level and age distributions of the respondents. Cocoa, oil palm and rubber production are male-dominated enterprises, with 75% of the respondents being men. Denkyirah *et al*. (2017) and Nunoo and Owusu (2017) have reported male dominance in cocoa production of about 80% and 84%, respectively. This is attributed to men having greater access to farmland than women, and the associated general physical drudgery of cocoa production in Ghana. The majority of farmers (60.7%) had a basic school education. Smallholder tree crop farmers with no formal education constituted only 10.7%, compared to the 18.8% reported by Denkyirah *et al*. (2017) for cocoa farmers, and 6.3% had tertiary education. This shows that the literacy level is high among tree crop farmers. Nunoo and Owusu (2017) have indicated that about 60.5% of cocoa farmers have a basic education, while 31% have no formal education. The age distribution indicates that the farmers are evenly distributed among the age groups, except for the age group 18 to 35.

Table 3: Sex, educational level and age of the respondents

Variable	Frequency	Percentage (%)
Sex		
Male	541	75.00
Female	179	25.00
Educational level		
None	77	10.69
Primary	94	13.06
Junior high school/middle	437	60.69
Senior high school/technical/vocational	67	9.31
Tertiary	45	6.25
Age group		
18 to 35	46	6.39
36 to 50	229	31.81
51 to 60	223	30.97
Above 60	222	30.83
Total	**720**	**100.00**

The average household size was six persons, similar to the seven persons reported by Denkyirah *et al*. (2017). The average farm size for cocoa, oil palm and rubber production were 6.27 ha, 5.17 ha and 2.39 ha per household, with standard deviations of 3.59 ha, 3.21 ha and 1.21 ha, respectively. The average farm size for cocoa was higher than the 2.0 ha reported by Nunoo and Owusu (2017) for cocoa farmers in Sefwi Wiawso District in Ghana. About 15.83% of households had tree crop farm sizes less than or equal to two hectares, while 84.17% had farm sizes greater than two hectares. The average farm size of a tree crop farm household was 4.6 hectares.

3.2 Estimated profitability (returns to land and management)

The estimated NPV per hectare and BCR, presented in Table 4, indicate positive net present values of \$271.24, \$238.21 and \$112.49 per hectare, and benefit-cost ratios of 1.14, 1.13 and 1.06 for cocoa, oil palm and rubber production, respectively. The estimates suggest that cocoa, oil palm and rubber production are profitable under their current production systems. Cocoa production is the most profitable tree crop, while rubber is the least profitable. The result of the NPV analysis for cocoa production is consistent with the findings of Nunoo and Owusu (2017), who found that cocoa production under no shade, low shade, medium shade and heavy shade was profitable in Ghana, with NPVs of \$770.29, \$934.10, \$1 629.86 and \$1 041.95 per hectare, respectively, at a discount rate of 20%. Svatoňová *et al*. (2015) estimated a very high NPV of \$10 670 per hectare for oil palm production in Indonesia.

Table 4: Profitability estimates for tree crop production

Profitability indicators	Cocoa	Oil palm	Rubber
Total present value of costs (USD/ha)	1 913.65	1 880.27	1 776.25
Standard deviation of present value of costs (\$)	134.06	146.72	157.30
Total present value of benefit (USD/ha)	2 184.89	2 118.48	1 888.74
Standard deviation of present value of benefit (\$)	98.13	86.55	72.92
NPV (USD/ha)	271.24	238.21	112.49
Benefit cost ratio	1.14	1.13	1.06

Notes: Authors' computation from field data, 2021; exchange rate: GHS 5.72 = USD 1

3.3 Optimal crop enterprise combination

3.3.1 Optimal enterprise combination under the target income of USD 822.90

Table 5 presents the results of the target MOTAD LP analysis. The expected net return ranged from \$1 096.99, when negative income deviations were not permitted ($\lambda = 0$), to \$1208.44, when negative income deviations were ignored ($\lambda \geq 515.38$). When λ was set to greater than \$515.38, the target MOTAD model was equivalent to a deterministic linear programming model (i.e. any value of λ above \$515.38 produced the same farm plan with the same net returns). The target MOTAD profit-maximising solution was to cultivate 3.4 ha of cocoa and 1.2 ha of oil palm, which would represent 73.9% and 26.1% of land allocation, respectively, giving a net return (NPV) of \$1 208.44 (i.e. \$262.70 per hectare). There was no land allocation for rubber in the profit-maximising solution. The estimated unit economic contributions of land and labour to the expected NPV (marginal/shadow values) of cocoa and oil palm were \$140.03 and \$0.92 per ha, respectively.

The trade-off between risk and return was explored by simulating four scenarios demonstrating various risk levels. The effects of the variations in risk were measured by considering the total absolute deviations from the target income on changes in the net present values. The optimal enterprise mix changed as the summation of absolute deviation from the target income (represented by λ) changed, although land allocation for rubber remained zero (Table 5). The simulation results show that increasing land allocation for cocoa production is associated with higher risk levels for oil palm production, and vice versa. Thus, risk-averse farmers will allocate more land for oil palm than for cocoa production, and vice versa. Hutchins et al. (2015) noted that the higher risk associated with increased cocoa production by farm size is because the yield of cocoa is easily reduced by increased temperature or excess rainfall. The reason why farmers will increase their cocoa production although it comes with higher risk may be due to the stability in cocoa prices in Ghana.

Table 5: Target MOTAD NPV and enterprise combination for cocoa, oil palm and rubber (estimated target income = $822.90)

λ (USD)	NPV (USD)	Cocoa (ha)	Oil palm (ha)	Rubber (ha)
≥ 515.38	1 208.44	3.40	1.20	0.00
512.24	1 165.50	2.10	2.50	0.00
509.62	1 128.80	1.0	3.6	0.00
507.34	1 096.99	0.00	4.60	0.00

Notes: Authors' computation from field data, 2021; exchange rate: GHS 5.72 = USD 1

Optimal farm plans were also evaluated for the averages of three groups of farm sizes, noting that smallholder farmers have farm holdings of two hectares or less (Ministry of Food and Agriculture [MoFA] 2019). Farm sizes less than or equal to 2 ha (smallholders), farm sizes greater than 2 ha but less than 5 ha (medium holders), and farm sizes greater than or equal to 5ha (large holders), with averages of 1.4 ha, 3.5 ha and 7 ha respectively, were evaluated under the targeted income of $822.90. The results of the MOTAG analysis are presented in Table 6. The optimal farm plan for (i) a 1.4 ha (small-scale) farm is allocating 1.1 ha for cocoa and 0.3 ha for oil palm, (ii) a 3.5 ha (medium-scale) farm is allocating 2.6 ha for cocoa and 0.9 ha for oil palm, and (iii) a 7 ha (large-scale) farm is allocating 5.2 ha for cocoa and 1.8 ha for oil palm, with very similar expected net returns of $263.24/ha, $262.72/ha and $262.73/ha, respectively. It is important to note that none of the optimal plans returned allocations for rubber production. The estimates suggest that, while the smallholders would allocate about 78.6%, the medium and large holders would allocate 74.3% of their land for cocoa production and the remaining for oil palm production.

Table 6: Target MOTAD NPV and enterprise combination results for different land size holders (target income = $822.90)

λ (USD)	NPV (USD)	Cocoa (ha)	Oil palm (ha)	Rubber (ha)
Smallholders (1.4 ha)				
≥ 729.37	368.54	1.10	0.30	0.00
728.67	359.19	0.80	0.60	0.00
727.80	346.95	0.40	1.00	0.00
726.92	334.72	0.00	1.40	0.00
Medium holders (3.5 ha)				
≥ 588.99	919.52	2.60	0.90	0.00
587.41	899.19	2.00	1.50	0.00
584.79	862.48	0.90	2.60	0.00
582.87	835.57	0.10	3.40	0.00
Large holders (7 ha)				
≥ 375.00	1 839.10	5.20	1.80	0.00
370.63	1 794.60	3.80	3.20	0.00
367.13	1 758.88	2.80	4.20	0.00
361.89	1 705.32	1.10	5.80	0.00
358.22	1 667.83	0.00	7.00	0.00

Notes: Authors' computation from field data, 2021; exchange rate: GHS 5.72 = USD 1

3.3.2 Sensitivity of the model to varying target income

The results from the Target MOTAD linear programming technique are sensitive to the level of specified target income. Three target incomes of Ghana currency (Ghana Cedi, GH₵), equivalent to $1 048.95, $524.48 and $349.65, were considered to examine the sensitivity of the estimated target income. When the target income was set at $1 048.95, at all feasible values of λ, which were higher values of λ, the optimal solution was to cultivate 3.4 ha of cocoa and 1.2 ha of oil palm, which is similar to the optimal solution obtained with the original model (with the estimated target income level set at $822.90). Table 7 shows the optimal farm plan at target income levels of $524.48 and $349.65.

When the target income was set at $524.48, land was still allocated to only cocoa and oil palm, with similar expected revenue as the original model, but at lower values of λ. However, rubber production entered the optimal solutions when the target income was set at $349.65, with land allocated between rubber and oil palm production, but at lower values of λ (from $67.31 to $73.43). The implication is that rubber production is associated with lower production risk when compared to cocoa and oil palm production. Risk-averse farmers should therefore cultivate more rubber and oil palm, because there is less risk (i.e. reduction in crop yield due to too high temperatures or excessive rainfall) associated with their production compared to cocoa production. The results of the sensitivity analysis indicated that the higher values of λ were associated with higher target income levels. This is consistent with Ayinde *et al*. (2010), who reported a positive relationship between target income and risk level, suggesting a higher target income is accompanied by a higher risk level. From the findings, it is not likely that a farmer will combine the production of the three tree crops as an enterprise mix. Instead, the farmers will likely combine two tree crops at a time.

Table 7: Target MOTAD NPV and enterprise combination for cocoa, oil palm and rubber

λ (USD)	NPV (USD)	Cocoa (ha)	Oil palm (ha)	Rubber (ha)
		Target income = $524.48		
≥ 231.82	1208.44	3.40	1.20	0.00
227.27	1162.72	2.00	2.60	0.00
224.65	1135.94	1.20	3.40	0.00
220.80	1096.66	0.00	4.60	0.00
		Target income = $349.65		
≥ 88.64	1208.44	3.40	1.20	0.00
83.92	1173.29	2.30	2.30	0.00
78.67	1132.84	1.10	3.50	0.00
73.43	1072.48	0.00	4.40	0.20
69.06	839.66	0.00	2.60	2.00
67.31	746.53	0.00	1.80	2.80

Notes: Authors' computation from field data, 2021; exchange rate: GHS 5.72 = USD 1

4. Conclusions and recommendations

The study examined optimal land resource allocation for tree crop enterprises by farmers. The profitability of cocoa, oil palm and rubber enterprises were estimated using NPV and BCR. The optimal resource allocation was examined using the target MOTAD LP technique. Structured questionnaires were used to obtain relevant information from selected farmers. The estimated NPVs (BCRs) for cocoa, oil palm and rubber production were $271.24, $238.21 and $112.49 per hectare (1.14, 1.13 and 1.06), respectively. Cocoa production was found to be the most profitable enterprise.

The target MOTAD LP profit-maximising enterprise combination was to cultivate 3.4 ha of cocoa and 1.2 ha of oil palm, representing 73.9% and 26.1% of land allocation, respectively, with no land allocated to rubber cultivation. The estimates suggest that the smallholders and the medium and large holders would allocate about 78.6% and 74.3% of their land, respectively, for cocoa production and the remaining for oil palm production. In terms of risk, moderately risk-averse farmers would allocate more land for oil palm than cocoa. The sensitivity analysis revealed that, at a highly risk-averse level, land allocation would be considered for rubber production. Cocoa production continues to be a strong pillar in Ghana's economy. However, the findings imply that farmers may begin to devote more land to the production of oil palm, which could be extended to rubber rather than cocoa if they are more risk-averse. The policymaking, therefore, needs to be deliberate to motivate farmers to increase cocoa production, as failure to do so could have negative consequences for cocoa production in favour of other tree crops like oil palm and rubber in the future. The findings suggest that a production mix of all three tree crops is unlikely to feature in the farmers' tree crop-enterprise combinations. Policies to promote and expand other tree crops beyond cocoa should tackle associated risk factors.

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Appendices

Appendix 1: Cost items of the production systems

Item	**Amount: USD ($) per ha**
Fixed inputs	
Land	2,185.31 for 99 years
Cutlass	6.12
Sickle	43.71
Wellington boot	8.74
Drying mat	87.41
Knapsack sprayer	17.48
Tapping knife	34.97
Variable inputs	
Labour (hired)	
Initial clearing	65.56
Felling of trees	152.97
Planting cost	Cocoa – 174.93 Oil palm – 87.41 Rubber – 131.12
Watering	43.71
Weed control	43.71
Pruning	5.24 per worker per day
Harvesting	5.24 per worker per day
Fertiliser application	5.24 per worker per day
Planting material	
Plantain suckers	218.53
Cost of planting material	Cocoa – free (normally given by Cocobod, at 1 000 seedlings per ha) Oil palm – 1.75 per seedling (150 seedlings per ha) Rubber – 0.61 per seedling (1 300 seedlings per ha)
Chemicals	
Weedicide	2.97 per litre
Fertiliser	34.97 per bag

Appendix 2: Estimated production cost and revenue (undiscounted)

Crops	**Production cost ($/Ha/year)**		**Production revenue ($/Ha/year)**		**Profit ($/Ha/year)**	
	Average	**Standard deviation**	**Average**	**Standard deviation**	**Average**	**Standard deviation**
Cocoa	357.06	159.47	683.39	558.80	326.33	517.55
Oil palm	357.72	325.28	749.59	1 625.27	391.86	1 337.10
Rubber	347.02	170.87	615.32	551.88	268.31	400.91