Research on World Agricultural Economy
https://journals.nasspublishing.com/index.php/rwae

RESEARCH ARTICLE

Lessons Learned from Adopting Sustainable Agricultural Practices to Address Food Insecurity and Climate Change Risks: Opportunities, Constraints, and Limitations

Gebrecherkos Gebregiorgis[1], Woldegebrial Zeweld[2*], Assefa Hdgot[2], Dawit Gebregziabher[2], Hossein Azadi[3], Guido Van Huylenbroeck[4], Girmay Tesfay[1], Stijn Speelman[4]

1 Department of Cooperative Studies, Mekelle University, Mekelle, Tigrai, Ethiopia
2 Department of Agricultural and Resource Economics, Mekelle University, Tigrai, Ethiopia
3 Department of Geography, Ghent University, Gent, Belgium
4 Department of Agricultural Economics, Ghent University, Gent, Belgium

Abstract: Conventional agriculture has been blamed for its ecological and economic concerns. Consequently, sustainable agriculture has emerged as a feasible and viable alternative for addressing food insecurity and climate change risks, despite its low uptake and unmet expectations. This study examined the opportunities, challenges, and limitations of adopting sustainable agriculture. To do this, a questionnaire survey and group discussions were used to collect information from a random sample of households. The collected data were examined using the percentage, priority ranking, and content analysis. Farmers have mentioned several economic benefits and ecological viability of sustainable agriculture: enhanced soil fertility, improved vegetation coverage, reduced land degradation, generated employment, and increased water availability. These results have then led to increased agricultural productivity, reduced carbon emissions, and improved food security. However, it was found that lack of information, limited institutional support, labour shortages, and fragmented farmland are the major constraints to adopting sustainable agriculture. Other problems include an increased workload, waterlogging, sedimentation, loss of cultivated and grazing land, the spread of external predators, and the emergence of diseases and pests. All of these problems may prohibit farmers from fully accepting and implementing sustainable agriculture. Hence, it is imperative to organize on-the-spot demonstrations, information-sharing, and capacity building for farmers and extension workers in order to comprehend the attributes, benefits, and constraints of sustainable agriculture. Farmers should also be given technical and financial assistance to implement sustainable agricultural practices. It is imperative that policymakers and development actors must establish and empower local institutions to promote sustainable agriculture, in order to fully explot its potential benefits and expand its reach to areas that are prone to drought and water shortages.

Keywords: Farm households; Benefits; Barriers; Challenges; Sustainable Agriculture

*Corresponding Author:
Woldegebrial ZEWELD,
Department of Agricultural and Resource Economics, Mekelle University, Tigrai, Ethiopia;
Email: woldegebrial.zeweld@gmail.com

Received: 15 June 2024; **Received in revised form:** 13 July 2024; **Accepted:** 17 July 2024; **Published:** 2 September 2024

Citation: Gebregiorgis, G., Zeweld, W., Hdgot, A., et al., 2024. Lessons Learned from Adopting Sustainable Agricultural Practices to Address Food Insecurity and Climate Change Risks: Opportunities, Constraints, and Limitations. *Research on World Agricultural Economy*. 5(3): 60–75. DOI: https://doi.org/10.36956/rwae.v5i3.1131

DOI: https://doi.org/10.36956/rwae.v5i3.1131

1. Introduction

In low-income nations, traditional or subsistence agriculture is the most common farming system. Its distinguishing features include a heavy reliance on family labor and rudimentary technologies with a limited capital endowment, continuous cropping systems, free grazing habits, and presence of weak institutions [1–3]. It is also self-contained and self-sufficient farming, where the majority of its products being consumed for family survival or subsistence [4,5]. In such nations, for example, Rwanda, Malawi, Uganda and Ethiopia, livestock play a vital role in ploughing, threshing, harvesting, and transportation [6,7].

In fact, agriculture is unable to provide sufficient production to fulfill food demand [8]. Using a poverty headcount ratio of $1.90 per day, low-income nations account for roughly 60% of the global poor, with Sub-Saharan Africa accounting for 79% [9]. Numerous traditional agricultural activities contribute to land degradation, resource depletion, biodiversity loss, carbon-dioxide emissions, and biodiversity decrease [2,8,10]. Many farmers have been using natural resources in an inefficient manner. The collection and sale of firewood or charcoal, as well as continuous plowing, have caused the topsoil to be washed away by wind and water. This directly affects agricultural production and eventually harms ecosystems. Overall, traditional agriculture is accused of being responsible for non-sustainability of agricultural systems.

Industrialized agriculture, often known as the green revolution, is a popular type of mainstream agriculture that is widely implemented in both developed and emerging nations. It is defined as a farming system distinguished by large-scale monoculture production using genetic technology, extensive use of biocide inputs (antibiotics, insecticides, and vaccines), greater use of farming machinery, and confined livestock feeding operations [1–3]. Following the introduction of the green revolution in the 1970s and 1980s in Asian and Latin American countries, improved seed varieties and disease -resistant varieties were introduced and released [3,10]. The incidence of crop and animal infections have declined significantly. The elimination of farm waste and invasive weeds has been accomplished. These collectively have tripled or quadrupled the volume of production to meet the national food demand. Numerous individuals have been exempted from experiencing food insecurity. Certain industries have also flourished to manufacture these inputs, resulting in generating employment opportunities [11,12].

Nevertheless, the residues from heavy use of agrochemicals and machinery have an irreversible impact on topsoil, water, biodiversity, aquatic life, and natural habitats, which are eventually toxic to crops, animals, and the environment [5]. Chemicals not absorbed by plants are discharged into lakes, seas, and oceans, posing hazards for water bodies and human health [3]. Rice, wheat, soybeans, corn, cattle, and poultry have often been targeted, while pulses, vegetables, and small ruminants have been neglected, leading to a loss of genetic diversity. Furthermore, farmers are not happy with seeds introduced and selected by donors/governments, and subsequently prefer indigenous varieties [12]. In conclusion, industrialized agriculture has huge external costs. The World Watch Institute estimates the hidden costs of green revolution to society, for example, cost of removing pesticides from drinking water, repairing damage to rivers, reservoirs, and roads caused by soil erosion, treating air pollution from emissions, dealing with animal deaths due to chemicals, and dealing with the adverse impact of chemicals on biodiversity and human health. The overall cost was found to be $112 per hectare for the United States, $337 per hectare for the UK, and $274 per hectare for Germany [11].

It is noteworthy that conventional agriculture, both traditional and industrialized, is incapable of addressing both food insecurity and climate change simultaneously. This has geared the world to explore alternatives and introduce paradigm shifts into the current agriculture systems. Subsequently, some non-governmental organizations (NGOs) have expanded to offer environmentally friendly agricultural extension services [13]. Some movements, civic organizations, scholars, and activists have questioned the economic and environmental concerns of conventional agriculture and have put pressure on governments and NGOs to provide attention and provide remedies [2,14]. Farmers, scholars, and development practitioners have continued to reorient their agricultural practices in order to produce more at lower costs while preserving ecosystems [15]. These causes have jointly contributed to the notion of sustainable agriculture emerging and gaining global attention [6]. As a result, sustainable agriculture is described as a farming system that promotes greater use of local and on-farm inputs while lowering external inputs [16]. It also improves farmers' skills and knowledge in managing agricultural productivity [3]. It has recently become part of the mainstream agriculture by integrating livestock husbandry and crop production in order to shift conventional agriculture to more environmen-

tally friendly systems while retaining productivity and competitiveness [17].

To name a few benefits, they include an enhanced natural resource base, a better water table, lower carbon dioxide emissions, less fuel consumption, and less land degradation [10]. Sustainable agriculture has the potential to mitigate risks of drought and climate change while maintaining agro-ecosystem balance [16,17]. The practices of sustainable agriculture are numerous, for example, crop diversification, row-cropping systems, rotational grazing management, integrated pest management, minimum tillage, biodegradable pots, water harvesting schemes, animal manure, improved fallow management, farm waste recycling, and biological processes [7,18]. Overall, sustainable agriculture has the potential to boost food security and rehabilitate ecosystems.

Coming to Ethiopia, a mixture of traditional and industrialized agriculture has been recently used albeit subsistence agriculture remains the predominant farming system. Following the experience of some Asian and Latin American countries, the government of Ethiopia has given more attention to green revolution technologies to improve agricultural productivity and eradicate food insecurity since the end of the 1990s. According to Agbahey [5] and National Plan Commission [19], synthetic fertilizers, high-yielding cultivars, insecticides, and herbicides were imported and marketed to farmers. The volume of inorganic fertilizer utilized has increased dramatically. Chemical fertilizer consumption was 5.7 kg/ha in 2003, but climbed to 61 kg/ha in 2017, as stated in the Global Economy Database 2018. In 2016, Ethiopia imported and consumed 1.1 million tonnes of inorganic fertilizer. This figure was quadruple that of 2010. According to the Central Statistics Agency of Ethiopia in 2017, roughly 41% of the total planted cropped areas have been exposed to chemical fertilization. Given the risks of inorganic fertilizers and its fast spread, undertaking research connected to sustainable agriculture is, therefore, not only urgent, but also vital and extremely relevant.

In every country, agriculture constitutes a significant proportion of the economy [20], albeit the magnitude of its relevance varies greatly and is particularly pronounced in low-income nations [8]. According to the World Factbook of Central Intelligence Agency 2019, agriculture in Belgium accounted for approximately 1.3% of the labor force and 1% of the gross domestic product in 2018. In contrast, the figures for Ethiopia were 73% and 36%, respectively. Nearly two-thirds of the population of the SSA depends on agriculture for their livelihoods, while the corresponding figure is nearly 10% for most developed countries [8]. According to National Plan Commission 2017, agriculture is a significant source of employment, income, and food for the majority of farmers in Ethiopia. However, the sector is unable to sufficiently feed the population. At present, approximately 25–30% of the populace is experiencing food insecurity. This phenomenon can be largely attributed to topographic characteristics, rapid population growth, per-capita income growth, and low use of technologies [2,19]. The majority of highland regions that are favorable for agriculture are primarily characterized by gorges, plateaus, and mountains. These are highly susceptible to land degradation, which will lowered agricultural productivity. The old-style tillage, fragmented landholdings, continuous cropping systems, and free-grazing have also contributed to food insecurity. Furthermore, the growth of per-capita income and population have placed additional burdens on agriculture to produce more production to meet the food demand. For example, Ethiopia is the second populous country in Africa. Its population reached approximately 0.11 billion in 2019, with an average growth rate of 2.6%, as indicated in the Worldometer Data 2020.

Although the green revolution has been introduced to solve food insecurity, several concerns have still been posed. These external inputs are neither affordable to nearly 90% of poor farmers nor accessible to marginalized farmers because of their physical isolation [5]. These have led to economic inequality and regional disparities. Additionally, the spraying of pesticides, herbicides, and fungicides in order to control pests, diseases, or weeds has damaged apiculture, small ruminants, and water bodies [17]. Moreover, many farmers have also been unaware of the risks, for example, they have misused them to protect crops from weeds/diseases, sprayed them without protective clothes, and dumped the equipment in open areas to expose children. Unless farmers are aware of their associated risks, this could lead to a loss of biodiversity and incur a huge cost for reimbursement. Furthermore, topographic features have made it difficult for farmers and private investors to use small-scale capital-intensive inputs like tractors and machinery. The returns of inorganic fertilizers are extremely low, whereas the fertilizer-to-output ratio is high due to low farm gate output prices, high prices for chemical inputs, and erosion-induced low yields [5].

It is evident that increasing agricultural productivity and eliminating food insecurity cannot be ac-

complished under the current agricultural production system. Therefore, with the socio-economic and ecological setting of Ethiopia, sustainable agriculture can be a viable, effective, and pragmatic option. It has profound effects on reducing the negative externalities of conventional agriculture: it conserves natural resources, halts biodiversity loss, reduces greenhouse gas emission, enhances agricultural productivity, and improves the quality of life for present and future generations [21]. For instance, local farmers can mitigate the prevalence of weeds, diseases, and external parasites by implementing crop diversification (including spatial and temporal cropping sequences) and utilizing their indigenous knowledge (including homemade medicines). The planting of multipurpose trees, the implementation of water harvesting schemes, and the implementation of conservation measures have the potential to enhance agricultural productivity and mitigate environmental degradation. Nevertheless, the adoption of sustainable agriculture has remained insignificant, sparse, and below expectations in SSA [22,23]. There have been very limited research studies that have examined the adoption, disadoption, and nonadoption of sustainable agriculture. According to Zeweld [24], the availability of empirical studies regarding the opportunities, constraints, and limitations of sustainable agriculture is extremely limited. Therefore, it is prominent to explore adoption levels of sustainable agriculture in the country.

More importantly, sustainable agriculture is a resource-saving practice [25]. However, its adoption has waxed and waned over the years [6]. This is linked to several factors, including attitudes of farmers, advantages of the practices, availability of production inputs, and uncertainty of the practices [14,17]. Other factors also encompass the socioeconomic structure of the communities and institutional settings, biophysical factors, demographic characteristics, and socio-psychological issues [24,26]. Obayelu [26] mentioned land tenure, the cost of adoption, labor demand, and farmers' need for short-term economic viability as major factors. This suggests that, although the literature is not silent on revisiting sustainable agriculture, its adoption and diffusion are highly variable across location, time, regions and agroecology. Barriers to adoption in one region might be enabling factors in other regions. Today's limitation may not necessarily be the limitation of tomorrow. Therefore, it would be advantageous to conduct additional research to evaluate sustainable agriculture from a farmer-agent-perspective (local and contextual) to comprehend explicitly the factors that influence its promotion in the areas under consideration.

The classical adoption theory serves as another bottom-line aspect of this investigation. Initially, the possibility of non-adoption was ignored. However, this may contribute to the low adoption [13]. Additionally, the importance of localities (specificities) was overlooked because of the one-size-fits-all or uniform-and-universal assumption [12]. But certain farmers may opt out of the adoption even with incentives, while others may opt in if they receive technical and financial support. Moreover, the importance of having a strong linkage between researchers/government and farming communities was disregarded by the top-down approach to technology adoption [20], although having weak connections can speed up to the abandonment of technology introduced by governments/NGOs. Ultimately, as noted by Anderson [23], low-income nations exhibit inadequate formal institutions, resulting in incomplete or absent input markets. In Ethiopia, the government has distributed chemical inputs and forced farmers to purchase them at a recommended price. Unless farmers purchase, they are not permitted to participate in food-for-work schemes. Farmers then sold these inputs on the black market at half of the purchase price for those who did not need any government support or rejected buying the inputs from the government, such as agricultural investors, merchants, and some farmers [1]. Because of this fact, the government and NGOs have recently shown strong interest in understanding the factual reasons for the low adoption. They have also acknowledged the significance of sustainable agriculture in addressing the limitations of both traditional and industrialized agricultural systems.

Therefore, the purpose of this study is to investigate farmers' perceptions of the opportunities, constraints, and limitations of sustainable agricultural practices. In doing so, the research outcome of this study reveals the actual gaps pertaining to the adoption and promotion of sustainable agriculture. It also provides an understanding of the complexity of adoption in specific environmental conditions when farmers are actively involved in the adoption decisions. Equivalently, the output helps to identify drivers that are either preventing from or motivating adopting sustainable agriculture. Finally, the research output is expected to provide useful micro-level information to policy-makers, extension workers, agri-business, development practitioners, farmers, and scientific communities, which will help them design specific strategies for the promotion of sustainable agriculture.

2. Materials and Methods

2.1 Description of the Study Areas

This study was conducted in northern Ethiopia (see Figure 1). Nearly 55% of the area is found in the highland (2300–3069 m.a.s.l.), 36% in the midland (1500–2300 m.a.s.l.) and 9% in the lowland (1000–1500 m.a.s.l.) The northern regions have experienced significant degradation owing to their mountainous terrain and prolonged population settlement. The northern regions of Ethiopia are situated in close proximity to the Afar depression, and are frequently subjected to the hazards of drought and heat waves resulting from this depression. Local communities, government, and development actors have been compelled to adopt community-based sustainable strategies to adapt, mitigate, and overcome these obstacles. Therefore, the selected regions are suitable for conducting researches primarily focused on sustainable agriculture.

2.2 Sampling Techniques Used

A multi-stage sampling framework was followed to choose farm households and agricultural practices, which are the analysis units. Villages in the regions were classified into two distinct groups based on agro-ecology: two villages found in the midland (*Eirra and Kelisha Emni*) and highland (16 villages). Secondly, six villages, namely, *Felege Weyni, Habes, Hayelom, Michael Emba, Eirra and Ruba Feleg* were selected using a lottery method. During the survey, these villages had 9230 household heads and 350 sample size was determined following the Yamane (1967) formula. After allocating the sample size proportionately to each village, the target farmers were systematically selected. Regarding agricultural practice, farmers have implemented different agricultural practices to maximise their agricultural productivity, improve food security and promote healthy ecosystems. In consultation with extension workers in the regions, agricultural practices that are widely applied in the regions have been identified: animal manure, crop rotation, agroforestry systems, soil bunds, zero-grazing, bench terracing, improved seed varieties, exclosure, integrated soil fertility management, conservation tillage, crop diversification, forage planting, water harvesting schemes, and pasture management. As indicated in Table 1, of these practices, six were randomly selected to study the opportunities, constraints and challenges of sustainable agriculture. These include agroforestry, crop rotation, manure fertilisation, compost fertilisation, soil and water conservation, and crop residues.

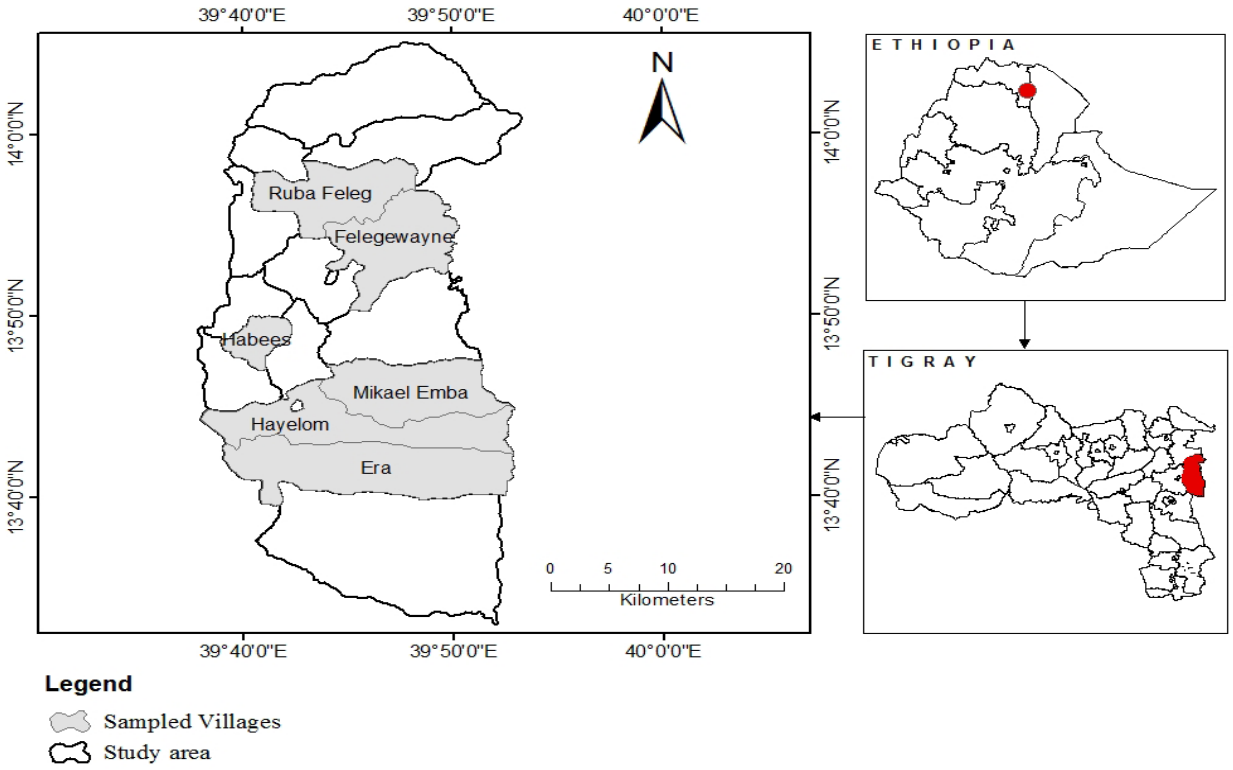

Figure 1. Overview of Map of the Study Area in Ethiopia, Tigray and the District.

Table 1. Local Context-based Description of Sustainable Agricultural Practices.

Practices	Explanation
Agroforestry systems	The planting of trees with multiple purposes on private fields with crop or livestock under the same management: forage trees, commercial trees, moringa trees, silkworm trees, acacia trees, olive trees, eucalyptus, grass strip or shrubs.
Compost fertilisation	The utilization of organic materials such as weeds, farm waste, straw/hay leftovers, dry leaves, ash, and wasted food as organic fertilizer, following their proper decomposition, to enhance agricultural productivity and production
Crop rotation with legumes	Use of different types of crops in the same area in sequential growing seasons: legumes (bean, chickpea, or pea) following cereals (wheat, barley or maize)
Manure fertilisation	The use of animal faeces (cattle dung, chicken manure, sheep/goat droppings, chicken poop) as organic fertilisers on private plots
Crop residue retention	The retention of residues from grain production on agricultural fields, such as stalks, straw, stems, leaves, cobs, seed pods, stubble, and other leftovers.
Soil and water conservation	The use of land management practices such as stone walls, soil bunds, and bench terracing on private fields to reduce land degradation and improve soil fertility.

2.3 Data Collection and Analysis Methods

The data were collected through a questionnaire and a group discussion. During the survey, preliminary discussions were held with extension experts (positional sampling), who have specific expertise, to understand farming management practices and then construct draft questions. A pilot survey was conducted to validate the questions' content and clarity. Farmers were interviewed to ascertain the current production system and to identify the opportunities and challenges of sustainable agriculture. When conducting focus group discussions, open opinion-based group discussions were used since the purpose was to allow participants to openly and freely express their opinions, thoughts, and perspectives on the opportunities, limitations, and challenges of sustainable agricultural practices. Representatives from extension offices, farmers' associations, women's associations, religious institutions, non-governmental organizations, early warning and preparedness committees, local governments, model farmers, poor households, and cooperatives participated. They were asked to identify opportunities, limitations, and constraints of sustainable agriculture and evaluate them using 50-stone counter beans. Their responses were categorized into some clusters based on their similarity, and subsequently ranked according to their severity or importance. Ultimately, the initial data were analyzed using the percentage, priority ranking method, and content analysis. The priority ranking index was constructed by weighing two-thirds of the results from the questionnaire survey and one-third of the group discussions to form an aggregate weight index.

3. Results

3.1 Farmers' Adoption, Dis-adoption, and Non-adoption Decisions Regarding Sustainable Agricultural Practices

This section assessed whether farmers in the regions adopted the stated agricultural practices. For those who have not yet adopted, they were asked whether they are interested in adopting them in the future. We have purposefully divided the adoption decisions① into four distinct categories: current adoption, future adoption, dis-adoption, and non-adoption. According to Table 2, approximately 55% of farmers are currently implementing these practices in order to mitigate soil erosion and land degradation, thereby enhancing their agricultural productivity, while approximately 45% are yet to adopt them. Of the non-adoption figures, about 28% of farmers are interested in adopting these and other practices in the future.

Precisely, nearly 67% of the farmers have applied different types of soil and water conservation measures on their private or communal plots to reduce severe soil erosion and land degradation. But around 11% do not want to adopt even in the future. About 51% of the farmers have retained the residues in their fields to improve the soil quality, while nearly 45% do

① *Adoption decisions: (a) Current adoption is the proportion of farmers who are currently adopting these practices (b) Future adoption is farmers who have never used these practices but plan to use them after the survey year (c) dis-adoption refers to farmers who previously used these practices but abandoned them for various reasons and do not intend to use them again in the future (d) non-adoption represents to farmers who have never used these practices and have no plans to do so in the near future.*

not have interest in retaining crop residues in their fields, because they have often used as fodders. As discussed during group discussions, crop residues have been harvested, stored, and used for animal feed for centuries in Ethiopia. Animals have been allowed to graze crop residues in agricultural fields. However, this has recently changed, and crop residues are being left on the soil to reduce water evaporation, prevent soil erosion, improve soil structure, and enhance water retention.

Similarly, agroforestry systems have been introduced into Ethiopia. Farmers are encouraged to plant trees that possess multiple functions in their private and communal plots. Consequently, approximately 46% of farmers have planted multipurpose trees at present, whereas 34% are not currently applying, but are interested in implementing this in the future. Nearly one-seventh of the respondents have never implemented or intend to implement an agroforestry system in their plots. Approximately 6% of farmers have previously utilized agroforestry, but have abandoned it due to certain factors and have no desire to reapply it.

3.2 Potential Advantages of Adopting Sustainable Agricultural Practices

As farmers explained in the survey and group discussions, sustainable agriculture offers several opportunities, which can be classified into nine broad groups: (1) creating job opportunities for families; (2) reducing soil erosion and land degradation; (3) increasing firewood/charcoal production and construction materials; (5) regulating soil fertility, quality, and nutrition; (6) improving water availability, retention, and discharge; (7) increasing vegetation, bushes, and tree coverage; (8) increasing the availability of forage and grass for livestock; and 9) increasing agricultural productivity and yields. Table 3 shows the major benefits obtained from implementing sustainable agriculture.

Nearly 79% of farmers in the regions have applied these agricultural practices to promote soil fertility, health, and nutrition both on private and communal plots. About 72% of farmers have adopted sustainable agriculture as a means to combat soil erosion and land degradation. Nearly 51 and 60% of farmers acknowledge the potential of sustainable agriculture to boost fodder availability and vegetation coverage, respectively. In group discussions, participants selected improving soil fertility, boosting productivity, and lowering land degradation as the first to third advantages of sustainable agriculture operations. In conclusion, the survey and group discussions identified improved soil fertility management, improved agricultural productivity, and lowered land degradation as the top three benefits of sustainable agriculture.

Table 2. Proportion of Farmers Who Adopt or Intend to adopt Sustainable Agricultural Practices (%).

Agricultural practices	Current adoption	Future adoption	Non-adoption	Dis-adoption
Agro-forestry systems	46	34	14	6
Use of green compost	55	28	11	6
Use of crop rotation	59	26	10	5
Retaintion of crop residues	51	30	13	6
Use of animal manure	54	27	11	8
Soil and water conservation	67	21	8	4
Unweighted mean score	55	28	11	6

Table 3. Perceived Benefits of Sustainable Agricultural Practices Identified by Farmers (%).

Perceived opportunities	Household Survey		Group discussion		Priority rank method	
	%	Rank	%	Rank	%	Rank
Increased agricultural productivity	75	2	14	3	34.3	3
Improvement of tree coverage	60	5	11	5	27.3	5
Soil fertility improvement	79	1	19	1	39.0	1
Reduction of land degradation	72	3	16	2	34.7	2
Employment creation	29	9	6	8	13.7	8
Increased firewood and materials	32	8	4	9	13.3	9
Saving resources	43	7	8	7	19.7	7
Increased forage availability	51	6	10	6	23.7	6
Increasing water availability	66	4	12	4	30.0	4

3.3 Barriers to Adoption of Sustainable Agricultural Practices

This section assesses the major impediments for implementing sustainable agricultural practices. Open-ended questions were posed to survey and group discussion participants to identify, describe and list limiting factors preventing them from implementing sustainable agriculture. Their responses were summarized into six key constraints: (1) inadequate information or knowledge about sustainable agriculture (2) weak institutional or organizational support (3) insufficient landholding size and fragmentation (4) labor shortages (5) limited financial resources (6) farmer-specific qualities and attitudes. Table 4 provides a summary of the major constraints discovered during the survey and group discussion.

Almost 90% of farmers cite a lack of information or knowledge as the primary barrier to adopting sustainable agriculture. In the group discussion, lack of information was identified as the second most significant barrier to adopting sustainable agriculture practices. Many farmers (73%), claimed a labor shortage as a barrier to implementing sustainable agriculture, which is the first obstacle to adoption, according to focus group talks. Farmers' ages, farming experiences, and familiarity with sustainable agriculture are all issues that impede the adoption and promotion of sustainable agricultural practices.

Farmers were asked whether financial resources are a determining factor in adopting sustainable agriculture. Many farmers (55%) have perceived financial constraints as obstacles to implementing water harvesting schemes, improved seed varieties, and other agricultural practices. Numerous participants in group discussions have also claimed financial insufficiency as one of the difficulties. Furthermore, many farmers (85%) consider the lack of technical assistance from governmental and non-governmental organizations to be a serious problem in implementing sustainable agriculture. Overall, the first three constraints that prevented farmers from adopting sustainable agriculture were lack of information, shortage of labour supply, and limited institutional support.

Table 4. Constraints of Adopting Sustainable Agricultural Practices Identified by Farmers (%).

List of constraints	Household Survey		Group discussion		Priority rank method	
	%	Rank	%	Rank	%	Rank
Financial resource shortage	55	5	12	5	26.3	5
Labour supply bottleneck	73	3	29	1	43.7	2
Limited information	89	1	24	2	45.7	1
Landholding size inadequacy	61	4	14	4	29.7	4
Lack of institutional support	85	2	18	3	40.3	3
Farmer-specific characteristics	47	6	3	6	17.7	6

3.4 Limitations of Adopting Sustainable Agricultural Practices

In this section, farmers were asked to identify and explore problems or challenges associated with the adoption of sustainable agriculture. Their responses are summarized into seven clusters (see Table 5): (1) grazing/pasture land reduction; (2) labour/time demanding for implementing the practices; (3) falling cultivated farmland size; (4) increasing waterlogging and sedimentation; (5) decreasing livestock quantity and diversity; and (6) occurring diseases and pest. As per the survey, one of the most significant hindrances or limitations associated with the implementation of sustainable agriculture is the decline in grazing or pasture area, followed by a decrease in cultivated farmland. In the focus group discussion, both were ranked as the first and fourth limitations to the implementation of sustainable agriculture. In a similar vein, approximately 83% of farmers hold the belief that high labor demands and time constraints constitute among the primary limitations to adopting sustainable agricultural practices. During the focus group discussion, this difficulty was also identified as a second limitations of sustainable agriculture. Around 52% of farmers stated that the spread of wild animals and external predators, particularly those that damage crops and livestock, are important limitations of sustainable agriculture. In general, the first three limitations of sustainable agriculture are a loss of grazing land, a high labor and time requirement, and a decrease in cultivated farmland.

Table 5. Limitations Associated with the Adoption of Sustainable Agricultural Practices (%).

Lists of limitations	Household survey		Group discussion		Priority rank method	
	%	Rank	%	Rank	%	Rank
Demanding for labour/time	83	2	21	2	41.7	2
Waterlogging/siltation problem	66	5	8	6	27.3	5
Destocking problem	76	3	14	4	34.7	4
Decreasing landholding size	70	4	24	1	39.3	3
Grazing/pasture land reduction	93	1	18	3	43.0	1
Disease/pest incidence	61	6	10	5	27.0	6
Prevalence of external predator	52	7	5	7	20.7	7

4. Discussion

As stated expressly in Section 4, many farmers have implemented the aforementioned sustainable agriculture practices in order to reap both tangible and intangible benefits. However, a significant proportion of farmers did not embrace them. Hillbur [27] found comparable results in Tanzania for the proportion of farmers who adopted and did not adopt agroforestry systems. In Vietnam, just 2% of farmers used compost to increase agricultural production [3]. Clearly, farmers are motivated by a variety of factors when deciding whether or not to practice sustainable agriculture. In this section, we explore both the benefits that motivate farmers to embrace sustainable agriculture practices and the barriers that prohibit them from doing so.

4.1 What are the Benefits of Implementing Sustainable Farming Practices?

The household survey and focus group discussions revealed numerous economic, social, and environmental benefits of sustainable agriculture. Similar reports were discovered in the literature. Hillbur [27] and Araya [15] discovered that agroforestry, crop rotation, and intercropping systems can improve soil fertility, reduce soil erosion, and enhance water quality. The use of compost, manure, and crop rotation has been shown to increase crop yields, soil chemical and physical qualities, water retention, and farm revenue [15,28]. Soil and water conservation also reduced soil erosion from runoff and wind, boosted soil fertility by conserving organic matter, and alleviated water shortages, resulting in excellent yields [21,26,29].

Because of their topography, the majority regions of Ethiopia are very vulnerable to land degradation. For several decades, many farmers have implemented intensively community-based development practices such as hillside soil and water conservation, community resource management, gully reclamation, and zero-grazing to reduce the extent and impact of environmental degradation, allowing natural shrubs to regenerate and increasing livestock forage availability. Farmers have donated 20 days of voluntary labor each year to conduct soil and water conservation actions aimed at improving soil fertility, reducing environmental degradation, and restoring forest cover. According to Ashoori [21], sustainable agriculture has greatly improved soil fertility and organic matter.

As described in the group discussion, the utilization of compost, animal dung, and agroforestry systems allows farmers to reduce their dependency on inorganic fertilizers. Farmers can save money that would otherwise have been spent on these inputs. Crop rotation, intercropping, and crop diversity (multiple varieties) have reduced crops' susceptibility to diseases and pests. Other authors have discovered that organic fertilizers can assist farmers save money on agrochemical inputs, machinery, and energy consumption [4,28]. Crop rotation, intercropping, and residual retention, for example, have been shown to reduce energy consumption in farming operations by 15 to 50%, increase energy productivity (yield/energy) by 25 to 100%, and save machinery depreciation and maintenance costs of approximately 97€/hectare [15,26]. Consequently, farmers that practice sustainable agriculture are less likely to consume and apply chemical fertilizers, agrochemicals, and other inorganic inputs, as these inputs and sustainable agriculture have a substitution impact.

Importantly, agricultural tasks are typically labor-intensive to prepare and implement, particularly when agrochemicals and mechanization are not used or are used sparingly. The same is true for the implementation of sustainable agriculture practices such as construction of water harvesting schemes, use of physical conservation measures, and application of composting. Effectively, many farmers have also recognized the benefits of sustainable agriculture, including the creation of jobs. Some family members are assigned to perform

these farming tasks, while others are involved in other pursuits. For example, Mr. Getachew Redae has small ponds where he grows fruits and forages. His children and wife frequently participate in clearing, digging, watering, weeding, and harvesting.

Apparently, farmers who planted eucalyptus, olive trees, silkworm trees, and fruits not only gained employment but also fuelwood production, home utensils, fencing, farm implements, shelter construction, and other direct economic benefits. Farmers have also made money by selling charcoal, fuelwood, dry wood, farm implements, and construction supplies on the local market. Soil and water conservation has been shown in the literature to prevent soil erosion caused by runoff and winds while also improving soil fertility by preserving organic matter [21,29]. As a case, Mr. Abebe Hayelom owns approximately 200 eucalyptus trees and earns between 800 and 1000 birr per year from their sales. For the past decade, he has never set aside money to buy fuel, charcoal, or farm tools. Anderson [23] discovered that crop residuals boost farm yields and income. Therefore, sustainable agriculture is an important source of employment and income.

Equivalently, farmers have widely implemented a wide range of physical and biological conservation measures to boost river volume, revive dried-up springs, and improve water retention capacity. In many locations, water resources have been conserved, stored, and protected for use in agriculture, drinking, and industry. These measures include river diversion, spring development, ground wells, and community ponds. The direct and indirect goals of implementing sustainable agriculture are to increase agricultural productivity while conserving the ecosystem. Therefore, multiple benefits of sustainable agriculture can help to significantly enhance food supply and household income.

4.2 What are the Barriers to Implementing Sustainable Agriculture Practices?

Farmers have identified several reasons that impede the implementation of sustainable agriculture practices. Previous authors have found results that are compatible with this study, such as a lack of understanding about the benefits of sustainable agriculture, land ownership issues, a lack of funds, labor problems, and a high reliance on short-term benefits [13,14,26]. The most significant barriers to implementing sustainable practices were the cost of doing so, the complexity and low profitability of the practices, a lack of technical experience, farmers' economic situation, and a lack of supportive services [20].

More specifically, one of the most significant constraints is a lack of knowledge or information on sustainable agriculture. Farmers are reluctant to adopt new techniques unless they are aware of their benefits and features. In this regards, previous reports revealed that limited access to information has been blamed for limiting the dissemination of improved technology [28]. Lack of knowledge was identified as an impediment to producers adopting grassed waterways [30], as well as a barrier to transitioning from conventional farming to sustainable farming and implementing minimum or no-tillage [10,18]. Many Iranian farmers struggled to embrace sustainable farming practices due to a lack of information and technical assistance [20].

Farmers in the areas under consideration who have chosen sustainable agriculture are demanding a reduction in inorganic inputs in order to limit their negative impact on ecosystems. However, this directly raises the demand for labor and time spent on farm operations such as weed removal. Children are also enrolled at schools and are unlikely to be actively engaged on farms. Some adults are relocated to other locations in search of better occupations or more money than they would receive on farms, making them less interested in working on farms. Working on farms has a higher opportunity cost because it is less productive and profitable for them. Meanwhile, older farmers are hesitant to adopt labor-intensive agricultural practices. These factors have jointly reduced their motivation to pursue sustainable agriculture. According to the literature, farmers are discouraged from using agricultural practices such as crop residues, minimum tillage, and multipurpose trees due to labor constraints [18].

Landholdings in northern Ethiopia are small and fragmented, sometimes less than a hectare with an average of four plots [19]. This was mentioned as a deterrent to some farmers. They opposed allocating plots for the construction of water harvesting schemes, the implementation of soil and water conservation measures, and the planting of multipurpose trees. In contrast, other farmers had set aside plots to implement various types of agricultural practices in order to boost agricultural productivity. Aside from land size, some farmers expressed concerns over land ownership legislation or policy of the country. Kheiri [20] stated that farmers with unstable property rights lacked a clear perspective of the future and thus unintentionally damaged the environment. Some landlords with small farmlands adopted grass waterways, but others with vast farmlands did not [30]. Therefore, landholding size

and ownership rights have remained continious concerns in the adoption of sustainable agriculture.

Financial resources were identified as a challenge to adopting sustainable agricultural practices, such as water harvesting schemes and improved seed varieties. As explained in the group discussions, there was a failure to offer credit to poor farmers, which prevented them from implementing these practices. The literature reported mixed results regarding this. Money was identified as a significant constraint to widespread improved practices. Two-thirds of producers in Indiana watersheds did not implement grassed waterways because these practices were costly and time-consuming to install and maintain [30]. Many Iranian farmers have also switched from conventional to sustainable farming when the government offered them financial incentives [20]. In contrast, many sustainable agricultural practices do not require significant amounts of money, equipment, agrochemical inputs, or fuels because they are implemented with locally available materials and on-farm inputs [5,16,22,25]. Economic resources and rural infrastructures were found to have little effect on farmers' intentions to use minimum tillage and row cropping systems [24]. Thus, financial incentives are critical for raising farmer awareness and motivating them to practice sustainable agriculture.

Apparently, some agricultural practices such as improved seed varieties, biological disease control, new animal breeds, and row planting appeared to be incompatible with the existing traditional norms and cultural standards. Farmers have dreaded and failed to accept them, at least initially, until they learned about their benefits through technical training or exposure visits. Unless they are technically or financially supported, they are more inclined to wait until they have witnessed the success or failure of others. The government can provide new breeds to some farmers for free. As a result, their friends and neighbours can visit and get the benefits. Alternatively, the new breeds can be housed at farmer training facilities for demonstrations. Furthermore, extension personnel lacked the enthusiasm and skills to help farmers embrace sustainable agriculture practices. Other research, such as Nyssen [1] and Jacobsen [2], suggested that insufficient government assistance could hinder the adoption of new technology. Extension personnel and the government were found to be failing to provide farmers with technical information to encourage them to practice sustainable agriculture [20].

Under normal circumstances, old farmers who are ready to retire see sustainable agriculture as impossible for them and prefer traditional practices. Some are similarly focused on short-term gains and so unwilling to use agroforestry and physical soil and water conservation techniques, where they have long-term benefits. Even when offered incentives, some people are hesitant to modify their conventional practices in favor of new ones. Some farmers who lack confidence may be late adopters. This implies that farmers are unsure whether the imported (exogenous) practices are consistent with their current farming system or profitable. As a result, they frequently choose to wait and observe other successful farmers. Kheiri [20] and Reimer [30] observed that farmers' age and attitudes impeded their adoption of sustainable agriculture, for example, it was discovered that elderly farmers were not implementing water harvesting schemes. Fisher [18] and Presley [14] argued that unwillingness has been cited as a reason for non-adoption and dis-adoption of drought-tolerant maize varieties and water harvesting schemes in Africa and Colorado.

4.3 What are the Main Limitations to Adopting Sustainable Agricultural Practices?

The practices of sustainable agriculture have some limitations that discourage and refrained farmers from adoption. As noted during the field visit, some agricultural fields, especially those conserved by stones and soil, are affected by waterlogging, especially during the rainy season. In addition, some fields, particularly those found in the lower parts of hillsides are deposited by sands, silts and other unnecessary materials, which subsequently these fields remain unused for crop production. Therefore, problems of waterlogging and siltation caused by physical soil and water conservation measures and gully reclamation still threaten farmer's in adopting sustainable agriculture. Reddy [16] found waterlogging problems in protected and forested areas.

In many low-income countries, livestock production is still as important as crop production for livelihood. Years ago, several pockets of areas were allocated for grazing. Many farmers had more livestock and sent them freely to meadows and communal areas. Recently, zero-grazing system has been introduced by the government and also received more attention. However, local communities did not accept the system, although they have noticed its importance to reduce degradation of natural resources, because the quantity and diversity of their livestock have been reduced. In the group discussion, reduction of pasture land and livestock size was stated as third and fourth limita-

tions of sustainable agriculture. As the farmers stated, livestock are healthier when they have grazed freely than fed being confined. Their products (milk, yoghurt or meat) are normally tastier and savorer if they are allowed to graze freely. Halbrendt [13] reported reduction of livestock size with introduction of zero-grazing systems.

As explained in the survey and group discussion, some creatures have been seen in exclosure and conserved areas, such as foxes, birds, lizards, snakes, rats, ants, bats, wolves, hyena, squirrels, apes and monkeys. Farmers are in fear of them because they are endangered for children, livestock and crops. In the areas, there is an expereince that some herders were beaten by hyena and fox. Sheep and goats were also attacked and killed by tiger, snake, wolf and fox. Besides, birds, lizards, snakes and rats have often damaged different crops. Furthermore, several bee colonies were destroyed by ants, lizards and other predators. Presley [14] also argued that areas implemented by some practices like agroforestry, exclosure and physical conservation are exposed to different external predators, which negatively affect crops and animals.

Noteworthy, the prevalence of malaria, water-borne diseases, and others is another limitation associated with the adoption of sustainable agriculture. As illustrated in the group discussion, these problems are common in villages closely located to ponds, ground wells and dams. In addition, some children have sometimes drowned into those water harvesting schemes and then followed by several damages and deaths. Concurrently, these practices have led to the propagation of insects, spiders, ticks and mites. These can further attack crops, animals and enable farmers to have uncertain life.

Evidently, farmers who adopting sustainable agriculture are encouraged to use more of locally available resources, instead of herbicides, chemical fertilizers, and other inorganic inputs. Following this, wild weeds and unnecessary farm wastes have been propagated more on farms. This has made sustainable farmers difficult to easily manage sustainable agriculture. They are forced to use more labour and spend time for implementing land preparation, threshing, weeding and harvesting activities. These have kept them not to easily adopt soil and water conservation measures, organic fertilizers and water harvesting schemes. Previous studies reported that plots with organic fertilizers demanded more labours compared to plots with inorganic fertilizers [1,2,5].

These limitations are resulted from poor management and lack of information. For example, provision of relevant and update information might help farmers to understand how they can protect themselves from wild predators. Provision of capacity building training might help farmers to prepare in advance and search indigenous ways to reduce the prevalence of malaria and water-borne diseases. As expereinced farmers enlightened, some animals like ladybugs, spiders, fly parasite and lacewings are useful to control for weeds and pests that damage crops. Considering the ecological difference, technical training can be provided for farmers and extension workers on how to release these animals onto their farm crops. Additionally, farmers have various indigenious knowledge and expereince to control for different diseases, pests and predators, which impact crops, animals and human.

5. Conclusions

This study focuses on the prospects, obstacles, and limitations associated with sustainable agriculture. Many proactive farmers have adopted sustainable agriculture to improve soil fertility, increase water-holding capacity, increase fodder availability, reduce land degradation, and increase agricultural productivity. It is expected that many farmers who do not currently use them will adopt them in the future. However, there are still some farmers who are not interested in adopting these practices as they require a lot of labour and time, as well as widespread of pests/diseases, external predators and wild weeds. Some obstacles to adoption also include a lack of information, reduction in grazing and cultivated land, reduction in livestock size, limited institutional support, lack of resources, and unfamiliarity with sustainable agriculture. In fact, the most frequently cited problems pertain to a dearth of information and inadequate institutional support. In the early stages of adoption, farmers may be concerned about practices they are not aware of. They are reluctant to change their traditional farming methods. They may prefer the status quo. They do not want to adopt until they can observe and prove that the practices work effectively without violating existing norms. Parallel to the fear of failure, the farmers' training centres are only partially equipped. Extension staff are reluctant to persuade farmers to change their way of thinking. They have limited knowledge about sustainable agriculture. For this reason, 60% of the farmers have no confidence in the competence of agricultural advisors. In this particular case, the key question is how can the opportunities of sustainable agriculture be effectively exploited and the impediments removed?

Primarily, additional efforts and investments are needed to bring about a change in the mentality of farmers and advisors. It is essential that farmers receive regular training to improve their understanding of risk management and encourage them to practice sustainable agriculture. They should also be convinced through demonstrations and agricultural field days that the practices are compatible with their existing traditions. They should be informed about the attributes, benefits, and limitations of sustainable agriculture. Equivalently, farmer-training centers should be equipped with qualified manpower and the necessary materials. Extension workers ought to receive consistent training and engage in experience-sharing to enhance their proficiency in contextualizing sustainable agriculture and provide technical assistance to farmers.

Another focus could be the creation of model farmers. Local communities living in certain areas and bordering each other not only have relatively similar attitudes and norms, but also common interests, resources, and problems. They have strong beliefs, bonds and trust in terms of collective action and decision-making. If successful farmers are developed in villages, even with incentives, they will be able to exert positive energy on others. They are able to adopt technologies when their peers, neighbours, families and cliques have accepted them. They can observe the improved agricultural practises of model farmers to increase their yields. Farmers should also note that their farmlands would be productive, sustainable and profitable if they had invested labour, time and money in sustainable agriculture. Furthermore, it is imperative to consider the opportunity cost of farm labour when advocating for sustainable agriculture.

In Ethiopia, the government has recently compelled farmers to use chemical fertilizers to increase their agricultural production in order to meet the national food demand. During this process, the government may not be able to recognize the detrimental consequences of this use. This may be due to a lack of awareness, but it need not be culpable. Normally, industrialized agriculture is in conflict with sustainable agriculture. The former brings short-term benefits without caring about the environment, while sustainable agriculture achieves long-term benefits by simultaneously addressing food insecurity and climate change. Therefore, it is imperative to provide capacity-building training to policy-makers and development practitioners to educate them on the trade-off, joint effect, and coexistence of both farming practices, thereby formulating specific strategies to maintain balance between short- and long-term advantages.

More importantly, communication channels are crucial when it comes to changing mindsets. In these regions, information can be obtained from various sources, including but not limited to mass media (television and radio), capacity-building trainings (field demonstrations), agricultural extension services, formal rural organizations (farmer associations and cooperatives), and informal community groups (friends, neighbors, relatives, and families). Farmers were asked to rate these sources on a five-point Likert scale according to their effectiveness or ability to motivate them to understand the information strategies. The most effective method of communication was on-site demonstration, followed by interpersonal communication. Once again, farmers were questioned regarding their level of confidence in these information sources. They have confidence in field demonstrations and the mass media, which are comparatively reliable, credible, timely, impartial and preferable to agricultural advisory services and interpersonal communication. Therefore, policy-makers, development practitioners and other actors should recognize that interpersonal communication and agricultural extension services are short-term policy priorities to inspire farmers to adopt improved agricultural practices, but these should gradually be replaced by mass media and field demonstrations.

Alternatively, the introduction of a complete enclosure system has forced farmers to reduce the quantity, diversity, and variety of livestock. Farmers are automatically enrolled in the system, and lead to negative consequences. In the short term, they are right to complain, because livestock is just as important to livelihoods as crop production. The two are inextricably linked and have synergistic effects. A reduction in livestock can directly and immediately lead to a reduction in income. Therefore, a flexible rotation system should be introduced to preserve and protect the common areas. Initially, let the cattle graze freely during the dry season. Then introduce a zero-grazing system (cut-carry feeding) that potentially has no impact on natural resources and allows farmers to collect hay, grass and fodder from forage from exclosure areas. This would help address feed shortages without harming the environment. Farmers should also receive regular training on how to combine livestock farming and arable farming without harming the environment.

According to the standard adoption theory, farmers would not adopt sustainable agriculture if its costs exceed the costs of conventional agriculture. The same is true if there is no effective communication system

or if development actors misunderstand sustainable agriculture. According to social exchange theory, the adoption of sustainable agriculture may be possible even if its costs of adoption are higher than the costs of conventional agriculture because the multidimensional benefits of sustainable agriculture are beyond and above costs. Accordingly, specific and effective strategies are needed at country level to make sustainable agriculture cost-efficient, successful and popular. For example, technical support for sustainable farmers is needed to increase their competitiveness compared to conventional farmers. In addition, local institutions that promote sustainable agriculture should be strengthened. Policy-makers, researchers and development practitioners should work together and advocate for the common goals, including changing values, policies, institutions and strategies in favour of sustainable agriculture (change agent theory). Academicians and activist groups should also educate local communities about the economic, social and environmental benefits of sustainable agriculture for current and future generations. All economic actors need to learn from well-known countries on how they have built and strengthened pro-sustainable agriculture institutions.

Finally, the overall results of this study are valid for the sample areas and other areas with similar characteristics in terms of farming management systems, agro-climatic conditions and socio-cultural aspects. However, the study has limitations that suggest caution in generalizing the results. First, it is less likely that the results can be automatically extrapolated to other areas, but rather if some adjustments are made. Secondly, cross-sectional data were used for this study. For this reason, the results may not be able to show a longer duration and could show various forms of bias due to the ever-changing psychosocial, socioeconomic and demographic factors. Therefore, we suggest further large-scale studies with a larger sample size and wider geographical coverage across different agro-ecological zones and multi-sociocultural practices over time. The results of this research would be useful to generalize and draw conclusions about the overall constraints, opportunities and limitations of sustainable agriculture. Policy-makers, development practitioners and other stakeholders would also gain pertinent information to help them develop effective strategies to encourage farmers to adopt sustainable agriculture to increase their productivity, reduce the risks of drought and improve the resilience of local systems.

Author Contributions

This work is an excerpt from the dissertation of the corresponding author, who completed his doctoral program under the supervision of Guido Van Huylenbroeck, Girmay Tesfay and Stijn Speelman. They were responsible for the entire work on this study. Gebrecherkos Gebregiorgis, Assefa Hdgot and Dawit Gebregziabher wrote the manuscript. They also contributed to the execution of the calculations. Woldegebrial Zeweld is involved in the entire process of this research design. Hossein Azadi reviewed the manuscript and verified the analytical methods. Hossein Azadi and Stijn Speelman were primarily responsible for proofreading the language. All authors read, reviewed and approved the final manuscript.

Funding

This research, in particular the costs associated with the fieldwork, was supported by Ghent University (BOF grant), Mekelle University (Recurrent Research Budget and NORAD-NORHED) and the Open Society Foundations-Africa Climate Change Adaptation Initiative (ACCAI).

Acknowledgments

We express our gratitude to the University of Ghent and the University of Mekelle for their financial support. We also wish to thank the local communities, the enumerators, and others involved in this study for their time and effort. Ultimately, we express our gratitude to the independent reviewers for their constructive feedback and suggestions.

Data Availability

As this work is based on a dissertation, the questionnaire and data supporting the results of this study can be found in other published articles or upon request to the corresponding author. In addition, the data set used in this analysis is considered confidential.

Conflict of Interest

The authors declare no conflict of interest.

Compliance with ethical standards

Throughout the research process, we prioritized ethical considerations such as anonymity, informed consent, privacy, confidentiality and professionalism. We obtained informed consent from respondents. To

ensure their voluntary participation, we informed them explicitly and in detail about the research. Confidentiality, especially of personal and sensitive information, was strictly maintained to protect the identity of respondents.

References

[1] Nyssen, J., Biruk, B., Tesfamariam, Z., et al., 2017. Geographical determinants of inorganic fertiliser sales and of resale prices in north Ethiopia. *Agriculture, Ecosystems and Environment.* 249, 256–268.
DOI: https://doi.org/10.1016/j.agee.2017.07.037

[2] Jacobsen, R., 2016. *Tools for sustaianbility assessment and management: food chains and household waste case studies* [PhD thesis]. Ghent: *Ghent University*.

[3] Van Thanh, N., Yapwattanaphun, C., 2015. Banana Farmers' Adoption of Sustainable Agriculture Practices in the Vietnam Uplands: The Case of Quang Tri Province. *Agriculture and Agricultural Science Procedia.* 5(67–74).
DOI: https://doi.org/10.1016/j.aaspro.2015.08.010

[4] Fagwalawa, L.D., Yahaya, S.M., 2016. Effect organic manure on the growth and yield of Okra. *Imperial Journal of Interdisciplinary Research.* 2(3), 130–133.

[5] Agbahey, J.U., Grethe, H., Negatu, W., 2015. Fertilizer supply chain in Ethiopia: structure, performance and policy analysis. Afrika Focus. 28(1), 81–101.
DOI: https://doi.org/10.21825/af.v28i1.4740

[6] Dogliotti, S., García, M. C., Peluffo, S., et al., 2014. Co-innovation of family farm systems: A systems approach to sustainable agriculture. Agricultural Systems. 126, 76–86.
DOI: https://doi.org/10.1016/j.agsy.2013.02.009

[7] Wezel, A., Casagrande, M., Celette, F., et al., 2014. Agroecological practices for sustainable agriculture. A review. Agronomy for Sustainable Development. 34(1), 1–20.
DOI: https://doi.org/10.1007/s13593-013-0180-7

[8] FAO, IFAD, UNICEF, WFP, WHO, 2019. The state of food security and nutrition in the world 2019: safeguarding against economic slowdowns and downturns. Food and Agriculture Organization: Rome.

[9] World Bank, 2019. Ending Poverty, Investing in Opportunity. *World Bank Group*, 319.
DOI: https://doi.org/10.1109/ITCS.2009.35

[10] Khatri-Chhetri, A., Aryal, J.P., Sapkota, T.B., et al., 2016. Economic benefits of climate-smart agricultural practices to smallholder farmers in the Indo-Gangetic Plains of India. Current Science. 110(7), 1251–1256.
DOI: https://doi.org/10.18520/cs/v110/i7/1251-1256

[11] Muir, P.S., 1998. BI301, Human Impacts on Ecosystems. Corvallis, OR: Oregon State University.

[12] P. Pingali, 2012. Green Revolution:Impacts, Limits, and the path ahead. *Proceedings of the National Academy of Science.* 109(31), 12302–12308.
DOI: https://doi.org/10.1073/pnas.0912953109

[13] Halbrendt, J.M.C., 2014. Assessing the barriers to adoption of conservation agriculture practices among Chepang communities in the central mid-hills of Nepal [PhD thesis]. Honolulu, HI: University of Hawai'i at Manoa.

[14] Presley, L., 2014. Understanding barriers to agricultural conservation practice adoption. Agriculture and Integrated Resource Management. Fort Collins: Colorado State University.

[15] Araya, T., 2012. Conservation agriculture-based resource saving technology for land resilience in northern Ethiopia [PhD thesis]. Ghent: Ghent University.

[16] Reddy, V.R., Saharawat, Y.S., George, B., 2017. Watershed management in South Asia: A synoptic review. Journal of Hydrology. 551, 4–13.
DOI: https://doi.org/10.1016/j.jhydrol.2017.05.043

[17] Abubakar, M.S., Attanda, M.L., 2013. The concept of sustainable agriculture: Challenges and prospects. IOP Conference Series: Materials Science and Engineering. 53, 012001.
DOI: https://doi.org/10.1088/1757-899X/53/1/012001

[18] Fisher, M., Abate, T., Lunduka, R.W., et al., 2015. Drought tolerant maize for farmer adaptation to drought in sub-Saharan Africa: Determinants of adoption in eastern and southern Africa. Climatic Change. 133(2), 283–299.
DOI: https://doi.org/10.1007/s10584-015-1459-2

[19] National Plan Commission, 2017. The 2017 Voluntary National Reviews on SDGs of Ethiopia: Government Commitments, National Ownership and PerformanceTrends [Internet]. Available from: The 2017 Voluntary National Reviews on SDGs of Ethiopia: Government Commitments, National Ownership and Performance Trends | Planipolis (unesco.org) (cited 10 May 2024).

[20] Kheiri, S., 2015. Identifying the barriers of sustainable agriculture adoption by wheat

farmers in Takestan, Iran. International Journal of Agricultural Management and Development. 5(3), 159–168.
DOI: https://doi.org/10.5455/ijamd.175275

[21] Ashoori, D., Bagheri, A., Allahyari, M.S., et al., 2016. An examination of soil and water conservation practices in the paddy fields of Guilan province, Iran. Annals of the Brazilian Academy of Sciences. 88(2), 959–971.
DOI: http://dx.doi.org/10.1590/0001-37652016 20140613

[22] IPES-Food, 2016. From Uniformity to Diversity: A paradigm shift from industrial agriculture to diversified agroecological systems. Available from: www.ipes-food.org (cited on 10 May 2024).

[23] Anderson, W.K., Siddique, K.H.M., 2015. The role and value of crop residues in dryland agriculture. Indian Journal of Agronomy. 60(3), 332–340.
DOI: https://doi.org/10.59797/ija.v60i3.4468

[24] Zeweld, W., Van Huylenbroeck, G., Tesfay, G., et al., 2017. Smallholder farmers' behavioural intentions towards sustainable agricultural practices. Journal of Environmental Management. 187(1), 71–81.
DOI: https://doi.org/10.1016/j.jenvman.2016.11.014

[25] Rodriguez, J.M., Molnar, J.J., Fazio, R.A., et al., 2009. Barriers to adoption of sustainable agriculture practices: Change agent perspectives. Renewable Agriculture and Food Systems. 24(1), 60–71.
DOI: https://doi.org/10.1017/S1742170508002421

[26] Obayelu, O.A., Adepoju, A.O., Idowu, T., 2014. Factors influencing farmers' choices of adaptation to climate change in Ekiti State, Nigeria. Journal of Agriculture and Environment for International Development. 108(1), 3–16.
DOI: https://doi.org/10.12895/jaeid.20141.140

[27] Hillbur, S., 2014. Farmer's perceptions of agroforestry: A case study about the obstacles and opportunities for agroforestry adoption in Babati, Tanzania [Bachelor's thesis]. Flemingsberg: Södertörn University.

[28] Saleem, R., Iqbal, Z., Anees, M.A., et al., 2016. Relative impact of integrated use of poultry manure, NPK, and biofertilizers on yields of three cropping systems and studies on performance of systems for productivity, sustainability and economic viability of the systems. Academia Journal of Biotechnology. 4(4), 153–163.

[29] Prusty, S.R., Mishra, S.N., Tripathy, S., 2016. Impact of soil and water conservation practices in Central North Plateau zone of Odisha. Current World Environment. 11(1), 150–155.
DOI: http://dx.doi.org/10.12944/CWE.11.1.19

[30] Reimer, A.P., Weinkauf, D.K., Prokopy, L.S., 2012. The influence of perceptions of practice characteristics: An examination of agricultural best management practice adoption in two Indiana watersheds. Journal of Rural Studies. 28(1), 118–128.
DOI: https://doi.org/10.1016/j.jrurstud.2011.09.005