Hawassa University Journals - Ethiopia
Ethiopian Journal of Engineering and Technology (EJET)
Volume 5, 2026, Pages 99 – 117. https://doi.org/10.82127/ejet.v5i1.2311

Investigating Socio-Technological Barriers to Mechanization in Ethiopian Smallholder Agriculture

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Abstract

This study examines the socio-economic, demographic, and technological factors influencing agricultural practices across three rural regions in Ethiopia: Melkasa, Halaba, and Loka Abaya. A pronounced gender disparity was observed, with male respondents constituting 86.66% in Melkasa, 100% in Halaba, and 93.33% in Loka Abaya, highlighting the limited participation of women in farming due to household responsibilities. The majority of respondents in all regions were middle-aged (26–55 years), with 83.3%, 80%, and 70% in Melkasa, Halaba, and Loka Abaya, respectively, underscoring their critical role in agricultural productivity. Educational diversity revealed that while 23.3–30% of farmers had completed secondary education, up to 16.6% lacked formal schooling, emphasizing the need for tailored knowledge dissemination to bridge educational gaps. Landholding patterns varied significantly, with Melkasa featuring smaller plots (2 – 4 Timad), Halaba showing moderate variability (3 – 7 Timad), and larger *holdings (4.5–8 Timad). The adoption of improved technologies remained low, with 16.7% in Melkasa, 23.3% in Halaba, and only 3.3% in Loka Abaya utilizing modern tools. Barriers to adoption included limited awareness, resource constraints, and resistance among older farmers, as reflected by the significant negative correlation between technology use and age ($r = -0.224$, $p < 0.05$). Traditional power sources dominated farming practices, with reliance rates of 67.7%, 70%, and 96.7% in Melkasa, Halaba, and Loka Abaya, respectively. While improved plow technologies demonstrated potential to reduce drudgery ($r = -0.300$, $p < 0.01$) and enhance productivity, adoption rates were hindered by high costs and resource shortages, such as oxen. Correlations revealed that experienced farmers were more likely to adopt advanced systems, but socio-economic barriers persisted. This study highlights the need for targeted interventions, including subsidies, mechanization programs, and gender-inclusive policies, to bridge productivity gaps and promote sustainable farming practices. Tailored extension services, awareness campaigns, and equitable resource distribution are essential to empower farmers and improve agricultural outcomes in the surveyed regions.*

***Keywords**:* Small Holders, Soil Plow, Land Holding, Draft Animals, Implements, Harness.

1. Introduction

Soil plow practices have long been studied for their role in agricultural mechanization and labor productivity. Research in developed countries has reconstructed the history of mechanization, particularly in agriculture, and assessed the carbon track of traction using life cycle analysis (Aguilera et al., 2019). These studies explore alternative energy sources and technologies that reduce emissions and address the environmental, social, and economic trade-offs of sustainable practices.

European approaches addressing smallholder socio-technological barriers through tailored mechanization have also been analyzed. For example, Franco et al. (2020) studied co-designed solutions for small-scale mountain farmers in Italy's Piedmont region, finding that lowland-focused innovations often fail there—exacerbating siltation. South Asia has seen significant rural mechanization over the past 50 years. Biggs and Justice (2015) suggest integrating these advancements into policy frameworks, while Mottaleb, Krupnik, and Erenstein (2016) emphasize improving infrastructure and understanding adoption factors to support smallholder farmers, especially in Bangladesh.

In Africa, mechanization faces unique challenges. Daum et al. (2023) proposed a "best-fit" framework for traction systems (animal-powered and motorized). Mudamburi et al. (2018) called for studies addressing geographic, technological, and social disparities. Baudron et al. (2015) noted that farm power shortages in Sub-Saharan Africa hinder sustainable intensification but can be reduced with energy-saving tools like conservation agriculture and two-wheel tractors. Similarly, Ehui et al. (1993) highlighted the economic and ecological limits of draft animals and the promise of small, affordable technologies.

Challenges for smallholders include seasonal limits, droughts, and declining oxen populations. Muvirimi and Ellis-Jones (1999) studied draft animal efficiency in Zimbabwe, while Gebresenbet et al. (2016) assessed donkeys' traction capacity and welfare needs. Boto and Mofolo (2016) emphasized broader research on regional applicability of conservation tillage.

In Sub-Saharan Africa, farming energy comes from human labor (65%), animal traction (25%), and engine power (10%) (Boto & Mofolo, 2016). Ethiopia relies heavily on hand plowing and oxen traction (Wako, 2016). Draft animals remain a key renewable energy source (Dube & Mulder, 2014), though misconceptions and neglected optimization limit their potential (Amare et al., 2016; Daum & Birner, 2020).

Efforts to optimize soil plow practices and mechanization in Ethiopia must focus on sustainable, affordable, and context-specific solutions. Addressing these challenges can significantly enhance productivity, food security, and economic opportunities while promoting gender equality in agriculture. Future research should validate these technologies across diverse geographical and socio-economic conditions to ensure long-term applicability and success.

Sustainability and energy efficiency Promotion by using renewable energy and conservation agriculture (Baudron et al., 2015) in relation with skill development; Intermediate technologies such as walking tractors offer practical solutions for Ethiopia's smallholders. Implement training programs for smallholders (Boto & Mofolo, 2016). Policy Integration optimizing animal traction by incorporating mechanization through small engine plows system into national agricultural policies for widespread impact. Furthermore, the draft animal plow system as a renewable energy source lies in the lack of integration of modern technological advancements, such as mathematical modeling and computer-based simulations, to minimal draft power requirement, optimize implement designs and operational conditions, which could significantly improve efficiency and performance beyond the traditional reliance on cultural practices and human experience (Gebregziabher, 2006).

Field surveys in Bukito, Halaba, and Melkasa demonstrate their potential to reduce labor intensity and enhance productivity. These technologies, combined with customized tools, could transform rural farming by bridging the gap between traditional and large-scale mechanization. The findings also highlight the importance of learning from successful practices in India, Latin America, and other regions with similar conditions of smallholder farmers (Derpsch, 2008). To address the barriers to mechanization, researchers emphasize are Area-Specific Mechanization and adapt technologies to Ethiopia's diverse soil types, climate, and small landholdings (Amare et al., 2016). Also, local manufacturing develops local industries for machinery production and repair (Gebresenbet, 1995).

2. Materials and Methods

2.1. Description of the Area

The survey was conducted three areas; Loka Abaya, Halaba and Melkasa. From Loka Abaya Bukito Burra kebele in the Loka Abaya woreda was selected located at the western border of the

Sidama region located about 89 km southwest of Hawassa and 337 km from Addis Ababa. The woreda is situated at 6°26'0″- 6°48'0″N latitude and 38°00'0″- 38°21'0″ E longitude as shown in Figure.1. The total area is 1,190 km^2 and it represents moist kola agro-ecology in Sidama region with altitude ranging from 1170 up to 1500 meters above sea level. Annual rainfall for Loka Abaya ranges between 670-1050 mm.

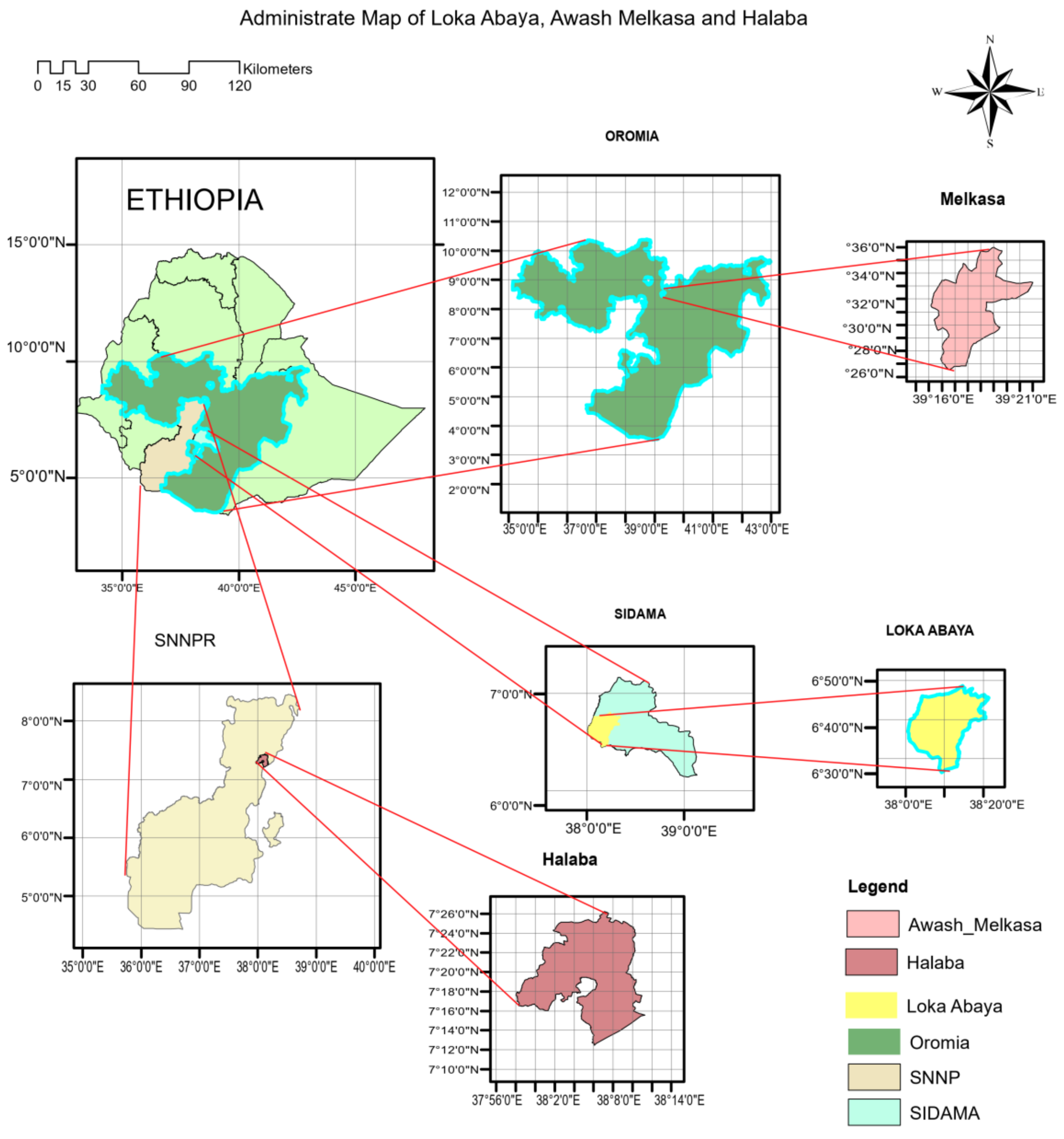

Figure 1 Map of the study area, Loka Abaya woreda

The second site Halaba area is found 313 km away from Addis Ababa. Its absolute location is between 70 17'19" and 70 19'25"N of latitude and 380 4'10"and 380 6'17"E of longitude and it has an elevation of 1726 meters above the mean sea level. zonal total land coverage is 64, 116.25 ha of which 43,337 ha (75%) are considered suitable for agriculture. The major land uses are;

arable, grazing, forest, potentially cultivable, uncultivable lands (hills and others miscellaneous are the categories represents the existing land features. Mixed agriculture mainly; maize teff, pepper, sorghum, wheat, haricot bean, finger millet and barely are annual crops grown by farmers. The climate is characterized as temperate or locally called *woinadega*, the mean annual temperature is about 17.6 - 22.5 C and the mean annual rainfall falls between 601-1200mm (Abbute, 2003).

The third experimental site is located in one of Ethiopia the biggest regions of Oromia. This woreda is located between 1400 m and 2500 m above sea level and from 8º24' to 8º 45' northern latitude and from 39º 21' to 39º 54' eastern longitude of (1,300 – 1,800 m +MSL (mean sea level). According to a survey of the land in this woreda, 23.2% is arable or cultivable, 10.6% is used for pasture, 4.3% is forest, and the remaining 42% is mountainous (Ham, 2008). The geographical map of the sites is shown in Figure 1. The farm field selected was (60 m by 100 m) total with an area of 6000 m^2 and was conventionally tilled approximately for more than 25 years.

2.2. Data Collection, Research Instruments / Designs

2.2.1. Primary Data

Primary data were collected by conducting household surveys, focus group discussion (FGD), key informant interviews (KII), and field-observation. A total of 90 household surveys were conducted by face-to-face technique using semi-structured pre-tested interview questionnaire for the collection of primary data, as described by (Chhetri, 2023). Respondents were interviewed with questions seeking demographic, educational, socio economic, and questions regarding tillage technology. Various published and unpublished secondary sources of data, proceedings and booklets of various governmental organizations, non-governmental organizations and international nongovernmental organizations were referred to supplement the data from primary sources. Related documents like journal articles, previous surveys, leaflets, newspaper articles, reports, etc. were also reviewed.

2.2.2. Field Sampling Technique

Sampling rationale of three kebeles; Loka Abaya, Halaba, and Melkasa were purposively selected based on agro-ecological relevance and regional diversity. From each kebele k, a total of nk=30 smallholder farmers practicing primary tillage were sampled, resulting in an overall sample of n=90. Within each kebele, the population Nk was partitioned into relevant strata {1, 2…, Sk}, and proportional stratified sampling was applied using Equation 1.

$$n_{k,s} = \left(\frac{N_{k,s}}{N_k}\right) \times n_k \qquad \text{Equ…1}$$

Where $N_{k,\,s}$ is the number of farmers in stratum S of kebele k, Nk is the total population in kebele k, and nk is the number of selected respondents in stratum s. All respondents within each stratum were chosen randomly which means via a random number generator. This combined purposive (kebele-level) and stratified random (within-kebele) approach ensured representation of different farming contexts and key strata among primary tillage practitioners.

2.3. Data Analysis Techniques

Both qualitative and quantitative data were recorded under consideration. Before analysis, all of the collected data were carefully examined, thoroughly investigated and refined. It was then coded and entered into MS-Excel 2019 and Statistical Package for Social Sciences (IBM SPSS; Version 20). Using SPSS and MS-Excel tools, the data were analyzed to draw reasonable inferences. Different variables like family size, ethnicity, and land-holding were analyzed by using descriptive statistical tools such as percentage, means etc. Descriptive statistics, mean comparison, frequency distribution, and other methods were used for the analysis of the results. Tables, figures, bar graphs, pie-charts and other visual aids were used to depict and illustrate the results.

2.4. Methodology

This study employed a mixed-methods approach to investigate socio-economic, demographic, and technological factors influencing agricultural practices in three rural regions of Ethiopia: Melkasa, Halaba, and Loka Abaya. Data were collected through structured surveys administered to 90 respondents, with 30 participants sampled from each region. The survey instrument captured data on gender, age, marital status, education, land size, and farming practices, as well as the adoption of improved agricultural technologies. A stratified random sampling technique was used to ensure the inclusion of diverse demographics and farm sizes, while maintaining representation of the key characteristics of each region. In addition, observational methods were employed to verify self-reported data and gain further insights into farming practices, division of labor, and resource utilization. The overall procedural method of the research is summarized with flow chart Figure 2.

Quantitative data were analyzed using descriptive and inferential statistics, including correlation analysis to identify relationships between demographic factors and technology adoption. Variables such as gender, age, education, and land size were examined to determine their impact on technology use and productivity. A combination of frequency distributions, percentages, and cross-tabulations was used to illustrate patterns in farming practices and resource allocation. Qualitative data from open-ended survey responses and observations were thematically analyzed to provide context for the quantitative findings. This comprehensive approach ensured a robust understanding of the socio-economic dynamics and challenges in the surveyed regions, allowing for actionable recommendations tailored to local needs.

All methods were carried out in accordance with the relevant guidelines and regulations to ensure ethical integrity and scientific validity. The experimental protocols were reviewed and approved by national Institutional Review Board (IRB) and Ethics Committee to ensure compliance with ethical standards. Informed consent was obtained from all subjects or their legal guardians prior to participation in the study.

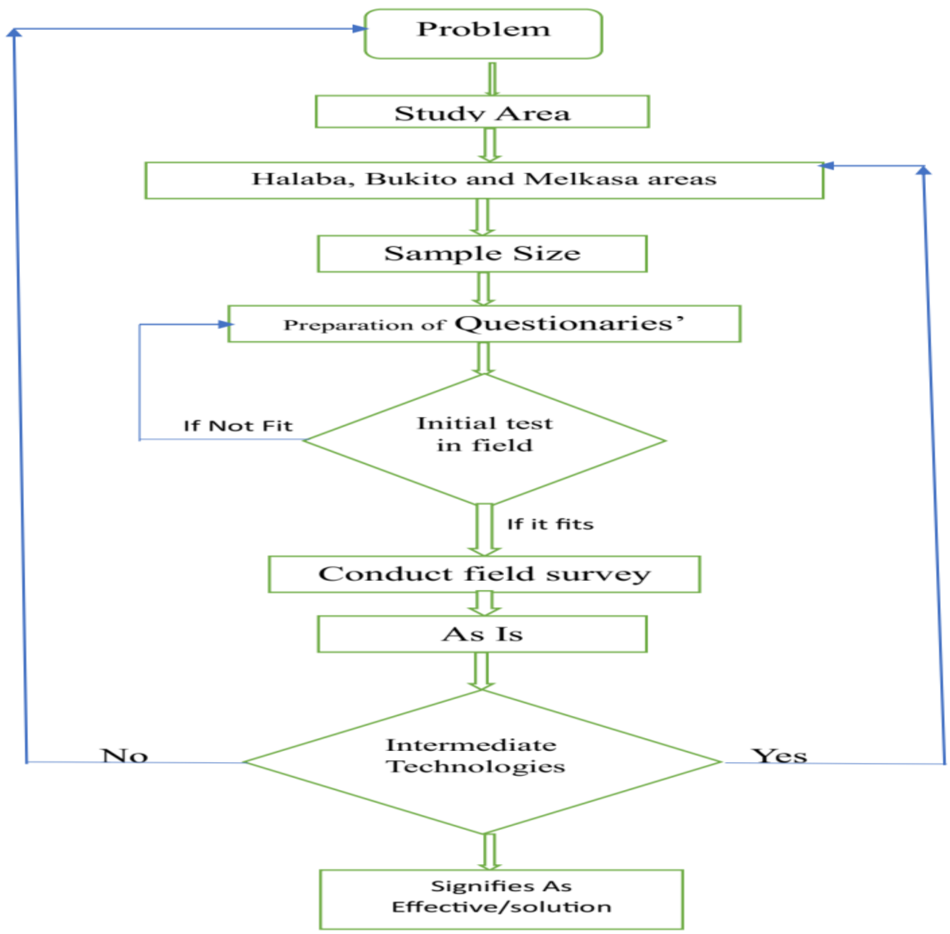

Figure 2. Methodology flow chart

3. Results and Discussion

3.1. Socio-Demographic Characteristics of the Respondents

In the surveyed regions of Melkasa surveyed area the gender disparity among the respondents was observed, with 86.66% (26) from the total (30) being male and 13.33% female. For the Halaba surveyed area all the respondent 100% (30) from the total (30) was male this indicates the female's participation in agricultural work is zero percent. There was a pronounced gender gap among the respondents in the Loka Abaya district, with 6.67% of the total (30) being female and 93.33% (28) being male. This skew towards male participants is attributed to the greater availability of time among males for study participation, as females are predominantly engaged in household responsibilities for all three areas. This implied that the responsibility of house hold of the farmers is male.

The demographic distribution across all three rural municipalities with age wise also investigated. For the Melkas survey area in age-wise, the majority of respondents (83.3%) fell within the 26 - 55 age bracket, indicating the youngest and experienced farming population. Only 3.3% of respondents were below 25 years old, while 13.3% were above 56 years old. For the Halaba survey area in age-wise, the majority of respondents (80%) fell within the 26-45 age bracket, indicating the youngest and experienced farming population. Only 6.6% of respondents were below 25 years old, while 13.3% were above 46 years old.

For the Loka abaya survey area in age-wise, the majority of respondents (70%) fell within the 26-55 age bracket, indicating the youngest and experienced farming population. Only 30% of respondents were below 25 years old, while 0% was above 56 years old as shown on Table 1. This demographic trend underscores the significance of middle-aged farmers in the study area, suggesting that they play a pivotal role in shaping agricultural practices.

Table 1. Socio-demographic characteristics of the respondents

Variables	**Village of Respondents**					
	Melkasa		**Halaba**		**Loka Abaya**	
	Number	%	Number	%	Number	%
Male	26	86.7	30	100	28	93.3
Female	4	13.3	0	0	2	6.7
Total	30	100	30	100	30	100
Below 25 years	1	3.3	2	6.7	9	30.0
26-35 years	10	33.3	12	40.0	10	33.3
36-45 years	12	40.0	12	40.0	8	26.7
46-55 years	3	10.0	1	3.3	3	10.0
Above 56 years	4	13.3	3	10.0	30	100.0
Total	30	100.0	30	100.0	30	100.0
Married	21	70.0	27	90.0	25	83.3
Unmarried	9	30.0	3	10.0	5	16.7
Total	30	100.0	30	100.0	30	100.0
Illiterate	3	10.0	4	13.3	7	23.3
Read & write	3	10.0	5	16.7	3	10.0
Primary (1-4)	2	6.7	2	6.7	2	6.7
Junior (5-8)	5	16.7	6	20.0	7	23.3
Secondary (9-10)	7	23.3	9	30.0	10	33.3
Tertiary	4	13.3	3	10.0	1	3.3
Diploma	6	20.0	1	3.3	0	0
Total	30	100.0	30	100.0	30	100.0
Head	19	63.3	28	93.3	23	76.7
Wife	5	16.7	0	0	2	6.7
Son	5	16.7	2	6.7	5	16.7
Daughter	1	3.3	0	0	0	0
Total	**30**	**100.0**	**30**	**100.0**	**30**	**100.0**

Educational attainment emerged as a key determinant, with implications for improved technological adoption in agricultural sector. The Table 1 for Melkasa survey area indicates that 23.3% of farmers had completed secondary school 9-10 education, 20% had received their diploma, 16.6% had learned 5-8 primary education, 13.3% had learned 11-12 secondary education, 10% had not attended school, 10 % had undergone adult education classes read and write, and 6.6% had achieved 1-4 grade education.

For Halaba education distribution survey indicates that 30% of farmers had completed secondary school 9-10 education, 3.3% had received their diploma, 20% had learned 5-8 primary education, 10% had learned tertiary 11-12 secondary education, 13.3% had not attended school, 16.6 % had undergone adult education classes read and write, and 6.6% had achieved 1-4 grade education.

For Loka abaya the education survey indicates that 30% of farmers had completed secondary school 9-10 education, 3.3% had received their diploma, 20% had learned 5-8 primary education, 10% had learned tertiary 11-12 secondary education, 13.3% had not attended school, 16.6 % had undergone adult education classes read and write, and 6.6% had achieved 1-4 grade education.

The educational diversity among respondents suggests a nuanced relationship between education levels and agricultural practices, emphasizing the need for tailored extension services and knowledge dissemination.

In the surveyed regions of Melkasa surveyed area the Marital status distribution of the respondents was observed that 70% (21) from the total (30) being married and 30% are unmarried. For the Halaba surveyed area 90% (27) from the total (30) being married and 10% (3) from the total (30) was unmarried. In case loka abaya district, a clear gender disparity among the respondents was observed, with 83.33% (25) from the total (30) being are married and 16.67% was unmarried, this indicates the unmarried participation in agricultural work is less percent compared to married participant.

3.2. Socio-Economic Information

3.2.1. Responsibility in the Household

Across the three farm fields (Melkasa, Halaba, and Loka Abaya), the "Head" consistently takes the majority of responsibility for soil tillage operations, contributing 68.97%, 93.33%, and 73.33%, respectively. In Melkasa, the "Wife" (17.24%), "Son" (10.34%), and "Daughter" (3.45%) provide some support, while in Halaba, the "Wife" and "Son" contribute minimally (3.33% each) and the "Daughter" has no involvement. In Loka Abaya, the "Son" plays a more notable role (20.00%), with limited contributions from the "Wife" (6.67%) and no involvement from the "Daughter." This distribution highlights a gendered division of labor, where soil tillage is predominantly the responsibility of the household "Head," with minimal participation from other family members, reflecting cultural norms or the physical demands of the task. The graph is clearly showed the responsible of soil operation and related activities of household in the study area is by head. This indicated that sharing responsibility of farm work of wife and son is rare in all study areas as shown on Figure 3.

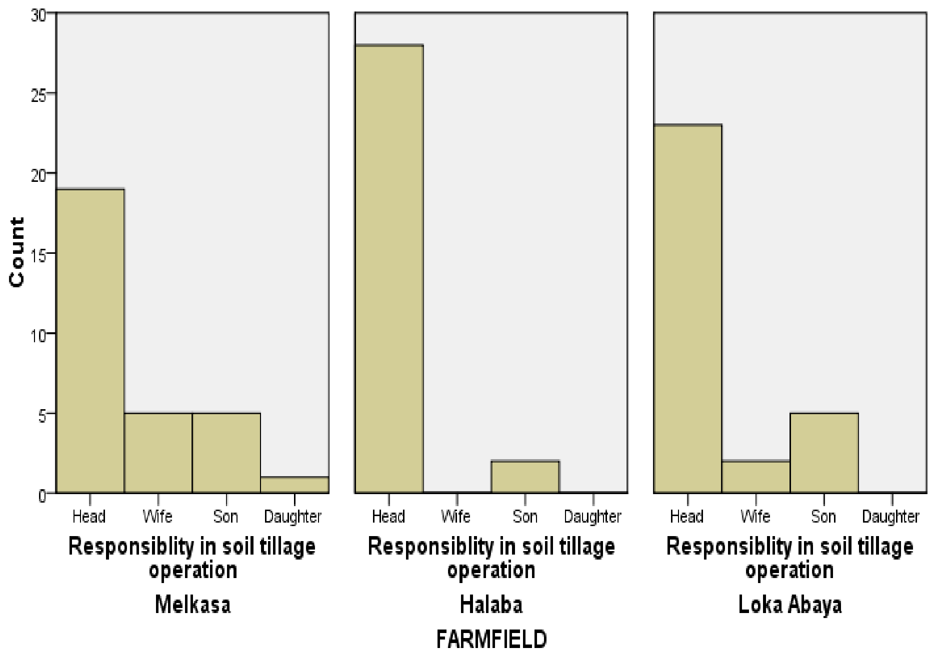

Figure 3. Responsibility in the household distribution of the respondents

3.2.2. Land Size and Utilization for Crop Plantation

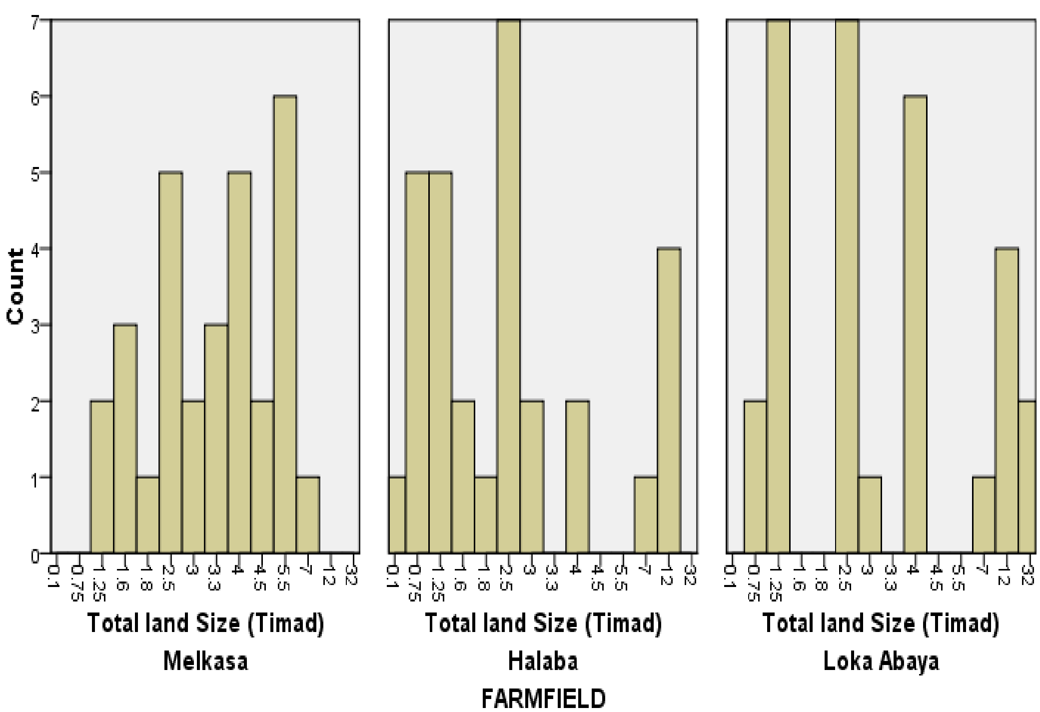

Figure 4. Total land size distribution of the respondents

The histogram analysis across the three farm fields reveals distinct patterns in land size distributions. In Melkasa, land sizes are concentrated around medium values (2–4 Timad), with the median (50th percentile) at approximately 3 Timad and most farms falling between 2 and 4 Timad. Halaba shows greater variability, with land sizes ranging from smaller holdings (2 Timad) to larger ones (7 Timad), a median size of around 5 Timad, and the majority between 3 and 7 Timad. Loka Abaya, on the other hand, has a strong concentration at larger land sizes, with a median of 6 Timad and most farms ranging from 4.5 to 8 Timad. The 90th percentile in Loka Abaya reaches 10 Timad, reflecting a trend toward larger land holdings compared to the other regions. These results suggest regional differences in landholding patterns, with Loka Abaya tending towards larger farms, while Melkasa and Halaba feature smaller to moderate-sized farms.

Most respondents in the Melkasa study area have around 1 up to 4 timad, they are 20 from the total respondents (30). However, only 10 farmers have above 4 timad as shown on Figure 4.

3.2.3. Types of Power Sources in Farming Systems Used

In the Melkasa region, 67.7% of respondents relied on traditional power sources, while 16.7% used improved technologies, 6.7% adopted motorized systems, 6.3% combined motorized and traditional methods, and 3.3% utilized other types as shown on Figure 5. This shows a moderate uptake of modern technology alongside traditional methods.

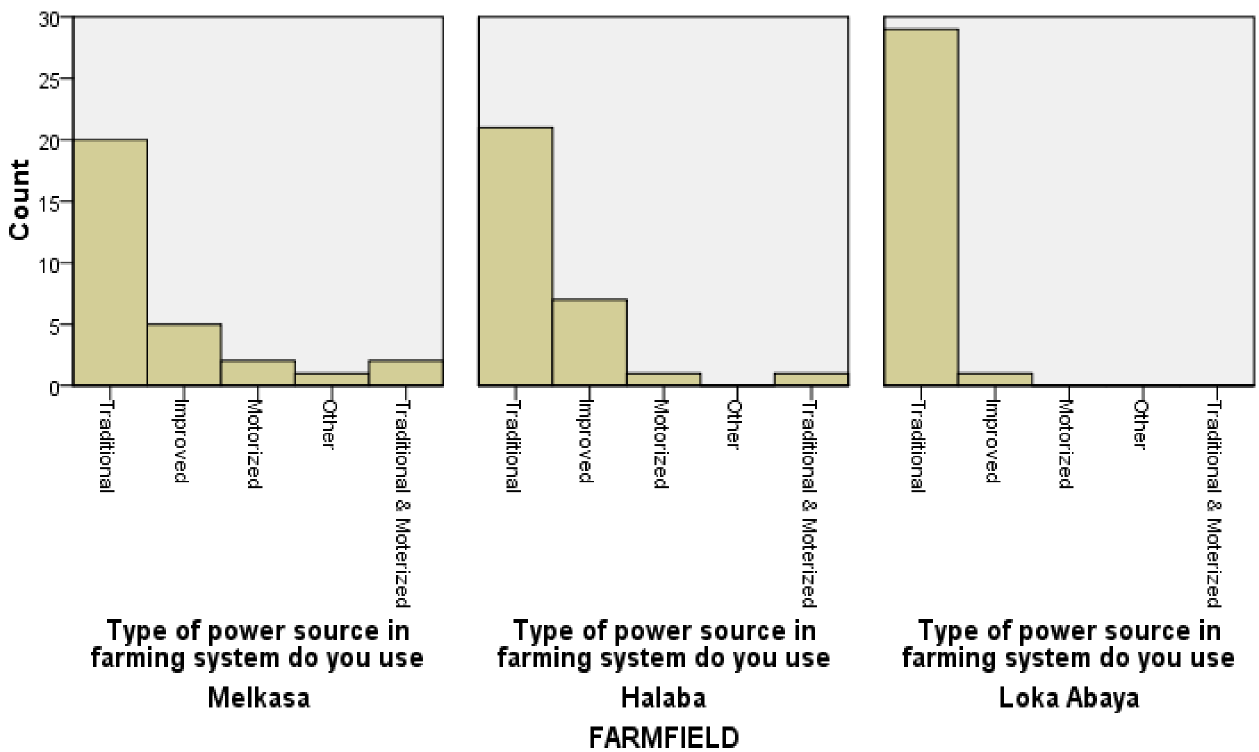

Figure 5. Types of power source distribution of the respondents

In Halaba, 70% of respondents used traditional power sources, with 23.3% adopting improved technologies, and 3.3% each relying on motorized or mixed systems. The region shows slightly higher adoption of improved technologies compared to Melkasa but still depends heavily on traditional methods.

In Loka Abaya, 96.7% of respondents used traditional power sources, with only 3.3% adopting improved technology. This highlights an overwhelming reliance on traditional systems, with minimal integration of modern tools in the region.

3.2.4. Improved Technologies used for Soil Tillage Operation

Across all three farm fields, there is a general trend of low adoption rates of improved plough technologies. The highest adoption is in Halaba at 33.33%, followed by Loka Abaya at 20%, and the lowest in Melkasa at 10%. This may indicate potential barriers such as lack of access, high costs, lack of awareness, or resistance to changing traditional farming practices. Targeted Interventions: Melkasa might need significant intervention to increase awareness and accessibility to improved plough technologies. Halaba shows a relatively better adoption rate but still has majorities who have not adopted the technology, indicating room for improvement. Loka Abaya also requires efforts to increase the adoption rate, though the situation is slightly better than in Melkasa as shown on Figure 6.

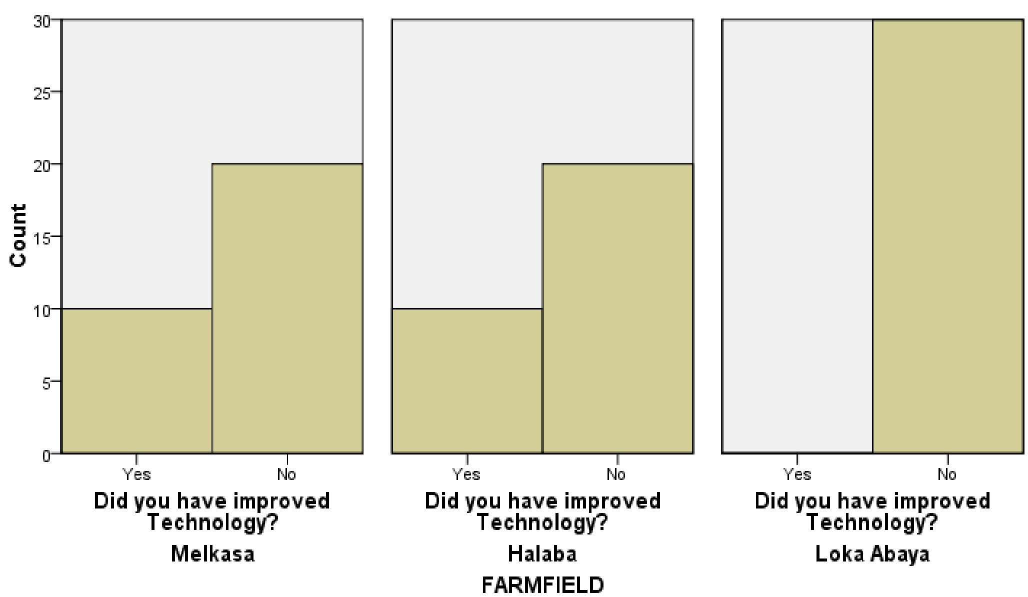

Figure 6. Improved technology distribution of the respondents

3.3. Correlation Analysis

The analysis revealed several noteworthy relationships between variables related to tillage practices and farming technologies. The type of power source exhibited a significant positive correlation with farmers' years of experience in tillage ($r = 0.230$, $p < 0.05$), suggesting that as farmers gain more experience, they may be more inclined to diversify or optimize their power sources to align with their evolving needs and expertise.

The adoption of improved technology was found to have a significant negative correlation with age ($r = -0.224$, $p < 0.05$). This indicates that older farmers may demonstrate a lower propensity to adopt advanced technologies, potentially due to factors such as a preference for traditional methods, limited exposure to modern innovations, or a perceived lack of cost-effectiveness. Conversely, younger farmers may be more open to integrating innovative solutions into their practices.

The issue of drudgery and overload on drought animals presented a complex relationship with other variables. It was negatively correlated with the use of improved plow technologies ($r = -0.300$, $p < 0.01$), suggesting that the adoption of modern equipment could reduce the physical strain on animals. Simultaneously, it was positively correlated with recommendations to utilize equines for tillage ($r = 0.527$, $p < 0.01$), highlighting a potential shift toward alternative draft animals in regions where traditional options, such as oxen, face challenges as shown on Table 2.

A shortage of oxen emerged as another critical factor, showing a significant negative correlation with reliance on other means of power ($r = -0.267$, $p < 0.01$). This relationship underscores that farmers facing oxen shortages are actively exploring alternative solutions, including mechanized equipment or other draft animals, to sustain their agricultural productivity.The adoption of improved plow technologies demonstrated a strong positive association with the use of advanced animal-drawn implements ($r = 0.342$, $p < 0.01$), reflecting a synergy between modern implements and traditional farming methods. Additionally, there was an inverse correlation between improved plow technologies and the perception of drudgery and overload ($r = -0.300$, $p < 0.01$), reinforcing the idea that technology adoption can alleviate labor intensity and improve efficiency.

Finally, the performance of the plow system appeared to be influenced by various factors, albeit with weak correlations across most variables. However, significant influences were noted from the availability of oxen and the adoption of improved technologies, which likely play pivotal roles in determining overall productivity and effectiveness in plowing practices. These findings collectively underscore the intricate interplay between technology, resources, and farmer demographics in shaping agricultural outcomes.Socio-economic factors and land size play a crucial role in improving agricultural efficiency and driving technology adoption. Larger landholders are more likely to adopt advanced systems, though factors like resource availability and perceived benefits also influence this decision. Bridging productivity gaps requires targeted interventions focusing on equitable access to resources and tailored support for smaller farmers.

The cost-effectiveness of tillage systems depends on reducing labor intensity and improving efficiency. Farmers using advanced plow technologies report less drudgery and better productivity, while shortages of oxen are driving a shift toward mechanization and improved animal-pulled implements. Experienced farmers are more likely to adopt these systems due to accumulated knowledge, but barriers remain, such as resistance among older farmers and the strain on traditional draft animals. Equines offer a partial solution in regions with oxen shortages, though their impact is limited without proper tools and training.

Table 2. Correlation Analysis

Pearson Correlation	Age of Farmer	years engaged in soil tillage practice	Type of power source	The major reasons for the less performance in plough system?	Improved plough technologies?	Drudgery and over load on drought animals	shortage of oxen for plough work	experience on using other means of power than oxen	Improved animal pulled implement
Age of Farmer	1								
years have you engaged in soil tillage practice	.689**	1							
Type of power source in farming system	.138	.228*	1						
The major reasons for the less performance in plough system?	.056	.105	.003	1					
Improved plough technologies	-.109	-.015	-.067	-.229*	1				
Drudgery and over load on drought animals	.105	-.030	.110	.159	.051	1			
Shortage of oxen for plough work?	.074	-.004	.136	-.050	.016	-.038	1		
Experience on using other means of power than oxen	.028	.105	-.016	-.268*	.111	-.094	.051	1	
Improved animal pulled implement?	-.188	-.029	.081	-.219*	.342**	.034	-.141	.170	1
***. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).**									

Promoting mechanization through subsidies, training for older farmers, and lightweight, efficient tools can boost adoption rates and reduce drudgery. While initial costs may be high, long-term benefits—such as lower labor costs, increased efficiency, and sustainability—make these investments worthwhile.

4. Conclusion

The findings from the surveyed regions of Melkasa, Halaba, and Loka Abaya reveal significant disparities in gender participation, age demographics, educational attainment, and farming practices, all of which influence agricultural outcomes. A stark gender imbalance was observed, with 86.66% male respondents in Melkasa, 100% male in Halaba, and 93.33% male in Loka Abaya. This highlights the unequal division of labor, as women's participation in agricultural work is limited by household responsibilities. Addressing this gender gap is crucial for promoting inclusivity in farming activities.

Middle-aged farmers (26–55 years) comprised the majority in all regions, representing 83.3% in Melkasa, 80% in Halaba, and 70% in Loka Abaya, underscoring their pivotal role in agricultural practices. Educational diversity showed that 23.3% of farmers in Melkasa, 30% in Halaba, and 30% in Loka Abaya had completed secondary education (grades 9–10). However, a significant portion in all regions (10–16.6%) lacked formal schooling, emphasizing the need for targeted extension services to bridge the knowledge gap and promote technology adoption.

Landholding patterns differed regionally, with Melkasa farmers predominantly managing 2–4 Timad plots (67%), Halaba showing variability (3–7 Timad), and Loka Abaya leaning towards larger holdings (4.5–8 Timad, with a median of 6 Timad). Technology adoption was low across all areas, with 16.7% in Melkasa, 23.3% in Halaba, and only 3.3% in Loka Abaya using improved farming tools. The correlation between technology adoption and demographic factors indicates that younger farmers are more inclined to adopt innovations, while older farmers exhibit resistance, evidenced by a significant negative correlation ($r = -0.224$, $p < 0.05$).

Resource constraints such as oxen shortages (negatively correlated at $r = -0.267$, $p < 0.01$) further hinder productivity, with 96.7% of Loka Abaya farmers relying on traditional power sources, compared to 70% in Halaba and 67.7% in Melkasa. Improved plow technologies, which reduce drudgery ($r = -0.300$, $p < 0.01$) and enhance productivity, remain underutilized, with adoption rates of 10% in Melkasa, 33.3% in Halaba, and 20% in Loka Abaya.

To drive agricultural efficiency and sustainability, targeted interventions must prioritize mechanization, training, and equitable access to resources. Subsidies and lightweight tools should be provided to smaller landholders and older farmers. Improving access to advanced plow technologies and mechanized systems will alleviate labor intensity and improve efficiency, particularly in resource-limited areas like Loka Abaya. Gender-inclusive policies and initiatives to raise awareness, especially among less-educated farmers, can further empower stakeholders to bridge productivity gaps and promote sustainable farming practices across the regions.

Awareness Campaigns: Educate farmers on the benefits of improved plough technologies through workshops, demonstrations, and training sessions. Subsidies and Financial Support: Provide financial assistance or subsidies to make these technologies more affordable. Access and Distribution: Improve the distribution channels to ensure that the technologies are readily available to farmers in all regions. Follow-up Studies: Conduct further studies to understand specific barriers faced by farmers in each region and tailor interventions accordingly. Adoption of Appropriate soil tillage Systems, small engine machine and implement: The integration of improved implement use by various draught animals with small engine machine as an intermediate technology system is not well-explored. Further research is needed to understand how these systems can be effectively combined to enhance sustainability and productivity for smallholder farmers.

Funding

No Funding has been received.

Competing Interests

The authors declare no competing interests.

Concerns to Publish

All the authors concern to the publication of this article.

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