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Pathways and Interactions for Integrating Mechanisation into Sustainable Agricultural Production: The Case of Rice Production in Asutsuare, Ghana

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Abstract: Environmentally sustainable small-scale rice production mechanisation is a feasible intervention to help enhance yields and reduce food insecurity. Using machinery for rice production can help small farmers economically and promote sustainability through agroecological principles. The study analyses machinery ownership models and suggests stakeholder interactions for sustainable rice production. The study uses primary data from a field survey of 320 farmers within Asutsuare, a rice production hub in Southern Ghana, and secondary data from various sources. Four different ownership models have been proposed and evaluated. The cooperative-owned machinery (COM) model, with a sharing of the initial investment capital outlay for the machinery acquisition, and the individual ownership model, where the farmer owns and offers hiring services to other farmers (the FOHM-2B and FOHM-2T models) were the most economically viable models. The study also identifies necessary stakeholder engagement and pathways for affordable, sustainable, mechanised small-scale rice production. The models and interactions can promote machinery ownership and strengthen social connections in the community. This local knowledge base can help expand the use of machinery within the community. These models and interactions can be replicated easily in Sub-Saharan African farming communities with similar dynamics. This will improve mechanised farming throughout the continent.

Keywords: rice production; agroecology; sustainable mechanisation; stakeholder interactions

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1. Introduction

Recent trends in population growth show that global food demand will increase by up to 56 per cent between 2010 and 2050 [1]. Feeding a projected population of nine billion by 2025 will require significant agricultural intensification [2,3]. However, agricultural production is threatened by climate change, which has resulted in increased mean temperatures and changes in precipitation patterns [4]. These changes have increased crop pests, and crops grown under these extreme weather conditions experience decreased yield. The unpredictability of weather patterns and precipitation changes, unsustainable production practices, and finite production resources, including land, challenge agricultural intensification [5]. An effective way to mitigate climate change's impact is by promoting sustainable technologies for agricultural production that rely on conservation practices.

One way to promote sustainable agriculture technologies is through sustainable agricultural mechanisation (SAM) of production practices. SAM is when mechanised farming promotes environmental conservation and economic viability over a considerable period [6]. Sustainable practices that conserve production resources like land based on sound ecological principles must be adopted in addition to SAM's integration into agricultural production. This form of agricultural production is the main focus of studies around transforming agricultural production into more agroecological production systems [7,8]. Gliessman [7] proposes a framework comprising five change levels for transforming towards a sustainable food system. The first three levels of change describe the steps that farmers can take to achieve agroecological production systems on their farms; the fourth and fifth levels of transformation deal with how producers need to interact with consumers as well as their integration into a broader social context. Implementing agroecological farming practices in Africa is an excellent idea, given the large number of smallholder farmers in the region [9]. However, most smallholder farmers face issues with reliable input supply for agricultural production that need to be considered through empirical case study research in different societal and agroecological contexts.

Among the inputs required for production, the access and control of quality farm power required for smallholder production affects the productivity and the timeliness of farm operations. For example, a smallholder farmer with access to a combine harvester who uses it for harvesting may harvest the field in a shorter time than when only human power is used. However, if the mechanical power is not of good quality and there are breakdowns, it can result in losses (both economic and timeliness of operation). SAM strategies can improve labour input into production for smallholder farming and reduce the drudgery in production in a manner that is economical, socially, environmentally, and culturally appropriate [6]. This study evaluates existing mechanisation service delivery models and determines the most economically feasible option for smallholder rice production while proposing stakeholder engagements that can enhance SAM.

Background

Rice is a major cereal crop worldwide, and it has the potential to provide food security to numerous countries. Research shows that there will be a steady increase in rice consumption by about 1.2% per year by 2030 in Africa [10]. This indicates that production must be increased to avoid overdependence on imports to meet local demand. Over the years, there has been a steady increase in rice production in Africa, with countries such as Tanzania, Uganda, Kenya, Senegal, Nigeria, and Ghana experiencing significant growth in the total land area of cultivation, yield, and harvest from rice [11]. However, significant changes and improvements are still needed in rice production within Sub-Saharan Africa (SSA) to ensure self-sufficiency. The similarities in the production methods provide promise for easily improving rice production across SSA [12]. In Ghana, there is a deliberate effort to increase rice production through government- and donor-sponsored projects.

In Ghana, as in Africa, smallholder farmers dominate agricultural production. However, the value chain of production of most agricultural commodities needs to undergo modernisation to ensure sustainable production and adherence to agroecological production methods [7–9]. As of 2020, local rice production figures were 987,000 MT, an increase of about two hundred thousand tonnes from 721,465 tonnes in 2017 [13,14]. However, rice consumption reached 1,450,000 MT in 2020, which indicates that around 500,000 MT of rice were imported to meet local demand. This highlights the need for increased production locally to meet demand and achieve household food security. In addition, it is important to promote sustainable rice production methods to improve rural livelihoods and reduce inequality.

Sustainable rice production ensures the efficient use of production resources to prevent loss and misuse while delivering optimal productivity. It entails integrated pest management, optimal water use techniques, and promotion of technologies that ensure the removal of drudgery in production [15]. While rice production in Sub-Saharan Africa (SSA) constitutes about 3.7% of worldwide rice production, the potential to increase production still exists, which must be coupled with the right sustainable production measures [11].

Rice is a major staple in Ghana, and a major transition to efficient production will support the shift towards sustainable agroecological production. Rice production in Ghana has received support from the government, developmental agencies, and the private sector to improve its productivity. This support includes the introduction of input supply programs, improved rice varieties, education, and the addition of massive irrigation schemes. The 2008 National Rice Development Strategy sought to double the domestic rice production by 2018 [16]. The combined activities of the government, developmental agencies, and the private sector have resulted in positive impacts and a steady increase in rice production. However, these gains have started to plateau. For this reason, it is necessary to promote the adoption of SAM to sustain the gains in rice production. In addition to the reduction in overall household labour usage, SAM promotes equipment use that is environmentally, socially, and economically sound along the production value chain [6].

Rice production involves several stages: field preparation, planting, maintenance, harvesting, and broadly post-harvest processing. While the technology exists to fully mechanise all activities within the rice production value chain, in Ghana, like most SSA countries, farmers only have to access tractor-mounted land preparation equipment and combine harvesters for harvesting operations through hiring schemes [12,17]. The post-harvest value chain often lacks vital machinery, resulting in low-quality grains [18]. In Ghana, most rice cultivation systems rely heavily on human power for farming, with access to other resources (seeds, fertiliser, etc.) needing improvement [17]. There are three methods of rice cultivation in Ghana: rain-fed upland, rain-fed lowland, and irrigation schemes. Each system involves different planting methods, including nursing and transplanting the seeds or direct planting through broadcasting [19]. The current techniques and characteristics of rice production indicate that it is still in the first level of agroecological transformation, according to Gliessman's proposed five levels [7,20].

Transitioning rice production to modernised techniques will ensure that the rice production schemes have access to the needed inputs (seeds, fertilisers, etc.) and the appropriate technology to realise the full benefits of agroecological production and sustainable production activities [21,22]. The implementation of SAM has proven to be highly beneficial for mechanisation projects in Nigeria and Tanzania, resulting in significant improvement in production figures and farmers' incomes [23,24].

Despite the benefits of SAM, its implementation in Africa has been challenging due to the various bottlenecks (unfavourable land tenure systems, limited income of farmers, inadequate spare parts delivery, lack of adequately trained technical experts, poor stakeholder collaborations, etc.) that arise in the execution of mechanisation interventions [25]. Several countries have found ways of implementing mechanisation through different levels of public–private partnerships [26–30]. Mechanisation interventions in Ghana have taken various forms, including government-supported, public–private, and solely private interventions [31–33]. Because of farm size and the capital-intensive nature of the initial investment in mechanisation [28,34,35], government interventions for machinery ownership are widespread.

In Ghana, whilst private sector involvement in the provision of equipment and machinery for agriculture production is steady, government interventions have undergone different reforms and modes of implementation. Notably, the Agricultural Mechanisation Service Centres (AMSECs) approach prevails due to the public–private initiative adopted in implementing the AMSECs model [25,31,32,36]. The AMSECs model of mechanisation service delivery is built on a government–private sector collaboration that seeks to create a mechanisation hub within accessible distance for smallholder farmers. The AMSECs provide accessible and reliable mechanisation services to farmers. The AMSECs model also makes it easy for the government to provide subsidies that directly aid the farmers using the AMSECs machinery-hiring services [37].

However, over time, the AMSECs had high operating costs due to high staff numbers and, most importantly, the inability to mechanise the entire production value chain. This led to long periods of no field activities to generate income for the AMSECs within a calendar year. For farmers, this leads to delayed farm activities and the rippling effect on the quality of grains after harvest and the market price of their grains [38]. Moreover, since the AMSECs do not own the complete set of equipment needed for mechanising production, farmers still have to rely on human power. Consequently, the AMSECs have become less profitable, while the private-led mechanisation drives were more successful due to their ability to diversify activities [32,34].

The need to ensure timely production of quality grains and increase farm income, an integral aspect of ensuring food security, has led to the drive to develop new machinery ownership models that allow smallholder farmers to own and control their production timeline. However, to achieve successful implementation, it is essential to consider the needs of the smallholder farmers and ensure they have access to affordable machinery that can be effectively utilised. In addition, it is crucial to identify the machinery required for increased rice production and propose methods of ensuring the effective use of machinery. Earlier studies have evaluated the level, intensity, profitability, and ownership models of mechanisation on rice fields in Ghana [16,17,39–41]. While only 86% of farmers surveyed had access to and utilised mechanised methods [39], private ownership has shown promise of being profitable and feasible [16,17,40,41]. However, achieving these recommendations requires exploring the support pathways and stakeholder interactions necessary to mechanise rice production activities. In addition, since an integral aspect of agroecological change is the social integration of agricultural production, by exploring the integration of agroecology with efficient mechanisation, farmers can exchange knowledge and build a stronger sense of community ownership of the machinery ownership models through mutual learning and knowledge sharing. Therefore, it is vital to understand the enabling stakeholder interactions needed for sustainability and smooth socio-cultural integration.

The study aims to evaluate different machinery ownership models and outline the necessary actions for key stakeholders to maintain efficient mechanisation, using rice production as the case study. This paper analyses and proposes pathways that stakeholders can adopt to effectively interact and promote the modernisation of rice production through practical, sustainable agricultural mechanisation. To achieve our aim, the study formulated the following research questions: (i) Can smallholder rice farmers own all the necessary and appropriate machinery for production and remain profitable? (ii) Can identifying and highlighting stakeholder interactions promote and sustain sustainable agricultural mechanisation?

2. Materials and Methods

2.1. Study Area

The study used both secondary and primary data. The primary data were collected in Asutsuare in 2022. Asutsuare is a major rice-producing area close to Accra's large urban centre, with most producers being smallholder farmers. It is located at 6°05′33.1″ N 0°11′43.1″ E in the Shai Osudoku district of Ghana (Figure 1). Rice production is performed along one of the main irrigation canals developed by the government. Access to irrigation is one factor that makes Asutsuare rice producers capable of economically producing rice all year, making it possible to use machinery effectively during most times of the year.

2.2. Data Sources and Sampling Strategy

The secondary data used in this study comprised a desk review of the literature on sustainable mechanisation. Previous survey data comprised interview data from stakeholders, including machinery manufacturers, sales, and importers. Data collected in an earlier study on the optimum machinery model for smallholder production were also used [17,42]. The previous research was based on a sample size of 150 farmers from rice production centres in both the southern and northern parts of Ghana. The secondary interview data consisted of interviews with mechanisation stakeholders located in Accra. Discussions focused on the stakeholders' capacity, challenges, and opportunities for effective collaborations.

Primary data were collected from 320 individual farmers from Asutsuare. A structured questionnaire was administered through a random sampling approach for the data collection. Before data collection, the questionnaire was pre-tested on a group of rice farmers exempted from the primary data collection samples. The questionnaire captured basic demographic and socioeconomic data and relevant information on the farm size, the type of machinery available and accessible, and the level of interaction of stakeholders.

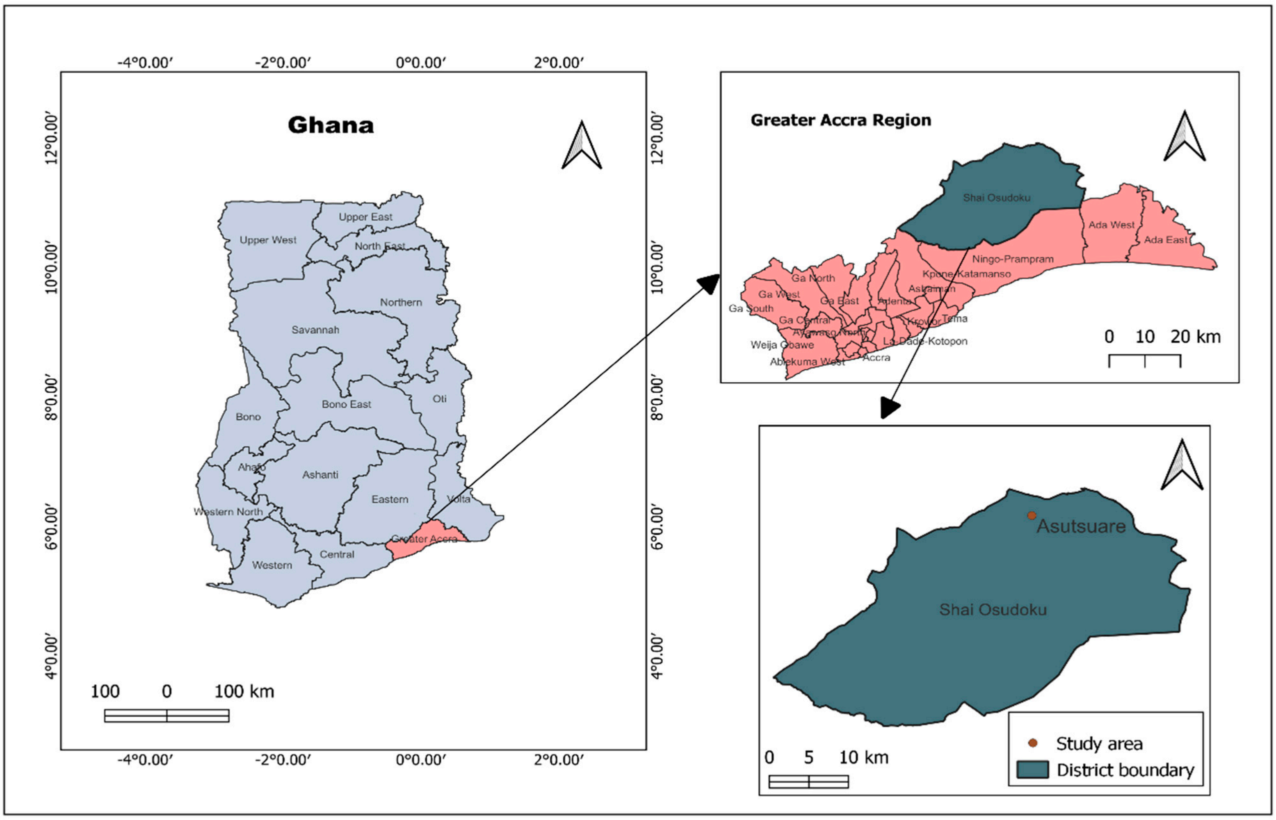

Figure 1. Study area map of Asutsuare.

2.3. Ethics Consideration

The study received ethical clearance from the College of Basic and Applied Sciences Ethics Committee, University of Ghana. Signed informed consent was obtained from the respondents regarding the data to be collected. Respondents were guaranteed anonymity throughout the data analysis process and assured that the data would be used strictly for the study objectives. Participants were also informed that they could withdraw from the study at any point without any consequences. Explicit consent was obtained from respondents to use their videos and photos for publications and media activities.

2.4. Data Management and Analysis

The data collected from the survey were coded and analysed using SPSS v25 and MS Excel 2016 software. SPSS was used to develop means, percentages, frequencies, standard deviations, and chi-squares. The chi-square was generated to compare the categorical and continuous demographic variables. Excel was used to perform economic analysis of the rice production data and machinery ownership models, among others.

2.5. Farm Power and Machinery Selection

When preparing for the rice cultivation season, assessing the field capacity (the rate at which a machine will work without any interactions) is crucial to guarantee that all field operations can be executed promptly. This assessment aids in the appropriate selection of equipment size that can efficiently function for the entire duration of the season. The required field capacity for each task to ensure the timely completion of activities was calculated based on equations found in the American Society of Agricultural Biological

Engineers (ASABEs) Manual [43]. Data on production time, planting, and harvesting schedules from the field were used to accurately determine field capacity and power needs. Efficient operations during the transition from minor to major seasons are crucial, which was factored into the computations.

The machinery selection process prioritised the accessibility and availability of equipment to encourage smooth integration. As such, the machinery selected for the analysis was determined through field observations of the farmers' production methods, the types of machinery being used, and data on farmland size.

2.6. Benefit Costs Analysis

The study analysed different machinery ownership models using the machinery selected to mechanise the production value chain. These were evaluated using the overall input cost of production (Equations (1)–(8)) and the total capital outlay for each scenario. The total input cost was calculated as the sum of each machinery's fixed and variable costs [44–47]. The fixed cost was calculated from the depreciation (*D*), interest on initial capital (*IRR*), and cost associated with Tax, Insurance, and Shelter (*TIS*). The variable cost was calculated as the sum of costs related to repair and maintenance (*R&M*), fuel and lubrication (*F&L*), and labour cost (*LC*). The equations used for the total fixed cost calculations are

$$Total\ fixed\ cost = D + IRR + TIS \tag{1}$$

$$Depreciaiton\ (D) = \frac{Cost\ price - Salvage\ value}{Lifespan\ of\ machine\ (hours)} \tag{2}$$

$$IRR = \frac{0.3\ *\ Cost\ Price}{Hourly\ work\ rate\ in\ a\ year} \tag{3}$$

$$TIS = \frac{0.275\ *\ Cost\ Price}{Hourly\ work\ rate\ in\ a\ year} \tag{4}$$

The total variable cost is calculated using Equations (5)–(8).

$$Total\ variable\ cost = R\&M + F\&L + Labour\ cost \tag{5}$$

$$R\&M = \frac{0.15\ *\ Cost\ Price}{Hourly\ work\ rate\ in\ a\ year} \tag{6}$$

$$F\&L = 0.1\ \times\ (Hourly\ fuel\ use) \tag{7}$$

$$Labour\ cost = \frac{Total\ labour\ cost\ per\ activity}{Total\ hours\ of\ work} \tag{8}$$

The net present value (*NPV*) and benefit–cost ratio (*BCR*) were estimated for each developed ownership model, and the model with the best *BCR* was proposed as the optimal model. The total benefits for each model were computed as the total revenue/income the farmer generates while using the proposed model. The benefit sources include the sale of farm produce and income from providing machinery hire services. Further, the *BCR* and *NPV* computations were performed at two discount rates of 10 per cent and 28 per cent using Equations (9) and (10). The discount rate of 28 per cent represents the current policy rate of Ghana, and the 10 per cent is used to depict a scenario where the farmer is offered soft loans at that rate. In addition, as acquiring machinery for each ownership model requires a significant investment, it is important to compute the Return on Investment (*ROI*) using Equation (11). This calculation will assist in determining the overall gains from the total investment made into machinery ownership.

$$NPV = \sum\nolimits_{t=1}^{T} \frac{C_n}{(1+r)^n} \tag{9}$$

$$BCR = \frac{\sum Present\ Value\ of\ future\ benefits}{\sum Present\ Value\ of\ future\ costs} \quad (10)$$

$$ROI = \frac{\sum Total\ benefits\ from\ investment}{\sum Total\ cost\ of\ investment} \times 100 \quad (11)$$

The different stakeholders involved in rice mechanisation were identified using the desk review, secondary interview data, and primary field data. Quadrant analysis was used to determine the level of interest and the level of influence of each stakeholder. The current interactions reported by the respondents were assessed, and based on the stakeholder responses, new collaborations to enhance the effectiveness of machinery supply and utilisation were proposed.

3. Results and Discussion

3.1. Descriptive Analysis of Household Demographic and Socioeconomic Characteristics

The distribution of male to female and the level of education among respondents are presented in Table 1. A chi-square test was performed on each parameter between male and female farmers to ascertain any significant difference between the means obtained. Significant differences existed between the mean values for gender, education, and farmland size. More male farmers had education up to the Junior High School level (JHS), and only 7.2 per cent of men had tertiary education. The respondents who had a tertiary education were either retired workers residing in the village and had taken up farming or current workers who are farming as an additional activity and mostly rely on hired labour. The average age of the respondents was 48.0 ± 12.7 and 47.7 ± 12.0 for the male and females, respectively. This trend in age and education shows how feasible it will be for the farmers to be trained, have a long farming career, and engage in farming as a business venture.

Table 1. Socioeconomic and demographic characteristics of respondents.

Parameters	Statistics	
	Male	**Female**
Gender of respondents (%)	64.5%	35.5%
Average Age, Mean ± SD (years)	48.0 ± 12.7 *	47.7 ± 12.0 *
Education status (%)		
No formal education	6.3%	15.8%
Primary	11.1%	21.9%
JHS	50.2%	49.1%
SHS	24.2%	13.2%
Post-Secondary	1.0%	0
Tertiary	7.2%	0
Farmland size, Mean ± SD (Ha)	1.50 ± 2.04	0.71 ± 0.47
Land tenure (%)		
Leased	74.4% *	69.3% *
Owned (inherited)	19.3% *	20.2% *
Sharecrop arrangement	1.0% *	4.4% *

Values are mean ± standard deviation (SD). Mean values with * have no significant differences ($p > 0.05$).

The availability, access, and size of farmland affect the methods of farming adopted. In selecting farm power and the corresponding equipment, farmland size influences the choices made. The respondents were asked about the size of their farms and the land tenure-ship of their rice fields to establish whether the farmland was owned or under lease. There was no significant difference between the farmland sizes for both male and female farmers ($p = 0.019$). Most of the farmers had leased their farmland, while the remaining 19.3 per cent of males and 20.2 per cent of females were farming on private lands acquired through inheritance. Land leased from the government, which has been earmarked for rice farming, is easier to ensure continuity of production on the land than other land tenure systems. The initial land allocation was performed with each farmer given a hectare of land. However, the average farmland size was more than 1 Ha. The farmers explained that some farmers had leased their lands, hence the increase in land size for some respondents.

It was noticed that each farm was near the irrigation canal, allowing for easy irrigation of the farmlands through the flooding method. This makes it easier for the farmers to plan their farming activities reliably. The interactions with the farmers during the field survey showed that land preparation and harvesting have higher levels of machinery use when compared with the other farm operations (planting, bird scaring, and husbandry activities).

3.2. Available Machinery for Mechanising Smallholder Rice Production

The study considered the complete mechanisation of the whole value chain of rice production. The machinery selected for the complete mechanisation of production of small-scale rice farms is based on the technical features observed during the fieldwork and the technical specification of each machine listed in Table 2. The machinery was selected based on the smallholder farmer's technological feasibility (equipment field performance, ease of use, suitability for field activities, etc.). For each machine, the field capacity and the timeliness of operation were determined to ensure it could effectively complete farm activities within the required time. This selection was made to ensure the smallholder farmer can own the full complement of the machinery needed for their production and give the farmer complete control of the timeliness of field activities, which is a major challenge the farmers face when having to rely on the existing hiring schemes that aim to serve all farmers.

Table 2. Proposed scale-appropriate machinery for total mechanised production.

Field Activity	Current Machinery Being Used by Farmers	Type of Scale-Appropriate Machinery Proposed
Field preparation	Tractor-and-rotavator aggregate; power tiller; Tractor-and-plough aggregate;	13 hp power tiller
Planting	Human labour	Drum seeder
Husbandry activities	Knapsack sprayer	Knapsack sprayer
Bird scaring	Human labour	Human labour
Harvesting	Combine harvester	Mini Combine
Threshing	Thresher	

Table 2 displays the machinery options currently accessible to farmers for production. Typically, only field preparation and harvesting have machinery available, and these machines are larger in size and require a significant amount of capital to purchase. However, since smallholder farmers usually have smaller land sizes, it is proposed that the machinery feature smaller capacities that are appropriate for their scale and require comparatively less initial capital. In addition, the use of a knapsack sprayer is the most scale-appropriate.

The proposed machinery is familiar to the farmers, increasing the likelihood of adoption. The drum seeder was chosen for its suitability, low operating cost, and planting efficiency. The power tiller provides the farmer with the needed farm power for tillage at an initial cost, which is more affordable and sustainable than owning a tractor-and-rotavator or tractor-and-plough aggregate. Due to the average land size, the farmer can easily use the knapsack sprayer for most of the husbandry activities on the farm. Whilst there exists an array of bird-scaring methods, the current manual techniques used by all the farmers interviewed were the easiest to access and use. The current mode of bird scaring involves using catapults by farmers or hired labour to pelt stones at the birds, thereby scaring them off the field (Figure 2). This is one point of production where innovations are needed to ensure more effective and labour-efficient bird scaring on rice farms. Comparatively, the mini combine ($\approx$1.1 m width of cut) is smaller than the combine harvester ($\approx$5 m width of cut), but it offers timely and affordable equipment for harvesting and threshing paddy for the smallholder farmers, hence the chosen alternative.

Figure 2. A female farmer demonstrates the use of the bird-scaring device (catapult) while carrying a knapsack sprayer on her back.

Using the machines listed in Table 2, various ownership models were created and assessed for their economic feasibility. For each ownership model, the full complement of equipment in Table 2 is proposed for the respective field activity, with variations only for planting methods (either transplanting seedlings or broadcasting seeds).

3.3. Ownership Models

The proposed ownership models with the respective economic model analysis are shown in Table 3. The first model proposes that farmers hire machinery for all aspects of their rice production under broadcasting (FHM-B) and farming by transplanting seedlings (FHM-T). The second model proposes that the farmer owns the required machinery for the various aspects of production. Similarly, the same is proposed for broadcastings (FOM-B) and transplanting (FOM-T). The third model proposes that the farmer owns the machine and hires it from other farmers to earn income under broadcasting (FOHM-B) and transplanting (FOHM-T). The fourth model proposes communal ownership of the machinery. Here, the group shares the initial investment cost of the machine. This is also for broadcasting (COM-B) and transplanting (COM-T). The final model proposes that the farmer owns machinery and hires it out to other farmers but also performs two productions within a calendar year. This is also for broadcasting (FOHM-2B) and transplanting (FOHM-2T).

Table 3. Net present value and benefit–cost ratio at two discount rates for the proposed mechanisation models.

	FHM		FOM		FOHM		COM		FOHM-2T	
	FHM-T	**FHM-B**	**FOM-T**	**FOM-B**	**FOHM-T**	**FOHM-B**	**COM-T**	**COM-B**	**FOHM-2T**	**FOHM-2B**
Fixed Cost (GHS)										
Cost of machinery	-	-	85,000.00	85,000.00	85,000.00	85,000.00	4250.00	4250.00	85,000.00	85,000.00
Recurring cost										
Cost of farm input (GHS)	6627.00	5956.00	4525.00	3854.00	4525.00	3854.00	4525.00	3854.00	9050.00	7708.00
Total Cost (GHS)	6627.00	5956.00	89,525.00	88,854.00	89,525.00	88,854.00	8775.00	8104.00	94,050.00	92,708.00
Benefit–Cost (GHS)										
Revenue from farm produce	15,000.00	15,000.00	15,000.00	15,000.00	15,000.00	15,000.00	15,000.00	15,000.00	30,000.00	30,000.00
Revenue from machinery hire	-	-	-	-	2000.00	2000.00	-	-	2000.00	2000.00
Total Benefits (GHS)	15,000.00	15,000.00	15,000.00	15,000.00	17,000.00	17,000.00	15,000.00	15,000.00	32,000.00	32,000.00
NPV at 10% discount rate	**51,448.46**	**55,571.46**	**−12,908.39**	**−8785.38**	**−619.25**	**3503.75**	**60,500.70**	**64,623.71**	**63,745.09**	**71,991.10**
BCR at 10% discount rate	**2.26**	**2.52**	**0.88**	**0.91**	**0.99**	**1.03**	**2.91**	**3.35**	**1.48**	**1.58**
NPV at 28% discount rate	**27,370.64**	**29,564.08**	**−32,164.35**	**−29,970.90**	**−25,626.51**	**−23,433.07**	**30,921.59**	**33,115.03**	**8615.39**	**13,002.28**
BCR at 28% discount rate	**2.26**	**2.52**	**0.60**	**0.62**	**0.68**	**0.70**	**2.71**	**3.08**	**1.09**	**1.14**
Return on Investment (%)	**151**	**168**	**21**	**21**	**25**	**26**	**150**	**167**	**42**	**43**

Green: recommended models; Red: Models not recommended.

In Table 3, the total cost is computed as the machinery cost (total purchase price of the selected machinery) and cost of farm inputs (total cost of all the farm inputs purchased per growing season). The FHM models (FHM-B and FHM-T) have no machinery cost because the models propose only machinery hire for field activities. Consequently, the farm input cost is higher for the two FHM models because of the machinery hire cost. Machinery costs for the two cooperative models (COM-B and COM-T) are lower than the single farmer ownership models (FOM-B, FOM-T, FOHM-B, and FOHM-T) as the farmers within the cooperative share the total cost of the machinery they communally own. Though the farmers practising the COM models (COM-B and COM-T) have low machinery costs, they do not have revenue from machinery hiring. This is because, with the communal ownership of machinery, the farmers will not have time left after servicing the cooperative members' fields to render service to other farmers. The maximum size of the cooperative was determined to be 20, using the total field size that can be worked with the selected machinery and the field capacity of the machinery that will ensure the timeliness of activities.

Farmers who operate under single ownership models have the option to rent out their machinery as a means of generating additional income, and this adds up to their total revenue. Farmers can ensure optimum use of machinery within each season by offering machinery-hiring services, thereby preventing long downtimes. However, the models with the machinery-hiring service option are based on the assumption that farmers will have other willing farmers to patronise the hiring service.

The total benefits in Table 3 show the varying revenue generated by each ownership model. The FHM-B, FHM-T, FOM-B, FOM-T, COM-B, and COM-T models are limited to earning income solely from the sale of farm produce. In contrast, the FOHM-B, FOHM-T, FOHM-2B, and FOHM-2T models have the potential to earn additional revenue by offering machinery-hiring services to other farmers. The FOHM-2 models stand out as they can produce crops twice a year, resulting in twice the total farm revenue compared to the other models.

The farm revenue was calculated as the average yield from the farm multiplied by the average market price of rice (4 GHS/kg). (Table 3 shows the total benefits from farm and machinery hiring.) Only the models (FOHM-B, FOHM-T, FOHM-2B, and FOHM-2T) having hiring services have hiring revenue as part of the total benefits. The *NPV*, *BCR*, and *ROI* analyses were performed assuming the current market price of rice, the average cost of machinery hiring (100 GHS/kg), and computed values of farm input cost from field data. The economic analysis shows that the ownership of the full complement of small-scale machinery could be a better economic mechanisation model at both discounted rates (Table 3). While all the models showed high returns on investment, the machinery ownership models, FOM-B, FOM-T, FOHM-B, and FOHM-T, gave *ROI* less than the prevailing market rate of 28% and are not better investment options for the farmers. Regarding the *NPV* and *BCR* analyses, at a 10 per cent discount rate, machinery ownership models (FOHM-B, FOHM-T, FOHM-2B, and FOHM-2T) with hiring services being run by the farmers is viable. The stakeholders, including governments and development agencies, can use the model to mechanise smallholder agriculture. This will enable them to offer low-interest rate loans to farmers. Also, looking at the scalability of this concept, countries with very low-interest rates can provide such machinery models to their farmers through existing extension agents or dedicated project collaborators. For example, MasAgro (a Mexican public–private mechanisation program for small- to medium-scale farmers) practised a similar concept of machinery provision for farmers, where the project provided the initial start-up capital investment for machinery acquisition [30].

The cooperative model also helps to socially build machinery ownership that integrates well into building stronger social connections across the community because the farmers get to provide service for their fellow farmers. It can also build a local knowledge base for expanding community machinery usage. However, the possible downside of these models is the farmers' ability to manage field activity scheduling and prevent abuse of communal ties, where cooperative members do not receive service on time and other farmers benefit without being charged. The issues with scheduling field activities can be solved when the farmers are offered proper training and the needed stakeholder support.

In Ghana, rice is grown in locations with irrigation facilities and without irrigation access (the rain-fed upland and lowland). The sites with irrigation access produce rice twice a calendar year, while those without irrigation only produce rice once a calendar year. The COM model considers only a single cropping season in a given calendar year. The cooperative-owned machinery (COM) models with a sharing of the initial investment capital outlay for the machinery acquisition prove very viable at both discount rates. Therefore, it is a viable option for the average Ghanaian rice farmer without access to irrigation. Also, this model is suitable for small-scale rice production in most Sub-Saharan African countries with only rain-fed rice production schemes or one growing season.

The FOHM-2B and FOHM-2T models are well-suited for small-scale rice production in areas with reliable irrigation systems that support cultivating rice crops twice a year, like Asutsuare. This also suggests that they can own machinery, hire it from other farmers, and then plan their production to ensure two cropping seasons within a calendar year. Therefore, the farmers using irrigated fields are encouraged to own their machinery, whilst the farmers away from the irrigation sites where twice-a-year production will not be possible can form farm groups of up to 20 farmers and acquire machinery for their production. The FOHM and COM models promote socially inclusive methods of machinery ownership, which promotes communal ownership and capacity building.

3.4. Possible Interactions to Promote Smallholder Mechanisation

Promoting the models recommended in this study could increase demand for local machinery manufacturing and trigger the emergence of new enterprises that increase local machinery production. The promotion of SAM relies heavily on the effectiveness of the relationship and interaction of its stakeholders. An analysis of the mechanisation service delivery by Diao & Takeshima [25] and Fonteh [31] explains Ghana's mechanisation service delivery landscape. The bottlenecks identified (land tenure, the inadequate workload for service providers, low financial support for machinery acquisition, etc.) and the rethinking of proposed interventions highlight the need for better stakeholder interactions. Our research emphasises the importance of stakeholder engagement to support the implementation of the different machinery ownership models available.

A vibrant private sector that can aid in service delivery is needed to promote machinery ownership by smallholder farmers. It is essential to consider all the major stakeholders within the machinery service provision sector regarding their characteristics, roles, and incentives for being part of sustainable machinery provision and utilisation for farmers. The main stakeholders around effective machinery use are the equipment manufacturers, research and development experts, equipment sales (made up of importers, sales, and after-sales personnel), NGOs, development agencies, government (made up of Agricultural Engineering Services Directorate (AESD), Ghana Standard Authority, extension agents, and the central government), and smallholder farmers (Figure 3). Mutually beneficial interactions between these stakeholders are needed to safeguard effective mechanisation for smallholder farmers. For example, the farmers must be trained in machinery operation for the personal ownership models (FOM-B, FOM-T, FOHM-B, and FOHM-T) to be effective. In addition, the professional technical service sector (operators and after-sales technicians) needs to exist to ensure effective machinery maintenance, supply of adequate spare parts, and timely repair of machinery. The after-sales technicians will ensure that equipment is appropriately installed and routine maintenance is carried out periodically.

Our findings provide valuable insights into each stakeholder's level of interest, influence, and current interactions, as shown in Figure 3. With the objective of increasing effective SAM, the smallholder farmers are the main beneficiaries and have a major interest and influence on the overall outcome of effective mechanisation. The machinery operators and manufacturers who reside within the farming communities are closely connected to the smallholder farmer. Manufacturers develop and fabricate machinery for smallholder farmers, while machinery operators provide technical expertise to run the machinery efficiently. The machinery operators and manufacturers have moderate influence and high interest in implementing SAM because of their technical role in providing mechanisation services and the economic gains they stand to make from increased mechanisation.

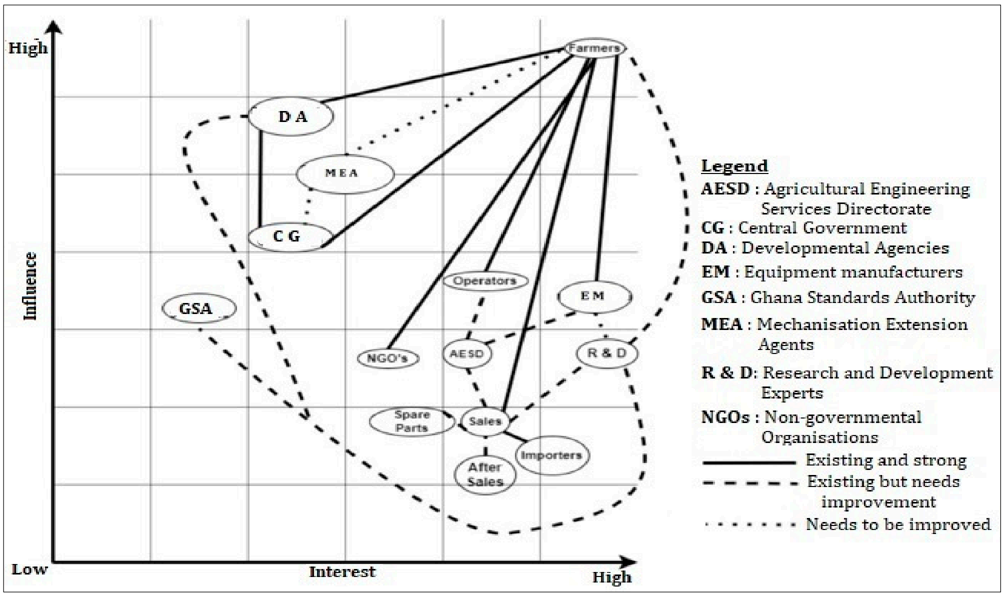

Figure 3. Level of stakeholder interest and influence showing needed interactions for effective mechanisation.

Development agencies and government entities such as the Ghana Standards Authority, extension agents, and the central government provide funding, regulations, technical expertise, guidelines, and frameworks for smallholder mechanisation practices. Examples of such programs include training programs aimed at rice mechanisation in Tanzania, Côte d'Ivoire, and the Philippines, organised by the FAO [48]. In Ghana, these stakeholders have supported several agricultural intensification projects by funding project activities, for example, the AMSEC program [37,42]. These stakeholders influence the implementation of SAM but have moderate interest in its outcome because their interest is mainly based on the specific project targets they must meet.

Other stakeholders have limited influence yet stand to gain significantly from the success of SAM initiatives. These stakeholders include research and development experts, who develop research projects based on the needs of smallholder farmers and provide policy guidelines or design new and improved equipment. The Agricultural Engineering Services Directorate (AESD) is responsible for implementing policies related to agricultural mechanisation. Other stakeholders include equipment sales personnel (including importers, salespeople, and after-sales support) and non-governmental organisations (NGOs). All of these groups have their own personal or organisational goals that are linked directly to the success of SAM. While the equipment sales group's influence on the mechanisation landscape has been moderate to date, they would still benefit from increased demand for machinery resulting from increased mechanisation.

Aside from the interest and influence of the stakeholders, each stakeholder has definite roles to perform, and through effective collaboration, these can be realised. The equipment sales, through the importers, ensure that the needed equipment is available within the market and easily accessible to the local rice farmer. Equipment accessibility will be improved when they operate effectively. Small-scale farmers often require more resources to purchase necessary farm inputs. One proposed solution to this challenge is using subsidies to support these farmers [29,37]. The government can apply targeted subsidy programmes to benefit small-scale farmers through the equipment sales market. In addition, NGOs and developmental agencies can aid the availability of machinery in the market through directed financial support.

The equipment (scale-appropriate machinery) within the market will be determined and constantly updated through the ongoing work of research and agricultural development experts. Their work will seek to standardise or provide (culturally appropriate or community-accepted) improved designs based on their research interactions with the farmers and the machinery manufacturers [6]. Through practical research, researchers can provide equipment designs that will help solve issues with bird scaring on rice farms and influence the adoption of farming technologies [49]. As such, researchers must interact with the users of the knowledge and product they seek to develop to provide innovative and relevant solutions [50]. This will help ensure that the solutions and policy directions about using scale-appropriate machinery are user-centred for the farmer and cost-effective for manufacturers. In effect, research and development specialists provide machinery manufacturers with the latest designs and specifications. These experts work in partnership with the Ghana Standards Authority to ensure consistency in the production and utilisation of machinery. New designs and specifications will form product changes, wholly or partly, before being sent back to the machinery sales points, where the sales agents deliver them to the farmers.

The mechanisation extension agents are responsible for training farmers in using new machinery and ensuring that the machinery is used efficiently for field activities. They also train operators and technicians in farming communities, which is crucial for successfully implementing mechanisation. These operators work closely with the Agricultural Engineering Services Directorate of the Ministry of Food and Agriculture in Ghana to standardise their operations and provide machinery operation services directly to farmers.

Regular training of operators and technicians is essential to ensure the efficient operation and handling of machinery. Mechanisation extension agents can provide this training. Operators are responsible for the smooth running of machinery, and they must perform regular maintenance and repairs and undergo periodic training. Therefore, maintaining a solid and collaborative relationship between the farmer and the operator is crucial for successfully implementing mechanisation in their fields.

Each stakeholder's role and resulting impact show the importance of the interactions between the stakeholders. The machinery manufacturer, operators', and extension agents' role in mechanisation service delivery within the farming community is crucial in the effective mechanisation of agricultural production. The role of after-sales technicians in effectively maintaining machinery also needs to be further strengthened. In order to effectively develop and improve mechanisation projects and technologies, smallholder farmers, R&D experts, manufacturers, and the GSA need to interact and collaborate. These interactions are necessary to build a vibrant support system around machinery use and ultimately achieve effective SAM.

4. Conclusions

Achieving environmentally sustainable, small-scale rice production mechanisation across African farming systems is feasible. This study in Ghana shows that there exist models for the ownership of machinery that can provide the smallholder rice farmer with the needed machinery to mechanise their production value chain effectively, efficiently, and sustainably. Applying these models in similar agricultural production landscapes can enhance farming practices and promote sustainable production.

The study provided an economic analysis of specific machinery ownership models. In addition, mutually beneficial stakeholder interactions and engagements that can enhance equipment availability, spare parts availability, timely interventions through R&D, etc., were proposed. Improving and enhancing the interactions between smallholder farmers, R&D experts, manufacturers, government, and development agencies is essential to make the most of the models. It is crucial to uphold the current strong connections among stakeholders, especially the links between the machinery operator, manufacturers, and smallholder farmers who reside in the farming communities, to guarantee that properly maintained machinery is accessible for the farmers to utilise.

The ownership models and interactions proposed in this study offer a socially inclusive approach to equipment ownership. However, the study did not address concerns regarding machinery use scheduling and the role of social relationships in implementing these models. In addition, the models did not include post-harvest machinery and the impact of land tenure on machinery use. Further research is necessary to explore these issues and also (a) ensure the models are effective and sustainable when applied, (b) assess factors that influence the choices of the local farmer, and (c) determine the constraints on local production and supply of equipment. These studies will be critical to fully operationalising the models and stakeholder interactions required to deliver sustainable agricultural mechanisation to small-scale African rice farmers.

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