frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 07 April 2025
DOI 10.3389/fsufs.2025.1529846

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RECEIVED 17 November 2024
ACCEPTED 18 March 2025
PUBLISHED 07 April 2025

CITATION
Chidimbah Munthali GN, Puming H, Banda LOL and Ngulube PSD (2025) Diversities of conservation agriculture technologies being adopted by rural farmers in sub-Saharan Africa region: a case study from Vibangalala extension planning area, Mzimba District, Malawi.
Front. Sustain. Food Syst. 9:1529846.
doi: 10.3389/fsufs.2025.1529846

Diversities of conservation agriculture technologies being adopted by rural farmers in sub-Saharan Africa region: a case study from Vibangalala extension planning area, Mzimba District, Malawi

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Background: Food insecurity remains a significant challenge in many developing economies, including Malawi, where agriculture plays a crucial role in enhancing livelihoods, ensuring food security, and promoting rural development. This study investigates the diversity of conservation agricultural technologies (CATs) adopted by rural farmers in Vibangalala EPA, Malawi.

Methods: A survey was conducted with 390 respondents utilizing a purposive sampling technique to capture insights on farmers' awareness and adoption of CATs. Data analysis was performed using NVIVO software to compute frequency tables and percentages of categorical variables, with statistical significance set at $p < 0.05$.

Findings: The findings reveal that while 96.9% of farmers were aware of CATs, the actual adoption rates were significantly lower due to challenges such as high labour costs and limited resources. Specifically, intercropping was adopted by 36.92% of farmers, and organic manure by 29.49%. Conversely, mulching and mixed cropping saw much lower adoption rates at 7.8 and 2.56%, respectively. Key barriers to the adoption of CATs included innovation barriers, limited access to resources, and labour constraints.

Recommendations: Despite farmers' substantial knowledge of CATs, various constraints hinder their effective implementation. To enhance the adoption of these technologies, it is recommended that strategies be developed to address labour and resource limitations, including context-appropriate training programs, resource enhancement initiatives, and targeted promotional efforts focused on local farming systems.

KEYWORDS

agriculture technology, sub-Saharan African region, food security, food insecurity, adoption of technology, climate resilience

Introduction

Agriculture plays a pivotal role in the economies of many developing countries, including Malawi (Banda and Banda, 2021; Munthali and Xuelian, 2020; Chidimbah Munthali et al., 2022), contributing significantly to livelihoods, food security, and rural development. A significant portion of the population, especially in rural regions, relies heavily on small-scale farming for livelihoods and subsistence, which is predominantly rain-fed and vulnerable to the impacts of climate change. In recent years, the introduction of conservation agricultural technologies (CATs) has been promoted as a solution to address challenges such as soil degradation, erratic rainfall, and low crop yields. These technologies, which include practices like intercropping, organic manure usage, crop rotation, and mulching, are designed to promote sustainable land management, improve crop yields, and enhance the resilience of farming systems in the face of environmental pressures (Jia et al., 2017; Freeman et al., 2023). Despite these efforts, the adoption of CATs remains inconsistent across different regions of Malawi, and many rural farmers need help in utilizing these technologies to their full potential.

In the Vibangala Extension Planning Areas (EPA), the adoption of agricultural technologies is shaped by a complex interplay of social, economic, and environmental factors. While awareness of CATs is high among farmers, with nearly 97% reporting familiarity with at least one conservation practice, the practical application of these technologies faces a range of challenges. Farmers in these areas often need access to the necessary resources, training, and support systems to implement more labor-intensive or resource-demanding practices. Furthermore, factors such as low educational levels, large household sizes, and limited market access exacerbate the difficulties in adopting sustainable agricultural methods. This research seeks to explore these challenges and provide a detailed analysis of the diversity of agricultural technologies adopted by rural farmers in Vibangalala, shedding light on the drivers of technology adoption and the obstacles preventing wider usage. The main contribution of this study is its localized focus on understanding the specific barriers and motivations for the adoption of CATs among resource-constrained farmers in Vibangalala. This approach aims to fill an important gap in the existing literature, which often overlooks the unique socio-economic challenges faced by these farmers.

This study investigated the adoption patterns of conservation agriculture technologies among rural farmers in these areas, focusing on the factors influencing their decision-making processes. By examining the socio-demographic characteristics of the farmers, the level of awareness of various technologies, and the specific challenges they encounter, this study aims to provide insights on how sustainable farming practices can be better promoted and supported in rural Malawi. Furthermore, the motivation for this research is grounded in the recognition that understanding the local context is essential for developing effective strategies to enhance the adoption of conservation agriculture. The research further seeks to identify the reasons behind the adoption of certain technologies over others and explore why some farmers remain hesitant or unable to adopt CATs despite being aware of their potential benefits.

The main aspect of this study is its exploration of the research gap concerning the local-level understanding of CATs adoption. While much of the existing literature focuses on the broader benefits of conservation agriculture, more research is needed on resource-constrained farmers' specific barriers to adopting these technologies. This study addresses this gap by providing a localized analysis of the adoption patterns and challenges in Vibangalala, contributing to a deeper understanding of how socio-economic and environmental factors influence the uptake of CATs. By focusing on this rural context, the research highlights the nuanced challenges of promoting sustainable agricultural practices in areas where access to markets, educational opportunities, and financial resources is limited.

The findings of this study hold important implications for both policy and practice. Policymakers, agricultural extension services, and development organizations can use the insights gained from this research to design more targeted interventions that address rural farmers' specific needs and constraints. For instance, efforts to improve the dissemination of CATs must go beyond awareness-raising and focus on providing the necessary support systems—such as access to credit, markets, and agricultural training, that enable farmers to adopt and sustain these technologies. Furthermore, addressing labor constraints and enhancing farmers' capacity to manage more intensive farming practices will be crucial in ensuring the long-term success of conservation agriculture in Malawi. By tailoring policies and programs to the local context, agricultural development initiatives can play a more effective role in promoting sustainable farming systems and improving the livelihoods of rural communities.

Thus, this study aimed to find the diversity of agriculture technologies being adopted by rural farmers in Malawi.

Socioeconomic factors influencing the adoption of agricultural technologies-a global perspective

Income levels, education, and household size all play significant roles in adopting agricultural technologies. Farmers with higher income levels are more likely to adopt new technologies because they possess the financial capacity to invest in such innovations, allowing them to absorb the risks and costs associated with them (Areri et al., 2022; Cheruiyot, 2020; Kiresur et al., 2017; Sarfraz et al., 2023). Larger households similarly demonstrate higher adoption rates, as increased household resources often correlate with better implementation of conservation practices (Areri et al., 2022; Cheruiyot, 2020; Kiresur et al., 2017; Sarfraz et al., 2023).

Education levels, too, positively correlate with technology adoption. Farmers with higher levels of education are better positioned to understand the benefits and long-term importance of adopting sustainable agricultural practices, such as soil conservation (Manan and Sharma, 2017). However, in some cases, higher education is associated with reduced use of traditional fertilizer application, as more educated farmers may shift towards alternative, more sustainable practices (Sarfraz et al., 2023; Manan and Sharma, 2017). Awareness also plays a crucial role, as heightened awareness of conservation technologies significantly facilitates adoption (Cheruiyot, 2020; Manan and Sharma, 2017; Jan, 2021). Despite widespread familiarity with these technologies, however, a notable gap exists between awareness and actual usage, suggesting that practical challenges, such as financial or operational constraints, may inhibit full adoption (Cheruiyot, 2020; Sarfraz et al., 2023).

Farm size has similarly been identified as a critical factor influencing the adoption of advanced agricultural techniques. Larger farms generally exhibit higher adoption rates due to their greater financial and operational flexibility, which allows them to manage better the costs and risks associated with new technologies (Areri et al., 2022; Khaspuria et al., 2024; Okidim et al., 2023). Additionally, farming experience contributes positively to adoption rates. Experienced farmers are typically more knowledgeable about the practical benefits of new technologies and are, therefore, more likely to incorporate them into their farming systems (Sarfraz et al., 2023; Manaf et al., 2019).

The influence of gender and age on technology adoption is more complex. Some studies indicate that male farmers are more likely to adopt new technologies, primarily due to greater access to financial resources and decision-making power within households and communities (Shahzad et al., 2021). Age, however, plays a more nuanced role. While younger farmers tend to be more open to adopting digital tools and new technologies due to their familiarity with such advancements, other studies have shown no significant correlation between age and technology adoption (Sarfraz et al., 2023; Shahzad et al., 2021) For example, (Khaspuria et al., 2024) found no significant association between age, gender, duration of residence, farm size, and adoption. Cheruiyot (2020) reported an essential influence of these variables, pointing to possible contextual or methodological differences in findings.

Farmers' personal goals, knowledge, and social networks ultimately influence the adoption of new technologies (Higgins et al., 2021). To bridge the gap between familiarity and usage, capacity-building initiatives focusing on low-income farmers are recommended. These initiatives could help address key challenges such as soil erosion and land degradation, promoting more widespread and effective adoption of soil conservation practices in the region (Cheruiyot, 2020; Sarfraz et al., 2023). Intercropping, crop rotation, and mulching are agricultural practices studied and implemented across various regions. They showcase their potential to enhance productivity, optimize resource use, and support environmental sustainability. However, adopting these practices varies significantly and is shaped by socioeconomic, institutional, and technological factors that present opportunities and barriers to their widespread implementation.

Intercropping has been widely applied in different parts of the world, demonstrating its adaptability to diverse environmental and socio-economic conditions. In Europe, the InterVeg project conducted field experiments in Italy, Slovenia, Germany, and Denmark, focusing on intercropping systems with living mulches to improve vegetable crop production (Higgins et al., 2021). In India, a study in the Shivalik foothills of Jammu and Kashmir explored intercropping maize with mash (*Vigna mungo*), showing varied impacts on maize yield depending on the tillage practices used (Brandt et al., 2017) More broadly, intercropping has been commercially applied with crops like corn and soybeans, often in combination with mulching, to improve nutrient management (Dwivedi et al., 2011).

Adoption trends highlight intercropping's global relevance. In Telangana, India, cotton farmers use intercropping with pulses to boost yields and economic returns. Here, farm size, education, and access to extension services influence adoption rates, though older and more experienced farmers are less likely to adopt such practices (Kota et al., 2021). In Uganda, maize-soybean intercropping is common among smallholder farmers as part of conservation agriculture, offering benefits like improved nutrient management and climate risk mitigation (Anyoni et al., 2023). In Sweden, the transtheoretical model has been employed to analyze intercropping adoption, revealing that knowledge, perceived financial gains, and ease of practice drive adoption. At the same time, barriers such as seed separation costs and lower education levels hinder progress (Ha and Kwon, 2024). Meanwhile, despite labor shortages and fluctuating maize prices in China, intercropping remains a historically entrenched practice that enhances agricultural efficiency and income (Hong, 2018). In Malawi, intercropping is adopted to improve land use efficiency and soil fertility, although it requires more labor and does not always increase primary crop yields compared to monocultures (Li et al., 2023).

The variation in intercropping adoption reflects the importance of addressing challenges such as labor shortages, limited machinery, and knowledge gaps. Policy interventions and technological innovations could significantly facilitate broader adoption and unlock the full potential of intercropping systems worldwide.

Crop rotation, another critical agroecological practice, the practice of growing different crops in succession on the same land, is known to improve soil health and break pest and disease cycles (Li et al., 2023). In Egypt, crop rotation has been shown to increase land productivity and support the sustainable use of natural resources, especially in densely populated areas (Li et al., 2023). Additionally, integrating crop rotation with intercropping can maximize land productivity and resource efficiency (Amponsah et al., 2013). It is similarly adopted across various regions, though its integration into mainstream agriculture has been slower. In temperate regions, crop rotation is recognized for its potential to enhance soil health and sustainability, though its broader application remains limited (Amponsah et al., 2013). In Mali, Ecofarm technologies, including crop rotation, are more likely to be adopted by larger households located near technological resources, though extensive landholdings can reduce the rate of adoption (Amponsah et al., 2013; Amponsah and Frimpong, 2020; Forkuor et al., 2022). In Odisha, India, the System of Rice Intensification (SRI) integrates crop rotation practices, attracting farmers with promises of higher production than traditional rice farming methods (Amponsah et al., 2013). On the North China Plain, crop rotation is part of precision agriculture, though socio-political factors and financial constraints limit its full adoption despite institutional support (Kendall et al., 2022).

Adoption of crop rotation is often contingent on farm size, income levels, and access to credit, with government policies and institutional backing playing a critical role in promoting wider implementation. Overcoming barriers such as financial limitations and knowledge gaps through incentives, education, and infrastructure development is essential for fostering crop rotation as a standard practice in sustainable agriculture globally (Khaspuria et al., 2024). Mulching is another practice that demonstrates significant agronomic benefits, particularly for soil health, water conservation, and yield improvement. In India, mulching has been studied alongside various tillage methods in Jammu and Kashmir, specifically focusing on its impact on maize yield (Amponsah and Frimpong, 2020). In China, straw mulching in maize and soybean fields has enhanced nitrogen uptake, crop growth, and yield performance (Amponsah and Frimpong, 2020). However, the adoption of mulching technologies varies by region, driven by economic incentives, environmental conditions, and educational factors. In Uganda, mulching significantly increased maize yield and leaf area index (LAI), demonstrating its benefits for crop growth

(Anyoni et al., 2023). Despite these advantages, the labor-intensive process of collecting mulch materials can limit its adoption (Anyoni et al., 2023).

In the Philippines, the adoption of mulching among cacao farmers is significantly influenced by knowledge and training, with educational initiatives leading to increased uptake (Lloren et al., 2023). In Nigeria, yam farmers are influenced by access to credit and seed availability, highlighting the role of financial factors in driving adoption (Amponsah et al., 2013). In India, the slow adoption of mulch-laying technologies points to the challenges of high costs and machinery inefficiencies (Namdeo and Shrivastava, 2021). Nonetheless, in China, the reuse of plastic mulch has helped reduce plastic waste while maintaining productivity, particularly in Faba bean systems (Hong, 2018). Meanwhile, in Punjab, India, awareness of biodegradable mulches still needs to improve despite farmers expressing a willingness to adopt environmentally friendly materials (Kamboj et al., 2022). The potential benefits of mulching go beyond yield improvements. Enhancing knowledge dissemination and ensuring access to biodegradable mulch options could drive higher adoption rates, contributing to more sustainable agricultural practices.

Adopting sustainable agricultural practices like intercropping, crop rotation, and mulching is shaped by a complex interplay of socio-economic, technological, and institutional factors. While these practices offer significant benefits for resource optimization, productivity, and environmental conservation, adoption is often hampered by financial constraints, knowledge gaps, and limited technological access. Targeted policy interventions, educational programs, and technological innovations will be essential for overcoming these barriers, facilitating the wider adoption of these practices, and ultimately supporting more resilient and sustainable agricultural systems worldwide.

Methodology

Study setting and description of study areas

The cross-sectional descriptive study was conducted in Mzimba District, located in the northern part of Malawi, which borders Zambia to the west, Mozambique to the east, and Tanzania to the north and northeast (Chidimbah Munthali and Wu, 2020; Xuelian et al., 2020). In Malawi, the study specifically conducted in the Vibangalala Extension Planning Area [EPA] of the Traditional Area (TA) of Inkosi Mabulabo and Kampingo Sibande. According to the 2018 census reports, the district covers an area of 10,430 km^2 and has a population of 610,944, which represents 7.8% of the total land area of Malawi (118,484 square kilometers). The district has a total of 47,060 households. The district is known for its agriculture, i.e., corn and legume production, and the world-conservative reserve, which serves as a tourist attraction, including Kasungu National Park. The district receives an annual rainfall of about 177.87 millimeters (7.0 inches) and has approximately 159.08 rainy days (43.58% of the time) annually (World Health Organisation, Government of Malawi, 2010). Vibangalala EPAs were purposely selected as some are also affected by high levels of food insecurity in Mzimba. See Figure 1, which shows the study area.

Sampling frame and sample size

The total population of the research narrowed down to residents in Vibangalala with a population of 13,152. The sample size number was calculated using the formula (Equation 1).

$$Sample\ size(SS) = \frac{z^2 * p(1-p)}{e^2} \quad (1)$$

Given a confidence level of 95%, from the z-tables z will be taken as 1.96. The above formula is adjusted to consider the population in the research area to (Equation 2):

$$Adjusted\ sample\ size = \frac{SS}{1+\frac{(SS-1)}{N}} \quad (2)$$

From equation (i) we will have, $SS = \frac{1.96^2 * 0.5(1-0.5)}{0.05^2}$=384.16.

Substituting SS into equation ii, we have $= \frac{384.16}{1+\frac{(384.16-1)}{13152}} = 373.285.$

The sample size without the ±5%precision error is 373. We included a positive 5% of the total sample size 373, giving us 18.65, ≅ 19 more samples. This totaled a sample size of 392, and we chose to use 390 respondents as it fell between the minimum and maximum values.

Data collection and management

The study primarily focused on smallholder farmers and employed purposive sampling. Data for the study were obtained from a rural farm household survey conducted between June and July 2024 by well-trained enumerators. The sample was drawn from smallholder farmers in Vibangalala, Mzimba District, ensuring that the population most relevant to the research was adequately represented. Primary data were collected using questionnaires administered during the survey in these specific areas. Secondary data were collected from various journals, databases, and the Malawi National Statistical Office, providing a broader context for the study and allowing for a comprehensive analysis of the research questions.

The choice of purposive sampling was motivated by the need to focus specifically on the smallholder farmers directly impacted by the adoption of Conservation Agricultural Technologies (CATs), as these farmers represent a critical demographic for understanding the effectiveness and challenges of CATs.This method allowed for targeted data collection, ensuring the findings were highly relevant to the core research objectives. Additionally, using well-trained enumerators was critical for ensuring the accuracy and reliability of the data. Their ability to clarify questions and provide consistent information helped to mitigate potential challenges related to respondent literacy and understanding. Another strength of the study was its combination of primary and secondary data, which allowed for firsthand insights from farmers while incorporating broader statistical and academic data to validate and contextualize the findings. The interviews

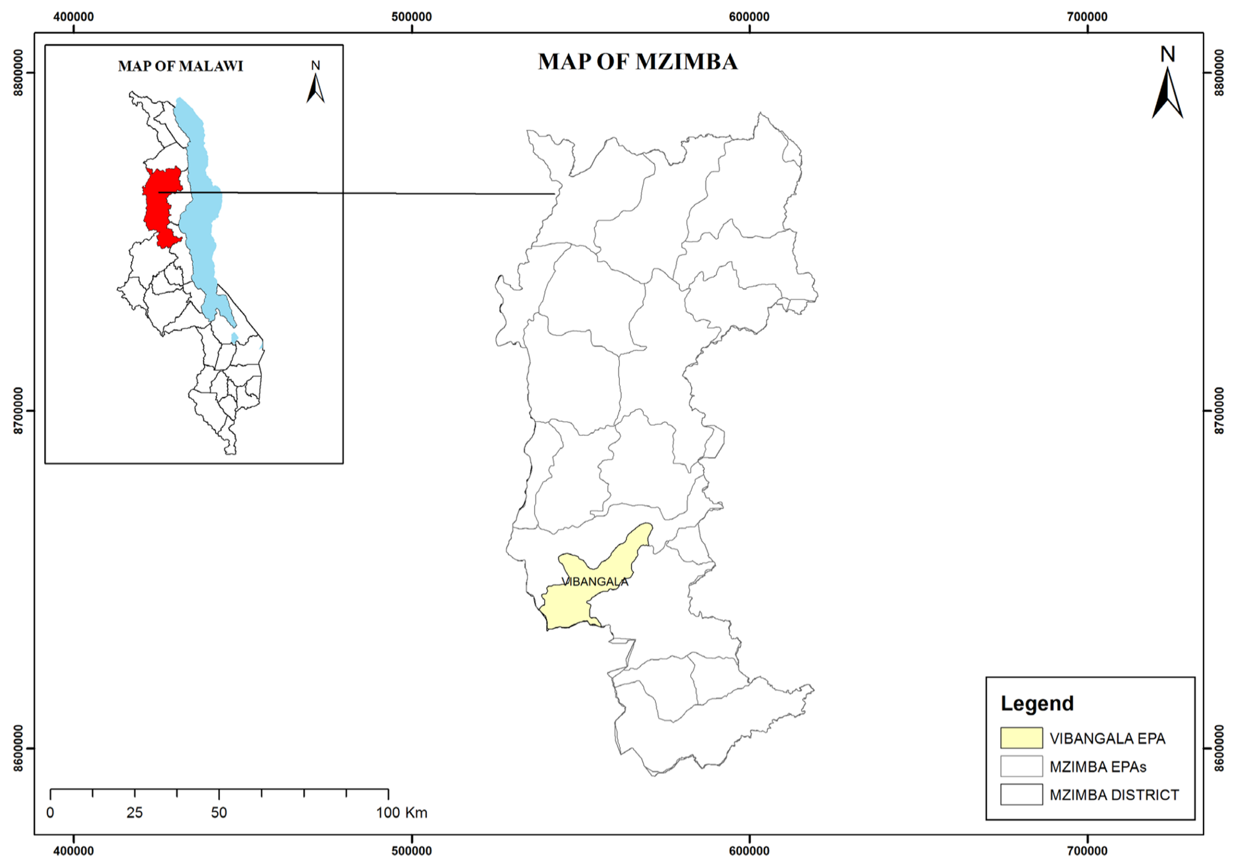

FIGURE 1
Map of study area of Vibangalala in Mzimba District. Source: Authors 2024.

provided rich, qualitative data about local practices and challenges, while the secondary data added depth by incorporating findings from national and international sources.

Validity and reliability

The research instrument was tested with 50 rural farmers and other PhD students before the actual data collection. All comments and errors were recorded and rectified before sending the enumerators to the field. Lastly, the instrument was also tested using Cronbach's Alpha, with a result of 0.8.

Data analysis

The study was primarily qualitative in nature; factor analysis and Cronbach alpha values were determined for reliability and validity analysis. NVivo version and SPSS version 25. software was used for qualitative and quantitative data analysis, where frequency tables and charts were presented.

Ethical clearance

This study was approved by the Yangtze University in China with reference number RU/REC/MW012024. Before collecting data in the Vibangalala EPA, a clearance letter from Vibangalala EPA was granted dated 24 March 2024. The respondents were communicated clearly about the study's objectives and that this research was voluntary, with them having the right to withdraw at any time. Consent was sought for names where necessary, and the respondents had to sign for them especially those involved in key stakeholder interviews.

Results

Social demographics

Responses were collected from 168 females (43.1%) and 222 males (56.9%). Two hundred twenty-one (221) respondents were in the age group of above 35 years, representing 56.7%, followed by the age group 26–35 with 101 respondents and lastly, 18–25 with 68 respondents. A total of 358 respondents were married, while 32 were single. In terms of education, 327 respondents held a primary level of education (83.8%), 58 had a secondary level of education, and 5 had a tertiary level of education. Regarding household size, 265 respondents had more than five people, 112 had between 2 and 5 people, and 13 had a household size of one person. Out of the respondents, 369 practiced crop farming, 10 kept livestock, 7 were involved in business and trading, 3 were formally employed, and 1 indicated piecework as their occupation. Of the respondents, 384 had their own land and were free to farm, while 6 rented their land. The sizes of land were categorized into three levels: less than 1 acre with 204 people, 2–4 acres with 122 respondents, and above 5 acres with 65 people. A total of 385 respondents reported not being in contract farming, while 5 relied on contract farming. The majority of the farmers (334 respondents) lived 2 kilometers away from the market, with 55 respondents within 1–2 kilometers and 1 respondent being 1 km away from the market (see Table 1). The demographics are summarized in the table below.

Diversity of agriculture technologies being adopted by rural farmers in Malawi

Knowledge of CAT

Farmers were asked if they had heard about any Conservation Agricultural Technology (CAT) before, and 96.9% showed a high level of awareness (see Table 2: Farmers who had heard about Conservation Agricultural Technology (CAT)). Being aware of CATs is the first step toward adoption. The 3.1% of farmers who had yet to hear about CATs indicates gaps in outreach, particularly in disadvantaged farming communities, pointing to a need for more targeted awareness programs to disseminate information.

TABLE 1 Socio-demographic characteristics of the respondents (*N* = 390).

Variable	Category	F	%
Gender	Female	168	43.1
	Male	222	56.9
Age Group	18–25	68	17.4
	26–35	101	25.9
	Above 35	221	56.7
Marital Status	Single	32	8.2
	Married	358	91.8
Education Level	Primary Level	327	83.8
	Secondary	58	14.9
	Tertiary	5	1.3
Household Size	Less than 1	13	3.3
	Above 2 less than 5	112	28.7
	Above 5	265	67.9
Occupation	Crop Farming	369	94.6
	Livestock Keeping	10	2.6
	Trading	7	1.8
	Formal Employment	3	0.8
	Piecework	1	0.3
Type of Land Ownership	Right to Farm	384	98.5
	Rent	6	1.5
Size of Farm	Less than 1	204	52.3
	Between 2–4	122	31
	Above 5	65	16.7
Type of Farming	Not on Contract	385	98.7
	Contract	5	1.3
Distance to nearest market (km)	Less than 1	1	0.3
	Between 1–2	55	14.1
	Above 2	334	85.6

F=Frequency, % = Percentage, Km = Kilometers,

Reason and usage of CAT

The farmers further highlighted that they were using different CATs, with intercropping counting 144 (36.92%) and organic manure counting 115 (29.49%) as the most popular practices (see Table 3). These practices are relatively simple to implement and require fewer external inputs, which could explain their popularity among resource-poor farmers. The lower adoption rates for more labor-intensive or resource-demanding practices, such as mulching (7.18%) and mixed cropping (2.56%), highlight an important issue: while farmers know these techniques, they may find them too challenging or costly to implement. Despite the farmers being aware of CAT, 3.08% of these farmers did not see the immediate value in using the technologies. This is a significant finding that speaks to the gap between awareness and practical use.

As explained in Table 3, mulching, and mixed cropping were not often practiced. This is ascertained in Table 4). Mulching (26.59%) and mixed cropping (25.89%) are the most well-known but underutilized technologies. This could be due to various reasons, as is reported in Tables 5, 6. The fact that monocropping, pit planting, and crop rotation are also well-known but not widely practiced further underscores the complexity of agricultural decision-making in rural Malawi. Farmers may be hesitant to adopt new methods without clear evidence of their effectiveness or without support in the form of training and resources.

In Table 2, Farmers who had heard about Conservation Agriculture Technology (CAT)), 378 farmers reported having heard about CAT but only 367 adopted new technologies (Table 7), indicating a decrease from 96.9% (awareness) to 94.1% (adoption). Nonetheless, the 5.9% who have not adopted any technology are worth focusing on. This group could represent the least resource-endowed farmers who might not have access to the necessary resources to implement CATs.

Adopted CAT

Table 8 further breaks down the CATs adopted by farmers, with crop rotation (35.95%) being the most popular, followed by mixed cropping (20.00%) and mulching (14.52%). The high adoption of crop rotation (35.95%) could be attributed to its long-established benefits in soil fertility and yield improvement (Table 5). On the lower end of the adoption spectrum are pit planting (1.90%), mono-cropping (0.95%), and compost manure (0.24%). It is also noteworthy that 23 people reported being unable to till their land, highlighting the challenges faced by some farmers in adopting any of these technologies (Table 6). Figures 2 and 3 illustrate the Conservation Agriculture Technologies Adopted.

TABLE 2 Farmers who had heard about conservation agriculture technology (CAT).

Variable		F	%
Heard about CAT	Yes	378	96.9
	No	12	3.1
	Total	390	100.0

F=Frequency, % = Percentage.

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TABLE 3 Currently used CAT.

Variable	Length	C	Weighted percentage (%)
Intercropping	13	144	36.92
Organic manure	13	115	29.49
Crop rotation	12	80	20.51
Mulching	8	28	7.18
None	4	12	3.08
Mixed cropping	13	10	2.56
Pit planting	11	1	0.26

F = Frequency, % = Percentage, C = count.

TABLE 4 CATs that are known but not used.

Variable	Length	F	Weighted percentage (%)
Mulching	8	113	26.59
Mixed cropping	25	110	25.89
Mono cropping	12	52	12.24
Pit planting	11	44	10.35
Crop rotation	12	27	6.35
Intercropping	13	26	6.12
None	4	17	4.00
Organic manure	13	10	2.35
Bush fallow	10	7	1.65
Manure making	12	6	1.41
Relay	5	5	1.18
cover	5	2	0.47
Crop	5	2	0.24
Inorganic fertilizer	19	1	0.24
Terrace	14	1	0.24
Shift cultivation	16	1	0.24

Table 5 provides insights into the reasons behind the adoption of various CATs, with increased crop yields (36.04%) and soil health improvement (34.52%) being the primary drivers. The farmers also indicated other CATs that were available in the region (Table 9).

Challenges faced and recommendations for CAT usage

The farmers had several challenges when it came to adopting more than one CAT. Time constraints, high labour, illiteracy, and hunger issues were among great barriers, standing at 25.10, 21.13, 12.76, and 6.49%, respectively (Table 6). Despite these challenges, the farmers positively recommended the diversity and effectiveness of CATs, with the majority of farmers (65.57%) acknowledging the good impact of these technologies (13.44% indicating that they are sustainable and 1.42% agreeing that with better support and adaptation, CATs can significantly enhance agricultural outcomes. All the farmers (390) admitted to playing a role in advancing the diversity of the use of CAT in the region (Figure 4).

TABLE 5 Reasons for choosing various CATs.

Variable	Length	F	Weighted Percentage (%)
Increased crop yields	19	142	36.04
Soil health improvement	21	136	34.52
Reduced labor requirements	24	66	16.75
Shortage of food	14	32	8.12
Water conservation	17	7	1.78
Reduced crop yield	16	6	1.52
Increased labor requirements	26	4	1.02
None	4	1	0.25

Discussion

Knowledge of conservation agricultural technology (CAT)

The findings of this study reveal a high level of awareness (96.9%) of Conservation Agricultural Technologies (CATs) among farmers in Vibangalala EPA of Mzimba District in Malawi. This aligns with Rogers' Diffusion of Innovations Theory, which highlights awareness as a critical first stage of the adoption process. However, the gap in outreach to 3.1% of farmers, particularly in disadvantaged areas, reflects the challenges noted by Kamboj et al. (2022) in Punjab, India, where awareness of biodegradable mulching materials was limited, despite the willingness to adopt environmentally friendly technologies. This illustrates a global trend where certain farmer groups remain outside the purview of awareness campaigns, highlighting the need for more targeted strategies to disseminate information, especially in marginalized areas. The high awareness in this study corroborates the findings of Wang et al. (2022) in Nigeria, where yam and cacao farmers, respectively, demonstrated high awareness but faced challenges in moving from knowledge to adoption due to other constraints. Recent studies, such as those by Setiawan and Choiriyah (2024) and Diyyala et al. (2024), further emphasize the importance of targeted interventions to enhance awareness among underrepresented farmer groups, reinforcing the need for comprehensive outreach efforts.

Reasons and usage of CAT

Despite high levels of awareness, the study reveals that only 94.1% of farmers adopted any CATs, a gap that emphasizes the complex decision-making process that follows initial knowledge. The study's findings show that simpler, less resource-intensive technologies such as intercropping (36.92%) and organic manure (29.49%) were the most widely adopted, while more demanding practices like mulching (7.18%) and mixed cropping (2.56%) saw significantly lower adoption rates. This mirrors patterns observed by Anyoni et al. (2023), where the adoption of high-labor or resource-intensive agricultural technologies was hampered by the socio-economic constraints faced by smallholder farmers. In Sweden, Ha and Kwon (2024) also noted that despite high levels of awareness, labor and economic constraints limited the adoption of intercropping systems, reinforcing the notion that

TABLE 6 Challenges faced when implementing more than one CAT.

Variable	Length	F	Weighted percentage (%)
Time consuming	13	120	25.10
High labour	10	101	21.13
Illiteracy	10	61	12.76
Hunger	6	31	6.49
Shortage of fertilizer	20	13	2.72
Time	4	13	2.72
Fertilizer	10	10	2.09
Frame	5	10	2.09
Sick	4	10	2.09
Less skills	10	8	1.67
Stalk bore	9	8	1.67
Cultural practices	17	7	1.46
Fertilizer was not enough	22	7	1.46
rainfall	8	7	1.46
Shortage of food	14	6	1.26
drought	7	5	1.05
Long term benefit	15	5	1.05
intercropping	13	4	0.84
Poor	4	4	0.84
Taken	5	3	0.63
timeframe	9	3	0.63
expensive	9	2	0.42
Food	4	2	0.42
Hoe	3	2	0.42
information	11	2	0.42
knowledge	9	2	0.42
Less	4	2	0.42
Poor education	13	2	0.42
Shortage of land	14	2	0.42
Ant	3	1	0.21
benefit	7	1	0.21
Crop rotation	12	1	0.21
Currently drought	16	1	0.21
drought	6	1	0.21
equipment	9	1	0.21
Less	4	1	0.21
Inadequate	10	1	0.21
Inadequate techniques	20	1	0.21
Income	6	1	0.21
Increased labour requirements	27	1	0.21
Input	5	1	0.21
Long	4	1	0.21
Loss	4	1	0.21

(Continued)

TABLE 6 (Continued)

Low education	12	1	0.21
Money	5	1	0.21
No weeding	9	1	0.21
Poor information	15	1	0.21
Poor knowledge	13	1	0.21
Shortage	8	1	0.21
Skills	6	1	0.21
Technically	11	1	0.21
Techniques	10	1	0.21
Term	4	1	0.21
Transportation	14	1	0.21
Yes	3	1	0.21

TABLE 7 Farmers who adopted new technologies.

Variable		F	Percent	Valid Percent	Cumulative Percent
Adopted CAT	Yes	367	73.7	94.1	94.1
	No	23	4.6	5.9	100.0
	Total	390	78.3	100.0	

TABLE 8 Conservation agriculture technologies adopted.

Variable	Length	F	Weighted Percentage (%)
Crop rotation	12	151	35.95
Mixed cropping	13	84	20.00
Mulching	8	61	14.52
Organic manure	13	37	8.81
intercropping	13	35	8.33
None	4	23	5.48
Manure making	12	15	3.57
Pit planting	11	8	1.90
Mono cropping	12	4	0.95
Compost manure	7	1	0.24

awareness alone does not guarantee widespread adoption. Recent findings by Diyyala et al. (2024) indicate that decision-making frameworks that incorporate farmer input can lead to higher adoption rates of CATs, suggesting that understanding local contexts is crucial for effective implementation.

The slow adoption of labor-intensive practices, such as mulching, is consistent with the findings of Namdeo and Shrivastava (2021) in India, where technological improvements and cost reductions were necessary to overcome slow adoption rates. This slow adoption is further supported by Lloren et al. (2023) in the Philippines, where mulching adoption among cacao farmers was hindered by the labor-intensive process of gathering mulch materials. Moreover, a study by Miao et al. (2025) highlights the role of community-based decision-making in facilitating the adoption of more conservative agricultural technologies, indicating that collaborative approaches may enhance uptake.

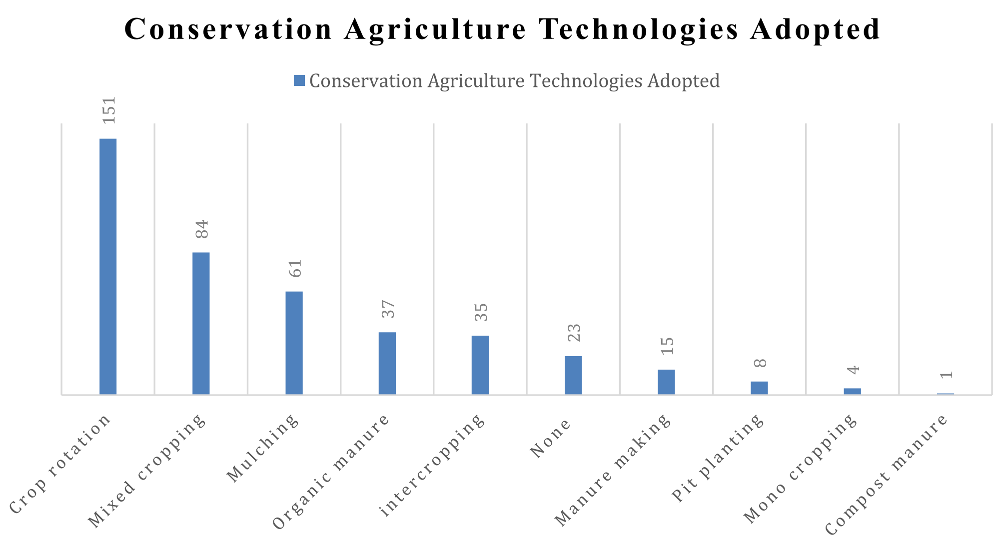

FIGURE 2
Quantitative analysis of conservation agriculture technology adoption rates.

FIGURE 3
Qualitative insights into barriers to technology adoption.

TABLE 9 Other specific CAT available in the region.

Variable	Length	F	Weighted percentage (%)
Intercropping	13	151	27.66
Crop Rotation	12	108	19.78
Mixed Cropping	13	88	16.12
Mulching	8	76	13.92
Pit Planting	11	64	11.72
Manure making	12	28	5.13
Mono cropping	12	23	4.21
Organic Manure	13	6	1.10
Inorganic fertilizer	19	1	0.18
None	4	1	0.18

Adopted CAT

The widespread adoption of relatively low-cost, low-tech CATs such as crop rotation (35.95%), intercropping, and organic manure is in line with the relative advantage concept in Diffusion of Innovations Theory (DOI), where farmers prefer technologies that offer clear benefits with minimal risk. These findings are in agreement by studies in Uganda, where perceived benefits in terms of yield and resource efficiency drive the adoption of intercropping systems (Anyoni et al., 2023), and in India's Shivalik foothills, where intercropping of maize with mash was adopted due to its positive impact on yield (Brandt et al., 2017). Similarly, a study in Egypt reported high adoption rates of technologies that offered immediate and observable benefits, which also aligns with the perceived benefits as described in Canali et al. (2015) in Europe. Recent literature, including (Miao et al., 2025), supports these findings, showing that farmers are increasingly drawn to technologies that promise quick returns and ease of implementation.

Conversely, this study highlights that high-tech and resource-demanding technologies, such as precision agriculture and mechanization, were largely not adopted by farmers in Mzimba district. These findings reflect global challenges, where high-input technologies require significant investments in capital, labor, and knowledge, which rural farmers often lack. The study's respondents cited challenges such as time constraints (25.1%), high labor demands (21.13%), and illiteracy (12.76%), which mirror barriers identified by Kaine and Wright (2022) and De Peixoto et al. (2023) in other regions. These challenges, as framed by DOI's complexity and compatibility dimensions, illustrate why certain CATs, despite their known benefits, remain out of reach for resource-constrained farmers. Emerging research by Miao et al. (2025) suggests that integrating technology training and financial support can alleviate some of these barriers, fostering greater adoption of high-tech solutions.

Challenges faced and recommendations for CAT usage

The challenges farmers face in adopting more than one CAT highlight the barriers to innovation in agriculture. Issues such as time constraints, labor shortages, and limited access to resources identified as key barriers in this study are corroborated by the findings of Namdeo and Shrivastava (2021) in India and (Ha and Kwon, 2024) in Sweden. In both cases, labor demands and costs were significant

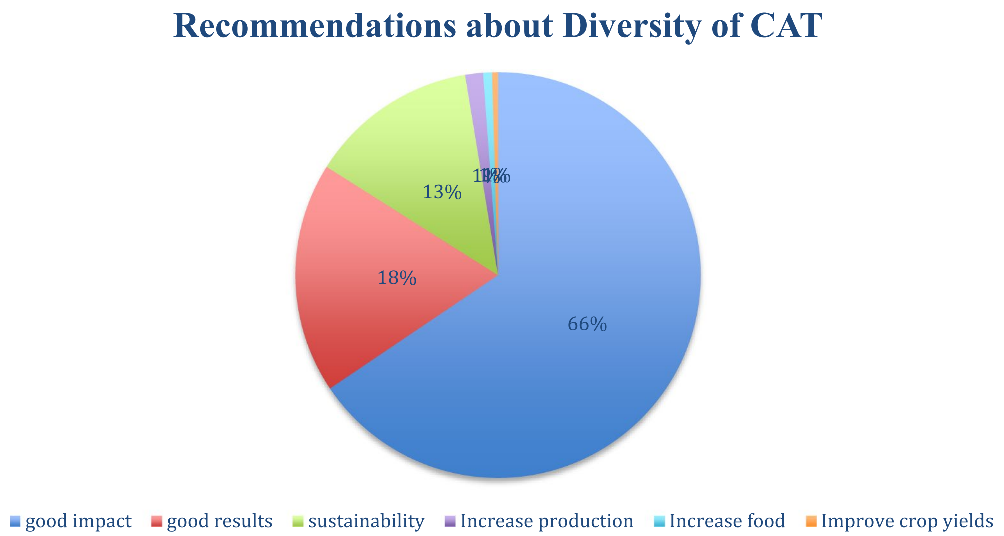

FIGURE 4
Showing recommendations about the diversity of CAT.

impediments to adopting conservation agriculture practices. Similarly, a study in Africa observed that resource-poor farmers were less likely to adopt labor-intensive practices, even when aware of their potential benefits (Anyoni et al., 2023). This gap between knowledge and practice highlights the importance of tailoring interventions to the specific socio-economic realities of rural farmers. New insights from Miao et al. (2025) recommend collaborative approaches that engage farmers in the decision-making process, which may enhance their commitment to adopting multiple CATs.

Additionally, the study's findings on trialability and observability, two critical factors in DOI, suggest that the limited adoption of technologies like mulching and mixed cropping could be addressed through demonstration projects that allow farmers to experiment with these practices on a smaller scale. The lack of access to observable evidence of success in using these technologies may discourage adoption, as noted by IFAD in other contexts. Farmers in Malawi, much like those in Uganda and India, may benefit from interventions that reduce the complexity of implementing these technologies while enhancing their perceived benefits. Recent evaluations by Dutta and Prasad (2022) indicate that peer-led demonstrations significantly improve farmers' willingness to adopt new practices, underscoring the value of community engagement in agricultural innovation.

Conclusion and recommendations

This study reveals that awareness of CATs among rural farmers in Malawi is high, but several challenges hinder the transition from awareness to practice. These include labor and resource constraints, as well as knowledge gaps, which have been observed in various contexts, such as in Uganda (Anyoni et al., 2023) and Sweden (Ha and Kwon, 2024). The findings, viewed through the Diffusion of Innovations Theory lens, reflect global trends in agricultural technology adoption, where high awareness does not necessarily lead to widespread implementation.

Addressing these barriers by implementing contextually sensitive strategies that align with local farming practices is crucial to improving the adoption of CATs. This can be achieved through extensive training, resource access, and targeted outreach, ultimately enhancing agricultural productivity and sustainability in the region. The variation in technology uptake across regions highlights the importance of demonstration projects and tailored resource support to bridge the gap between awareness and practical implementation.

The issues identified in this study provide valuable guidance for designing specific strategies to improve farmers' capabilities and strengthen the agricultural sector. By addressing the economic, educational, and practical challenges faced by farmers, more complex and labor-intensive technologies can be adopted, leading to a more robust and sustainable agricultural system in Malawi.

Further studies

A valuable further study emerging from this research would be to investigate the impact of tailored intervention strategies on the adoption rates of CATs among resource-constrained farmers in Malawi. This study could focus on evaluating the effectiveness of targeted outreach, demonstration projects, and resource support, analyzing how these interventions influence the transition from awareness to practical adoption. It would also assess whether different interventions are more effective for certain technologies (e.g., low-tech vs. high-tech) and specific farming communities, offering insights into optimizing support programs for sustainable agricultural development.

In addition, future research should explore the role of farmer cooperatives in facilitating technology adoption. By examining how collective action impacts resource sharing, knowledge dissemination, and the overall acceptance of CATs, researchers can identify best practices that strengthen community-based approaches. Investigating the impact of digital platforms in disseminating information and providing resources to farmers represents another critical area for future work. Digital tools can bridge the communication gap and foster real-time support for farmers in adopting new technologies.

Moreover, longitudinal studies that track the long-term effects of CAT adoption on agricultural productivity, soil health, and economic sustainability will provide valuable insights. Investigating the gender dynamics in technology adoption and understanding how different socio-economic factors impact farmers' willingness and ability to adopt new practices would also enhance our knowledge and inform inclusive strategies.

Closing the gap

However, there is a significant difference in the perceived value of CAT among farmers. This study revealed that 65.57% of farmers had a positive perception of CAT; however, other studies revealed a negative perception of CAT. For example studies revealed that only 50% of the farmers they interviewed had a positive attitude toward conservation practices, which they blamed on previous negative experiences with agricultural practices. It is essential to understand these differences in perceptions to increase the motivation of farmers and to match strategies with the perceptions of farmers better.

Study limitation

Just as any study is prone to limitations, this study also had the following limitations: Firstly, the study was conducted in one EPA in Mzimba district, which has 11 EPA. It is difficult to generalize the results in Malawi because of the limited scope. This could be due to the factors such as social and culture that are affected by regional differences. However, the researcher tried to overcome this limitation by increasing the sample size.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The researcher got the identification letter and research clearance from Yangtze University with Reference number RU/REC/MW012024. Before collecting data in the Vibangalala EPA, a clearance letter from Vibangalala EPA was granted dated 24 March 2024. The respondents were communicated clearly about the study's objectives and that this research was voluntary, with them having the right to withdraw at any time. Consent was sought for names where necessary, and the respondents had to sign for them especially those involved in key stakeholder interviews.

Author contributions

GN: Writing – original draft, Writing – review & editing, Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization. HP: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. LB: Writing – original draft, Writing – review & editing. PN: Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

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