Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Integration of Indigenous and Introduced Soil Management Practices in Sayo District Kellem Wollega Zone Oromia Regional State Ethiopia

Zeleke Gonfa Werdofa

zelekegonfa@gmail.com

Madda Walabu University

Asmare Negash

Tullu Dimtu Highschool

Research Article

Keywords: Agroecology, extension service, Intercropping, soil fertility, Soil mangement

Posted Date: August 13th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10461915/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Integration of Indigenous and Introduced Soil Management Practices in Sayo District Kellem Wollega Zone Oromia Regional State Ethiopia

Zeleke Gonfa Werdofa
Department of Geography and Environmental Studies, Madda Walabu University, Robe, Ethiopia
Asmare Negash
Department of Geography and Environmental Studies, Tullu Dimtu Highschool, Sheger City Ethiopia.
Email address zelekegonfa@gmail.com

Abstract

This study aimed to to examine the status and practice of integrated indigenous and introduced soil management strategies in Sayo District, Kellem Wollega Zone, Oromia. A cross-sectional design with stratified random sampling selected 370 rural households for demographic and geographic representation. Qualitative data were gathered through focus group discussions and key informant interviews, and filed observation supported by secondary sources including government reports, state policies and development strategies on soil management practices. Findings indicate that all the traditional, modern and integrated soil management practices were in-place . Empirical evidences reveal that the most widely practiced traditional soilmanagement techniques across the three rural villages under investigation include crop rotation (95.9%), intercropping (95.7%), agroforestry (74.9%), farmyard manure application (68.1%), and compost use (56.5%). furthermore, the most prevalent and widely adopted modern practice of soil managment is the application of chemical fertilizers. It implied that modern soil management practices play a dual role in improving farm productivity and promoting environmental sustainability. The finding also revealed that among the integrated soil management practices, the combination of manure and chemical fertilizer is the most widely adopted practice, with 94.6% of respondents reporting its use. This high level of adoption reflects farmers' recognition of the complementary roles of organic and inorganic inputs in improving soil fertility. A comparison across types of soil management and yield obtained result shown that across all crop types, the highest mean yields are consistently recorded under integrated soil management practices, followed by modern practices, while the lowest yields are observed under traditional practices. Therefore, the research result indicated that The results imply that policies and development interventions should prioritize the promotion and scaling-up of integrated soil fertility management practices. Strengthening agricultural extension systems, improving farmers' access

to organic inputs such as manure and compost, and enhancing knowledge of conservation practices are essential steps toward increasing adoption. Furthermore, encouraging farmers to transition from traditional to integrated systems can significantly improve food security, increase farm income, and ensure environmental sustainability.

Keywords: Agroecology,extension service, Intercropping, soil fertility, Soil mangement

1. Introduction

1.1. Background of the study

Sustainable soil management is grounded in multiple interrelated theoretical perspectives, including agroecology, ethno-pedology, and integrated soil fertility management (ISFM). Agroecology emphasizes the ecological foundations of farming systems, advocating for practices that maintain and enhance the biological, physical, and chemical properties of soils through ecologically informed management (Altieri, 2018). Ethno-pedology, on the other hand, underscores the value of farmers' indigenous knowledge—accumulated through generations of local experience—in understanding soil characteristics, fertility indicators, and context-specific management strategies (Barrera-Bassols & Zinck, 2003). Complementing these perspectives, ISFM promotes the strategic integration of organic and inorganic nutrient sources, improved crop varieties, and soil and water conservation technologies to sustainably optimize agricultural productivity (Vanlauwe et al., 2015). Together, these approaches highlight that effective soil management is not a one-size-fits-all solution but requires combining local knowledge with scientifically developed practices to create adaptive, resilient, and context-specific interventions.

The importance of such integrated approaches becomes particularly evident when considered within a global context. Soil is universally recognized as a vital natural resource, forming the foundation for agriculture, food security, and rural livelihoods. Yet, accelerating soil degradation—including erosion, nutrient depletion, organic matter loss, and structural decline—poses a serious threat to agricultural productivity and ecosystem stability worldwide (FAO, 2021). In response, agricultural development initiatives increasingly advocate for approaches that blend traditional knowledge with modern conservation and nutrient management practices. Strategies such as conservation agriculture, agroforestry, and integrated nutrient management illustrate how local and scientific methods can complement one another to restore soil health and sustain productivity (Pretty et al., 2018).

This challenge is especially pressing in sub-Saharan Africa, where declining soil fertility remains a critical constraint on agricultural output. Factors such as continuous cultivation, reduced fallow periods, nutrient mining, limited fertilizer use, and widespread erosion have contributed to

widespread soil degradation (FAO, 2021). Historically, African farming communities relied on indigenous practices—such as crop diversification, fallowing, organic amendments, and traditional terracing—to sustain soil fertility (Teshome et al., 2016). While these methods are ecologically appropriate and culturally embedded, population growth and shrinking landholdings have reduced their effectiveness when used in isolation. Consequently, governments and development partners have introduced complementary soil management practices, including mineral fertilizers, conservation agriculture, agroforestry, and soil-water conservation structures (Pretty et al., 2018). Despite these interventions, adoption remains uneven, underscoring the need for strategies that respect and integrate indigenous knowledge while meeting contemporary productivity and sustainability demands.

In Ethiopia, soil degradation is a particularly pressing concern. Widespread soil erosion, nutrient depletion, deforestation, and unsustainable land use practices have significantly reduced soil fertility, posing major challenges to national efforts aimed at ensuring food security and promoting rural development (Hurni et al., 2016). Farmers across the country, including those in the Oromia Region, possess extensive indigenous knowledge and have long employed soil management practices such as crop rotation, mulching, composting, traditional terracing, and fallowing to maintain soil health (Teshome et al., 2016). Complementing these local strategies, government programs and development partners have promoted introduced practices—including inorganic fertilizers, improved tillage methods, agroforestry systems, liming, and conservation agriculture—to enhance agricultural productivity (Pretty et al., 2018). Despite these efforts, persistent soil fertility challenges, socio-economic constraints, and agro-ecological variability have limited the widespread and effective adoption of either indigenous or introduced approaches alone.

Within this national context, Sayo District in the Kellem Wollega Zone exemplifies a rural area where soil fertility is central to the livelihoods of smallholder farmers. The district is characterized by mixed farming systems in which households employ a variety of indigenous soil management strategies, such as organic manure application, crop residue retention, and locally adapted erosion control measures. Simultaneously, farmers also adopt introduced techniques, including mineral fertilizers, agroforestry with improved species, and modern soil conservation structures. However, there is limited empirical knowledge on how these practices are integrated, the degree to which they are adopted, farmers' perceptions of their effectiveness, and the socio-economic and

environmental factors that influence their use. Understanding these dynamics is critical for designing interventions that are both effective and locally appropriate.

Therefore, in order to fill the limited empirical gap identified on how indigenous and introduced soil management practice examining the integration of indigenous and introduced soil management practices in Sayo District is therefore essential. This research addresses a the identified knowledge gap by documenting how farmers combine diverse practices within their specific agro-ecological context. The findings can inform sustainable development by identifying strategies that enhance soil fertility, improve crop productivity, and strengthen livelihood resilience. Furthermore, insights from this study can guide agricultural extension programs and policy design, ensuring that interventions build upon farmers' existing knowledge while addressing their constraints and opportunities. Ultimately, generating context-specific evidence on integrated soil management contributes directly to combating land degradation, improving food security, and fostering sustainable rural development in Ethiopia..

1.2. Statement of the problem

Soil degradation remains a persistent challenge to agricultural production and rural livelihoods in Ethiopia, where the majority of smallholder farmers depend directly on soil fertility for crop production. Continuous cultivation, soil erosion, nutrient mining, and limited use of soil replenishment inputs have contributed to widespread declines in soil productivity across many farming systems (FAO, 2015; Hurni et al., 2015). These challenges are particularly acute in mixed-farming areas, where population pressure and shrinking landholdings intensify land use and reduce opportunities for fallowing or soil recovery.

In response to long-standing soil fertility constraints, Ethiopian farmers have developed and maintained a wide range of indigenous soil management practices that are closely adapted to local environmental and socio-cultural conditions. These practices include crop rotation, mulching, composting, traditional terracing, fallowing, biomass transfer from forests to cropland, controlled grazing, enclosure systems, soil-burning techniques to enhance phosphorus availability, crop residue retention, and the integration of nitrogen-fixing tree and legume species such as Faidherbia albida (Amede et al., 2001; Nyssen et al., 2008; Tadesse, 2002). Evidence from different parts of the country suggests that such practices have played an important role in maintaining soil fertility

and reducing land degradation. For example, in Tigray, stone bunds and soil and water conservation structures combined with organic amendments have reduced erosion and improved soil fertility, while the Gedeo agroforestry system in southern Ethiopia has sustained long-term soil productivity through the integration of trees and crops (Nyssen et al., 2007; Tadesse, 2002).

Alongside these locally developed practices, modern soil fertility management technologies—including mineral fertilizers, improved tillage methods, conservation agriculture, and agroforestry interventions—have been promoted through government policies and development programs. While these technologies are intended to address nutrient deficiencies and boost productivity, their adoption and effective use have remained uneven. Many smallholder farmers face constraints such as limited access to inputs, high costs, weak extension support, insufficient technical knowledge, and broader socio-economic challenges that limit sustained use or proper application of recommended practices (Tesfaye et al., 2016). As a result, soil fertility decline continues to affect agricultural productivity in many rural areas despite decades of intervention.

At the local level, limited attention has been given to how indigenous and introduced soil management practices interact in farmers' everyday decision-making. Few studies have examined how farmers combine these practices, why certain methods are preferred over others, or how environmental, economic, and institutional factors shape these choices. This gap in understanding often leads to development interventions that overlook local knowledge, underestimate farmers' adaptive strategies, and fail to build on the complementarities between indigenous and modern approaches.

In Sayo District, where mixed-crop farming is the dominant livelihood system, declining soil fertility poses a serious threat to household food security and income. Although farmers employ various indigenous soil management practices and have been exposed to modern technologies, little is known about how these practices are used together, how farmers perceive their effectiveness, or how local agroecological conditions influence management decisions. Moreover, the ethnopedological knowledge of farmers—such as local soil classifications, fertility indicators, and management strategies—remains largely undocumented in the district.

Agroecology offers a useful lens for understanding these dynamics, as it emphasizes the integration of ecological processes, local knowledge, and socio-economic realities in the design of sustainable farming systems (Altieri & Nicholls, 2017). Applying this perspective in Sayo District

can help identify soil management strategies that are both technically sound and socially acceptable.

The lack of empirical evidence on farmers' knowledge, perceptions, and use of integrated soil management practices represents a major barrier to developing effective and sustainable interventions in the district. Addressing this gap requires a focused investigation into how indigenous and modern soil management practices are applied, combined, and evaluated by farmers, as well as an assessment of the socio-economic and environmental factors influencing their integration. Such research is essential for informing context-specific soil fertility management strategies that enhance agricultural productivity, strengthen resilience, and support sustainable livelihoods in Sayo District.

1.3. Objective of the study

1.3.1. General Objective

The overall objective of this study was to examine the status and practice of integrated indigenous and introduced soil management strategies in Sayo District, Kellem Wallaga Zone, Oromia Region.

1.3.2.Specific Objectives

The specific objectives of the study were to:

1. Identify types and status of indigenous, introduced, and integrated soil management practices in Sayo District.
2. Compare the effect of indigenous, introduced, and integrated soil management practice on selected yield.
3. Examine key factors influencing making use of integrated soil management practice in Sayo district.

1.4. Research Questions

1. What are the types and status of currently used indigenous, introduced, and integrated soil management practice looks like in Sayo district?
2. What are the comparative effect of indigenous, introduced, and integrated soil management practice looks like on selected crop yield in Sayo district?

3. What are the key factors influencing adoption of indigenous and integrated soil management practices?

2. Matherial And Methods

2.1.Description of Study Area

The study was conducted in Sayo District, located in Kellem Wallaga Zone of the Oromia National Regional State, Ethiopia. The district is characterized by diverse agro-ecological conditions, ranging from highland to lowland areas, which contribute to variations in climate, soil properties, and agricultural practices. The climate of the district is generally sub-humid tropical, with annual rainfall ranging between 1,200 and 1,800 mm and mean annual temperatures varying from 12°C to 27°C (CSA, 2022). The rainfall pattern and relatively moderate temperatures create favorable conditions for agricultural production, although variability in rainfall can affect productivity.

Topographically, the district is dominated by undulating to gently sloping landscapes interspersed with some rugged terrains, which increase the susceptibility of land to soil erosion, particularly during the rainy season. The predominant soil types in the area are Nitisols and Cambisols. These soils are generally considered moderately fertile and suitable for crop production; however, they are increasingly vulnerable to degradation due to factors such as soil erosion, nutrient depletion, and continuous cultivation without adequate soil conservation measures (Hurni et al., 2016).

Land use in Sayo District is largely dominated by agricultural activities, with mixed farming systems forming the backbone of the local economy. A significant proportion of the land is allocated to crop cultivation, while other portions are used for grazing, forest cover, and settlements. Natural vegetation has been progressively reduced due to agricultural expansion, contributing to environmental degradation and declining soil fertility in some areas.

Agriculture constitutes the primary livelihood activity of the population, with most households engaged in subsistence and small-scale commercial farming. The farming system is predominantly mixed, integrating both crop production and livestock rearing. Major crops cultivated in the district include maize, teff, wheat, sorghum, and coffee, the latter serving as an important cash crop. Farmers employ a variety of soil management practices, combining indigenous knowledge—such as mulching, terracing, composting, and biomass transfer—with introduced technologies, including the use of inorganic fertilizers, improved tillage methods, and conservation agriculture practices.

Despite the widespread use of these soil management practices, important gaps remain in understanding their level of adoption, the extent to which indigenous and introduced methods are integrated, and their overall effectiveness in sustaining soil fertility and productivity. These gaps highlight the relevance of Sayo District as an appropriate and representative setting for investigating soil management practices and their implications for sustainable agricultural development.

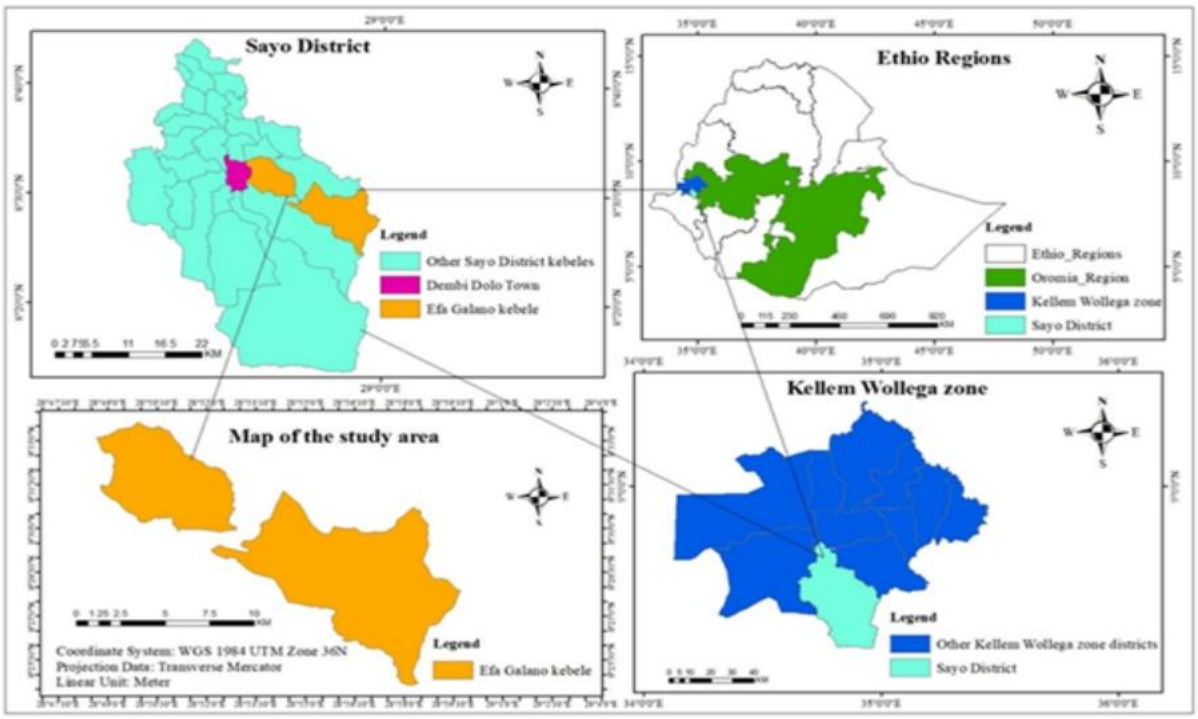


Figure 1. Map of the study area

2.2. Research Paradigm, Approaches, and Design

This study is grounded in the pragmatic research paradigm, which advocates for the use of multiple approaches to better address complex research problems. Pragmatism emphasizes practical solutions and supports the integration of both quantitative and qualitative methods, depending on the nature of the research questions.

In line with this paradigm, the study adopts a mixed-methods approach, which enables the researcher to draw on the strengths of both quantitative and qualitative techniques. Mixed-methods research facilitates the examination of measurable patterns and relationships while also capturing participants' experiences, perceptions, and contextual realities (Assalahi, 2015; Johnson & Onwuegbuzie, 2004). By combining numerical data with descriptive insights, this approach

provides a more comprehensive and balanced understanding of the research problem. The mixed-methods involves the systematic collection and analysis of both quantitative and qualitative data within a single study. These data can be collected either sequentially or concurrently, with integration occurring at different stages of the research process, including data collection, analysis, and interpretation (Creswell, 2009, 2012; Baker, 2016; Gunasekare, 2015). This integration enhances the validity and reliability of the findings by allowing for triangulation, where results from one method are cross-verified with those from another. Moreover, the mixed-methods approach helps to overcome the limitations associated with relying on a single method, while maximizing the strengths inherent in each (Ostlund et al., 2011; Creswell, 2014).

In this study, a concurrent triangulation design was employed, whereby qualitative and quantitative data were collected simultaneously during the same phase of the research process. This design enables the researcher to gather complementary data on the same phenomenon within a single time-frame, thereby improving the depth and breadth of analysis. The quantitative component provides measurable evidence on patterns and relationships, while the qualitative component offers deeper insights into underlying processes, meanings, and contextual factors.

The integration of qualitative and quantitative findings was carried out during the analysis and interpretation stages. By comparing and contrasting results from both data sources, the study seeks to validate and corroborate the findings, thereby enhancing their credibility and robustness. This approach allows for a more nuanced understanding of rural–urban linkages and their effects on household livelihood diversification, ensuring that both statistical trends and lived experiences are adequately represented (Creswell, 2014; Creswell & Creswell, 2018; Creswell & Plano Clark, 2011; Zheng, 2015).

2.3. Sample Design

The study population comprises rural households in Sayo District, which was served as an appropriate setting for investigating indigenous, introduced, and integrated soil management practices. To ensure that the findings are representative and meaningful, a combination of purposive and random sampling techniques was employed. Sayo District was purposively selected due to its diverse agro-ecological conditions and the prevalence of soil management challenges, making it particularly relevant for examining variations in soil management strategies and their adoption.

A two-stage sampling procedure was adopted. In the first stage, three rural *ganda (the smallest administrative unit in Oromia region)* were purposively selected from the district's 28 *gandoota* based on their pronounced soil management issues and the active use of various soil fertility practices. This purposive selection was ensure that the study focused on communities where soil management practices are both necessary and actively applied, providing rich and relevant data for analysis.

In the second stage, 370 household heads were randomly and proportionally selected from the total population of 4830 households using the Yamane (1967) formula. This random selection ensured that each household within the selected kebeles had an equal chance of inclusion, thereby reducing sampling bias and enhancing the statistical representativeness of the sample. By combining purposive selection of study sites with random sampling of households, the study balances contextual relevance with methodological rigor, ensuring that the results are both generalizable within the district and deeply informative for understanding local adoption, integration, and effectiveness of soil management practices.

The required sample size was determined using Yamane's (1967) formula at a 95% confidence level and 5% margin of error, ensuring statistical representativeness.

$$n = \frac{N}{1+N(e)2}$$

$$n = \frac{4830}{1+4832(0.05*0.05)} = \text{ 4830/12.075 =370}$$

Table 1: Sample size of the study area

Kebele	Total Households	Sample Size
A/Mikael	1162	89
Ifa Galano	2116	162
Shogo	1552	119
Total	4832	370

Source: compiled by researcher, 2025

Furthermore, primary data was gathered from carefully chosen key informants and FGD participants. In this sense, five important informants were involved. Their composition includes

three development agent workers, one from each rural ganda an expert from the woreda agriculture development office, one from department of natural resource management, who was chosen specifically for their access to the required information. Three focus group discussions (FGDs) was held at rural kebeles level with eight participants representing different ages, elders, and community leaders, genders, educational levels, and economic class.

2.4. Types and Sources of Data

To meet the study's aims, qualitative and quantitative data were gathered from primary and secondary sources. Structured questionnaires were used to collect primary data from rural households, while interviews and focus group discussions were conducted with chosen participants. Field observations and interviews with important informants and government officials were also carried out, using an observation checklist and an interview guide, respectively. Secondary data was acquired from relevant offices' reports and records, including office of agriculture, and natural resource management at various administrative levels. In addition, relevant material such as scientific journals, books, essays, and internet sources were consulted to enhance the data.

2.4.1. Instruments for Data Collection

Primary data, both quantitative and qualitative, were gathered from respondent households using structured questionnaires, interviews, field observations, and Focus Group Discussions (FGDs). Both open-ended and closed-ended questions were used to collect data on household demographics, socioeconomic characteristics, soil management practices; indigenous, introduced, and integrated approach, crop production, and yields. Secondary data, such as statistical records and government reports, will be gathered from relevant offices. For interviews with key informants and government officials, a structured interview guide will be prepared, and field observations will be conducted using standardized checklists. Detailed procedures are presented as follows:

I. Questionnaires

In this study, a questionnaire were the major data gathering instrument. It allows the researcher to collect detailed data on respondents' demographic and socioeconomic factors, such as age, gender, education, place of origin, occupation, income, and farming practices, crop production. The questionnaire also investigates the nature and types of soil management practices, such as

indigenous, introduced, and integrated approach, as well as the factors that influence these practices.

Separate questionnaires were prepared in English and then translated into Afan Oromo for administration. A pilot test was carried out to check that the questions were clear, intelligible, and capable of gathering the desired data. After the instruments was finalized, three enumerators will be chosen from the three sampled rural kebeles. They were trained on the study's objectives, questionnaire content, respondent engagement strategies, and ethical issues. Three of the enumerators were Development Agents from rural kebeles. Their familiarity with the local culture and context is expected to facilitate an effective and reliable data collection process.

II. Interview

Key informant interviews were conducted to supplement and validate data collected through household surveys and field observations. Interviewees was purposively selected based on their knowledge, experience, and involvement in local agricultural and natural resource management. They included officials from the District Rural Land Administration Office, the Office of Natural Resource Management, the Office of Agriculture and Rural Development, and development workers actively engaged in the district.

The interviews focused on several key themes, including the types and status of indigenous, introduced, and integrated soil management practices, crop yield performance, and farmers' practical experiences with these interventions. Participants were asked to provide insights into the effectiveness, adoption challenges, and socio-economic and environmental factors influencing soil management practices.

These discussions provided critical contextual information that helped interpret and validate quantitative findings from household surveys. In addition, the interviews offered a deeper understanding of the dynamics of soil management within local agro-ecologies, as well as how these practices interact with broader livelihood systems. By incorporating the perspectives of knowledgeable stakeholders, the study was able to triangulate information across multiple sources, ensuring a more reliable, nuanced, and comprehensive analysis of soil management practices and their implications for agricultural productivity and rural livelihoods.

III. Focus Group Discussions FGDs

Three focus group discussions (FGDs) will be conducted, one in each of the selected rural kebeles, with 6 to 9 carefully selected participants per session. The participants were purposefully chosen to represent diverse perspectives, including different age groups, genders, and socioeconomic backgrounds, ensuring that the discussions captured a wide range of experiences and viewpoints. Participants included elders, youth, men, women, and individuals from both relatively affluent and less advantaged households.

The FGDs focused on several key themes, including indigenous, introduced, and integrated soil management practices, as well as the socio-economic, institutional, and environmental factors that challenge or facilitate these practices. Each session will be facilitated by the researcher and documented through detailed notes and audio recordings, allowing for accurate transcription and analysis.

These discussions provided rich qualitative insights into local soil management strategies, community perceptions of effectiveness, and contextual challenges that are often not captured through structured surveys. By engaging diverse community members, the FGDs enhanced the study's understanding of the local knowledge systems, decision-making processes, and collective experiences related to soil management. This approach was allow the research to identify nuances in adoption, integration, and barriers to sustainable practices, complementing the quantitative data collected from household surveys and key informant interviews.

IV. Observation

Field observation was used as the major data gathering strategy in this study. Observational evidence adds useful insights to a study issue (Marczyk et al., 2005; Teddlie & Tashakkori, 2009). Field visits was made to rural regions (farms, and ranch lands). The observations concentrated on natural resource conservation methods, and dynamics. An organized observation checklist helped collect data on the types and quantities of marketable agricultural goods and commodities. Photographs were also taken to capture crucial occurrences and features seen in the field.

2.5. Method Data Analysis

Prior to analysis, all data was carefully examined to ensure consistency with the assumptions underlying the selected econometric models. This process involved checking the accuracy and coding of variables, validating the dichotomous or categorical structure of dependent variables, and confirming that all variables were mutually exclusive and exhaustive. Additional diagnostics included tests for normality and homogeneity of variance to guide the appropriate selection of statistical techniques for each research objective.

Quantitative data was analyzed using both descriptive and inferential statistics. Descriptive analyses will include counts, frequencies, percentages, means, standard deviations, and analysis of variance (ANOVA) to summarize and compare soil management practices across households. To identify the socio-economic, institutional, and environmental factors influencing household choices of soil management strategies (indigenous, introduced, or integrated), a multinomial logistic regression model was employed.

Before running the regression model, assumptions was rigorously checked. These include ensuring meaningful variable coding, verifying that the dependent variable is nominal and the independent variables are either continuous or categorical, assessing mutual exclusivity, testing for normality, examining linearity between independent and dependent variables, and detecting multicollinearity using Variance Inflation Factors (VIF) or tolerance values. Outliers were identified and addressed as necessary.

Model fitness was assessed using multiple criteria. The goodness of fit was evaluated through Chi-square or F-tests, while R^2, adjusted R^2, and root mean square error (RMSE) was examined to determine how well the model explains the variation in household soil management choices and the closeness of predicted versus observed values.

Qualitative data from key informant interviews and focus group discussions was transcribed and thematically analyzed. These findings will be used to triangulate with quantitative results, providing complementary insights into the motivations, perceptions, and contextual factors influencing the adoption and integration of soil management practices. The combination of quantitative and qualitative analyses were yield a robust, nuanced, and evidence-based understanding of soil management strategies in Sayo District.

3. Results, Discussion, and Interpretation

3.1 Demographic and socio-economic character of respondent households

This section presents and discusses the demographic and socio-economic characteristics of the sampled respondent households included in the study. Understanding these characteristics is essential, as they provide important contextual background for interpreting the study findings. Variables such as age, sex, educational level, household size, farming experience, and economic status are key factors that influence farmers' decision-making processes, including the adoption and use of different soil management practices. In addition, socio-economic conditions often determine access to resources, information, and technologies that shape agricultural productivity and sustainability. Therefore, this section provides a descriptive overview of these characteristics to help establish a clear foundation for the subsequent analysis and discussion of the study results.

Table 3: Demographic and socio-economic character of the respondent household

R.N	Variable	Variable description	Frequency	percentage
1	Sex	Male	324	87.6
		Female	46	12.4
2	Age	Less than 30yrs	61	16.5
		31-40 years	156	42.2
		41-50 years	105	28.4
		51-60 years	40	10.8
		61 years & above	8	2.2
3	Education status	Unable to read and write	106	28.6
		Primary school	123	33.2
		Secondary school	81	21.9
		Higher educ.	60	16.2
4	Family size	1-2 member	80	21.6
		3-4members	94	25.4
		5-6members	128	34.6
		7 & above members	68	18.4
5	Source of income	Only crop production	138	37.3
		Both crop production and animal husbandry (mixed)	232	62.7

Source: Developed by researcher, 2025

The information presented in Table 3 shows that the majority of respondent households (87.6%) are male-headed, while only 12.4% are female-headed. As will be discussed in subsequent sections, gender disparities in access to productive resources significantly influence the adoption and continuity of soil management practices.

Similarly, the age distribution of respondents reveals that 83.5% are 31 years and above, suggesting that older farmers dominate the study area. This has important implications for

traditional soil management, as older farmers tend to possess extensive indigenous knowledge accumulated through long-term farming experience.

The educational status of respondents further highlights important dynamics in soil management practices. About 28.6% of the respondents are unable to read and write, which limits their exposure to modern agricultural technologies and information. In addition, the data indicate that more than 53% of respondent households consist of more than five family members. Larger family sizes provide a substantial labor force.

Overall, the demographic and socio-economic characteristics of respondent households—namely gender, age, education, and family size—play a significant role in shaping traditional soil management practices.

3.2. Types and status of indigenous, introduced, and integrated soil management practices in Sayo District

3.2.1. Types and status of Indigenous Soil Management Practices in Sayo District

This section looks at the types and status of indigenous soil management practices used by households in the study area. These are traditional methods that farmers have developed and passed down over time based on their local knowledge and experience. Such practices are important for maintaining soil fertility, reducing erosion, and supporting crop production, especially where access to modern inputs may be limited. Examining these practices helps to understand how farmers manage their land using locally available resources and why these methods remain important in the farming system. Therefore, this section highlights the main indigenous soil management practices used by households, how commonly they are applied, and the reasons behind their continued use in Sayo District.

Table 4: Types and status of Indigenous Soil Management Practices in Sayo District

R.N	Types of Indigenous Soil Management	Yes Frequency	Yes %	No Frequency	No %	Chi-square (χ^2)	Sig. (p-value)
1	Crop rotation	354	95.9	16	4.1	$\chi^2 = 2.935$	0.050
2	Fallowing	178	48.1	192	51.9	$\chi^2 = 0.696$	0.499
3	Inter-cropping	354	95.7	16	4.3	$\chi^2 = 2.935$	0.050
4	Farmyard manure	252	68.1	118	31.9	$\chi^2 = 1.017$	0.340

5	Mulching	109	29.5	261	70.5	$\chi^2 = 4.114$	0.017
6	Traditional terracing	155	41.9	215	58.1	$\chi^2 = 1.298$	0.274
7	Use of compost	209	56.5	161	43.5	$\chi^2 = 1.699$	0.184
8	Agroforestry	277	74.9	93	25.1	$\chi^2 = 1.429$	0.249

As presented in Table 4 above, the most widely practiced traditional soil management techniques across the three rural villages under investigation include crop rotation (95.9%), intercropping (95.7%), agroforestry (74.9%), farmyard manure application (68.1%), and compost use (56.5%). These findings indicate that the majority of households rely heavily on biologically based and organic soil fertility management practices, which are deeply rooted in indigenous knowledge systems. Such practices are widely recognized for their role in maintaining soil fertility, improving soil structure, and enhancing long-term agricultural sustainability. As will be discussed in subsequent sections, the widespread adoption of these practices reflects both their effectiveness and their adaptability to local environmental and socio-economic conditions.

In contrast, other traditional soil management practices—such as fallowing (48.1%), traditional terracing (41.9%), and mulching (29.5%)—are less commonly used, with practice rates below half of the respondent households. This relatively lower level of practice may be attributed to constraints such as land scarcity, labor intensity, and limited availability of organic materials. For instance, fallowing requires sufficient land to allow plots to rest, which is often not feasible in areas with high population pressure. Similarly, traditional terracing and mulching demand considerable labor and resources, which may limit their adoption, particularly among households with smaller labor capacity. These variations in practice, as indicated in Table 4.2, highlight the differential feasibility and accessibility of traditional soil management techniques among rural households.

The pattern observed suggests that farmers tend to prioritize soil management practices that are less labor-intensive, require fewer land sacrifices, and provide relatively immediate benefits. This is consistent with findings from previous studies, which show that practices such as crop rotation and intercropping are more easily adopted due to their compatibility with existing farming systems and lower resource requirements (Altieri, 2004; Pretty, 1995). As will be elaborated later, these

differences in adoption levels have important implications for the sustainability and effectiveness of traditional soil management strategies in the study area.

The results presented in Table further reveal that there are statistically significant differences among the rural villages in the practice of indigenous soil management techniques, as indicated by the Chi-square test. Specifically, significant variations were observed in crop rotation ($\chi^2 = 2.935$, $p < 0.05$), intercropping ($\chi^2 = 2.935$, $p < 0.05$), and mulching ($\chi^2 = 4.114$, $p = 0.017$). These results suggest that the adoption of certain traditional soil management practices is not uniform across the study villages but instead varies significantly depending on local conditions.

These findings imply that indigenous soil management practices are highly context-specific and influenced by local environmental and socio-economic factors. As will be discussed in subsequent sections, such variations highlight the importance of location-specific interventions and the need to integrate local knowledge systems when promoting sustainable soil management practices. Moreover, the observed differences are consistent with earlier studies, which emphasize that the adoption of traditional agricultural practices is shaped by local ecological conditions, cultural preferences, and resource availability (Altieri, 2004; Pretty, 1995).

3.2.2. Types and status of Modern Soil Management Practices in study area

This section looks at the modern soil management practices used by households in Sayo District and their current level of use. Modern practices are those introduced through agricultural extension services, research, or development programs, and they are mainly designed to improve soil fertility, reduce land degradation, and increase crop productivity. These practices often complement or, in some cases, replace traditional methods, depending on farmers' access to information, inputs, and institutional support. Examining both the types of modern practices and how widely they are used helps to show the level of agricultural change in the area and the challenges that may affect their adoption. Therefore, this section presents the main modern soil management practices and describes how commonly they are practiced by households in the district.

Table 5. Modern practices of soil management

R.N	Types of modern (introduced) soil management practices	Responses			
		Yes		No	
		Frequency	Percentage	Frequency	Percentage

1	Use of chemical fertilizers	344	93	26	7
2	Soil band	170	45.9	200	54.1
3	Liming	165	44.5	205	55.4
4	Vermin composting	51	13.8	319	86.2

As Table 5 above indicates, sampled farm households exhibit varying levels of experience in the use of introduced soil management practices. Among these, the most prevalent and widely adopted practice is the application of chemical fertilizers, particularly diammonium phosphate (DAP) and urea. Out of the 370 respondent households, 344 (93%) reported using chemical fertilizers, underscoring their central role in maintaining soil fertility and enhancing crop productivity. This high level of adoption is consistent with findings by Food and Agriculture Organization (FAO, 2019), which note that smallholder farmers in Sub-Saharan Africa heavily depend on inorganic fertilizers to compensate for nutrient depletion and declining soil fertility.

Soil bund and lime application follows accounting for 45.9% and 44.5% of respondents, respectively. Lime application is particularly important in ameliorating soil acidity, a widespread constraint in many highland farming systems, including parts of Ethiopia (International Food Policy Research Institute, 2020). Soil conservation practices, such as terracing and contour plowing, play a critical role in reducing soil erosion and maintaining long-term soil productivity (FAO, 2017). However, the relatively moderate adoption rates of these practices suggest existing gaps in awareness, accessibility, or resource availability among farmers.

In contrast, vermin composting is the least practiced technique in the study area. This limited adoption may be attributed to a lack of technical knowledge, labor requirements, or insufficient extension support. Nevertheless, vermin composting is widely recognized as an environmentally sustainable practice that enhances soil structure, increases microbial activity, and improves nutrient cycling (Edwards et al., 2011).

The dominance of chemical fertilizer use, coupled with the relatively lower adoption of organic and conservation-based practices, indicates a potential imbalance in soil fertility management. While inorganic fertilizers provide immediate nutrient availability, their continuous and unbalanced use without complementary organic inputs can lead to soil degradation, nutrient imbalances, and reduced soil organic matter over time (FAO, 2019). Therefore, promoting integrated soil fertility management (ISFM)—which combines organic inputs, inorganic

fertilizers, and improved agronomic practices—is essential for ensuring long-term soil health and agricultural sustainability. Enhancing farmer awareness, improving access to lime and organic inputs, and strengthening agricultural extension services could facilitate the wider adoption of sustainable practices such as vermicomposting and soil conservation techniques.

Table 6. Source of information for the use modern soil management practice

R.N	Variables	Responses			
		Yes		No	
		Count	Percentage	Count	Percentage
1	Agricultural extension worker	325	87.8	45	12.2
2	Fellow farmers	341	92.2	29	7.8
3	FTC (Farmer Training Center)	196	53	174	47
4	NGO	51	13.8	319	86.2

As shown in Table 6, the majority of farm households access information regarding modern soil management practices primarily through local and institutional networks. A substantial proportion of respondents reported obtaining information from fellow farmers (92.2%), followed by agricultural extension workers (87.8%) and Farmer Training Centers (FTCs). This finding highlights the critical role of social learning and extension systems in promoting agricultural technologies. Similar results have been reported in Ethiopia, where farmer-to-farmer knowledge exchange is a dominant and trusted channel for disseminating agricultural innovations (Ethiopian Institute of Agricultural Research, 2016). This reflects the importance of informal networks in influencing farmers' decisions and accelerating the adoption of improved soil management practices.

The strong reliance on agricultural extension workers further underscores the significance of Ethiopia's extension system, which is considered one of the most extensive in Africa. Studies indicate that extension services significantly enhance farmers' awareness and adoption of soil and water conservation practices and improved input use (International Food Policy Research Institute, 2010; Ministry of Agriculture Ethiopia, 2017). Likewise, Farmer Training Centers play an important role in providing practical, demonstration-based learning that strengthens farmers' technical capacity and encourages behavioral change toward improved land management practices.

In contrast, only a small proportion of households (13.8%) reported accessing information from non-governmental organizations (NGOs), indicating their relatively limited role in the study area. This finding is consistent with studies in Ethiopia that show uneven NGO coverage and limited integration with government-led extension systems (IFPRI, 2010).

The dominance of peer learning and public extension services suggests that strengthening these channels is essential for promoting sustainable soil management practices. Enhancing the effectiveness of extension services, improving the functionality of Farmer Training Centers, and supporting structured farmer-to-farmer knowledge-sharing mechanisms can significantly increase the adoption of integrated soil fertility management practices. Furthermore, improving coordination between government institutions and NGOs could expand outreach and introduce more diverse and sustainable soil management innovations. Strengthening these information dissemination pathways is therefore crucial for improving soil health, increasing agricultural productivity, and ensuring long-term sustainability in Ethiopian farming systems.

The level of adoption of modern soil management practices was further analyzed using a five-point Likert scale, where responses were coded as: never = 1, rarely = 2, sometimes = 3, often = 4, and always = 5. The collected responses were subsequently aggregated by computing mean scores and then normalized to facilitate comparison and interpretation across households. This approach enables a more systematic assessment of adoption intensity and provides a quantitative basis for evaluating variations in farmers' engagement with modern soil management practices.

Table 7Level of adoption of modern soil management practices

variables	N	Minimum	Maximum	Mean	Std. Deviation
Adoption of chemical fertilizer	370	1	5	3.75	1.12
Adoption of soil band	370	1	5	2.59	1.2
Adoption of lime application	370	1	5	2.76	1.512
vermin compositing	370	1	5	2.13	1.317

As indicated in Table 7, the level of adoption of modern soil management practices varies across different techniques. The most widely adopted practice is the use of and application of chemical fertilizers, which has a mean value of 3.75. These relatively high mean scores suggest that farmers frequently rely on input-intensive practices to manage soil fertility and crop productivity. This finding is consistent with studies in Ethiopia, which show that smallholder farmers tend to

prioritize practices that provide immediate and visible benefits to crop yield (International Food Policy Research Institute, 2010).

In contrast, the least adopted practices include the use of vermin composting with a mean value of 2.13, and soil band construction, with a mean value of 2.59. The lower mean scores indicate limited adoption and infrequent use of these practices among the surveyed households. Similar evidence from Ethiopia suggests that labor-intensive and knowledge-demanding practices, such as organic soil amendments and physical conservation structures, are often less adopted due to constraints related to labor availability, technical know-how, and delayed economic returns (Ethiopian Institute of Agricultural Research, 2016).

The observed pattern of adoption highlights a strong preference for short-term, input-based soil management practices over long-term, sustainability-oriented approaches. While pesticides, herbicides, and chemical fertilizers can enhance productivity in the short run, their excessive and unbalanced use may lead to soil degradation, environmental pollution, and reduced soil biodiversity over time. Conversely, practices such as vermin composting and soil bund construction contribute to improved soil structure, moisture retention, and long-term fertility but remain underutilized. Therefore, there is a need to promote integrated soil management approaches that combine both organic and inorganic practices. Strengthening extension services, improving access to training, and providing incentives for sustainable practices could enhance the adoption of environmentally friendly soil management techniques and ensure long-term agricultural sustainability.

The effect of modern soil management practice is reported by respondent household included improved yield, reduced soil erosion, and improved soil fertility.

Table 8. Effect of modern soil management practice

variables	N	Minimum	Maximum	Mean	Std. Deviation
Improved crop yields	370	1	5	3.63	1.352
reduced soil erosion	370	1	5	3.53	1.482
Improved soil fertility	370	1	5	3.5	1.478
Reducing farming costs	370	1	5	2.39	1.076

Table 8, indicates that farming households have realized several important benefits from the adoption of modern soil management practices. The major outcomes reported include improved crop yield, reduced soil erosion, enhanced soil fertility, and reduced farming costs. Among these, improved crop yield emerged as the most significant benefit, with the highest mean score of 3.65 and a standard deviation of 1.352, suggesting both a generally positive perception and some variation in farmers' experiences. This is followed by reduced soil erosion, which recorded a mean value of 3.53, and improved soil fertility, with a mean value of 3.50. These findings indicate that farmers are not only experiencing productivity gains but are also recognizing the environmental benefits associated with improved soil management practices.

The relatively high mean values for these outcomes suggest that modern soil management practices are contributing positively to both agricultural productivity and land conservation in the study area. This is consistent with empirical evidence from Ethiopia, which shows that the adoption of integrated soil fertility and conservation practices can significantly enhance crop yields while simultaneously reducing land degradation (International Food Policy Research Institute, 2010; Ministry of Agriculture Ethiopia, 2017).

The results imply that modern soil management practices play a dual role in improving farm productivity and promoting environmental sustainability. The observed improvements in crop yield and soil fertility highlight the potential of these practices to support food security, while the reduction in soil erosion underscores their importance in conserving natural resources. However, the variation in responses, as reflected by the standard deviation, suggests that the benefits are not uniformly distributed among all households. This may be due to differences in access to resources, knowledge, or the extent of adoption. Therefore, policy interventions should focus on scaling up effective soil management practices through strengthened extension services, targeted training, and improved access to inputs. Emphasizing integrated approaches that combine productivity and conservation measures will be essential for ensuring long-term soil health and sustainable agricultural development.

3.2.3. Types and Status of Integrated Soil Management Practices

3.2.3.1. Types of Integrated soil management practices

Table 9 Iintegrated soil management practices

R.N.	Variables (combination of some selected integrated and modern soil management practices)	Response rate			
		Yes		No	
		Frequency	Percentage	Frequency	percentage
1	Manure and chemical fertilizer	350	94.6	20	5.4
2	Crop rotation with improved seeds	275	74.3	95	25.7
3	Mulching with chemical fertilizer	157	42.4	213	57.6
4	Agroforestry with soil band	271	73.2	99	26.8

The results presented in Table 9, reveal important variations in the adoption of combinations of integrated and modern soil management practices among farming households. Overall, the findings suggest that farmers tend to adopt combinations of practices that provide complementary agronomic benefits and immediate productivity gains.

The combination of manure and chemical fertilizer is the most widely adopted practice, with 94.6% of respondents reporting its use. This high level of adoption reflects farmers' recognition of the complementary roles of organic and inorganic inputs in improving soil fertility. Organic inputs such as manure improve soil structure, enhance microbial activity, and contribute to long-term nutrient availability, while chemical fertilizers provide readily available nutrients for immediate crop uptake. Empirical evidence from Ethiopia indicates that the combined application of organic and inorganic fertilizers significantly increases crop productivity and improves soil health compared to the use of either input alone (Hörner & Wollni, 2021; International Food Policy Research Institute [IFPRI], 2010).

The adoption of crop rotation combined with improved seeds is also relatively high, accounting for 74.3% of respondents. This suggests that a considerable proportion of farmers are aware of the benefits of integrating agronomic and technological practices. Crop rotation helps maintain soil fertility, reduce pest and disease incidence, and improve soil structure, while improved seeds enhance yield potential and resilience. Studies in Ethiopia confirm that the adoption of improved seeds is often positively associated with complementary practices such as crop diversification and fertilizer use, thereby enhancing overall farm productivity (Ahmed et al., 2017).

In contrast, the combination of mulching and fertilizer is less widely adopted, with only 42.4% of households practicing it. The relatively low adoption of mulching may be attributed to competing uses of crop residues, particularly as livestock feed, as well as labor and knowledge constraints. Previous studies in Ethiopia have shown that although mulching and other organic soil management practices are effective in improving soil moisture retention and organic matter

content, their adoption remains limited due to resource competition and labor requirements (Hailu & Feyissa, 2023).

The integration of agroforestry with soil bund construction is adopted by 73.2% of respondents, indicating a relatively strong uptake of combined biological and physical soil conservation practices. Agroforestry contributes to improved soil fertility, biodiversity, and microclimate regulation, while soil bunds play a critical role in reducing soil erosion and surface runoff. Evidence from watershed-based studies in Ethiopia suggests that farmers are increasingly adopting integrated approaches that combine biological and physical conservation measures to address land degradation and enhance long-term productivity (Shibabaw et al., 2024).

The findings indicate that farmers are more inclined to adopt integrated soil management practices that provide immediate and visible benefits, such as the combined use of manure and chemical fertilizers. However, the relatively lower adoption of practices such as mulching highlights persistent barriers, including labor constraints, competing resource uses, and limited technical knowledge. This suggests that adoption is influenced not only by the perceived benefits of practices but also by socioeconomic and institutional factors.

The results underscore the importance of promoting integrated soil fertility management (ISFM), which combines organic inputs, inorganic fertilizers, and conservation practices to achieve both productivity and sustainability goals. Strengthening agricultural extension services, enhancing farmer training through demonstration-based learning, and improving access to organic inputs are essential strategies for increasing the adoption of sustainable practices. Such efforts are critical for improving soil health, increasing agricultural productivity, and ensuring long-term sustainability in Ethiopian farming systems.

3.3 . A comparison of crop yield among traditional, modern, and integrated soil management practices on Selected crop Yield

This section presents a comparative analysis of crop yield outcomes under indigenous, modern, and integrated soil management practices in Sayo District. The comparison is based on farmers' reported yield levels as well as their perceptions of productivity under the different soil management approaches. Indigenous practices refer to locally developed and traditionally used methods of soil fertility and conservation, shaped through long-standing farmer experience. In

contrast, modern practices consist of externally introduced technologies and inputs designed to enhance soil productivity through scientific and technical interventions. Integrated soil management represents a combined approach, where indigenous knowledge is blended with modern techniques to improve soil health and crop performance in a more holistic and adaptive manner.

Comparing these three approaches is essential for understanding how different soil management strategies influence agricultural productivity under local conditions. It also provides insight into whether integrating traditional knowledge with modern innovations offers a more effective pathway for improving crop yields than relying on either system independently. Accordingly, this section examines and contrasts the relative performance of the three soil management systems, focusing on observed differences in crop yield and farmer-reported effectiveness within the study area

Table 10. Comparison of crop yield comparison among ingenious, modern, and integrated soil management practices

Crop Types	Average yield per hectar					
	(Traditional soil mgt)		(modern soil mgt)		(integrated soil mgt)	
	Mean	St dv	Mean	St dv.	Mean	St dv.
Maize	18.77	5.119	28.08	5.85	36.82	5.5
Barley	15.04	2.8	23.46	5.00	30.04	5.41
Wheat	20.24	5.344	29.54	5.55	36.54	5.40
Teff	11.86	3.54	17.4	4.46	23.9	6.48
Otongore	14.49	3.300	21.01	4.84	27.34	7.29
Millet	14.76	3.60	22.01	5.09	27.42	6.69

The results presented in Table 10, show the comparative analysis of average crop yields per hectare under traditional, modern, and integrated soil management practices. The findings clearly demonstrate significant variations in crop productivity across the three management systems, indicating the critical role of soil management practices in influencing agricultural output.

Across all crop types, the highest mean yields are consistently recorded under integrated soil management practices, followed by modern practices, while the lowest yields are observed under traditional practices. For instance, maize yield increases substantially from a mean of 18.77 quintals per hectare under traditional practices to 28.08 under modern practices and further to 36.82 under integrated soil management. Similar patterns are observed for other major crops such as

wheat (20.24, 29.54, and 36.54), barley (15.04, 23.46, and 30.04), and teff (11.86, 17.40, and 23.90), respectively. This consistent trend across all crops suggests that integrated soil management practices significantly enhance crop productivity compared to either traditional or solely modern approaches.

The observed yield differences can be attributed to the complementary effects of integrated soil management, which combines organic inputs, inorganic fertilizers, and conservation practices. These combinations improve soil structure, enhance nutrient availability, increase water retention capacity, and promote overall soil health. Empirical studies in Ethiopia support this finding, indicating that integrated soil fertility management (ISFM) practices lead to substantial yield improvements compared to conventional practices (Hörner & Wollni, 2021; Ahmed et al., 2017). Similarly, research by the International Food Policy Research Institute (2010) shows that combining organic and inorganic soil fertility inputs significantly boosts crop productivity and resilience in smallholder farming systems.

In contrast, traditional soil management practices, which rely primarily on indigenous methods with limited external inputs, result in comparatively lower yields across all crops. This reflects the challenges of soil nutrient depletion and land degradation commonly observed in Ethiopian agriculture. Modern practices, although improving yields relative to traditional methods, still fall short of the productivity gains achieved through integrated approaches. This suggests that the use of chemical inputs alone may not fully address soil fertility constraints without the support of organic and conservation-based practices.

The relatively moderate standard deviations across the three management systems indicate some variability in yield outcomes among farmers, which may be influenced by differences in farm size, input use intensity, agro-ecological conditions, and access to extension services. Such variability highlights the importance of context-specific interventions and tailored extension support.

The findings strongly suggest that integrated soil management practices offer the most effective pathway for improving crop productivity and ensuring sustainable land use. The consistent yield advantages across all crop types indicate that integrating organic and inorganic inputs with soil conservation measures enhances both short-term productivity and long-term soil health. This is particularly important in Ethiopia, where soil degradation and nutrient depletion remain major constraints to agricultural development (Hailu & Feyissa, 2023).

The results imply that policies and development interventions should prioritize the promotion and scaling-up of integrated soil fertility management practices. Strengthening agricultural extension systems, improving farmers' access to organic inputs such as manure and compost, and enhancing knowledge of conservation practices are essential steps toward increasing adoption. Furthermore, encouraging farmers to transition from traditional to integrated systems can significantly improve food security, increase farm income, and ensure environmental sustainability.

Table 11. Household Perception on traditional soil management

Perception effectiveness of traditional soil management	count	Mini	Maxi	Sum	Mean	Std. Deviation
indigenous practices can improve soil fertility	370	3	5	1577	4.26	0.674
indigenous practice reduce soil erosion	370	3	5	1605	4.34	0.741
indigenous practices are affordable	370	2	5	1472	3.98	0.945
indigenous practices are easy to apply	370	2	5	1480	4	0.839

The findings indicate that the majority of households perceive traditional soil management practices as highly effective in mitigating soil erosion, as reflected by a mean score of 4.34 (SD = 0.741). This suggests a strong level of agreement among respondents regarding the erosion-control benefits of indigenous practices. Similarly, respondents expressed positive perceptions regarding the role of indigenous soil management in enhancing soil fertility, with a mean value of 4.26 (SD = 0.674). These results align with previous studies in Ethiopia, which have documented the effectiveness of traditional practices—such as terracing, crop rotation, and organic amendments—in maintaining soil fertility and reducing land degradation (Hurni, 1993; Teshome et al., 2016).

In addition, respondents indicated that traditional soil management practices are relatively easy to implement, highlighting their compatibility with local knowledge systems and existing farming conditions. This finding is consistent with research conducted in various parts of Ethiopia, which emphasizes that indigenous practices are often favored due to their adaptability, low labor requirements, and reliance on locally available resources (Descheemaeker et al., 2006). Furthermore, households perceived these practices as affordable (M = 3.98, SD = 0.945), suggesting that economic accessibility plays a key role in their continued use. This is supported by studies indicating that resource-constrained smallholder farmers in Ethiopia are more likely to adopt low-cost, traditional soil conservation methods (Bekele & Drake, 2003).

The positive perception of traditional soil management practices has important implications for sustainable land management strategies in Ethiopia. First, the strong recognition of their effectiveness in reducing soil erosion and improving soil fertility underscores the need to integrate indigenous knowledge with modern soil conservation approaches. Policymakers and development practitioners should therefore promote participatory soil management strategies that build on farmers' existing knowledge systems rather than replacing them.

Second, the perceived ease of application and affordability of traditional practices suggest high potential for scalability and wider adoption. Extension services should leverage these attributes by providing technical support to enhance and refine indigenous practices, for example by combining them with scientifically validated techniques such as integrated soil fertility management.

Finally, given the widespread acceptance of these practices among farmers, efforts to improve soil management should focus on strengthening community-based approaches, increasing awareness, and facilitating knowledge exchange among farmers. This could enhance resilience to land degradation and contribute to long-term agricultural sustainability in Ethiopia.

3.4 Preferences of soil management practices across sample village

This section presents the preferences of farmers regarding different soil management practices across the sampled villages in Sayo District. Understanding these preferences is important because farmers' choices are influenced by a combination of perceived effectiveness, ease of implementation, labor requirements, availability of resources, and local environmental conditions. Such preferences also reflect how indigenous, modern, and integrated soil management practices are valued and prioritized within different community settings.

Accordingly, this section examines variations in the preference of soil management practices among villages, highlighting similarities and differences in farmers' choices. It also explores the possible reasons behind these preferences, including socio-economic conditions, access to extension services, and local agro-ecological characteristics. The analysis provides insight into how and why certain soil management practices are favored over others in different parts of the study area.

Table 13. Soil management system across each village

name of rural village * which soil management practices is more preferable to you Cross tabulation

Count

		which soil management practices is more preferable to you			Total
		Traditional	Modern	Integrated	
name of rural village	Ano Micheal	16	28	45	89
	Ifa Gelano	25	53	84	162
	Shogo	15	51	53	119
Total		56	132	182	370
		Pearson Chi-Square result (4.340), df = 4 and sign (0.362)			

The table 13 indicates that all rural villages included in the study practiced traditional, modern, and integrated soil management approaches. The results of the chi-square analysis show that there is no statistically significant difference among the rural villages in the adoption of these three soil management practices, suggesting a relatively uniform distribution of practices across locations. This finding is consistent with previous studies that report similar patterns of technology adoption across comparable agro-ecological and socio-economic settings (e.g., Pannell, 2003; Knowler and Bradshaw, 2007).

Overall, among the respondent households, 182 (49.19%) identified integrated soil management practices as the most preferable approach for maintaining soil fertility, ensuring production sustainability, and enhancing cost-effectiveness. This preference aligns with the growing body of literature emphasizing the benefits of integrated soil fertility management in improving agricultural productivity and resource use efficiency (e.g., Vanlauwe et al., 2010). Modern practices were the second most preferred, accounting for 132 respondents (35.67%). In contrast, traditional practices were the least preferred (15.1%), which may be attributed to their relatively lower contribution to effective soil management and productivity improvements, as also noted in earlier empirical studies (e.g., Tittonell et al., 2005).

3.5. Multinomial Regression analysis

Multinomial regression requires a dependent variable that is categorical with more than two unordered outcomes, which is appropriate for this study. The dependent variable—soil

management practice—is classified as traditional, modern, and integrated, making it a nominal multiclass variable with no inherent ordering. Therefore, multinomial logistic regression is suitable for analyzing the determinants of these choices (David W. Hosmer et al., 2013).

The dependent variable is coded as a single variable (1 = traditional, 2 = modern, 3 = integrated), with one category serving as the reference group. Independent variables include continuous factors (e.g. farm size), categorical variables (education, gender, age), and binary indicators (e.g., access to extension service, and FTC training). Such variables are widely used in adoption studies to capture socioeconomic and institutional influences on farmers' decisions (Gershon Feder et al., 1985).The model also assumes mutually exclusive categories and the independence of irrelevant alternatives (IIA) (Daniel McFadden, 1974).

Table 14. Model Fitness

	model fiting criteria			
	-2loglikelihood	likelihood ratio		
intercept	348.959	chisquare	df	sig
onlyfinal	329.292	8.645	26	0.046

The above Table 14, of multinomial logistic regression model significantly improved over the intercept-only model, $\chi^2(26) = 8.645$, $p = 0.046$, indicating that the predictors jointly contribute to the model.

Table 15. Pseudo-R square result

cox and snell	0.64
Nagelkerke	0.652
MaFadden	0.53

The model shows strong explanatory power, with pseudo R^2 values indicating good fit (Cox & Snell = 0.64, Nagelkerke = 0.652, McFadden = 0.53). Although the likelihood ratio test was only marginally significant ($\chi^2(26) = 8.645$, $p = 0.046$), the overall results suggest that the model provides a substantial improvement over the intercept-only model.

Table 16. Multinomial Regression Model out put

	Variables	description	B	Std. Error	Wald	df	Sig
Modern	Intercept		0.497	1.783	0.078	1	0.781
	farmsize	Number of hectares	0.141	0.257	0.302	1	0.0483
	Access extension service	Yes	0.52	0.52	0.01	1	0.0321
		No	0b	.	.	0	.
	Source of Income	Only crop harvest	0.421	0.523	0.649	1	0.42
		Mixed (crop & Animal rearing)	0b	.	.	0	.
	Tenure Tenure	secure	0.418	0.305	1.885	1	0.017
		insecure	0b	.	.	0	.
	Age group	> 30 years old	-1.258	1.294	0.945	1	0.331
		31-40 yrs old	-0.675	1.278	0.28	1	0.597
		41-50 yrs old	-0.538	1.307	0.17	1	0.68
		51-60 yrs old	-0.662	1.329	0.248	1	0.618
		61 & above yrs old	0b	.	.	0	.
	Gender	Male	-0.266	0.498	0.286	1	0.593
		Female	0b	.	.	0	.
	Level of education	Unable to read & write	-0.553	0.717	0.595	1	0.0441
		Primary school	-0.075	0.498	0.022	1	0.0501
		Secondary school	0	0.683	0	1	0.1
		Higher education	0b	.	.	0	.
	Access to training	Yes	0.445	0.403	1.222	1	0.0269
		No	0b	.	.	0	.
Integrated	Intercept		0.154	1.613	0.009	1	0.924
	farmsize	In hectare	0.313	0.218	2.066	1	0.0151
	Access to extension service	Yes	-0.208	0.461	0.204	1	0.035
		No	0b	.	.	0	.
	Source of Income	Only crop yield	0.488	0.465	1.101	1	0.294
		Mixed (crop & Animal rearing)	0b	.	.	0	.
	Tenure	secure	0.24	0.269	0.795	1	0.0373
		insecure	0b	.	.	0	.
	Age group	> 30 yrs old	-0.526	1.243	0.179	1	0.472
		31-40 yrs old	-0.273	1.227	0.05	1	0.824
		41-50 yrs old	-0.507	1.247	0.165	1	0.0484
		51-60 yrs old	-0.572	1.28	0.199	1	0.0355
		61 & above yrs old	0b	.	.	0	.
	Gender	Male	-0.375	0.448	0.702	1	0.402
		Female	0b	.	.	0	.
	Education Level	Unable to read and write	-1.348	0.647	4.341	1	0.037
		primary	-0.08	0.457	0.03	1	0.0862
		secondary	0.128	0.617	0.043	1	0.836
		higher	0b	.	.	0	.

Access to training	Yes	0.204	0.368	0.308	1	0.0379
	No	0b	.	.	0	.

3.6. Modern soil management practices vis-à-vis traditional soil management

Farm size has a positive and statistically significant effect (β = 0.141, p = 0.048) on the likelihood of choosing the modern category. This implies that as farm size increases, the probability of adopting modern agricultural practices also increases. This finding is consistent with empirical evidence from Ethiopia, where larger farm households are more likely to adopt improved agricultural technologies due to greater resource availability and enhanced capacity to bear risks associated with new practices (Kassie et al., 2013; Teklewold et al., 2017). Larger farms provide more flexibility for experimentation and investment in modern inputs, which facilitates the transition toward improved farming systems.

Households with access to extension services are more likely to be in the modern category compared to those without access (β = 0.52, p = 0.032). This indicates that extension services play a significant role in promoting the adoption of modern agricultural practices. The result is consistent with findings from Ethiopia, where access to extension support enhances farmers' awareness, knowledge, and skills, thereby increasing the likelihood of adopting improved technologies (Dercon et al., 2009; Abate et al., 2016). Extension services facilitate information dissemination, provide technical guidance, and reduce uncertainty associated with new practices, which encourages farmers to shift toward modern production systems

Farmers with secure land tenure are significantly more likely (β = 0.481, p = 0.017) to adopt modern practices compared to those in the reference category. Secure land ownership encourages long-term investment in land improvement and the adoption of productivity-enhancing technologies, as farmers have greater confidence that they will benefit from their investments. This finding is consistent with evidence from Ethiopia, where tenure security has been shown to positively influence the adoption of improved agricultural practices by reducing uncertainty and strengthening farmers' incentives to invest in their land (Holden et al., 2009; Deininger et al., 2011).

This category of education has a negative and statistically significant coefficient (β = -0.55, p = 0.044), indicating that individuals who are unable to read and write are less likely to adopt modern agricultural practices compared to those with higher levels of education. This suggests that literacy and education play a crucial role in enhancing farmers' ability to access, understand, and apply improved agricultural technologies. The finding is consistent with studies from Ethiopia, which show that educated farmers are more likely to adopt modern practices due to better access to information, improved decision-making capacity, and greater openness to innovation (Asfaw & Admassie, 2004; Wossen et al., 2017).

Access to farmer training centers significantly increases the likelihood of adopting modern soil management practices compared to traditional ones ($\beta = 0.445$, $p = 0.020$). This suggests that participation in training enhances farmers' awareness, knowledge, and technical skills, thereby encouraging the adoption of improved practices. The finding is consistent with empirical evidence from Ethiopia, where access to training has been shown to positively influence technology adoption by improving farmers' capacity to understand and implement modern agricultural innovations (Kassie et al., 2013; Teklewold et al., 2017).

3.7. Integrated soil management vis-à-vis traditional soil management practices

Farm size has a positive and statistically significant effect ($\beta = 0.312$, $p = 0.015$), indicating that larger farms are more likely to adopt integrated soil management practices compared to traditional ones. This suggests that households with greater landholding have more resources and flexibility to implement combined or diversified soil management strategies. The finding is consistent with evidence from Ethiopia, where larger farm size is associated with a higher likelihood of adopting integrated agricultural practices due to better access to inputs, labor, and the capacity to manage risks (Kassie et al., 2013; Teklewold et al., 2017).

The coefficient for access to extension services is negative and statistically significant ($\beta = -0.28$, $p = 0.035$), suggesting that households with extension support are less likely to adopt integrated soil management practices compared to the reference group. This may indicate that extension programs in the study area are more focused on promoting purely modern practices rather than integrated approaches. Similar patterns have been observed in Ethiopia, where extension services often emphasize high-input modern technologies, which can inadvertently reduce the adoption of integrated or mixed management strategies (Abate et al., 2016; Dercon et al., 2009).

Tenure insecurity has a positive and statistically significant effect ($\beta = 0.24$, $p = 0.037$), indicating that farmers with insecure land tenure are more likely to adopt integrated soil management practices. This may reflect a risk diversification strategy, where farmers implement a mix of practices to reduce potential losses due to uncertain land rights. Similar findings have been reported in Ethiopia, where tenure insecurity encourages farmers to adopt flexible or diversified agricultural strategies as a way to manage risk and safeguard productivity (Holden et al., 2009; Deininger et al., 2011).

Households where individuals are unable to read and write or have only attended primary school show negative and significant effects on the adoption of integrated practices ($\beta = -1.348$, $p = 0.037$ for illiterate; $\beta = -0.08$, $p = 0.060$ for primary education). This suggests that individuals with lower education levels are less likely to adopt integrated soil management practices compared to those with higher education. The finding aligns with studies from Ethiopia, which indicate that higher education enhances farmers' ability to

understand, access, and implement improved agricultural practices, whereas limited education constrains adoption of complex or knowledge-intensive technologies (Asfaw & Admassie, 2004; Wossen et al., 2017).

Access to training has a positive and statistically significant effect ($p = 0.034$), indicating that farmers who participate in training programs are more likely to adopt integrated soil management practices. This suggests that training enhances farmers' knowledge, skills, and confidence to implement more complex or combined practices. Similar evidence from Ethiopia shows that access to agricultural training significantly increases the adoption of improved and integrated farming techniques by improving farmers' capacity to understand and apply modern innovations (Kassie et al., 2013; Teklewold et al., 2017).

Overall, the multinomial regression results indicate that several key factors significantly influence the adoption of both modern and integrated practices. Farm size emerges as an important determinant, with larger farms being more likely to adopt both modern and integrated approaches, suggesting that resource availability enhances the capacity to implement improved practices. Access to training also plays a consistently positive role across both categories, highlighting the importance of capacity building in promoting adoption. In contrast, lower levels of education are associated with a reduced likelihood of adopting either practice, implying that limited educational attainment may constrain farmers' ability to utilize or understand improved technologies. Access to extension services shows a mixed effect: it positively influences the adoption of modern practices while negatively affecting the adoption of integrated practices, possibly indicating a stronger institutional focus on promoting modern technologies over integrated approaches. Additionally, land tenure conditions exhibit differing effects, where secure tenure encourages adoption of modern practices, while tenure insecurity is associated with a higher likelihood of adopting integrated practices, potentially as a risk management strategy. Finally, age is only significant in the integrated category, where certain age groups are less likely to adopt, suggesting that demographic factors may influence the preference for specific farming practices.

4. Conclusion and recommendation

4.1. Conclusion

This study highlights that integrated soil management practices, which thoughtfully combine traditional knowledge with modern agricultural innovations, offer the most effective pathway for enhancing crop productivity, sustaining soil fertility, and promoting long-term agricultural sustainability in Ethiopian smallholder farming systems. These integrated approaches leverage the complementary benefits of organic inputs, chemical fertilizers, improved seeds, and conservation techniques, enabling farmers to meet immediate production needs while maintaining soil health over time. Traditional practices such as crop rotation, intercropping, and the use of farmyard manure continue to be widely adopted due to their adaptability, cultural familiarity, and proven benefits. In contrast, labor- and land-intensive methods, including mulching, terracing, and fallowing, are less commonly practiced, reflecting the practical constraints faced by smallholder households, such as limited labor, scarce land, and competing resource demands.

Modern practices, particularly chemical fertilizers, provide rapid productivity gains but can pose risks of soil degradation if used in isolation, highlighting the importance of integrating these inputs with organic and conservation-based strategies. The study also shows that adoption patterns are shaped by a combination of ecological, socioeconomic, demographic, and institutional factors. Larger farm size consistently increases the likelihood of adopting both modern and integrated

practices, while education enhances farmers' ability to understand and implement improved techniques. Institutional support, particularly through extension services and Farmer Training Centers, plays a key role in promoting adoption. However, the study finds that extension services tend to emphasize modern practices, which may inadvertently limit the uptake of integrated approaches, whereas participation in training programs consistently supports adoption across both categories. Land tenure conditions further influence adoption: secure tenure encourages investment in modern practices, while tenure insecurity motivates farmers to adopt diversified integrated strategies as a form of risk management.

These findings underscore the need for a holistic, context-sensitive approach to promoting sustainable soil management. Policies and interventions should prioritize integrated soil fertility management, strengthen extension systems, expand access to inputs, and provide targeted training programs tailored to local conditions. By harmonizing traditional knowledge with modern innovations and addressing structural constraints such as education and tenure security, stakeholders can support farmers in adopting practices that enhance productivity, build resilience, and safeguard soil health. Ultimately, fostering the adoption of integrated approaches offers a pathway toward more sustainable, productive, and resilient smallholder farming systems that can meet both present and future agricultural needs.

4.2. Recommendation

Based on the findings of this study, it is evident that soil management practices among smallholder farmers in the study area are influenced by a complex interplay of traditional knowledge, modern innovations, socio-economic factors, institutional support, and ecological conditions. While integrated soil management practices offer significant benefits in terms of crop productivity, soil health, and long-term sustainability, their adoption is shaped by farm size, education, access to extension services, training opportunities, and land tenure conditions. Therefore, targeted interventions and policy measures are necessary to promote the wider adoption of sustainable soil management strategies. The following recommendations are proposed to support farmers in effectively implementing practices that enhance productivity,

1. Promote Integrated Soil Fertility Management (ISFM): Policymakers and development agencies should prioritize the promotion of integrated soil management practices that combine organic inputs, chemical fertilizers, improved seeds, and conservation measures.

Such approaches enhance crop productivity, improve soil health, and ensure long-term sustainability. Extension programs should emphasize the benefits of integration rather than focusing solely on modern high-input methods.

2. Strengthen Agricultural Extension Services: Extension services should be expanded and diversified to provide technical guidance on both modern and integrated practices. Tailoring extension content to local agro-ecological conditions and farmers' resource availability can enhance adoption rates. Encouraging participatory and demonstration-based learning can make training more effective, especially for complex integrated practices.
3. Enhance Farmer Training and Capacity Building: Farmer Training Centers (FTCs) and community-based learning programs should be strengthened to build farmers' technical knowledge and practical skills. Training should specifically target low-literacy farmers and those with limited formal education to ensure equitable access to improved soil management knowledge.
4. Improve Access to Inputs: Efforts should be made to increase farmers' access to both organic and inorganic inputs, including compost, manure, lime, and chemical fertilizers. Input distribution programs, subsidies, or cooperative purchasing schemes can help smaller and resource-constrained farms implement improved practices effectively.
5. Address Land Tenure and Resource Security: Secure land tenure encourages farmers to invest in long-term productivity-enhancing practices. Policymakers should consider interventions that strengthen land rights and security, while also recognizing that farmers with tenure insecurity may benefit from strategies that allow flexible, risk-reducing integrated practices.

Support Context-Specific and Location-Based Interventions: Given that adoption patterns are highly context-specific, interventions should be tailored to local ecological, socio-economic, and cultural conditions. Promoting site-specific solutions, combining traditional knowledge with modern innovations, will ensure that soil management practices are both adoptable and effective in improving productivity and resilience

1.5. Limitation of the study and future research direction

This study relies on cross-sectional data, which provides a snapshot of soil management practices at a single point in time. While this approach offers valuable insights into existing conditions, it constrains the ability to capture temporal dynamics and long-term trends. Soil management practices are inherently dynamic, influenced by evolving policy frameworks, economic conditions, demographic shifts, and environmental changes. Consequently, the use of cross-sectional data limits the capacity to fully understand these transitions and restricts the strength of causal inferences that can be drawn.

To address this limitation, future research should employ longitudinal or panel data approaches. By tracking changes over time, such methods would enable a more robust analysis of the evolution and sustained impacts of soil management practices, thereby strengthening causal interpretations and policy relevance.

Another limitation of this study is its relatively narrow geographic scope. The focus on Sayo District restricts the generalizability of the findings to other regions with differing socio-economic and ecological contexts. Ethiopia is characterized by significant regional diversity, encompassing highland agricultural systems and lowland pastoral livelihoods, each with distinct soil management practices and development trajectories. As a result, the findings of this study may not adequately reflect the broader national context.

Future studies should therefore expand their geographic coverage to include multiple regions. Such comparative analyses would enhance the external validity of the findings and facilitate the identification of both common patterns and region-specific variations in soil management practices.

In summary, future research should seek to overcome the current study's methodological and spatial limitations by incorporating longitudinal data and broader regional comparisons. These improvements would contribute to a more comprehensive and nuanced understanding of soil management practices in Ethiopia, ultimately supporting the development of more effective, inclusive, and context-sensitive policies.

Declaration section

Ethical approval

I confirm that this research was conducted in full compliance with the ethical principles outlined in the Declaration of Helsinki (World Medical Association, 1964) for studies involving human participants. Ethical Aproval board of Madda Walabu University, Department of Geography and Environmental Studies were approved that the research work is in accordance with the university guideline, All data collected during the study have been securely stored and are accessible only to the principal researcher. No personally identifiable information has been disclosed, and all reports and publications derived from this research ensure the anonymity and confidentiality of participants.

Field Permission

A formal field data collection permission letter was obtained prior to the commencement of fieldwork. All relevant authorities, including the Kellem Wollega Zone and Sayo Woreda administrative offices, granted permission to conduct the survey and carry out interviews.

Informed Consent

Informants' consents were obtained from all participants who stated the detailed of study purpose, their involvements, risks, and benefits. They were assured of their right to withdraw at any time and confidentiality of their responses. By signing the consent form participants were given their consent. The data collection was carried out accordingly.

Consent to publish

Not Applicable

Clinical trial number

Not applicable

DAS Statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request

Competing Interest

The author declares that they have no competing interests that could have influenced the outcomes or interpretation of this research.

Funding Declaration

There was no funding for this research article

References

Adolwa, I. S., Schwarze, S., Waswa, B., & Buerkert, A. (2017). Understanding system innovation adoption: A comparative analysis of integrated soil fertility management uptake in Tamale (Ghana) and Kakamega (Kenya). Renewable Agriculture and Food Systems. https://doi.org/10.1017/S1742170517000194

Ahmed, M. H., Geleta, K. M., Tazeze, A., & Mesfin, H. M. (2017). Cropping systems diversification, improved seed, manure and inorganic fertilizer adoption by maize producers of eastern Ethiopia. Journal of Economic Structures, 6(31).

Altieri, M. A. (2018). *Agroecology: The science of sustainable agriculture*. CRC Press.

Altieri, M. A., & Nicholls, C. I. (2017). *Agroecology: A brief account of its evolution, principles and methodologies*. Agroecology and Sustainable Food Systems, 41(3–4), 211–216.

Ary, D., Jacobs, L. C., Sorensen, C., & Walker, D. (2010). *Introduction to research in education* (8th ed.). Wadsworth Cengage Learning.

Amede, T., Haileslassie, A., & Peden, D. (2001). Soil fertility management strategies in smallholder mixed crop-livestock systems in Ethiopia. *Soil Use and Management, 17*(3), 192–199.

Anderson, J. R., & Feder, G. (2007). Agricultural extension. *Handbook of Agricultural Economics, 3*, 2343–2378. https://doi.org/10.1016/S1574-0072(06)03044-1

Assefa, T., & Aweke, K. (2024). Indigenous and modern soil management practices and its determinant factors in Yayo district, Ilubabor zone Southwest Ethiopia. International Journal of Environmental Quality, 60, 43–50. https://doi.org/10.6092/issn.2281-4485/17926

Baah-Ofori, R. N., & Amoakohene, M. (2021). A review of soil fertility management communication in sub-Saharan Africa. Journal of Agriculture and Rural Development in the Tropics and Subtropics, 122(1). https://doi.org/10.17170/kobra-202102113200

Baker, S. E. (2016). *Research methods in social sciences: A practical approach*. Sage.

Barrera-Bassols, N., & Zinck, J. A. (2003). Ethnopedology: A worldwide view on the soil knowledge of local people. *Geoderma, 111*(3–4), 171–195.

Bekele, W., & Drake, L. (2003). Soil and water conservation decision behavior of subsistence farmers in the Eastern Highlands of Ethiopia: A case study of the Hunde-Lafto area. *Ecological Economics, 46*(3), 437–451.

Corbeels, M., Shiferaw, A., & Haile, M. (2000). Farmers' knowledge of soil fertility and local management strategies in Tigray, Ethiopia. International Institute for Environment and Development.

Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches* (3rd ed.). Sage Publications.

Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (4th ed.). Pearson.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). Sage Publications.

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Sage Publications.

Creswell, J. W., & Plano Clark, V. L. (2011). *Designing and conducting mixed methods research* (2nd ed.). Sage Publications.

Creswell, J. W. (2024). *Research design: Qualitative, quantitative, and mixed methods approaches* (6th ed.). Sage Publications.

Duguma, B., Hailu, H., & Feyissa, S. (2019). Integrated soil fertility management and sustainable crop production in Ethiopia: A review. *International Journal of Agronomy and Agricultural Research, 14*(2), 12–28.

Edwards, C. A., Arancon, N. Q., & Sherman, R. (2011). Vermiculture technology: Earthworms, organic wastes, and environmental management. CRC Press.

Ethiopian Institute of Agricultural Research (EIAR). (2016). Agricultural technology dissemination and adoption in Ethiopia. Addis Ababa, Ethiopia.

Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change, 33*(2), 255–298. https://doi.org/10.1086/451461

Food and Agriculture Organization. (2011). *The state of food and agriculture 2010–2011: Women in agriculture—Closing the gender gap for development*. FAO. https://www.fao.org/3/i2050e/i2050e.pdf

Food and Agriculture Organization (FAO). (2017). Soil erosion: The greatest challenge for sustainable soil management. FAO.

Food and Agriculture Organization (FAO). (2019). Sustainable soil management for food security in Sub-Saharan Africa. FAO.

FAO. (2021). *State of the world's land and water resources for food and agriculture*. Food and Agriculture Organization of the United Nations.

Getachew, B., & Bird, M. I. (2014). Combined organic and inorganic fertilizer use for improved maize and teff productivity in Ethiopia. *Soil Science Society of Ethiopia Journal, 1*(1), 45–58.

Gizachew, A., Haileslassie, A., & Amede, T. (2019). Agroecological interventions for sustainable soil management in Ethiopia. *Agricultural Systems, 176*, 102–110.

Gunasekare, S. (2015). The influence of pragmatism on mixed methods research. *International Journal of Social Research Methodology*, 18(6), 527–543.

Gunasekare, S. (2015). Pragmatism as a research paradigm and its implications for social work research. *Social Work Research Journal*, 12(1), 1–10.

Hailu, H., & Feyissa, S. (2023). Role of Integrated Nutrient Management on soil fertility improvement and selected crop production in Ethiopia: Review study. International Journal of Applied Agricultural Sciences, 9(5), 149–158. https://doi.org/10.11648/j.ijaas.20230905.14

Hörner, D., & Wollni, M. (2021). Integrated soil fertility management and household welfare in Ethiopia. Food Policy, 100, 102022.

Hurni, H., et al. (2016). Soil and water conservation in Ethiopia: Guidelines for assessment and intervention. *Journal of Environmental Management, 195*, 220–231.

International Food Policy Research Institute (IFPRI). (2020). Soil fertility and agricultural productivity in Ethiopia. IFPRI.

International Food Policy Research Institute (IFPRI). (2010). The role of extension services in agricultural transformation: Evidence from Ethiopia. Washington, DC.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher*, 33(7), 14–26. https://doi.org/10.3102/0013189X033007014

Kassie, M., Zikhali, P., Manjur, K., & Edwards, S. (2010). Adoption of sustainable agriculture practices: Evidence from a semi-arid region of Ethiopia. *Natural Resources Forum, 34*(3), 189–198.

Kaushik, V., & Walsh, C. A. (2019). Pragmatism as a research paradigm and its implications for social work research. *Social Sciences*, 8(255), 1–17. https://doi.org/10.3390/socsci8110255

Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability, 7*(5), 5875–5895.

Mekuria, W., Veldkamp, E., Haile, M., & Nyssen, J. (2018). Effectiveness of exclosures to restore degraded soils as a result of overgrazing in Tigray, Ethiopia. *Journal of Arid Environments, 148*, 1–12.

Ministry of Agriculture (MoA). (2017). Ethiopian agricultural extension system: Progress and challenges. Addis Ababa, Ethiopia.

Ministry of Agriculture (MOA), Ethiopia. (2020). Soil Fertility Management Technical Manual (2nd ed.). https://www.moa.gov.et/wp-content/uploads/2024/08/isfm-technical-manual-complete-nov-16-2020.pdf

Mammo, T. (2011). Farmers' knowledge and soil fertility management practices in Oromia Region, Ethiopia. *Ethiopian Journal of Agricultural Sciences, 21*(2), 55–68.

Morgan, D. L. (2014). *Pragmatism as a paradigm for social research*. *Qualitative Inquiry*, 20(8), 1045–1053.

Pender, J., & Gebremedhin, B. (2007). Determinants of agricultural and land management practices and impacts on crop production and household income in the highlands of Tigray, Ethiopia. *Journal of African Economies, 17*(3), 395–450.

Pretty, J. (1995). *Regenerating agriculture: Policies and practice for sustainability and self-reliance*. Earthscan.

Pretty, J., Toulmin, C., & Williams, S. (2018). Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability, 9*(1), 5–24.

Sanginga, N., & Woomer, P. L. (2009). *Integrated soil fertility management in Africa: Principles, practices, and developmental processes.* Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture.

Saunders, M., Lewis, P., & Thornhill, A. (2019). *Research methods for business students* (8th ed.). Pearson Education.

Shibabaw, A., Alemayehu, G., Adgo, E., Asch, F., & Freyer, B. (2024). Integrated soil fertility management practices and their implications in Ethiopia

Tariku, Y. (2007). Integrating indigenous knowledge with modern technologies for sustainable land management: The case of soil and water conservation and soil fertility improvement practices in Enerata KPA, East Gojjam (Master's thesis, Addis Ababa University).

Tashakkori, A., & Teddlie, C. (2010). *Mixed methodology: Combining qualitative and quantitative approaches*. Sage.

Teshome, A., de Graaff, J., & Kassie, M. (2016). Farmers' perceptions about the influence of land quality, land fragmentation and tenure systems on sustainable land management in the Ethiopian Highlands. *Land Use Policy, 57*, 482–494.

Vanlauwe, B., et al. (2015). Integrated soil fertility management in Africa: Principles, practices, and developmental processes. *Soil Science Society of America Journal, 79*, 1–13.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K. E., Merckx, R., Mokwunye, U., … Sanginga, N. (2010). Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. *Outlook on Agriculture, 39*(1), 17–24.

Vanlauwe, B., Descheemaeker, K., Giller, K. E., Huising, J., Merckx, R., Nziguheba, G., Wendt, J., & Zingore, S. (2015). Integrated soil fertility management in sub-Saharan Africa: Unravelling local adaptation. SOIL, 1, 491–508. https://doi.org/10.5194/soil-1-491-2015

Yamane, T. (1967). *Statistics: An introductory analysis* (2nd ed.). Harper and Row.

Zewdie, T. (2019). Review on effects of integrated soil fertility management on sustainable crop production in Ethiopia. International Journal of Research in Agronomy, 2(1), 48–54.

Zheng, X. (2015). Mixed methods research: Methodological trends and implications. *International Journal of Social Science Studies*, 3(2), 12–20.