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Soil Management Knowledge Transfer in Tanzania's Southern Agricultural Growth Corridor: Actors, Methods and Challenges

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Soil management technology is essential for sustainable agricultural production systems, social and economic development for farmers. This paper follows an ethnographic research method to investigate soil management technology knowledge among actors in the southern agriculture growth corridor in Mbeya. The key informant interview, 52 in-depth Interview, 2 focus group discussions, and observation data collection methods were used, and a thematic data analysis technique was employed to analyze data to understand the knowledge dynamic in agriculture. The study found that farmers use agroecology soil management technology (mulch application, planting of trees to add fertility and reduce erosion, crop rotation, intercropping, manure application, leaving

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crop and house/kitchen waste, minimal tillage), conventional soil management technology (soil testing, use of fertilizer and lime) and mix of the two. The study area used demonstration plots, farmer field school, training, agriculture shows, farm and home visits, mass media, and farmers' field days. Knowledge is transmitted by farmers, researchers, and extension agents from both the government and private sectors all these methods make adoption easier and faster for farmers. The study recommends increase in efforts to promote relevant soil management practices to the targeted groups in a coordinated way. Extension agents should capitalize on the farmers-to-farmer learning approach by creating e-lead farmers, empowering them, and closely working with them.

Keywords: Soil management technology; SAGCOT; knowledge transfer; extension agent; researcher.

1. INTRODUCTION

Soil is an essential agricultural medium because of its environmental, economic, and social roles. It is a primary source of sustenance for people. It is the interconnection point for realizing numerous United Nations Sustainable Development Goals (SDGs), accounting for a significant portion of global food systems and providing vital ecosystem services (Keesstra et al., 2016). However, the fact that food production is now in great demand has resulted in too much pressure on the usage of production resources, including soil, reducing its quality in many countries, including Tanzania. As the FAO (2015) observed, climate change, land degradation, and biodiversity loss have made soil one of the world's most vulnerable resources. This negatively impacts ecosystem services, food security, maintaining water quality and availability, protecting human health, and establishing the foundation for various socioeconomic activities (FAO, 2021). Thus, soil and land degradation must be addressed through proper and sustainable management strategies to achieve sustainable development.

Soil management is considered sustainable if the supporting, provisioning, regulating, and cultural services provided by soil are maintained or enhanced without significantly impairing the soil functions that enable those services or biodiversity. Implementing soil management practices can result in more contributions of the soil in building resilient agricultural ecosystems capable of coping with the impacts of climate change with mitigating effects. For this to happen, the creation and dissemination (knowledge transfer) of soil management technologies through research and extension systems should be correctly done through innovative knowledge systems (Ginzky et al., 2024).

In such a system, multiple actors are involved in agriculture knowledge creation and transfer;

basically, they can be grouped into public and private actors. Knowledge transfer in agriculture facilitates the exchange and application of research findings among farmers and stakeholders (Dirimanova et al., 2017). Knowledge transfer/dissemination is a sinuous to agriculture knowledge translation. Knowledge transfer emerged from pushing research results to users in the 1990s (Mitton et al., 2007). In the present context, studies show that the system is critical in disseminating soil management technologies to ensure soil productivity, hence increasing food production (Alexander et al., 2017; Popescu, 2019; Meya et al., 2019). For example, a study by Popescu (2019) showed that knowledge transfer has helped modernize agriculture. Meya et al. (2019) added that knowledge transfer on soil management would improve produce yields; farmers fail to produce in the correct quantity because they do not have the proper knowledge to combine different soil management technologies. Alexander et al. (2017) support the importance of knowledge transfer as the results clearly show that knowledge transfer can be a source of collaborative innovation among stakeholders, such as universities, government, and the agriculture industry—soil quality status in Tanzania and the need for improvement.

To date, 65% of Tanzanians, about 8 million households, are employed in agriculture (NBS, 2020). Recent studies (Munishi et al., 2021; Meya et al., 2020; Merumba et al., 2020) show that agricultural productivity is constrained by the declining quality of agricultural production resources, mainly soil. These studies report a nutrient deficiency in different ecological zones, causing poor microbial activity and P fixation, hindering crop development, and making soil management technology important. In Tanzania, the calls and efforts for knowledge dissemination on soil management are founded on the understanding that knowledge transfer is a flow of knowledge where knowledge moves from the

creation point (research) through the knowledge brokers (private and public extension agent, agronomist and other subject matter specialist) to morph into the community context. The process is successful when the knowledge and skills in terms of practices are adopted by beneficiaries (Elueze, 2016). To succeed, the process should consider the contextual realities of target users, including communication dynamics and social and economic settings. However, experience on the ground shows that the process has been a waystream where knowledge comes from those who create or own it to those who will use it. This implies that it is a process where many are affected by a few experiences (Mtenga et al., 2018), and the results regarding farmers' adoption of technologies have not been encouraging.

To this end, at the policy level, the government has committed to ensuring that the creation and transfer of knowledge regarding soil management technologies are supported, as stated in the Agriculture Policy 2013 section 3.5: *"Agricultural information.*

coordination and linkages strengthened to increase the effectiveness of agricultural information services." The Agricultural Development Program II (ASDP II) has been formulated to ensure this is implemented, among other strategies. Sub-component 4.5 of the program focuses on coordinating actors to support the technology transfer, including soil management technologies, among different value chain actors of the agriculture sector. The move aims to ensure efficient service delivery by avoiding wastage of resources through duplication of efforts. The program clearly states that the government will transfer knowledge to farmers through training and extension services and improve research and advisory capacities for soil nutrient management (URT, 2017: p.29).

In this connection, government institutions, including universities such as Mbeya University of Science and Technology (MUST), Sokoine University of Agriculture (SUA), Tanzania Agriculture Research Institute (TARI), Tanzania Coffee Research Institute (TaCRI), etc., have been strengthened to ensure knowledge transfer on the agriculture value chain. To contribute to implementing the government policy, the private sector, in this case, the Southern Agriculture Growth Corridor of Tanzania (SAGCOT), has joined hands to support knowledge transfer of soil management by training farmers and extension.

The SAGCOT initiative is one of the initiatives by the government under the public-private partnership (PPP) policy, which AIMS AT to promote and coordinate agriculture activities through strategic partners. The SAGCOT initiative was initiated at the World Economic Forum in 2010 to help boost agriculture productivity in Tanzania. SAGCOT uses a clustering approach with partnering to promote a harmonized approach by transferring knowledge. SAGCOT has been implementing its programs in the study area for about 14 years now; the significance and influence on knowledge creation and transfer in soil management practice are not yet documented (Smalley, 2017).

Further, although studies (Vanino et al., 2023; Rust et al., 2023) have been done on knowledge transfer across the agriculture value chain, there is limited research on knowledge transfer in the area of soil management technology across the SAGCOT corridor in Tanzania. Again, most studies elsewhere have adopted a robust quantitative approach, which does not consider co-creation and contextual realities. The qualitative study, borrowing much from the innovation system perspective, intends to investigate the soil management technologies available and who and how they were generated /introduced to different agriculture actors in the study area.

2. THEORY PERSPECTIVES

2.1 Research Paradigm

This study was guided by grounded theory. Grounded theory (Glaser & Strauss, 1967) assumes systematic data collection in a social situation, making it ideal for inductive, qualitative studies. Grounded theory aims to develop theoretical propositions or a visual picture of the theory through conducting many field visits, developing and classifying material based on saturation, and gathering interview data. This pertains to a particular issue and is known as substantive theory. The grounded theory is mainly descriptive, unlike other traditional theories. During the analysis of using grounded theory, each sentence is analyzed to identify themes. The themes developed are compared and checked for relation in different situations (Hardy., 2005).

2.2 Analytical Framework

During the theme development, it was found that the components of knowledge transfers (Argote,

2024) were present in the knowledge transfer among farmers in Iloilo village, which included a transferor, the message itself, and a transferee while taking into account the transfer mechanism. Simultaneously, the mechanism's effectiveness changes with the transferee's characteristics if they have voluntariness, image, and behavior. This is borrowed from the perceived characteristics of the innovating theory developed by (Moore & Bensabat, 1991). This applies to both scientific and indigenous knowledge. Knowledge transfer is affected by the mechanism of transferring as perceived by the transferee. The exact mechanism can be friendly in one case and complicated in the other case. The technology contributes to the easiness of transferring it to farmers. If it is easily accessible and easy to use and try out, then the technology knowledge transfer becomes easy.

3. METHODOLOGY

3.1 The Study Area

Rungwe district council is one of the 05 districts in the Mbeya region, located in Southern West Tanzania. Tukuyu town is the headquarters of the district, located roughly at the center of the district and about 72 km from Mbeya city. Tukuyu town has a moderate to cool temperature ranging from 10 °C in May and June to mid-20 °C around November. Tukuyu lies at 9° 15' 0" S latitude and longitude 33° 39' 0" E. Tukuyu is found in the southern agriculture corridor (SAGCOT) in the Mbalali cluster. The district occupies an area of 2211 km² of land, of which 1668 km² (75%) is suitable for agriculture. Forests cover the remaining part of 45 km² (2%), and 498 km² (23%) comprises mountains and residential areas. The topography varies from hilly to steeply dissected, with elevation ranges between 1500 meters in the South and 2981 meters at the summit (URT, 2011a). Steep sides of the mountain ranges are characterized by numerous small streams that drain to major rivers such as the Kiwira, Lufilyo, Mwalisi, and Mbaka. The district is divided into three sub-agroecological zones: the highlands, middlelands, and lowlands.

The high grasslands' soil is thin and rocky (McKone & Walzem, 1994; URT, 2011a). On the steep slopes of Mt Rungwe, soils are predominantly dark gray and dark brown, as well as dark yellowish brown with sandy and clay loams (McKone & Walzem, 1994). The soils of the central arable lands are of medium fertility, coarse or medium textured, ranging from sandy loams to

alluvial, conducive for growing bananas, beans, maize, potatoes, tea, coffee, paddies, and small woodlots.

According to the 2022 Population census, Rungwe district had 273 536 people, of which 129 417 (47%) were males and 44 119 (53%) were females. The average household size in the district was 3.7 persons. The annual population growth rate is at 1.2%. The growing human population in the area gives rise to increased demand for land, water, wood products, and the entire mountainous biodiversity. Land shortages, in turn, have led to converting natural vegetation to agricultural land; farmers opt for intensive agricultural practices (Charnley, 1997). The selection of the study area is informed by its suitability for producing a variety of crops (annual and perennial year-round) because of the availability of rainfall for a long time, the overuse of soil, and the fast growth of the population. More importantly.

The main crops produced include tea, coffee, banana, pyrethrum, maize, avocado, and cocoa (URT, 2017). The other reason is that SAGCOT's strategic partners work with smallholder farmers by training farmers and extension agents in different agricultural s, including soil management technology. They include the Agriculture Council of Tanzania, TARI, YARA, SUGECO, SUA, Mbeya University of Technology, Tanzania Coffee Research Institute, Tea Research Institute of Tanzania, Minjingu Mines Fertilizer Limited, Tanzania Horticulture Association, and the Rungwe District Council.

3.2 Data Collection

Data was well collected through Interviews, FGDs, and observations. Fifteen key informants and 52 farmer respondent interviews were conducted from May 16th, 2024, to August 22nd, 2024. Farmers' interviews were divided into three (3) phases. Each phase had a short break of 4 days, transcribing, studying the data, and validating possible themes. After household interviews with farmers, another data collection phase was done at the National Agriculture Show (nanenane) Dodoma to validate different data collected from farmers. After the nane nane show, the last data collection was done on farmers to validate the themes. Each Interview ranged from 45 minutes to 120 minutes.

All the interviews (KII and in-depth interviews) were audiotaped and recorded for transcription. Ethics were observed as respondents were

asked for consent to audiotape the Interview. A mobile phone and tape recorder were used to record the consented Interview. The key informants interviewed government officials and private sector stakeholders. They all had offices in Mbeya, extension agents, and researchers in Uyole. Also, an observation technique was employed where focused observation was done by concentrating on farm and farming activities and social interactions, and notes were taken simultaneously. An observation checklist was used to observe the soil management technologies used and the interaction between farmers and knowledge brokers. The observation was done throughout the data collection, even during in-depth interviews. With a clear picture of the main themes from analyzed farmers' interview data, two (2) focus group discussions (FGD) were conducted whereby each FGD had 10 participants (5 male and five female); the FGD was recorded and later transcribed. The FGD had a checklist that focused on collecting data on the decision-making process of knowledge, source of knowledge, barriers to knowledge transfer, community collaboration, and the extension services as a whole. All the data collected from interviews and observation were in line to answer the three research questions. To validate and sum up the data collection process, the information was collected from interviews, observation, and FGDs; a reflection workshop was done, and 30 participants attended.

3.3 Data Analysis

Qualitative data collection, processing, and analysis were done simultaneously. Analysis, founded on the thematic analysis technique, involved a series of steps: First, triangulation was done by reading and reflecting on the transcribed text to check for consistency of messages from the data set collected from various stakeholders using different methods. Second, sentences and paragraphs were coded and labeled before grouping them into major themes. Third, a back-and-forth process of reading through the data sets guided the development of codes to identify patterns and relations. The themes were also reviewed by several research team members and examined to check for coherence and connection. Finally, a detailed description of each theme and the relationship among and between themes was provided. The themes were validated by using experts from the Department of Agricultural Extension and Community Development, SUA, a research fellow from IDOS (German Institute of Development and Sustainability), and a postgraduate student from Bonn University Germany in the Science Futures program, and the stakeholders working on the SAGCOT during the reflection meeting which was conducted close to completion of data collection phase in Mbeya.

Table 1. Table of theme development

Code no	Data excerpt	Initial code	Subcode	Category code	Theme
1.	Animal manure is the only trusted source of nutrients for smallholder	Soil management by animal manure	Animal manure	Soil management	Agroecology soil management
2.	In the beans plot, we mix DAP and CAN. For annual crops, we use fertilizer because it stays short on the farm.	Soil management by fertilizer	Fertilization	Soil management	Conventional
3.	I use manure as a priority soil management tool in each crop: 3 buckets (20l) per avocado tree, six buckets (20l) per banana tree, and two buckets (20l) per coffee. Then, I supplement each crop equally with two bowls of inorganic fertilizer.	Soil management by mixing manure and fertilizer	Manure and fertilization	Soil management	Mixed method
4.	We (TARI-Uyole) it is our plan through outreach programs to work directly with farmers by conducting farmers' field days to communicate different technologies, including soil	Outreach programs to work directly with farmers	Disseminate research finding	knowledge from researchers	Research Institute

Code no	Data excerpt	Initial code	Subcode	Category code	Theme
	management technologies (soil testing) developed and tested through our research activities. However, because of our limited budget, our reach is minimal				
5.	We (farmers) prefer technologies that we can observe and learn practically, more importantly when learning from our fellow farmer	Observe and learn practically from fellow farmers	Learn and observe from fellow farmers	knowledge from farmer	Farmer to farmer
6.	"People who the Kuza Africa first employed came in with much knowledge that we did not have in the past."	Employed by Kuza came with much knowledge	An employee came with the knowledge	Knowledge from employer	Learning from workplace
7.	"I look at different agriculture programs at TBC, Star TV, and Channel ten	Look at different agriculture program	Agriculture programs	Knowledge from mass media	Mass media

4. RESULTS AND DISCUSSION

4.1 Perspectives on the Available Soil Management Technologies

The study aimed to understand knowledge and knowledge flow among farmers. The main question is to determine the types of soil management technologies commonly used by farmers and those promoted by other soil management stakeholders in the SAGCOT region.

Analysis of data collected from KIIs further shows that soil management technologies that were used varied and, for a matter of clarity, were divided into agroecology technologies, conventional technologies, and mixed technologies (a combination of the two). Agroecology soil management technologies used are sinuous to sustainable agriculture, as referred to by most stakeholders, which is an understanding that they developed among each other. Stakeholders promoting agroecology soil management say that conventional soil management measures exhaust the soil and are unsuitable for soil and human health. While those that used conventional technologies calmed that agroecology technology took time to show results, it was a tedious method. Most of the time, the results were not as good as those that used conventional measures. Lastly, those that used mixed methods calmed that each technology is suitable for a specific crop; annual crops require the conventional method because they do not have time to wait for the agroecology measures to show results, while perennial crops

such as avocado work best with the agroecology soil management technologies.

However, it was observed that most farmers used more than one soil management technology. When questioned, they always say they use manure alone, deeming inorganic fertilizer too small to mention too small to mention.

Agroecology soil management technology:

Agroecological soil management technologies that were identified are as follows: mulch application, planting of trees to add fertility and reduce erosion, planting in raised beds, crop rotation, intercropping, manure application, leaving crop and house/kitchen waste, burning the fields, planting in terrenes to avoid soil erosion, minimal tillage to zero tillage (Hosen *et al.*, 2020)

"We used to throw kitchen waste in these first three banana trees, and after some time, we observed that they looked healthier than the other one; hence, we started using kitchen waste in other tree crops, too." (in-depth Interview with the farmer, Iloilo village, June 25th, 2024).

"Animal manure is the only trusted source of nutrients for smallholder farmers. I see no difference with my neighbor who uses agro vets fertilizer "(in-depth interview farmers, Iloilo July 4th, 2024).

"I do not trust inorganic fertilizer; I trust chicken and cow manure; inorganic ruin the soil even though it produces and makes more sense

business-wise. "(in-depth interview farmers, Iloilo village, June 27th, 2024).

Most farmers in Iloilo trust animal manure more than inorganic and different researcher including (Goldan et al., 2023; Rayne et al., 2020) have concluded that compost manure made from cattle dung improved soil quality and production hence been preferred more to farmers.

The above soil management technologies are widely used in the community and quickly promoted amongst farmers because of their availability. It is also observed that most farmers do not get the intended results of the manure because most leave the manure to be washed by the rain and intense sun rays. However, it is still very popular over the years. A Study by (Rayne et al., 2020) emphasized that manure's physical property has a direct contribution to how it improves soil fertility, and the weather has a contribution to whether the manure will work or not (Köninger et al., 2021; Malomo et al., 2018) did differently.

studies on manure management and soil biodiversity, the key findings of the studies were similar: Farmers should observe manure quality over quantity, which most farmers do not. Most farmers concentrate on collecting manure, but they do not have modern or local facilities to store the manure before farm use.

The findings on soil management in agroecology indicate that much work remains for researchers and extension agents in farmer field schools or other collaborative learning environments. The goal is to determine whether manure truly outperforms fertilizer and to investigate whether unhealthy neighboring farms result from improper farm management technologies beyond soil management. Several studies contradict farmers' claims. Studies by Köninger et al. (2021) and Afolabi et al. (2021) show that combining organic and inorganic fertilizers significantly boosts soil sucrose, urease, and β -1,4-glucosidase activity, as well as soil organic carbon, nutrition, and fauna feeding activity. Additionally, their research highlights the individual contributions of organic manure and inorganic fertilizers. Other studies, such as Bashir et al. (2022), reveal that inorganic fertilizer, at a dosage of 3 grams, was more effective than organic fertilizer for the growth of local maize seedlings. Similarly, Alzamel et al. (2022) found that inorganic fertilizer generated more phenolic secondary metabolites and chlorophyll than organic fertilizer. Therefore,

verifying information to help farmers choose appropriate technology is essential.

Most farmers find manure an accessible option for soil management due to their dairy cattle, with each household typically having at least one unit. However, improper use of manure can lead to significant environmental issues. Studies (Chadwick et al., 2020; Golden et al., 2023) highlight that manure can cause phosphorus loading in water sources, soil acidification, and nitrate and phosphate contaminating surface and groundwater. Furthermore, manure can contribute to greenhouse gas emissions, causing air pollution. Despite its convenience, poor storage practices—like leaving manure exposed to sun and rain—reduce its quality and effectiveness, exacerbating these negative environmental impacts.

Mixed cropping was used because most farmers in the study area owned between 3 and 0.25 acres of land. The exception was that those people who were leaders or from chiefdoms owned between 12 acres to 8 acres of land. The main crops grown mostly were avocados and bananas, requiring larger spacing of up to 8x8 meters. This forced farmers to use mixed cropping or crop rotation as soil management practice (see extracts below). However, from their perspective, they used the practice to mitigate the challenges of land shortage. Hence, they start with maize, and in August, they plant beans.

"I do crop rotation. It is a good soil management technology, especially for us vegetable producers "(in-depth Interview with farmer Iloilo Village, June 27th, 2024)

"Scarcity of land leads to crop rotation according to season maize then beans" (in-depth Interview with farmer Iloilo village July 10th, 2024).

Crop rotation and mixed farming are agroecology soil management technologies widely used by farmers. In-depth Interviews and observations show that most farmers use these means without knowing they are suitable for the soil due to land scarcity brought about by the increase in population in Tukuyu and the introduction of new crops that take up much space, such as avocados.

Conventional soil management technology:
There is also the use of conventional soil

management technologies, which include soil testing, fertilizer application, and lime application for acidic soil. From May 16th to August 22nd, I visited 52 farmers' farms to observe soil management technology, and out of all five.

(5) were using manure as their primary soil management technology accompanied by mulch, crop residuals, and covering weeded grasses with soil during farm preparation; 47 farmers were using mixed methods of both manure and fertilizer. Out of 47 farmers, nine use inorganic fertilizer for both annual and perennial crops, while the remaining 38 use inorganic fertilizer for annual crops only, such as beans and maize. It was observed that most farmers who choose to use conventional soil management means use it for one particular crop alone. Farmers use different types of fertilizers, including DAP (diammonium phosphate), CAN (calcium ammonium nitrate), SA (Sulphate of Ammonia), and Urea, for their crops. CAN is commonly popular because it works best for flowering plants, and farmers have noted that it prevents flower and fruit abortion. The flowering process is important as it explains the harvest they can get. For years now, in Iloilo village, there has been an increase in the number of people who can use inorganic fertilizer, which is available, and some agro-dealers even sell it to farmers in the form of measuring kilograms. Analysis of data further shows that farmers' view on the effectiveness of inorganic and organic fertilizer is influenced by the type of crop, as demonstrated by the following remarks:

"In bananas, we use CAN more. It helps in fruiting and flowering. In part of the training, we learned that the CAN is helpful in flowering and fruiting," and annual crops work best with inorganic manure, unlike perennial." (farmer in-depth interview, Iloilo, 26th June 2024)

Further, it was revealed that inorganic fertilizer works faster and does not take time to absorb into the soil, unlike organic fertilizer, as demonstrated by the following remarks from key informants' interviews.

"In beans plot, we mix DAP and CAN. Annual crops we use fertilizer because it stays in the short period in the farm." (farmer in-depth interview, Iloilo village, July 5th, 2024)

"Beans is a short-term crop; hence, it requires more inorganic fertilizer, which can be quickly released to the soil. I use Yara Mira, CAN,

DAP, and NPK." (farmer in-depth interview, Iloilo village, May 28th, 2024).

"... some soil management technologies are more suitable for some crops only. For Example, annual crops work best with inorganic fertilizer unlike perennial." (farmer in-depth interview, Iloilo village July 19th, 2024).

This implies that most farmers have a general understanding of how organic and inorganic fertilizers work. They understand that the decomposition of animal manure might take time. This has been discussed and presented by so many scholars that inorganic fertilizers dissolve faster than animal manure (Lyimo et al., 2012; Liu et al., 2022; Guo et al., 2016; Wu et al., 2024; Mowo et al., 2006) presented that because the organic matter must break down and become a part of the soil ecology, the benefits of adding compost to soil may not be immediately apparent.

Mixed soil management technology: It was found (see extract below) that most farmers employed multiple soil management technologies. Furthermore, most farmers rely heavily on manure and applying inorganic fertilizer as supplemental soil management techniques for their perennial crops, which are mostly their source of income.

"I use manure as a priority soil management in each crop. I use as follows: 3 buckets (20l) per avocado tree, six buckets (20l) per banana tree, and two buckets (20l) per coffee. Then, supplement each crop with two bowls of inorganic fertilizer equally." (farmer in-depth interview, Iloilo village, 9th July 2024).

"Manure is a priority soil management technology for us. I use manure alone in the avocado trees and use a small quantity of CAN and DAP for the banana trees." (farmer in-depth interview, Iloilo village July 23rd, 2024).

"Mixing CAN and manure gives great results; this soil management technology CAN help flower my avocado trees." (farmer in-depth interview, Iloilo village, July 9th, 2024).

Farmers explain the combination of manure and inorganic as increasing production; however, it is also a means of cutting down costs brought about by using inorganic fertilizer alone. It was found that most farmers who only apply manure experience flower abortion in avocado trees.

Table 2. stakeholder profile and technology promotion

Sn	Stakeholder name and contacts	Profile	Technologies promoted
1	Kilimo Tija project	It operates in the SAGCOT region in Tanzania as the production areas Mbeya, Njombe, Iringa, and Morogoro) and Zanzibar (Unguja and Pemba) with market shed in Dar es Salaam, Songwe, Dodoma, and Arusha region operating from Sept 2022 – Sept 2027	Use manure, crop rotation, and the 6-meter rule in plantings to avoid soil erosion and reserve water resources.
	Mbozi, Ileje and Isangati Consortium (MIICO)	MIICO is a network-based NGO that works with smallholder farmers. Focusing on wealth creation, sustainable agriculture, strengthening civil society, policy engagement, and institution development, operating since 2001 and working as an NGO since 2005	Mulch, crop rotation, manure, lime, planting on raised seed beds, and soil testing are measures farmers can take to choose the proper soil management.
3	Rikoto Agriconnect (building inclusive and competitive agriculture)	It is an EU-founded project that has been operating from 2020-2024 and aims to increase the income of smallholder farmers by making sure farmers can adopt good agriculture technology through farmer field schools and demo plots	drip irrigation, use manure, promoting climate-smart agriculture greenhouse production (by contributing 40% of the total cost)
4	UWAMARU AMCOS Tukuyu	It was registered as an AMCOS in the year 2018 to serve the need for increased avocado production as needs raised to help member farmers maximize the marketing of their goods, keeping them updated on pricing changes and quality standards, and helping them build and maintain relationships with possible domestic and international customers.	Manure, fertilizer, mulch, and lime are used to correct the soil acidity of the area. They operate a shop selling fertilizer and lime at a minimal profit
5	Mbeya University Science and Technology	A public University MUST significantly improve soil health and farming productivity in the area by conducting essential research and providing training on sustainable agriculture methods. The Yara Knowledge Center, run by MUST in partnership with Yara, offers farmers and students information and training on crop nutrition, soil health, and fertilizer management. This collaboration aims to support sustainable farming methods and empower smallholder farmers.	minimal tillage, use of right fertilizer, drip irrigation, and training farmers through demo farms

Different studies further supported this (Al-Dulaimy et al., 2023; Diez et al., 2016), which found that soil fertility is an important factor in the flowering and fruit formation process. If all the nutrients the plant needs are unavailable during the flowering process, this will lead to a significant decrease in the number of flowers.

Applying 100 g/plant of fertilizer grade 10-20-20 for a year significantly increased the number of inflorescences per plant, decreased the abortion of flowers and immature fruits, and increased the number of fruits per plant in flowering and fruiting trees.

Soil Management technologies disseminated by various stakeholders: On the other hand, our engagement with stakeholders reveals that they promoted various soil management technologies (methods) to farmers, as presented in Table 2.

It was observed that farmers classify soil management technology into the use of manure, fertilizer, and a mix of manure and fertilizer. However, methods such as mulching, planting trees, planting on raised seed beds, and crop residuals are not termed methods of soil management but just daily farm management practices. Each time when we conduct interviews and farm visits, farmers will mention the use of

manure fertilizer or mixing both manure and fertilizer, but you will observe other methods. With in-depth discussion, you identify that some methods do it because that is how parents have been doing it for years. Different soil management technologies are promoted, but agroecology soil management is the most used soil management technology because it does not have a cost associated with it, and it has been used over a long period.

4.2 Who and How knowledge of Soil Management Technologies were Introduced to Different Agriculture Actors

Data analysis shows that the government, through the district extension service department, farmers, mass media TARI Uyole, Tea Research Institute of Tanzania (TRIT), Tanzania Coffee Research Institute (TACRI), and NGOs were the main promoters of soil management technologies in the study area.

District extension services department: The extension department mainly used the Farmer field school (FFS) approach to introduce and disseminate soil management technologies; this was revealed by the district agricultural extension officer, who said:

"The district promotes various farm practices, including soil management technologies such as manure, fertilizers, and lime, sometimes with cooperation with the cooperative UWAMARU through organizing farmer field schools focusing on a specific crop." (KII with the district extension agent, Iloilo village 24th July 2024)

The FFS is the prime method that the government uses to introduce and promote soil management technologies in the study areas. This finding is in line with the policy statement from the Agriculture Policy 2013 chapter 3.5, "A strong technology transfer and partnership entity shall be established in tandem with a semi-autonomous research institution to strengthen research-extension-farmer-training linkages." informs that in Tanzania, the primary agricultural extension approach is FFS.

Analysis of key informant interviews points out that Farmer Field School is perceived to be a suitable method of learning together practically from the beginning to the end. However, it comes with a cost, which makes it hard for the district extension office to conduct it alone due to

budgetary reasons. To mitigate that, the department does, in this case, with other stakeholders, as demonstrated by the following extract.

"Due to high costs connected to running FFS the department through extension, officers must cooperate with UWAMARU AMCOS, NGOs like Helvetes, Rikoto, and USAID to conduct them. Unfortunately, in such an arrangement, government extension agents do not directly control the curriculum and participants." (KII with district extension agent, Iloilo village, July 24th, 2024).

The implication of the above is that since the public extension has no direct influence, this impacts agents' work. One critical issue is that they do not directly influence the curriculum or type of farmers to be reached since the project at hand will directly influence such critical decisions. Since projects operate in specific areas with specific coverage, there is low coverage, and the farmer field school cannot reach more people at once.

It was observed that farmers in the study area have not been attending farmer field school because they are busy with other businesses, such as shops.

These findings align well with other scholars. For instance, studies (van den Berg et al., 2020; Charatsari et al., 2022; Norton et al., 2020) have reported the labor-intensive nature of farmer field schools, their comparatively expensive program and travel expenses, and their restricted outreach—that is, the small number of interested farmers.

On the other hand, farm and home visits and agricultural exhibitions (Nane Nane shows¹) are other methods used by the department to introduce and train farmers on soil management technologies. It is important to note that agricultural extension theoretically had direct contact with farmers, but in practice, very few contacts were made. The following extract from an Interview with farmers demonstrates this point.

"The agents hardly visit us and teach us soil management technology; we thank you(researchers) because it is for your visits that I have seen our ward extension officer." "I also attend exhibitions in a town like the Nane Nane agriculture" (Farmer, Iloilo village, July 10th, 2024).

It is important to note that it is clear from the data above that extension agents promote soil management technologies to all farmers in the study area. However, there are few extension agents, and those present are overwhelmed and less informed on the topic. Shortage of extension agents is one of the most significant limiting factors to the dissemination of technologies among farms (Antwi-Agyei et al., 2020; Chandio et al., 2021) presented findings showing the gap of knowledge among farmers is brought about by the shortage of extension agents.

Research institute: Institutions such as TARI work with all farmers, but TACRI works with coffee farmers, and TRIT works with tea farmers. Both contribute to promoting soil management technologies relevant to the crop of interest. The research institute disseminates its technology through field days, training extension agents, working with NGOs on projects, and answering farmers directly. Farmers acknowledge the contribution. For example, soil testing services are provided, as evidenced by the following extract from one of the interviews with farmers.

Through the technology dissemination section, the Tanzania Agriculture Research Institute (TARI) occasionally promotes technologies, including soil management, to farmers in the study areas. This was revealed during a key informant interview with the TARI Uyole coordinator, as per the following extract:

"We (TARI-Uyole) plan to work directly with farmers through outreach programs, conducting farmers' field days to communicate different technologies, including soil management technologies (soil testing) developed and tested through our research activities. However, because of our limited budget, our reach is very small. (KII, TARI-Uyole, 6th June 2024).

The Nanenane exhibition is an annual event held in Tanzania to commemorate the founding of Farmers' Day. It celebrates achievements in agriculture, livestock, and fisheries. It takes place from August 1st to 8th each year and features displays and demonstrations from various sectors related to Agriculture, Livestock, and Fisheries, including innovations, technologies, and practices aimed at improving productivity and sustainability.

It was found out that some farmers had received services from TARI -UYOLE, specifically soil testing services, as per the following remarks:

"I did soil testing. I heard that TARI was working on the next village in the banana project. I went with a few friends, and they helped me test the soils." (farmer, Iloilo village, 3rd July 2024).

It was learned that this development emanates from a recently established program, the National Soil Health Testing Program by the Ministry of Agriculture, to improve sustainable farming methods. This program aims to give farmers vital information on soil health so they may choose the best crops and fertilizers for their farms. However, from the observation, it was evident that most farmers have not gotten this service from the extension agents because the extension agents have not been supplied with soil test kits; there is only one available at the district level. Another observation is that most farmers lack awareness and understanding of the importance of soil testing in soil management even with most researchers reporting that soil management through soil testing is important as it contributes to managing Nutrients, Evaluating Soil Fertility, and Recommendations (Tiwari et al., 2023)

Another observation is that most farmers lack awareness and understanding of the importance of soil testing in soil management.

Unfortunately, although TARI has the soil testing kits and expertise, it lacks a strong relationship between the farmers of Iloilo village and extension agents. Due to low staffing levels and mandate, TARI experts come in occasionally for outreach or project-related activities. So, it takes efforts for innovator farmers to travel to TARI Uyole and seek consultation from the TARI soil department or even go to the next village when they hear there is a TARI outreach event. This finding resonates well with findings by (Wambura et al., 2015; Kihoma et al., 2021; Norton et al., 2020), who found that research institutes play a major role in disseminating technology. However, they have few contacts with farmers.

Farmer-to-farmer learning: The farmer-to-farmer extension approach was another method to disseminate soil management technologies in the study area. Data show that it was mostly preferred because farmers claimed to learn in real-time, where technology is explained in

simple, familiar terms by a familiar face while observing the action to the end. The fact that a fellow farmer has practiced the technology gives them confidence that the technology is appropriate and compatible with their situation and production system. Ultimately, take up the knowledge (Nakano et al., 2018).

Studies (Phillips et al., 2013; Omulol et al., 2020) inform that farmers worldwide frequently choose to pick up new methods and concepts from other farmers. This learning can happen informally, through impromptu discussions, or more consciously, with groups of farmers getting together to test new techniques and discuss outcomes. They can modify training to fit the culture and conditions of the area. This is the reason why extension agents also use the led farmers contact approach because most farmers feel more comfortable learning from fellow farmers (Skaalsveen et al., 2020; Stringer et al., 2020).

"We (farmers) prefer technologies that they can observe and learn practically more importantly when learning from your fellow farmer." (FGD, Iloilo, June 26th, 2024).

"I also learned from my parents the technology of covering grasses after slashing with soil or plowing under the grasses; the grasses will nourish the soil. This has been common for so many years. If a farmer does not do this, they will consider you a newcomer. We have been doing this since we were young as a cultural way of improving soil fertility." (KII, Iloilo village, 27th June 2024).

"Other farmers come to learn from me, especially on moisture conservation and seasons, to make manure application about flower abortion. (farmer, Iloilo village, 3rd July 2024).

Through observations, it was noted that almost all the farmers in Iloilo village who visited practiced *plowing under* technique during seed bed preparations. It follows that farmer-to-farmer knowledge flow makes learning easy for farmers from one generation to the other. The finding resonates well with one principle of adult learning, which stresses that adult learners do not need to be overloaded by information (Oywaya-Nkurumwa et al., 2018).

Farmers learning from workplaces where they provide casual labor: In this area, most of the

soil management technology used, especially fertilizer application, is learned from people who work as laborers with the Kuza Africa company and Mbise Enterprise. Kuza Africa is an avocado company that grows and sources avocados for processing oil and export. Kuza Africa taught farmers from the quality avocado seedlings how to take care of the soil's nutrient needs. At the same time, Mbise is a large-scale farmer who grows avocados in Iloilo village. The farmers working for Mbise enterprise, Kuza, and others who work outside the village learn firsthand by caring for the farms in their workplace.

Workers in different areas, either as managers or casual laborers, learn one or more new skills, which they later implement on their farms, and others learn from their results on their farms. The following extract confirms this:

"People whom the Kuza Africa first employed came in with a lot of knowledge that we did not have in the past" (farmer, Iloilo village, June 6th, 2024).

This implies that when some farmers get the opportunity to work in investors' farms, they develop experience and come out with such experience/ and practice it in their farms. This way, the relevant and useful technology or practice learned is spread from one farmer to another, and with time, it spreads in the target area.

Mass media: For years now, mass media has been getting so much popularity as a means of collective learning or a means for the message to reach a broader audience. However, the farmers in Iloilo village still have trouble adopting these to get knowledge. For the few farmers that use this to get knowledge, the standard mass media used includes radio, television, and YouTube channel content. Different programs are organized to determine which fertilizer to select, how to use the fertilizer, and how to conserve the moisture content in manure. Most farmers still have a hard time using the mass media to get knowledge. They are used to face-to-face means. Nevertheless, there are still farmers who get knowledge from the mass media (Chen et al., 2015; Cahyani et al., 2023)

"I look at different agriculture programs at TBC, Star TV, and Channel Ten. "(farmer, Iloilo Village, June 27th, 2024).

"I also learn from YouTube, especially South Africa." (farmer, Iloilo village, July 3rd, 2024).

"I hear TV and Radio stations talk about agriculture, but I do not follow up because I am too busy to listen. But I heard in Rungwe FM that urea is important in the maize and beans production "(farmer, Iloilo village, July 1st, 2024).

This shows that the mass media method of technology works; however, a gap still needs to be filled so that farmers can take mass media as seriously as any other media for technology transfer. YouTube is currently gaining popularity as a means of learning, and there is evidence that in years to come, it will be more popular among farmers because the few that have seen the technology and references from the different channels working (Kalyani et al., 2023; Farabi et al., 2023; Maertens *et al.*, 2021). Almost all the television channels in Tanzania have special programs for farmers to learn about different agricultural programs. The only thing left is for extension agents to emphasize the importance of farmers learning through this platform.

5. CONCLUSION

The findings of the study reveal that farmers soil management technologies promoted in the study area are divided into agroecology (mulch application, planting of trees to add fertility and reduce erosion, crop rotation, intercropping, manure application, leaving crop and house/kitchen waste, minimal tillage), conventional (soil testing, use of fertilizer and lime) and mix of the two. Further, the standard technology transfer brokers include farmers, researchers, and extension agents from the government and private sectors, who transfer technology through demonstration plots, farmer field schools, training, agriculture shows, farm and home visits, mass media, and farmers' field days. The above are the stakeholders' preferred means of transferring technology; however, farmers have their preferred means of technology transfer. First and foremost, farmers like a means that would incorporate more than one method, for example, a farm visit for follow-up, farmer field school, or demonstration plots for learning practically; farmers also prefer learning by doing and from a source they trust, for example, fellow farmers. It was also observed that the promotion of soil management technology is not coordinated, and there is a lack of a clear understanding of who is dealing with farmers as mandated extension agents. The diffusion of innovation theory is also applied in Iloilo village,

where most people are either early or late, and the majority prefer learning from other farmers.

6. RECOMMENDATIONS

The study recommends that the extension agent educate farmers on the appropriate means of using the available soil management technology because inappropriate means of storage and use reduce the effectiveness of soil management technology. Researchers and extension agents should bridge the gap between them to make the research findings reach many farmers or targeted audiences by strengthening extension-researcher collaboration through actors' platforms and forums, among other ways. The government and extension agents should work more on promoting soil testing because many farmers still don't know that the soil testing service is available and funded by the government. Extension agents should capitalize on the farmers-to-farmer learning approach by creating lead farmers, empowering them, and closely working with them. There is a need to ensure a clear understanding of the expected standards and skills for extension agents to engage with the farmers to maintain professionalism and integrity of the agricultural extension services as an institution and to ensure relevant information is delivered to farmers to avoid misinformation.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

CONSENT

As per international standards or university standards, respondents' written consent has been collected and preserved by the author(s).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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