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Development of climate smart agriculture based on empowering farmers around forests through triple-helix collaboration

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ABSTRACT

Background: The agricultural sector policy in Indonesia in facing climate change is to increase agricultural productivity and reduce GHG emissions through the development of Climate Smart Agriculture based on empowering farmers around forests. **Methods:** Qualitative methods produced descriptive data in the form of written or spoken words from people, and observable behaviour. **Findings:** Synergy and collaboration between the Government, Universities and the Community in the form of triple-helix collaboration through Climate Smart Agriculture activities, which are carried out through the following activity stages: 1) Technology Transfer Stage, including activities for making corn planting demonstration plots under coconut stands, making planting demonstration plots taro under cocoa stands, creation of Moringa plantation management demonstration plots on dry land; 2) Training Stage, activities are carried out to process agricultural products into secondary products, namely: Corn Flour, Corn Analog Rice, Taro Flour, Taro Analog Rice, Moringa Leaf Powder, and Moringa Leaf Tea; 3) Packaging and e-marketplace initiation stage, through packaging design, labeling, marketing via digital platforms and assistance; 4) Empowerment activities and strengthening the institutional capacity of agricultural extension workers and farmer groups are urgently needed to support the development of climate-smart agriculture. **Conclusion:** Innovations to support the development of Climate Smart Agriculture based on empowerment around forests through triple-helix collaboration will improve farming management through activities. **Novelty/Originality of this Study:** The research presents a novel triple-helix collaboration model for developing Climate Smart Agriculture, integrating government, university, and community efforts to enhance agricultural productivity while mitigating greenhouse gas emissions.

KEYWORDS: climate smart agriculture; empowering; triple-helix.

1. Introduction

Being an agricultural nation, the farming domain is a key sector in Indonesia. The agricultural sector plays a crucial role in fostering economic development in Indonesia, particularly in terms of national progress and generating job opportunities (Gina et al., 2023). At present, the role of agriculture in economic development is declining due to unpredictable global climate change. Global climate change variations significantly affect on agriculture and present a critical concern as they could jeopardize a country's national priorities (Malhi et al., 2021; Rahayu, 2017). Change in global temperatures lead to extended periods of drought and severe rainfall that can interrupt farming cycles. The reduction in land quality, fertility, and its capacity to sustain crops, along with the

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diminishing supply of water and its worsening condition, are responsible for the drop in both the amount and standard of agricultural output (Habib-ur-Rahman et al., 2022). The El Nino and La Nina phenomena significantly affect the climate pattern, leading to changes in the planting timelines for different agricultural products and raising the risk of harvest failure. Moreover, the rise in Greenhouse Gas (GHG) emissions from multiple activities contributes to global climate change, which in turn raises the earth's temperature. (Leng et al., 2019).

The Food and Agriculture Organization (FAO) is growing more worried about how worldwide climate changes affect farming progress and the availability of food. A drop in the output of crops will also influence the decrease in food security, which is a crucial element in a country's ability to withstand challenges (Mustapit et al., 2019). The emerging food shortage will lead to additional issues, including social and security challenges, a scenario already witnessed in various African nations. By the year 2050, Indonesia is expected to face a significant surge in its population due to a continuing high growth rate (Udmale et al., 2020). It is essential to plan for a 60% enhancement in food output compared to the existing levels. The plan to reach this goal should focus on lessening the effects of climate change, which can be achieved through stricter oversight and care of forested regions to stop unlawful deforestation and wildfires, decreasing reliance on synthetic materials like plastic and styrofoam, reducing the application of pesticides and hazardous substances in farming by advocating for natural alternatives, along with speeding up the integration of agricultural technology by engaging all community members (Adnan & Dadi, 2023).

The policy for agriculture in Indonesia regarding climate change aims to enhance productivity while minimizing greenhouse gas emissions. By applying knowledge of land and crops, it is possible to boost both output and farmers' earnings, along with lowering GHG emissions. Emissions of greenhouse gases from land that is cultivated using diverse crop approaches are significantly less than those from single-crop methods (Akmalia, 2022; Jumiyati et al., 2021a). In addition to that, utilizing organic farming methods by offering organic fertilizers will enhance growth and boost crop yields, as well as have the potential to capture 11% of greenhouse gas emissions (Jumiyati et al., 2021c). Sustainable land use and the use of farming techniques that help lower greenhouse gas emissions, such as varying crops, organic agriculture, and agroforestry, depend on the knowledge, understanding, and abilities of farmers in forested areas (Gamage et al., 2023). The participation of local communities, particularly farmers living near forests, in managing these areas is crucial, given that their engagement with forests is quite significant in nearly every part of Indonesia. This situation arises due to the fact that these farmers tend to be poorer and have lower levels of education. The primary factor driving them to cultivate forest land near where they live is the scarcity of usable farmland and their insufficient earnings (Ahmed et al., 2022).

Climate change poses a significant challenge to enhancing crop yields and efficiency. The adverse effects of severe climate changes worldwide include the deterioration of soil and water supplies, harm to farming and irrigation systems, the occurrence of floods and drought conditions, as well as a rise in assaults from pests and plant diseases (Alotaibi, 2023). Farmers require understanding and abilities related to farming that can adjust to climate change, which is referred to as Climate Smart Agriculture (CSA). CSA represents a necessary strategy to modify and realign farming methods to successfully promote growth and guarantee food safety amidst evolving climate circumstances (Mohanty et al., 2024). Essentially, CSA represents a method for formulating agricultural techniques aimed at achieving enduring food security while combating the effects of climate change. The technology associated with CSA enhances the methods of farming, particularly for rice and other crops. CSA prioritizes both food security and resilience to climate change, built upon four key foundations: sustainably boosting agricultural output and earnings, adapting and strengthening food security in response to climate variations, decreasing and/or lessening greenhouse gas emissions (mitigation), and making the best possible use of diverse resources (Van Wijk et al., 2020).

Initiatives aimed at enabling farmers near forests to address the challenges posed by climate change through agricultural management practices and forest use consist of two primary components: community involvement and enhancing productivity sustainably (Stringer et al., 2020). The cooperation and partnership among the Government, Universities, and Society, characterized by a triple-helix approach through CSA initiatives, is an essential strategy for the autonomy of both society and the agricultural industry in tackling the challenges posed by global climate change while enhancing the food sovereignty of the Indonesian nation (Abdillah et al., 2022). Strategies for adopting CSA to address global climate change encompass enhancing and expanding farmer engagement in the effective use of technologies and innovations through their adoption. This process also requires the adjustment of farming practices in response to climate change by modifying crop rotations and patterns informed by local knowledge and resource availability. An additional key strategy is to boost farmer participation and promote their institutional autonomy. Furthermore, establishing demonstration plots for the integration of agricultural technologies and strengthening farmer organizations is vital. Improving the skills and abilities of Farmer Groups and Agricultural Extension Workers in implementing climate-resilient farming practices is equally important. In addition, it is crucial to enhance planting frequency, increase crop yields, and improve productivity while also mitigating the impacts of GHG emissions. Solutions for implementing CSA in facing global climate change include building and increasing farmer institutional participation in the efficient and effective application of innovation and technology through adoption. It also involves implementing adaptive cultivation to climate change by regulating crop patterns and rotation based on resource availability and local wisdom. Another important solution is increasing participation and institutional independence of farmers. Additionally, carrying out pilot plots for adopting agricultural technology and empowering farmer institutions plays a crucial role. Increasing the capacity of Farmer Groups and Agricultural Extension Workers in implementing agricultural cultivation that adapts to climate change is also necessary. Moreover, increasing planting intensity (IP), plant production, and productivity is essential, along with reducing the effects of GHG emissions (Autio et al., 2021).

Increasing the abilities of human resources (HR) and enhancing the social networks of farmers near forests can be achieved via both formal and informal educational methods. Informal education can occur through training sessions, guidance, empowering farmer organizations, and supporting the achievements of joint initiatives (Jumiyati, 2019). Despite having limited HR capabilities, subsistence farmers residing near forests possess distinct local knowledge related to adaptive agricultural practices for managing marginal lands. This local understanding held by forest-adjacent farmers cannot progress due to varying views and priorities between the community and governmental (Ngongo et al., 2022). The triple-helix collaboration between the local government, educational institutions, and the community aimed at fostering CSA through enhancing community skills will provide valuable perspectives on the sustainable application of technologies that emerge from research (Luengo-Valderrey et al., 2020).

Implementation of the triple-helix model necessitates methods and tactics that are suitable for specific local circumstances and obstacles, which in turn calls for cooperation and alignment for the joint advantage of all aspects of the triple-helix. Through the understanding and joint initiatives of the three stakeholders, advancing the triple-helix can yield significant advantages for innovation and fostering CSA, while also influencing the empowerment of farmers in forested areas to enhance food availability and lessen GHG emissions (Rodrigues & Melo, 2013). Cooperation among the local government of Central Sulawesi, Muhammadiyah University (Unismuh) Palu, and farmers in forest-adjacent areas will promote the innovation needed to address challenges in executing Climate Smart Agriculture on farmland near these forests. The primary issues encountered by farmers in these regions when adopting CSA involve managing water, soil, crops, and agribusiness practices. Focusing on these areas, collaborative efforts through a triple helix approach can strengthen the capabilities of farmers in forest areas through educational initiatives, guidance (technology transfer), and training related to CSA (Kuntias et al., 2023).

Agricultural methods utilizing a CSA strategy that promote sustainable farming and guarantee food safety amid climate change have not been effectively put into practice at the level of farmers (Anuga et al., 2019). Enhancing the expertise of farmers regarding the use of CSA-related methods for growing, processing, and selling agricultural products is anticipated to boost both the productivity and sustainability of farming practices based on agribusiness (Arulmanikandan et al., 2024). Enhancing the knowledge and abilities of farmers is one approach to hasten the dissemination of agricultural technologies (Konfo et al., 2024). In enhancing agricultural progress, the understanding of farmers plays a crucial role, as their knowledge enhances their capacity to embrace innovative farming technologies. Elevating farmer understanding regarding CSA innovations is anticipated to foster a favorable mindset that can significantly enhance their proficiency in utilizing CSA technologies, which will be shared via partnerships among relevant organizations, academic institutions, and farmers in forested areas. Consequently, research is necessary to facilitate the advancement of climate-smart agriculture by empowering farmers in forest regions through a triple helix collaboration.

2. Methods

The progress of Climate Smart Agriculture in enhancing the output, processing, and promotion of farming enterprises must be communicated to farmers via empowerment initiatives such as agricultural extension services (Osumba et al., 2021). The approach of farming outreach entails sharing new developments by providing training and technical support for demonstration fields (Khan et al., 2009). The introduction of the extension program is anticipated to enhance farmers' expertise and abilities in utilizing CSA technology. This initiative unfolds in phases, beginning with the selection of sites and beneficiaries, where CSA tasks are performed by Agricultural Extension Workers and Groups of Farmers, which are distinct collectives aiming for common objectives by utilizing existing associations in the research area. The subsequent phase entails crafting plans for activities, which starts with pinpointing the requirements for executing the program, such as the size of land, necessary infrastructure, technology, and the accessibility of water and crops grown.

The strategy document specifies the nature of the activities, their locations, timelines for execution, and methods for establishing demonstration plots, producing Bokashi fertilizer, providing training in processed food production, beginning marketing efforts, and enhancing and bolstering institutional abilities. Supportive activities, or the transfer of technology, are conducted by the Regional Government of Central Sulawesi in cooperation with universities, aimed at empowering and encouraging Agricultural Extension Workers and Farmer Groups to promote CSA through the establishment of planting demonstration plots. Training for marketing processes and initiation occurs in conjunction with Agricultural Extension Workers and Farmer Groups, who benefit from this initiative, with the goal of boosting farmers' enthusiasm and involvement in diversifying agricultural products through the application of Climate Smart Agriculture (CSA). Ultimately, activities focused on empowerment and enhancing institutional capabilities are essential to reinforce CSA as the key element for agricultural advancement in rural areas.

The research took place in the buffer area of the Lore Lindu National Park (TNLL) forest located in Central Sulawesi, Indonesia, and included Farmer Groups near the TNLL forest. This investigation employed a quantitative methodology, as the information gathered consisted of numerical data acquired through quantification methods (Suryani & Utami, 2020). The quantitative methodology was utilized to evaluate the evolution of knowledge and abilities among participating farmers regarding the phases of CSA technology innovation efforts that were shared with the involvement of the Government, Universities, and local farmers through a triple helix partnership.

The selection of participants was conducted purposefully, focusing on all individuals involved in the CSA development training and technical support in Central Sulawesi. Consequently, there were 24 respondents comprising 20 farmers from 2 groups and 4

Agricultural Extension Workers. Information was gathered through the distribution of questionnaires that included inquiries about the CSA technology package both prior to and following the CSA training and guidance activities. The data were analyzed utilizing the Likert Scale, which ranges from 0 to 4. The acquired data were then organized into tables to determine the percentage of competency values based on the scores for each question item served as an indicator of the research instrument, demonstrating the strength of each indicator in forming competency, with the calculation formula for the Percentage of Competency Value (Ariyani et al., 2024) as follows:

$$Competency\ value\ percentage\ (\%) = \frac{The\ total\ score\ obtained}{The\ expected\ total\ score!}\ x\ 100\% \quad \text{(Eq.1)}$$

According to the percentage of competency value, certain criteria were set to assess the degree of change in knowledge and skill among farmer respondents concerning their adoption of various CSA technology innovation activities. These criteria divide the competency levels into five brackets. A percentage between 0% - 20% signifies very low competency. A percentage ranging from 20.01% - 40% represents low competency, while a range of 40.01% - 60% is seen as medium competency. When the percentage value is between 60.01% - 80%, it indicates high competency, and a percentage from 80.01% - 100% signifies very high competency.

3. Results and Discussion

3.1 Stages of CSA farmer empowerment activities

The establishment of CSA in Central Sulawesi Province focuses on enhancing the capabilities of farmers adjacent to forests through a collaborative approach involving multiple stakeholders. This initiative includes empowering agricultural trainers and farmer collectives to grow corn among coconut trees, to cultivate taro interspersed with cocoa plants, and to manage moringa farms in arid regions. It is complemented by the processing of these crops and the launch of marketing strategies for the processed goods. Up until now, farmers have predominantly utilized a single-crop cultivation method, selling their produce in its raw state without engaging in post-harvest processing to elevate the quality and value of their agricultural outputs. The drive to maximize agricultural land through CSA involves growing a diversity of crops in conjunction, aiming to secure food resources for farming families (Thornton et al., 2018). An additional advantage gained from this activity is that it lowers household costs and may also generate extra income if the results obtained exceed the family's food needs (Wakweya, 2023).

In accordance with Law Number 19 of 2013 in the Republic of Indonesia regarding the Empowerment and Protection of Farmers, it specifies that the empowerment of farmers encompasses all initiatives aimed at enhancing farmers' capabilities to manage their agricultural businesses more effectively. This is achieved through various means such as education and training, guidance and mentorship, advancements in marketing systems and processes for agricultural goods, ensuring agricultural land consolidation and security, facilitating access to knowledge, technology, and information, as well as bolstering institutions. It is essential to empower farmers so they can develop and thrive towards greater prosperity. Empowerment also consists of a range of activities designed to cultivate and reinforce awareness, skills, and resource access, thereby boosting self-governance and environmental management to achieve the welfare of farmers (Noventi, 2017). Empowering farmers creates an environment for them to enhance their skills and promotes individual self-sufficiency. The involvement of farmers is crucial in initiatives aimed at their empowerment. Farmers can engage in these empowerment activities at various stages, including planning, execution, monitoring, and assessment, ensuring that the empowerment initiatives are more focused and tailored to the farmers' requirements.

Fig. 1. Socialization of climate smart agriculture (Original photo)

The strategy for creating CSA takes place within the context of sustainable agricultural progress, utilizing support (transfer of technology) and education in the processing of agricultural goods while focusing on local resources and integrating traditional knowledge (Retnaningtyas et al., 2024). In addition, the farming community created a demonstration garden to serve as an educational resource for the members regarding growing techniques and crop care, along with producing Bokashi fertilizer. In addition, the farming community created a demonstration garden to serve as an educational resource for the members regarding growing techniques and crop care, along with producing Bokashi fertilizer. (Hakim et al., 2023). In addition to that, food production processes related to CSA are conducted by processing items like Corn Flour, Corn Imitation Rice, Taro Flour, Taro Imitation Rice, Moringa Leaf Powder, and Moringa Leaf Tea. The advancement of CSA initiatives focusing on supporting farmers near forests through a triple-helix partnership occurs in four distinct stages of activity, which are as follows.

3.1.1 Assistance stage (Technology transfer)

During the growing phase, the utilization of land and vegetation is enhanced by the principles of Climate Smart Agriculture, which encompasses these actions:

3.1.1.1 Creation of corn planting demonstration plots under coconut stands

The initiative commenced with the examination of agricultural fields belonging to farmers in Talaga Village, located in the Donggala Regency, recognized as a significant area for coconut production in Central Sulawesi. The coconut trees cultivated by the farmers are several decades old and feature tall trunks. The spacing for planting coconuts is set at 8 x 8 meters, allowing for the possibility of also growing corn as an intercrop, which could enhance both food security and the income of farmers. The combination of corn and coconut cultivation is highly beneficial for development, as it contributes to the reduction of greenhouse gas emissions by diminishing the amount of solar radiation absorbed, thanks to the coverage provided by the canopies of the plants. Additionally, this method of intercropping leads to a water utilization efficiency rating of 39.68%, offering greater productivity than the traditional monoculture farming approach.

3.1.1.2 Creation of taro planting demonstration plots under cocoa stands

The process started with an examination of the agricultural terrain belonging to farmers at the study site, specifically Kamarora Village in Sigi Regency, recognized as a key area for cocoa cultivation in Central Sulawesi Province. Growing taro alongside cocoa trees aims to achieve the best possible yield while preserving soil health. These intercropping schemes can enhance land productivity by making better use of resources like sunlight, water, and nutrients, while also helping to manage weeds, pests, and diseases, promoting sustainable farming practices. By adopting intercropping methods, farmers can boost their earnings and crop outputs, thereby supporting food security more effectively than through single-crop practices.

3.1.1.3 Creation of moringa plantation management demonstration plots on dry land

The initiative commenced with examinations of the agricultural fields belonging to farmers at the research site, specifically in Pangi Village within the Parigi Moutong Regency. Moringa trees can flourish in dry or suboptimal soils. This plant contributes positively to the ecosystem and supports the nutrition and well-being of individuals residing in arid regions. The initiative commenced with examinations of the agricultural fields belonging to farmers at the research site, specifically in Pangi Village within the Parigi Moutong Regency. Moringa trees can flourish in dry or suboptimal soils. This plant contributes positively to the ecosystem and supports the nutrition and well-being of individuals residing in arid regions (Afrianto & Metananda, 2024).

The various phases of tasks performed consist of establishing demonstration plots, intercropping, creating a water wheel, producing organic fertilizer, maintaining the land, and providing support. The initial steps in developing a demonstration plot start with preparation, which includes selecting the site for the demo plot belonging to the members of the Farmer Group. This necessitates an agreement regarding the distribution of roles and duties for overseeing the demonstration plot. Subsequently, technology transfer initiatives are executed to provide the Farmer Group with essential knowledge and skills for managing the plot effectively. The following phase includes acquiring corn and taro seeds, in addition to constructing water wheels for the Moringa plantation demonstration plot.

The process of carrying out activities starts with preparing the land, which involves clearing it and getting the soil ready. This is followed by actions like planting and taking care of the crops, including watering, applying fertilizer, removing weeds, and replacing any dead plants. For the site designated for planting Moringa, a water wheel is constructed in the current Moringa demonstration area. The activity ends with the harvest. The Farmer Group conducts monitoring and evaluation of the tasks weekly to observe the growth of the plants and holds monthly meetings with Agricultural Extension Officers and Farmer Group Leaders to review activities and address any problems in the planting space. Moreover, monitoring and evaluation take place during the fertilization and harvesting stages.

Fig. 2. Technology transfer of CSA cultivation (Original photo)

3.1.2 Training and mentoring stage

During the training phase, activities focused on processing agricultural goods are implemented to boost the added worth of basic items (Corn, Taro, and Moringa) into advanced products (Corn Flour, Corn Analog Rice, Taro Flour, Taro Analog Rice, Moringa Leaf Powder, and Moringa Leaf Tea). This involves actions such as: creating flour and analog rice from corn; producing flour and analog rice from taro; and making flour and tea from Moringa leaves. Following these processing sessions, group guidance is provided.

Support in the farming industry overall serves as a continuous outreach effort directed toward the community through activities related to CSA technology transfer (Rodríguez-Barillas, 2024). The guidance initiatives are designed to enhance the viability and durability of agricultural production progress while also promoting the empowerment and well-being of the community, particularly farmers, via the execution of the CSA program. Beyond agricultural extension agents, participants who can contribute and synergize as partners for farmers include academic professionals through joint endeavors. This partnership will create a mutually beneficial relationship among the government, academic institutions, and farming communities within the context of the Triple Helix, as illustrated in the figure below.

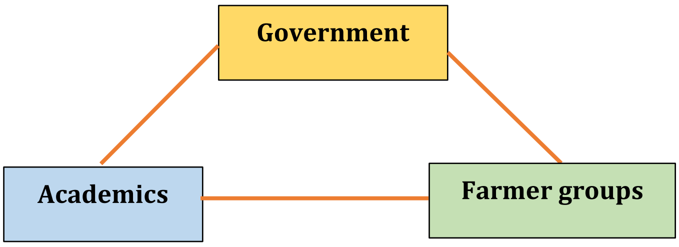

Fig. 3. Triple helix model relationship

The establishment of the triple helix partnership is connected to the responsibilities of each participant involved. The government establishes regulations to foster the advancement of CSA through local policies (Nijhoff & Dijk, 2023). Farmers contribute by enhancing production, boosting productivity and crop yields, improving quality, and developing agribusinesses based on CSA. The partnership that has emerged involves not just the assignment of roles but also encompasses an empowerment dimension to guarantee ongoing success. Given the constraints on the government's ability to provide facilitators for community empowerment, the involvement of academics is essential as they serve as guides during the empowerment process. The mentoring conducted by academic professionals is a way to fulfill one aspect of the Tri Dharma of Higher Education, specifically the activities related to Community Service.

3.1.3 Packaging and e-marketplace initiation stage

Currently, the digital space is becoming more important in the business world. This is due to the fact that the internet enables businesspeople to conduct transactions from virtually anywhere (Soegoto & Akbar, 2018). Without internet connectivity, individuals in the business sector who are separated by geographical locations and time would certainly encounter difficulties related to time management and costs when dealing with customers. Generally, business professionals continue to carry out their transactions through conventional approaches that require face-to-face interactions or the use of different communication methods. To address these issues, efforts are being made to provide both educational insights and hands-on experience focused on creating a footprint in the E-Marketplace, encompassing tasks such as packaging creation, labeling, online marketing, and assistance services.

Fig. 4. Marketing processing and initiation training (Original photo)

3.1.4 Strengthening institutional capacity

Agricultural organizations, particularly those involving farmers, play a significant role in the advancement of agriculture. In rural settings, farmer groups help speed up the socio-economic progress of farmers, improve access to agricultural resources, funding, infrastructure, markets, and promote the use of innovative farming practices. Furthermore, the presence of these groups simplifies the process for the government and various stakeholders to support and empower farmers. The critical role of farmer groups in agricultural progress is acknowledged. Nonetheless, the current situation reveals a weakness in these groups and highlights the considerable challenges faced in developing institutions within farming communities (Touch et al., 2024). Agricultural collectives are anticipated to assist farmers in overcoming the issue of economic disparities, yet so far, their effectiveness has not reached its full potential. To endure in a competitive economic landscape, farmers need proper understanding of agricultural methods and to enhance their competitiveness.

Actions aimed at boosting productivity, enhancing farming efficiency, and improving the competitiveness of farmers are undertaken by establishing agricultural organizations, which also involve empowering farmers' institutional skills. The situation indicates that it is becoming more challenging for development initiatives to effectively connect with individual smallholder farmers, who are quite numerous (Agarwala et al., 2022). The current financial environment, along with the infrastructure and government policies, frequently compels farmers with limited land and agricultural laborers to experience social and economic exclusion. Moreover, the restriction of limited farming land, coupled with low prices for agricultural products and policies that are not beneficial to farmers, contributes to their descent into poverty.

Enhancing the abilities of Agricultural Extension Officers and Farmer Groups is essential to promote the advancement of CSA as a leading aspect of farming growth in rural areas (Karim et al., 2012). The strengthening of agricultural educators and groups of farmers is achieved through outreach initiatives, guidance, mentoring, and the exchange of technology, as well as training designed to support the execution of climate-smart agriculture development efforts (Jumiyati et al., 2021b).

Several actions to enhance the capabilities of farmer organizations that concentrate on the execution of cultivation and crop management through the CSA approach include the following: The decision to implement the CSA framework follows an evaluation of climate influences and dangers relevant to the specific terrain and the characteristics of the farmers. For instance, when it comes to cocoa, pruning is crucial; however, it needs to be adapted to the local climate challenges: during heavy rainfall events, pruning should be performed more often to promote quicker and more robust recovery of the tree, while in extended dry periods, farmers ought to limit pruning to prevent excessive sunlight exposure to the main branches and trunk. Intense rainfall can erode the nutrient-rich top layer of soil, particularly on inclined surfaces. Utilizing ground cover can prevent soil erosion during heavy rain and is particularly useful in regions prone to drought since it aids in maintaining soil moisture. In regions at risk of flooding, agriculturalists can create drainage systems to protect fertile topsoil from being washed away. Any soil management techniques that enhance soil quality and structure also boost productivity, which are the primary goals of CSA.

Climate change can lead to an increase in harmful insects and deseases, which diminishes harvests and may completely ruin farms. At present, traditional methods for controlling pests frequently do not succeed. Over-reliance on chemicals results in higher expenses, harming helpful insects, and increasing the potential for pollution affecting people and the ecosystem. Training in CSA equips farmers with the skills to apply pesticides as per guidelines. The implementation of shade trees plays a crucial role in mitigating the dangers posed by climate change. The proper quantity of shade trees, selected species, and adequate canopy coverage can safeguard agricultural land from excessive heat, intense winds, and heavy downpours. Nevertheless, too much shade might lead to increased humidity in the growing area, promoting the growth of specific fungal infections. CSA education guides farmers in recognizing the most suitable types of trees, the optimal quantity of trees to cultivate, and the right shade tree arrangement. Agriculture accounts for 70 percent of the freshwater resources accessible worldwide. Climate change is resulting in a mix of prolonged dry periods that harden the soil, succeeded by intense rain, which can cause flooding. Constructing drainage systems and channels can direct surplus water and safeguard plants from diseases caused by excess moisture.

Enhancing the capabilities of Agricultural Extension Officers and Farmer Groups fosters the advancement of CSA, enabling them to improve the knowledge and abilities of Farmer Groups in areas such as business operations, farming practices, product processing, and marketing of agricultural goods (Patra & Babu, 2020). Activities aimed at empowering and bolstering the institutional capacity of Agricultural Extension Officers and Farmer Groups are executed through the provision of materials tailored to the execution of farming and crop management, as well as the production of Bokashi fertilizer and food items, which are established based on an assessment of requirements and specific local conditions.

3.2 Changes in CSA farmers' knowledge and skills competencies

3.2.1 Changes in CSA farmers' knowledge competencies

The indicators for the CSA technology elements include four main components: CSA Cultivation Innovation, CSA Product Processing Innovation, CSA Product Marketing Innovation, and CSA-oriented Institutional Capacity Building Innovation. The understanding of knowledge shows how well farmers are informed and able to obtain details regarding advancements in agricultural technology (Istriningsih et al., 2022). The amount of knowledge that farmers have will indicate their understanding, allowing them to embrace technology advancements in agriculture with a positive and receptive attitude. (Ayoub, 2023). Knowledge refers to the capability of farmers to understand all the subjects they have learned and to cultivate their intellect (Pratiwi & Suzuki, 2017). The shifts in farmers' knowledge proficiency in CSA Technology Technical Guidance are assessed based on their capacity to respond to various inquiries before and after receiving the Technical Guidance concerning the CSA Technology Innovation Component Package, detailed in Table 1 below.

Table 1. Percentage change in CSA farmers' knowledge competence

No	Indicator	Percentage value (%)		
		Before	After	Change
CSA cultivation innovation				
1	Intercrop planting	45	75	30
2	Making a water wheel	40	75	35
3	Use of organic fertilizer	20	70	50
Total		35.00	73.33	38.33
CSA product processing innovation				
1	Types of products	30	63	30
2	Processing efficiency	20	55	35
3	Product added value	20	55	35
Total		23.33	57.67	33.34
CSA product marketing innovation				
1	Packaging design	23	53	43
2	Labeling	20	50	40
3	Marketing via digital platforms	20	50	45
Total		21.00	51.00	42.67
CSA-based institutional capacity building innovation				
1	Identification of potential	20	68	53
2	Organizational management	25	68	53
3	Partnership	20	60	55
Total		21.67	65.33	53.66

(Primary Data, 2024)

Table 1 indicates that the knowledge levels of farmers concerning CSA Cultivation Innovation improved from a low level of competency (35.00%) to a high level (73.33%). This improvement is due to the research area being a buffer zone for a conservation forest, allowing farmer respondents to more readily grasp the CSA technology guidance materials, particularly those related to Intercrop planting, even though CSA technology remains relatively new for these farmers. Similarly, the competency of farmers regarding CSA-based Institutional Capacity Strengthening Innovation has also risen from a low level (21.67%) to a higher level (65.33%). This shift can be attributed to the fact that the farmers involved are part of groups that possess a fairly general understanding of institutions. The presence of agricultural information provided by extension agents and the media usually focuses on cultivation aspects and farmer institutions, thereby enhancing the pace of integrating knowledge about CSA Cultivation Innovation and CSA-based Institutional Capacity Strengthening.

3.2.2 CSA farmer skills competency changes

Enhancing the understanding of agricultural technology advancements among farmers is crucial for the adoption of new innovations and for empowering them. A farmer's knowledge can enhance their capabilities in utilizing novel agricultural technologies (Nazuri et al., 2018). When farmers possess adequate skills and maintain a favorable outlook, the utilization of CSA technology can become enduring and yield more satisfactory outcomes in both volume and quality. Farmer skills refer to the capacity to transform something into a more beneficial form, which can be achieved through the knowledge and creativity that farmers have (Toffolini et al., 2017). The evolution of farmer competency in CSA Technology Technical Guidance is assessed by evaluating their ability to respond to several inquiries both prior to and following the Technical Guidance that pertains to the CSA Technology Innovation Component Package, as illustrated in Table 2 below.

Table 2. Changes in CSA farmers' skill competencies

No	Indicator	Percentage value		
		Before	After	Change
CSA cultivation innovation				
1	Intercrop planting	50	80	30
2	Making a water wheel	25	55	30
3	Use of organic fertilizer	35	75	40
Total		36.67	70.00	33.33
CSA product processing innovation				
1	Types of products	30	60	30
2	Processing efficiency	35	60	25
3	Product added value	25	50	25
Total		30.00	56.67	26.67
CSA product marketing innovation				
1	Packaging design	25	60	35
2	Labeling	25	55	35
3	Marketing via digital platforms	20	50	30
Total		23.33	55.00	33.34
CSA institutional capacity strengthening innovation				
1	Identification of potential	30	60	30
2	Organizational management	40	65	25
3	Partnership	20	80	60
Total		30.00	68.33	38.33

(Primary Data, 2024)

Table 2 demonstrates that the proficiency of farmers in relation to CSA cultivation innovation improved from a low level of competence (36.67%) to a high level (70.00%). The enhancement of farmers' skills concerning CSA cultivation innovation was attributed to empowerment initiatives that involved the establishment of planting areas tailored to the environmental conditions of the study site, enabling participating farmers to engage in hands-on practice to enhance their abilities. Similarly, the proficiency of farmers in CSA-based institutional capacity building innovation rose from a low competency (30.00%) to a high competency (68.33%). This improvement resulted from empowerment efforts that included direct practice related to enhancing resource potential, organizational management, and fostering partnerships through collaborative mentoring by relevant governmental bodies and educational institutions.

The farmers' understanding of CSA Product Processing and Marketing Innovation (Table 1) demonstrates a shift from a low level of competence (23.33% and 21.00%) to a moderate level of competence (57.67% and 51.00%). Similarly, the proficiency of farmers concerning CSA Product Processing and Marketing Innovation (Table 2) transitioned from a low competency level (30.00% and 23.33%) to a medium competency level (56.67% and 55.00%). The transition from low to high competency in farmers' knowledge and skills regarding CSA Product Processing and Marketing Innovation occurs because, generally, farmer groups in rural settings remain primarily focused on on-farm issues and have not extensively explored off-farm elements linked to the processing and marketing of agricultural goods. In other terms, the initiatives undertaken by farmers at the research site to operate their farming ventures have yet to adopt an agribusiness approach.

Changes in farmers' knowledge and skills about CSA technology are very important, because they will increase farmers' motivation to manage CSA-based farming businesses. In addition, changes in farmers' knowledge and skills are also closely related to the role of researchers, agricultural extension workers, and related agencies ranging from socialization to assist in the application of CSA technology at the farmer level. Empowerment in the form of extensions and assistance in the development of CSA technology needs to be built better through participatory and collaborative methods (Venkatesan et al., 2023). Increasing farmers' knowledge and skills regarding CSA technology can be increased by increasing the frequency extension with various extension methods and media. Empowerment is carried out by involving farmers from the planning stage, implementation to evaluation of activities so that farmers can gain learning in an effort to increase the productivity of CSA-based farming businesses (Rodríguez-Barillas et al., 2024).

4. Conclusions

The establishment of CSA focused on enabling farmers near forests through collaborative efforts among multiple parties is anticipated to foster growth in the agricultural industry while reducing the conflict between economic gains and environmental sustainability. This will be achieved by adopting low-carbon farming methods and reducing the overuse of natural agricultural resources, including land, farming inputs, and agricultural infrastructure through the use of CSA practices. To effectively and efficiently promote the development of CSA through empowering farmers via a tripartite collaboration approach, various policy strategies are essential. These should prioritize the regular education of farmers on CSA technology through agricultural extension agents, NGOs, or academic institutions, as well as the establishment of baseline assessments and national and regional agricultural mitigation plans informed by data and regional modeling. Additionally, the design of a flexible and adaptive CSA technology application framework is critical. The successful implementation of these three strategies demands active cooperation among all agricultural stakeholders from the beginning to the end of the supply chain to attain an environmentally friendly and sustainable economic advancement based on CSA principles.

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Author Contribution
The author conceptualized the study, designed the methodology, conducted data analysis, and wrote the manuscript. The author is solely responsible for the interpretation and presentation of the findings.

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