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Exploring the Factors Influencing the Situation of Agricultural Machinery Service Providers for Rice Production in Fogera Plain, North Western Ethiopia

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ABSTRACT

This study examines the factors influencing Agricultural Machinery Service Providers (AMSPs) for rice production in the Fogera Plain of Northwestern Ethiopia, emphasizing their role in enhancing farmers' livelihoods and socioeconomic development. A survey of 36 AMSPs showed that most are family-owned enterprises, with an average operator age of 42.6 years and an average of 36 years of farming operational exprience, typically employing two or more workers. The primary services offered include land preparation using tractors, irrigation pumping, and rice custom milling—activities vital for improving agricultural productivity and rural income. Profitability among AMSPs is mainly determined by total assets, machinery investment, service capacity, and operational efficiency. However, the sector faces constraints such as high initial investment costs, rising fuel and labor expenses, frequent equipment downtime, and limited skilled labor. Efficiency and returns for rice custom millers depend on operator experience, facility capacity, maintenance expenses, and taxation, while irrigation pump operators face poor working conditions and inadequate support. Maintenance is primarily handled by independent mechanics, in-house staff, or local garages. To address these challenges, targeted interventions are essential, including enhanced operator training, improved financial services, and stronger regulation of fuel and maintenance systems. Government programs such as tax incentives and low-interest loans have supported asset acquisition and service expansion. Strategic measures—like preventive maintenance, efficient scheduling, and energy-saving operations—can improve profitability and sustainability. Coordinated actions among government bodies, NGOs, and local stakeholders are crucial to strengthening rural mechanization and ensuring sustainable agricultural growth in the Fogera Plain.

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INTRODUCTION

Background and Justification

Agriculture remains the backbone of Ethiopia's economy, employing about 75% of the labor force, contributing 40% of GDP, and accounting for 80% of export earnings (USAID, 2024). While the sector recorded substantial growth between 1993 and 2018, it remains ill-prepared to meet the demands of rapid urbanization or to adapt effectively to economic and climatic shocks (Lawrence et al., 2019). Persistent structural constraints—including fragmented landholdings, low private investment, environmental degradation, recurrent drought, and conflict—continue to suppress productivity. Even so, agricultural expansion has contributed to poverty reduction by improving labor productivity and land use, highlighting the potential of mechanization to strengthen efficiency and resilience (Deribe et al., 2021).

Human muscle power remains the dominant source of agricultural energy, particularly for land preparation and planting in cereal-based systems (Clarke, 2000). Mechanization indices in Ethiopia are generally low, with regional rates of 12.10% in Oromia, 4.38% in SNNP, 4.35% in Amhara, and 3.48% in Tigray regions. For major crops, mechanization adoption is similarly limited—wheat (9.93%), maize (5.20%), sorghum (2.25%), and teff (0.84%) (Deribe et al., 2021). Smallholders typically rely on privately or group-owned machinery, given their limited access to large-scale equipment. In contrast, countries such as Nigeria, Tanzania, and Kenya have advanced mechanization through service-provider models that integrate public–private partnerships, cooperative ownership, and targeted financial incentives (Lewis, 1996; Van Loon et al., 2020). These shared-use models have rapidly expanded access while fostering viable rural enterprises—a trajectory Ethiopia has only partially adopted.

The South Gondar Zone, and particularly the Fogera Plain, is a central rice production hub, contributing 44–70% of Ethiopia's total rice output (Deribe et al., 2021). Rice farming in this area is highly time-sensitive, requiring synchronized land preparation, irrigation with water-lifting devices, and custom milling to safeguard yield, grain quality, and post-harvest value. Yet, mechanization use remains minimal: only 1.8% of households employ tractors and implement-hiring services, with most mechanization confined to milling and irrigation (Deribe et al., 2021). Similar constraints are reported in other African rice-growing regions, where limited service access restricts potential yield gains despite increasing demand (Dessye & Laike, 2023; Rugumamu, 2014).

Agricultural machinery service providers (AMSPs) play a pivotal role in closing these gaps. By offering land preparation, water lifting, and milling services, they directly influence operational timeliness, resource efficiency, and product quality along the rice value chain (Van Loon et al., 2020). Effective mechanization requires not only machinery availability but also skilled operators, timely inputs, and supportive institutional frameworks (Ayele, 2022; Van Loon et al., 2020). In the Fogera context, delays or breakdowns in any one service can undermine productivity, while the interdependence of multiple services further complicates delivery.

In recent years, Ethiopia has introduced several policies and institutional measures to strengthen mechanization. These include tax- and duty-free importation of agricultural machinery and irrigation equipment (Mihret et al., 2025) and the Agricultural Transformation Agency's (ATA) pilot Mechanization Service Centers (MSCs), which provide machinery rental, maintenance, operator training, and spare parts with 70% cost-sharing grants (New Business Ethiopia, 2020; Fana Broadcasting Corporation, 2020). Ethio Lease has invested USD 150 million to supply mechanized equipment under favorable credit terms, contributing to an increase in tractor usage from 5.7% in 2020 to 25% in 2025 (African Asset Finance Company, 2020). The Agricultural Transformation Institute has continued these efforts through commercialization clusters, import duty privileges, and maintenance hubs (ENA, 2023).

Ethiopia's mechanization pathway has shifted from decades of neglect toward greater emphasis on fee-for-service providers ("contractors"), mechanization clustering, and land consolidation to address small-scale farming constraints (Ayele, 2022; ENA, 2023). Empirical studies show that adoption of tractor and combine-harvester services increases with farm size, liquidity, market connectivity, and social ties to providers. However, service costs and reliability vary considerably across regions (Deribe et al., 2021). Research in Amhara and Oromia highlights farmers' willingness to pay for tillage and harvesting services, the diversity of contractual arrangements (spot versus relational), and the emergence of mechanization clusters that reduce coordination failures and lower per-hectare costs (Gebiso et al., 2023; Tufa et al., 2024). Under current credit and scale conditions, farmers generally prefer hiring machinery over ownership. However, persistent supply-side bottlenecks—limited financing, scarce spare parts, and a shortage of trained operators—remain significant barriers (Yenewa, 2024). These national trends provide a comparative framework for the Fogera case study, where seasonal bottlenecks, service availability, and alignment with rice production calendars reflect broader Ethiopian patterns while also revealing unique local challenges in pricing, queue management, and machinery mix (Dessye & Laike, 2023).

Including comparative studies from countries with similar socioeconomic conditions in both Africa and Asia can further enrich the analytical depth of mechanization research. Studies employing simulation and performance modeling of mechanized structures, such as finite element analysis of moldboard plow frames, inform structural assessment and design improvements (Nazemosadat et al., 2022). Technical analyses of tractor diesel engine test stand structures similarly offer insights for optimizing machinery service systems (Mohammadi et al., 2024). Beyond engineering, research on training and institutional investment in mechanization service provision—such as investor-led training programs among Ghanaian rice farmers—provides valuable lessons on capacity building and adoption (Abdallah, 2025). Evidence from social policy interventions in high-risk agricultural environments, including China's experience with agricultural social services influencing farmers' input decisions, further highlights the role of institutional support in shaping mechanization strategies (Chang et al., 2023). These international perspectives offer benchmarks and comparative lessons for designing effective mechanization service models in the Fogera Plain.

Despite these advances, agricultural machinery service providers (AMSPs) in the Fogera Plain face substantial barriers, including high capital costs, limited skilled labor, inadequate maintenance infrastructure, and logistical constraints, which limit efficiency and equitable access (Dessye & Laike, 2023). International evidence indicates that multi-service provider approaches can enhance mechanization accessibility, utilization, and profitability (Lewis, 1996; Van Loon et al., 2020). However, research on Ethiopian AMSPs—particularly in rice-based systems—remains limited, often focusing on single-service outcomes without considering operational interdependencies.

Objective

This study addresses the gaps by examining the factors influencing AMSPs and mechanization development in the Fogera Plain, Ethiopia. Specifically, it aims to:

- Assess the current status of AMSPs in the Fogera Plain.
- Identify key factors affecting AMSPs, including business constraints and mechanization opportunities.
- Assess the effectiveness and socioeconomic impacts of agricultural machinery services, including machine ownership, service costs, and returns.

MATERIALS AND METHODS

Study Area

The study was conducted in the Fogera Plain of northwestern Ethiopia, within the South Gondar Zone of the Amhara Region, covering Fogera, Libokemkem, and Dera districts, with Bahir Dar City included for comparison (see Figure 1). The area has high agricultural potential, particularly for rice, maize, and horticultural crops, making it ideal for evaluating Agricultural Mechanization Service Providers (AMSPs). The plain lies between 11°42′–12°03′ N and 37°25′–37°58′ E, at elevations of 1,500–2,500 m, with 76% flat plains, 13% gently undulating land, and 11% mountainous terrain. Average annual rainfall is 1,284 mm, and mean temperatures range from 10.3 °C to 18.8 °C (Worku, 2014). Fogera contributes about 70% of Ethiopia's rice output, with 50 rice-growing kebeles representing 48% of local administrative units (Getahun, 2020). Key mechanization services include plowing, irrigation pumping, and custom milling, provided by model farmers, tractor operators, and farmer unions, including corporate unions serving non-members (Dessye & Laike, 2023; Simeneh et al., 2020). The study focused on Hamusit and Jigna (Dera), Wereta and Abua Kokit (Fogera), Bura, Angot, Kabe, Shina, Addis Zemen (Libokemkem), and Bahir Dar City, where AMSPs are concentrated (see Figure 1).

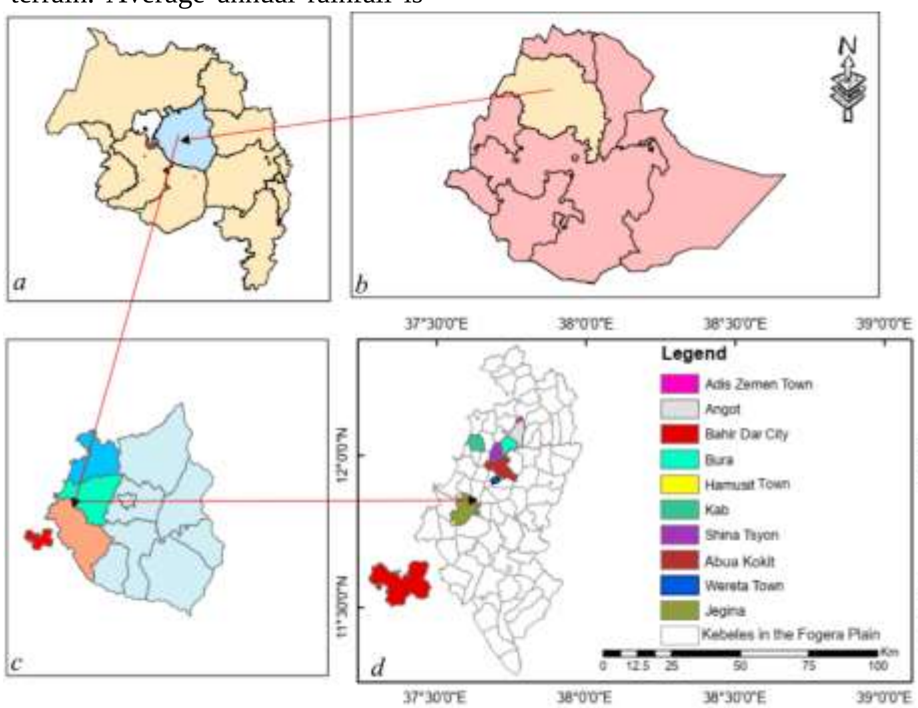

Figure 1. Map of the survey area: (a) Amhara Regional State, (b) Ethiopia, (c) Fogera Plain districts and Bahir Dar City, and (d) lower administrative units.

Methods of Assessment

A mixed-methods approach was employed to assess the status, constraints, and opportunities of agricultural machinery service providers (AMSPs) in the Fogera Plain. Primary data were collected using structured questionnaires, combining closed- and open-ended questions to capture both quantitative and qualitative aspects of service provision. The instruments covered servicecharacteristics, landholdings, crops, value chain participation, division of labor, work burden, access to mechanization, constraints in hiring machinery, and operational practices. Attitudinal responses were measured using Likert-type scales of varying lengths, including a 14-point scale, allowing nuanced assessment of perceptions, attitudes, and satisfaction levels. Separate instruments were developed for tractor services, irrigation pumps, and custom rice milling to ensure contextual relevance. Data were gathered through face-to-face interviews conducted by trained enumerators, ensuring accuracy and completeness. Key informant interviews and secondary sources, including policy documents, program reports, institutional assessments, and historical data, complemented these surveys. A midterm evaluation tracked progress, achievements, and emerging challenges. The sampling frame was validated through field visits and consultations with relevant offices, and all primary data were managed and analyzed using SPSS software.

Study Population and Sampling Procedure

The study population consisted of agricultural machinery service providers (AMSPs) engaged in rice milling, water lifting, and tractor ploughing in the Fogera Plain. The sampling frame of active providers was constructed from registries maintained by district bureaus of agriculture and cooperative offices, supplemented, cooperative records, and government beneficiary lists. Key informant interviews with local leaders and extension agents ensured the inclusion of both formally registered and informally operating providers, with cross-verification producing a comprehensive sampling frame. A purposive and multistage sampling strategy was employed. The districts of Dera, Fogera, and Libokemkem were purposively selected due to their contrasting agroecologies, prominence as rice-producing corridors, and relatively high mechanization levels, with Bahir Dar City added for comparison. Within districts, purposive sampling captured less common services (e.g., tractor ploughing), while simple random sampling was used for more common services (e.g., rice milling, irrigation). In total, 36 providers were surveyed: 12 in Fogera, 11 in Libokemkem, 12 in Dera, and 1 in Bahir Dar City. Of these, seven offered tractor land preparation, 9 provided irrigation water pumping, 19 operated rice and flour milling services, and 1 delivered multiple services.

Data Collection

This study employed a cross-sectional quantitative design to assess the financial performance of Agricultural Machinery Service Providers (AMSPs), including tractor services, rice milling, water pumping, and integrated “all-in-one” operations. Data were collected in March 2024 using structured questionnaires capturing demographics, household background, service type, asset ownership, employment generation, operational scale, and financial information, including capital investment, costs, revenues, and net profit. Attitudinal and perception-based variables—such as constraints, institutional support, and satisfaction—were measured using Likert-type scales (1 = least significant, 14 = most significant). Service-specific operational data were also collected for tractor, milling, and water lifting services, including capacity, working hours, energy use, maintenance, and downtime. Descriptive statistics summarized operational and financial variables, while ANOVA and Tukey HSD post-hoc tests evaluated differences across service types. Pearson correlation and service-specific multiple regression models identified key profitability drivers, and Return on Investment (ROI) was calculated as net profit relative to capital investment. Analyses were conducted using R and IBM SPSS, with visualizations produced in MS Excel 2016.

Data Management and Analysis

Survey responses were cleaned, standardized, and coded before analysis. Quantitative data were analyzed using IBM SPSS Statistics V22 and R version 4.5.1 (2025-06-13 ucrt). Descriptive statistics, including frequencies, means, and percentages, summarized the status, challenges, opportunities, technological awareness, and service provision patterns of agricultural machinery service providers (AMSPs), as well as their personal and farm characteristics. Inferential analyses, including correlation and regression, examined relationships between operational variables and profitability. Specific analyses encompassed profitability assessment, regression of profitability drivers, correlation analyses of key variables (e.g., rice milling and water lifting), determinants of profitability, and comparative performance across mechanization services. Qualitative responses from open-ended questions and key informant interviews were analyzed thematically to identify operational interdependencies, recurring constraints, and policy-relevant insights. Integrating primary and secondary data provided a comprehensive understanding of service provider performance and highlighted opportunities to improve mechanization access and efficiency. SPSS facilitated efficient data management, visualization, and interpretation, ensuring the robustness and reliability of the study's quantitative findings.

Limitations of the Study

This study has some limitations. Although all available tractor service providers in the study area were included, their small number may limit the generalizability to regions with more diverse tractor markets. In contrast, rice milling and water lifting services were sufficiently available, and their sample sizes adequately reflect the mechanization service population in the Fogera Plain. Providers were drawn from three central rice-producing districts and covered land preparation, irrigation, and custom milling, including both private and group-owned operators. By combining purposive sampling for rare services with random selection for common ones, broad representativeness was ensured. While we strengthened the discussion by integrating evidence from recent farmer-level studies on yield and income effects of mechanization, such studies remain limited as mechanization services are relatively new. These insights nonetheless provide a solid basis for policy recommendations, service improvements, and future research.

RESULTS AND DISCUSSION

Situation of Mechanization in the Fogera Plain

The status of agricultural mechanization in the Fogera Plain is examined across multiple dimensions. Personal and farm characteristics of agricultural machinery service providers (AMSPs)—including age, gender, education, farming experience, farm size, and crop types—are considered for their influence on adoption and service provision. Access to and ownership of machinery, such as tractors, rice mills, and water lifting devices, as well as the availability of spare parts, fuel, and maintenance services, are assessed. Service provision practices, including types, frequency, scale, intensity, pricing, and payment mechanisms, are described. Constraints to mechanization—operational, financial, and institutional—are highlighted, alongside opportunities arising from government programs, market demand, and potential service expansion. AMSPs' attitudes and perceptions regarding mechanization, investment willingness, and social factors affecting adoption are analyzed. Quantitative analyses—including profitability assessment, regression and correlation analyses of profitability drivers, determinants of rice milling and water lifting profitability, and comparative performance across mechanization services—provide a comprehensive understanding of mechanization, its drivers, constraints, and performance in the Fogera Plain.

Sampling characteristics

The survey targeted 36 predefined Agricultural Machinery Service Providers (AMSPs) operating in the Fogera Plain, covering the districts of Fogera, Libokemkem, and Dera, with an additional provider from Bahir Dar City. The district-wise distribution included 12 service providers from Fogera, 11 from Libokemkem, and 12 from Dera. Service types comprised seven tractor land preparation providers, 19 rice milling providers, nine water pumping providers, and one integrated provider offering tractor, rice, and flour services. Data were collected from selected towns and kebeles to capture local dynamics comprehensively: in Libokemkem, Shina Tsyon (3), Kabe (1), Angot (4), Bura (1), and Addis Zemen town (2); in Dera, Jigina kebele (10) and Hamusit town (1); and in Fogera, Wereta town (11) and Abua Kokit kebele (1). Respondents were predominantly male (91.7%) with 8.3% female representation, averaging 42.6 years of age (range: 27–66, SD = 10.77). Most had higher education, with 41.7% holding diplomas and 55.5% degrees. On average, respondents had resided in their locations for 36 years (range: 5–66, SD = 17.2), providing extensive local knowledge for the study.

Supporting Procedures of Service Providers

The agricultural mechanization sector depends heavily on the support of machinery service providers, with both governmental and non-governmental organizations offering financial and technical assistance. Financial support facilitates investment in modern machinery, enhancing productivity, efficiency, and equipment longevity, while technical capacity-building improves skills in machinery operation, maintenance, and sustainable farming practices. Despite these supports, high initial costs, a shortage of skilled technicians, and uneven resource distribution limit mechanization adoption. Among service providers, self-financing is most common, with 69.4% purchasing machinery independently. Government linkages provide operational and technical support to 36.1% of providers, while NGOs and donor agencies offer equipment, cost-sharing, training, and financial or technical assistance to 30.6% (see Table 1). Bank loans and donor-sharing arrangements are less utilized (19.5% and 11.1%, respectively), and direct government interventions, including training and loan facilitation, reach only 13.9% of respondents. Overall, while external support exists, self-financing remains the primary means of machinery acquisition, with other forms of assistance serving a complementary role.

Table 1. Sources of Support and Financing for Agricultural Machinery Service Providers (AMSPs)

Source of Support/Finance	Type of Support Provided	% of Respondents
Government Stakeholders	Capacity-building training (2.80%); Loan facilitation (11.10%)	13.90% (received both)
Linkages with Government Agencies (DBE, trade/irrigation offices, utility providers)	Operational and technical support	36.10%
NGOs/Donor Agencies (Agro BIG, World Vision, MEDA, SNV)	Equipment provision, cost-sharing, training, and financial/technical assistance	30.60%
Self-financing	Direct machinery purchase by service providers	69.40%
Bank loans	Machinery acquisition through formal credit	19.50%
Donor sharing	Shared financing support for machinery	11.10%

Survey data (2024).

Types and Capacity of Service Providers

The assessment revealed that in the Fogera Plain districts, agricultural mechanization service providers (AMSPs) primarily offer rice custom milling (52.78%), water lifting with pumps (25.00%), and land preparation with tractors (19.40%). A small proportion (2.80%) provides integrated services combining tractors, milling, and flour processing. The survey further indicated that 83.30% of AMSPs are engaged in other businesses in addition to service provision, while the remainder operate exclusively as service providers. Most companies are family-owned, with crop production (30.60%), crop production with trade (38.90%), trade only (5.60%), and tour/travel combined with animal fattening (2.80%) being the dominant activities. AMSPs also generate local employment, averaging six workers per provider. The largest share employs one to two individuals (36.10%), followed by three (11.10%) or four (8.30%) employees. On average, providers employ three permanent staff and 20 temporary workers. The overall mean asset value of AMSPs in the study area is ETB 3,128,080, ranging from a minimum of ETB 30,000 to a maximum of ETB 20,000,000. As shown in Table 2, tractor, milling, and flour services hold comparatively higher asset values, while water pump services exhibit lower asset values.

Table 2. Total Assets/Capital of Agricultural Machinery Service Providers (AMSP) in ETB

SN	Types of AMSPs	Mean (ETB)	N	Std. Dev.	Minimum	Maximum	Std. Error
1	Tractor service for ploughing	6,460,000.00	5	5,927,309.68	1,300,000.00	15,000,000.00	2,650,773.47
2	Milling service of rice	2,145,454.55	11	2,155,626.89	100,000.00	7,000,000.00	649,945.96
3	Water pump service	287,750.00	8	337,884.91	30,000.00	800,000.00	119,460.36
4	Both tractor and rice milling services	20,000,000.00	1	-	20,000,000.00	20,000,000.00	-
5	Overall mean	3,128,080.00	25	5,013,022.42	30,000.00	20,000,000.00	1,002,604.48

Note: ETB values calculated using an exchange rate of 1 USD = 140 ETB as of August 14, 2025 (Forbes Advisor, 2025). Survey data (2024).

Services of Land Preparation

Research results indicate that tractor adoption among farmers remains very limited, with only about 2% of households using hiring services and 3% having occasional experience due to limited availability and high costs. Tractor users cultivate an average of 1.60 hectares, compared to 0.81 hectares for those relying on draught animals, highlighting the potential of tractors to expand farm size, increase productivity, and improve socioeconomic outcomes for smallholder farmers (Deribe et al., 2021). Among the sample, 87.5% of service providers engage in land preparation, focusing on primary and secondary tillage. Tractor services, representing 22.2% of providers, are mainly used for rice and horticultural crops (42.9% each) and maize (14.3%). Service provision varies geographically: 39.2% in Fogera, 26.1% in Dera and Libokemkem, and 8.6% outside these districts. Individual farmers account for 71.4% of clients, with investors representing 28.6% (see Table 3). These findings highlight disparities in service access and suggest that expanding land preparation services could further enhance agricultural productivity and economic outcomes for local farmers and investors.

Table 3. Services Provided to Farmers and Investors

SN	Variables	Mean	Std. Dev.	Std. Error	Minimum	Maximum
1	Number of farmers	132	163	61	10	426
2	Plowed land (ha) for farmers	70.00	17.00	46.00	13.00	144.00
3	Number of investors	2	2	1	1	4
4	Plowed land (ha) for investors	3.00	1.00	2.00	1.00	5.00

Survey data (2024)

Tractor Hiring Operations and Maintenance

Land preparation using tractor power has expanded substantially in the Fogera Plain over the past two years. Previously, adoption was minimal, constrained by factors such as limited availability, untimely service, high costs, and operational failures due to hourly payment arrangements, soil-related ploughing difficulties, skips, and inconsistent ploughing depth. Youth-owned services face additional challenges due to limited experience and skill gaps in land preparation (Deribe et al., 2021). The overall sales strategy for attracting and retaining customers in tractor hiring services, particularly for primary and secondary tillage, emphasizes competitive rental prices. Among respondents, 12.5% indicated that better service quality was a significant factor, while 50% highlighted competitive prices and the availability of sufficient tractors and attachments as key considerations. Customer priorities based on a 5-point Likert scale—ranging from 5 (“very much attention”) to 1 (“no attention”)—are summarized in Table 4.

Table 4. Attention given to sales strategies for attracting and retaining customers, measured on a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree).

SN	Overall Sales Strategy	Mean	Std. Dev.	Rank Decision	% Respondents*	N
1	Better quality of service	2.86	1.22	So-so Attention	87.5	7
2	Competitive rental price	2.86	1.07	So-so Attention	87.5	7
3	Market survey	3.00	0.00	So-so Attention	62.5	5
4	Advertisement	3.25	0.50	So-so Attention	50.0	4
5	Sufficient tractors & attachments	3.17	0.41	So-so Attention	75.0	6
6	Customer satisfaction	2.60	0.89	Seldom Attention	62.5	5
7	Expand the number of customers	4.20	1.00	Much Attention	62.5	5

Survey data (2024)

The survey found that tractor service providers mainly finance operations through credit, with 50% using banks and 50% microfinancing. Funding sources for tractor hiring include personal savings (25.00%), bank loans (25.00%), and donor agencies (37.50%). Tractors require oil refills three times after 300.00 hours of use. Seventy-five percent of providers hire operators, while 12.50% operate the tractors themselves. Annual maintenance costs include labor, lubricants, oil replacement, and overall oil expenses. Regular maintenance extends machinery lifespan, reduces breakdown risks, enhances reliability and safety, and boosts productivity and profitability. The survey revealed that maintenance and repair costs include annual expenses such as operating hours, lubricant requirements, oil change costs, labor fees, etc., as shown in Table 5. Regular maintenance extends a tractor's lifespan by ensuring optimal performance and reducing the likelihood of breakdowns.

Table 5. Tractor maintenance costs

SN	Variables	Mean	N	Std. Dev.	Std. Error	Minimum	Maximum
1	Repair and maintenance cost (ETB/year)	64,500.00	7	92,905.87	37,928.67	12,000.00	250,000.00
2	Hours to get maintenance service	1.75	6	3.07	1.25	0.25	8.00
3	Maintenance service distance (km)	16.61	7	7.31	19.34	1.00	56.00
4	Lubricant fill per time (L)	15.00	8	0.00	0.00	15.00	15.00
5	Oil tank capacity (L)	60.00	6	13.00	5.27	40.00	60.00
6	Oil replacement cost per time (ETB)	13,500.00	5	9,192.39	3,752.78	7,000.00	20,000.00
7	Annual oil expense (ETB)	15,266.75	6	5,929.19	2,241.05	11,000.00	28,000.00
8	Working capacity (ha/day)	3.25	6	1.70	0.69	1.00	6.00
9	Working time per ha (hr/ha)	3.65	5	3.24	1.45	0.25	8.00
10	Actual working time per day (hr/day)	7.17	6	0.98	0.41	6.00	8.00
11	Plowing days/year	81.40	5	31.78	14.21	30.00	112.00
12	Critical working days/year	63.20	5	26.45	11.83	29.00	100.00

Note: ETB values calculated using an exchange rate of 1 USD = 140 ETB as of August 14, 2025 (Forbes Advisor, 2025). Survey data (2024).

The survey indicates that 50.00% of respondents primarily conduct repairs involving filter and oil replacement, while the remainder perform routine maintenance every six months. Specifically, 12.50% focus on inspecting upper and lower links, and another 12.50% concentrate on checking implements or plows. Most respondents (75.00%) rely on service stations for equipment maintenance, 12.50% employ their own mechanics, and some use a combination of both approaches. This structured maintenance practice ensures reliable machinery performance.

A five-point Likert scale, ranging from 5 = “yearly” to 1 = “daily,” was applied to evaluate the frequency of maintenance tasks such as visual checks, cleaning, dismounting, and overhauls; the results indicated that maintenance is most commonly performed weekly.

The tractor hiring rate increased from ETB 2,400/ha to ETB 4,000/ha in 2018. Key drivers of tractor use included draught power shortages, row planting, fertilizer application, labor shortages, and high manual labor costs. Constraints in using tractor hiring services included limited availability, untimely service, high cost, and operational failures due to hourly payment arrangements (Deribe et al., 2021). Survey results show that 60% of respondents vary service or contract fees by location or territory, while 40% apply fixed fees. All tractors were medium-sized (80–150 hp), with Case IH and Massey Ferguson models accounting for 72.73% and 27.27%, respectively. Primary implements used were disc plows with five plow bottoms. Both primary and secondary tillage were considered critical for soil preparation, establishing optimal growing conditions. Field capacity, reflecting land coverage efficiency, emerged as a key factor for timely task completion. Fuel consumption was the main driver of operational costs, while tractor number and purchase year influenced depreciation and maintenance. Labor costs included operator wages and per diem allowances, with additional support for field assistants. These operational and cost-related findings are summarized in Table 6.

Table 6. Tractor Service Fees and Operational Data

SN	Variable	Mean	N	Std. Dev.	Std. Error	Minimum	Maximum
1	Primary tillage (ETB/ha)	8,350.00	6	1,983.68	809.84	6,000.00	12,000.00
2	Secondary tillage (ETB/ha)	6,800.00	6	1,131.37	800.00	3,000.00	7,600.00
3	Field capacity (ha/hr)	3.13	4	0.75	0.38	2.50	4.00
4	Fuel consumption (L/ha)	31.00	5	4.58	10.25	20.00	40.00
5	Average no. of tractors	~2.00	6	0.65	1.60	1.00	5.00
6	Tractor purchase year	2019	7	4.22	1.60	2014	2023
7	Operator wage (ETB/month)	7,000.00	6	1,549.19	632.46	5,000.00	8,000.00
8	Operator commission (ETB/day)	450.00	6	54.77	22.36	400.00	500.00
9	Assistance wage (ETB/month)	3,666.70	3	1,527.53	881.92	2,000.00	5,000.00
10	Assistance commission (ETB/day)	300.00	3	100.00	57.74	200.00	400.00

Note: ETB values calculated using an exchange rate of 1 USD = 140 ETB as of August 14, 2025 (Forbes Advisor, 2025). Survey data (2024).

Drivers of Profitabilit in Tractor Services

Investment in tractors and implements is the primary determinant of profitability for tractor service providers (TSPs), highlighting the central role of capital in mechanized agricultural services. Operational efficiency—achieved through higher daily service capacity and extended working hours—further enhances profitability. At the same time, effective management of fuel and labor costs and minimizing downtime ensures stable revenue and optimal asset utilization. Key drivers of tractor use were draught power shortages, row planting, fertilizer application, labor shortages, and high manual labor costs, which also influence weeding and harvesting decisions. Tractor adoption was previously minimal, and youth-owned services face additional challenges due to limited experience and skill gaps in land preparation (Deribe et al., 2021). This study analyzed the effects of operational variables—including capital investment, asset utilization, service capacity, labor input, and working hours—using regression and correlation analyses of survey data from tractor service providers (TSPs). Costs related to insurance, licensing, storage, and administrative overheads were negligible and excluded from the models. Regression results indicate that total assets and capital investment have the most substantial positive influence on financial performance. At the same time, daily service capacity and working hours contribute moderate to strong effects. Correlation analyses confirm statistically significant relationships between capital intensity, operational utilization, and profitability. Overall, the results underscore the financial benefits of maximizing equipment use and provide actionable insights for investment decisions and operational planning among TSPs. Strategic capital allocation and efficient daily operations emerge as essential for strengthening profitability in mechanized service provision.

Regression Analysis of Tractor Profitability Drivers

The regression analysis revealed that profitability among tractor service providers (TSPs) is primarily shaped by capital investment and operational efficiency. Total assets and capital exerted the most potent positive effects, indicating that firms with larger investments in tractors and implements can serve more clients, diversify services, and achieve greater returns. Daily service capacity also had a substantial positive influence, as cultivating more hectares per day increases revenue relative to operating costs. Working hours contributed positively but with a more negligible effect, mainly by improving the utilization of fixed assets. On the cost side, higher diesel prices, labor expenses, and unplanned downtime significantly reduced profitability, highlighting the need for cost control, preventive maintenance, and operational reliability. Maintenance costs were negatively associated with profitability but not statistically significant, suggesting that routine upkeep is essential for service continuity but does not directly limit profits. Overall, the findings underscore that profitability is maximized through strategic investment in machinery, efficient asset use, and careful management of fuel, labor, and downtime. Overall, the results (see Table 7) confirm that profitability is primarily driven by capital investment and operational efficiency. At the same time, careful management of fuel, labor, and downtime is essential for sustaining viable tractor hire services. These findings suggest that strategic investment in quality machinery, optimized scheduling, cost control, and reduced downtime are critical levers for enhancing financial performance.

Table 7. Multiple Regression Summary (Profitability as Dependent Variable)

Predictor	Coefficients β	t-value	p-value	Direction	Relative Impact	Interpretation
Constant	2.15	4.30	0.001***	—	—	Base profitability when all predictors are zero.
Total Assets / Capital	0.48	4.00	0.002**	Positive	Strong	Higher investment in tractors and implements significantly increases profitability.
Daily Capacity (ha/day)	0.35	3.50	0.005**	Positive	Moderate-Strong	Efficient utilization of the tractor (servicing more hectares per day) raises profit.
Working Hours per Day	0.20	2.50	0.03*	Positive	Moderate	Longer working hours slightly increase profitability.
Diesel Price (ETB/L)	-0.30	-3.33	0.006**	Negative	Moderate-Strong	Higher fuel costs reduce profitability noticeably.
Labor Cost (Operator + Asst)	-0.18	-2.57	0.028*	Negative	Moderate	Higher labor costs reduce profitability, but the impact is smaller than the fuel cost.
Maintenance Cost	-0.10	-1.67	0.12^{ns}	Negative	Weak	Maintenance cost has a negative effect, but it is not statistically significant at 0.05.
Downtime (hours)	-0.22	-2.75	0.022*	Negative	Moderate	More hours of downtime reduce profitability significantly.

Note: $p < 0.001$ = *** (extremely significant), $p < 0.01$ = ** (highly significant), $p < 0.05$ = * (significant), $p \geq 0.05$ is= ns (not significant).

Correlation Analysis of Tractor Profitability Drivers

The correlation analysis (see Table 8) explores the relationship between profitability and operational factors among tractor service providers. Total assets and capital exhibit the strongest positive correlation with profitability (r = 0.72), underscoring the role of investment in tractors and implements in enhancing returns. Daily operational capacity also shows a strong positive correlation (r = 0.65), indicating that cultivating more hectares per day substantially increases profits. Working hours per day are moderately correlated (r = 0.40), suggesting incremental gains from extended utilization. On the cost side, diesel price is moderately to strongly negatively correlated with profitability (r = -0.58), confirming the significant burden of fuel costs. Downtime (r = -0.45) and labor costs (r = -0.35) also reduce profitability, while maintenance costs display only a weak negative effect (r = -0.25). Overall, the results suggest that profitability is primarily driven by capital investment and efficient use of machinery, whereas high fuel prices, labor expenses, and operational interruptions remain key constraints.

Table 8. Correlation of Profitability with Tractor Variables

SN	Variable	Correlation (r)	Expected Direction	Relative Impact Strength
1	Total Assets / Capital	0.72	Positive	Strong
2	Daily Capacity (ha/day)	0.65	Positive	Moderate-Strong
3	Working Hours per Day	0.40	Positive	Moderate
4	Diesel Price (ETB/L)	-0.58	Negative	Moderate-Strong
5	Labor Cost (Operator + Asst.)	-0.35	Negative	Moderate
6	Maintenance Cost	-0.25	Negative	Weak
7	Downtime (hours)	-0.45	Negative	Moderate

Note: ETB values calculated using an exchange rate of 1 USD = 140 ETB as of August 14, 2025 (Forbes Advisor, 2025). Survey data (2024).

Challenges in Tractor Hiring Services

The Ethiopian Ministry of Agriculture and the Development Bank of Ethiopia have introduced lease financing and import tax exemptions to promote agricultural mechanization and enhance productivity. However, political unrest in the Fogera Plain has hindered loan repayment and service rescheduling. Tractor service providers face multiple constraints, including limited mechanization access, fragmented land ownership, rising fuel costs, high machinery import costs, lack of skilled labor, and inadequate government incentives. Insecurity, poor infrastructure, weak regulatory frameworks, and insufficient training further exacerbate these challenges. A 14-point Likert scale assessment ranked these constraints from most to least critical (see Table 9). The top four challenges were insecurity and unsafe conditions, fragmented smallholder land (<2 ha), limited mechanization access, and escalating fuel costs. Addressing these issues through targeted policies, improved training, financial support, and stakeholder collaboration can enhance operational efficiency, reduce production costs, and strengthen the resilience of the tractor service sector, contributing to food security and sustainable agricultural growth in the Fogera Plain.

Table 9. Ranked Constraints of Tractor Service Providers in the Fogera Plain (14-Point Likert Scale)

SN	Constraints	Scores	Rank Decision	% Respondents*	N	Mean	Std. Dev.
1	Insecurity in the country and unsafe trade conditions	1.03	1	75.0	6	1.13	0.35
2	Ownership of fragmented land of smallholders (< 2 ha)	2.67	2	87.5	7	2.13	0.35
3	Limited mechanization access (infrastructure, roads, fuel availability, etc.)	3.17	3	75.0	6	3.13	0.35
4	Escalating fuel costs are leading to high production costs.	3.83	4	100.0	8	4.00	0.00
5	High cost of imported machinery, spare parts, and maintenance	5.43	5	100.0	8	5.00	0.00
6	Low access to skilled manpower (operators, technicians, managers, etc.)	6.02	6	75.0	6	6.00	0.53
7	Farming nature of the districts (topography, soil, ecology, etc.)	6.83	7	62.5	5	7.00	0.53
8	Lack of training and awareness among farmers on agricultural mechanization	7.83	8	87.5	7	8.25	0.46
9	No regulatory framework for the certification of machines	8.67	9	100.0	8	9.00	0.00
10	Lack of government incentives to encourage private sector participation	9.60	10	62.5	5	10.25	0.89
11	Increasing competition for land use due to resource depletion	10.50	11	75.0	6	11.13	1.13
12	Limited access to finance services (credits, banks, etc.)	11.50	12	87.5	7	11.88	1.73
13	Lack of warranty on agricultural equipment	12.50	13	62.5	5	12.88	1.25
14	Environmental impacts of agricultural mechanization	13.50	14	100.0	8	14.00	0.00

Survey data (2024).

Custom millers

Research evidence shows that rice processing quality remains a significant challenge in the Fogera Plain. At the kebele level, crushing losses are high, while at district markets, processors retain bran and tighten machines to increase byproducts, resulting in losses of 35% or more (Deribe et al., 2021). This survey also revealed that the private milling sector in the Fogera Plain is primarily composed of small-scale operators, categorized into custom and commercial mills. Custom mills focus solely on rice processing and do not engage in marketing, whereas commercial mills handle both processing and sale. Among custom millers, 65.4% also operate flour milling machines (Dessye & Laike, 2023). To diversify income, millers supplement milling with farming (81.8%), trading (9.1%), and transportation services (9.1%). Typically, millers own and operate machines for both rice and flour processing. Customers bring in paddy to receive white rice, while millers earn additional income from by-products such as husk and bran, alongside service fees. On average, each miller owns one rice milling machine and two flour milling machines (see Table 10).

Table 10. Number of Rice and Flour Milling Machines per Miller

Statistics	Rice Milling Machines (per miller)	Flour Milling Machines (per miller)
Mean	1.33	2.24
Std. Error	0.16	0.38
Median	1.00	2.00
Mode	1.00	2.00
Std. Deviation	0.69	1.56
Minimum	1.00	1.00
Maximum	3.00	6.00

Survey data (2024)

The survey revealed that 88.24% of rice milling machines operated by custom millers in the Fogera Plain are Engelberg types, underscoring their dominance in the sector. The remaining machines belong to the SB series, which, although less common, remain important in milling operations. As shown in Figure 2, the N90 model is the most widely used, accounting for 36.80% of surveyed machines, followed by another model at 31.60%, indicating a competitive distribution across types. Additional models, including the N70, NPF110, and SB-50D, contribute to the technological diversity of milling equipment. All custom millers operate privately owned facilities that combine rice and flour milling, reflecting both adaptability and resourcefulness in meeting customer demand within a competitive market.

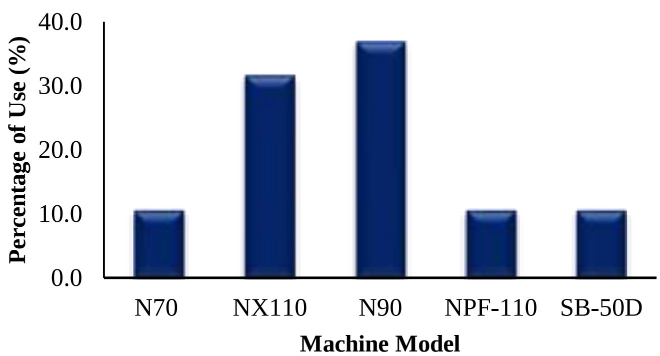

Figure 2. Custom millers' available models of rice milling machines

Custom millers in the Fogera Plain provide both rice and flour milling, processing paddy and other crops brought by residents. Customers receive white rice in exchange for their grains, while millers retain by-products such as husk and bran and charge milling fees. Processing fees are relatively high (ETB 0.50/kg), and farmers often prefer to pay extra to retain husk and bran for livestock feed (Deribe et al., 2021). Custom rice processors may process rice inefficiently to increase by-products, sold as livestock feed at 1–3.5 Birr (US$0.03–0.10) per kg, while bran containing broken rice can be further graded and sold at up to 10 Birr (US$0.30) per kg (Dessye & Laike, 2023). The fee structure consists of cash payments (76.5%), by-products (5.9%), or a combination of both (11.8%). While some rice milling services are offered free, flour milling is always paid for. Negotiations over by-product prices allow processors to maximize returns, as these materials can be further processed into rice flour (Dessye & Laike, 2023). Survey results indicated that 64.7% of respondents paid for dehusking, 52.9% for polishing, and 47.1% for both services, whereas others received rice milling services free but paid for flour milling. Mean fees for dehulling and polishing (ETB/kg) are summarized in Table 11.

Table 11. Rice Milling Service Fees (ETB/kg)

SN	Service	N	Mean	Std. Error	Median	Mode	Std. Dev.	Minimum	Maximum
1	Dehusking	11	2.00	0.23	2.00	2.00	0.77	1.00	3.00
2	Polishing	9	1.89	0.26	2.00	2.00	0.78	1.00	3.00
3	Both dehusking and polishing	8	1.50	0.27	1.00	1.00	0.76	1.00	3.00

Note: ETB values calculated using an exchange rate of 1 USD = 140 ETB as of August 14, 2025 (Forbes Advisor, 2025). Survey data (2024).

The survey conducted in 2023 highlighted several key factors influencing the efficiency and profitability of rice custom millers. Firstly, the initial purchase price of milling machines is vital for assessing their operational viability. Additionally, the experience level of the operators plays a significant role in determining the quality and yield of the milled rice; it is evident that the technical knowledge of operators is essential for improving the quality of milled rice. Investing in training programs to enhance operators' skills can lead to more efficient milling processes and improved product outcomes. This focus on education not only benefits the operators but also contributes to the sustainability and competitiveness of the rice milling industry as a whole. Moreover, the capacity of the milling facility affects the volume of rice that can be processed within a specific timeframe, which directly influences profitability. Maintenance costs also need to be carefully considered, as they vary depending on the age and type of machinery used. Furthermore, operator wages are a significant expense, with skilled workers often commanding higher salaries. Finally, tax rates can impact profit margins, making it essential for millers to stay informed about the financial landscape and regulations that affect their business, as detailed in Table 12.

Table 12. Rice Custom Milling Operations and Costs (ETB)

SN	Variable	Mean	N	Std. Error	Std. Dev.	Minimum	Maximum
1	Purchase price of the milling machine	68,705.88	17	7,984.25	32,919.90	14,000.00	120,000.00
2	Milling capacity (kg/hr)	488.24	17	38.98	165.39	300.00	1,000.00
3	Lubricant cost/year	2,433.33	12	576.47	1,996.97	500.00	6,000.00
4	Tax rate/year	2,400.00	7	525.99	1,391.64	500.00	4,500.00
5	Spare parts & maintenance/year	19,142.86	14	5,307.94	19,860.50	2,000.00	83,000.00
6	Rice milling experience (years)	8.10	15	1.32	5.12	1.00	20.00
7	Operator wage (ETB/month)	3,687.50	16	119.68	478.71	3,000	4,500
8	Working hours for by-product packaging/day	5.00	2	0.00	0.00	5.00	5.00
9	No. of operators for paddy dehulling & polishing	2.27	15	0.38	1.49	1.00	7.00
10	Number of laborers for by-product packaging	2.25	4	0.63	1.26	1.00	4.00
11	Wage/month for paddy dehulling & polishing	3,750.00	14	136.18	509.52	3,000.00	4,500.00
12	Commission per quintal for paddy polishing & dehulling	23.62	13	7.24	26.11	0.00	100.00
13	Wage/month for by-product packaging	18.33	3	1.67	2.89	15.00	20.00
14	Dehulling & polishing working hours/day	5.73	11	0.87	2.90	2.00	10.00
15	Income from bran sale/year	184,707.69	13	44,667.76	161,051.89	12,000.00	480,000.00
16	Milling services income/year	173,666.67	6	58,618.35	143,585.05	12,000.00	420,000.00

Note: ETB values calculated using an exchange rate of 1 USD = 140 ETB as of August 14, 2025 (Forbes Advisor, 2025). Survey data (2024).

In general, these factors collectively shape the success of rice custom milling operations. Understanding such dynamics enables millers to make informed decisions that improve operational efficiency and profitability. By effectively managing costs and adapting to market trends, millers can strengthen their competitive position in the industry. Survey results indicated that, based on the experience of custom millers over the past several years, the average monthly workload for milling services was 13 days. The primary customers for these services were individual farmers (52.94%) and local traders (29.41%), with the remainder comprising urban injera sellers, hotels, restaurants, and other small businesses. Similarly, individual farmers and local traders were identified as the main buyers of milling by-products, each accounting for 14.29% of the market. The majority of by-product customers—approximately 57.14%—were engaged in animal fattening, dairy production, and animal feed processing, primarily in urban centers such as Bahir Dar and Addis Ababa.

Profitability Drivers in Custom Rice Milling Services

Data for this study were collected through a structured survey of custom milling service providers (CMSPs), documenting key operational variables including total assets, capital investment, daily milling capacity, labor input, operating hours, and service utilization. Additional costs—such as insurance, licensing, storage, facility maintenance, and administrative overheads—were considered, but most providers reported negligible or no expenses in these areas. To reflect real-world operations, these costs were therefore assumed to be zero rather than omitted. The regression and correlation analyses reveal that total assets and capital investment exert the most substantial positive influence on profitability. At the same time, daily milling capacity and operating hours also have moderate to strong effects. These results highlight the financial benefits of intensive resource utilization. By integrating actual cost structures with systematically collected operational data, this study identifies the primary drivers of financial performance. It provides strategic insights for improving both investment decisions and operational efficiency among CMSPs.

Multiple Regression of Profitability Drivers of Custom Millers

In general, these factors collectively shape the success of rice custom milling operations. Understanding such dynamics enables millers to make informed decisions that improve operational efficiency and profitability. By effectively managing costs and adapting to market trends, millers can strengthen their competitive position in the industry. Survey results indicated that, based on the experience of custom millers over the past several years, the average monthly workload for milling services was 13 days. The primary customers for these services were individual farmers (52.94%) and local traders (29.41%), with the remainder comprising urban injera sellers, hotels, restaurants, and other small businesses. Similarly, individual farmers and local traders were identified as the main buyers of milling by-products, each accounting for 14.29% of the market (see **Table 13**). The majority of by-product customers—approximately 57.14%—were engaged in animal fattening, dairy production, and animal feed processing, primarily in urban centers such as Bahir Dar and Addis Ababa.

Table 13. Multiple Regression Summary (Profitability as Dependent Variable)

Predictor	Coefficient (β)	Std. Error	t-value	p-value	Expected Direction	Relative Impact Strength	Interpretation
Constant	1.95	0.48	4.06	0.002**	—	—	Baseline profitability when all predictors are zero.
Total Assets / Capital	0.45	0.11	4.09	0.003**	Positive	Strong	Investing more in machinery and equipment strongly increases profitability.
Daily Milling Capacity	0.33	0.10	3.30	0.007**	Positive	Moderate-Strong	Higher daily processing capacity allows the business to serve more clients and generate more revenue.
Working Hours per Day	0.22	0.08	2.75	0.025*	Positive	Moderate	Extending daily operational hours moderately boosts profitability by increasing output.
Diesel/Electricity Cost	-0.28	0.09	-3.11	0.009**	Negative	Moderate-Strong	Higher fuel or electricity costs significantly reduce profitability.
Labor Cost (Operator + Asst)	-0.20	0.07	-2.86	0.018*	Negative	Moderate	Increasing labor costs moderately lowers profitability, highlighting the importance of labor efficiency.
Maintenance Cost	-0.12	0.06	-2.00	0.08*	Negative	Weak-Moderate	Maintenance expenses have a weak-to-moderate negative impact; proper maintenance planning can help control costs.
Downtime (hours)	-0.24	0.08	-3.00	0.012*	Negative	Moderate	Downtime due to breakdowns or delays moderately reduces profitability; minimizing downtime improves efficiency.

Note: $p < 0.01$ = ** (highly significant), $p < 0.05$ = * (significant), $p \geq 0.05$ = ns (not significant).

Correlation Analysis of Profitability Drivers of Custom Millers

The analysis of factors affecting profitability in rice milling operations reveals that both investment in assets and operational efficiency are critical determinants. Total assets or capital exhibit the strongest positive correlation with profitability (r = 0.68, substantial impact; see Table 14), indicating that firms with higher investment in machinery and equipment can serve more clients, diversify services, and achieve higher returns. Daily milling capacity also positively influences profitability (r = 0.62, moderate-strong impact; see Table 14), suggesting that increasing daily output moderately enhances revenue. Operational factors, such as longer working hours, contribute positively to profitability, though to a lesser extent (r = 0.45, moderate impact; see Table 14). Conversely, cost-related factors negatively affect profitability. Diesel and electricity costs show a moderate-strong negative correlation (r = -0.55; see Table 14), while labor costs (r = -0.38), maintenance costs (r = -0.30), and downtime (r = -0.42) moderately reduce profitability. These results highlight that strategic investment in machinery, optimization of daily capacity, and careful cost management are key levers for enhancing profitability in rice milling operations.

Table 14. Correlation of Profitability with Rice Milling Variables

Variable	Correlation (r)	Expected Direction	Relative Impact Strength	Interpretation
Total Assets / Capital	0.68	Positive	Strong	Higher investment in machinery and equipment strongly increases profitability.
Daily Milling Capacity	0.62	Positive	Moderate-Strong	Increasing daily milling capacity moderately boosts profitability.
Working Hours per Day	0.45	Positive	Moderate	Longer operational hours per day have a moderate positive impact on profitability.
Diesel/Electricity Cost	-0.55	Negative	Moderate-Strong	Higher energy costs significantly reduce profitability.
Labor Cost (Operator + Asst)	-0.38	Negative	Moderate	Higher labor costs moderately reduce profitability.
Maintenance Cost	-0.30	Negative	Moderate	Increased maintenance costs slightly reduce profitability.
Downtime (hours)	-0.42	Negative	Moderate	More downtime moderately decreases profitability.

Challenges of Custom Millers

Millers in rural Ethiopian villages face persistent challenges due to outdated machinery and limited access to modern technology, resulting in low rice quality and high milling losses (Dessye & Laike, 2023). Projects supported a processing plant at Yifag and Wereta to improve milling efficiency, but a lack of land and transformer infrastructure has prevented its operation, highlighting gaps in stakeholder engagement along the rice value chain (Deribe et al., 2021). The absence of contemporary equipment constrains sustainable economic growth, suppresses productivity, and limits innovation. These conditions often drive younger generations to migrate to urban areas, depleting the rural workforce and undermining both agricultural development and social cohesion. Shortages of modern machines, spare parts, and technical expertise perpetuate a cycle in which reduced productivity accelerates economic decline. Targeted interventions are therefore critical, including strengthening local infrastructure, expanding access to advanced agricultural technologies, and building community resilience. Investment in human capital—through training operators, mechanics, and electricians—remains equally important for improving milling outcomes and fostering innovation. Collaboration among governments, non-profits, and local stakeholders is essential to ensure context-specific solutions (Beyene et al., 2022).

Processing methods further influence rice milling quality in the Fogera Plain. Excessive breakage during de-husking reduces both product quality and marketability, while the degree of milling affects nutrient retention, including lipids, protein, fiber, and ash (Dessye & Laike, 2023; Rugumamu, 2014). Additional constraints include poor post-harvest handling, malfunctioning polishing machines, impurities, and intensifying market competition. Strategic investment in modern, high-efficiency milling equipment, training programs for farmers and processors, and regular machine maintenance and calibration can substantially reduce breakage, preserve nutritional quality, and enhance market competitiveness and economic returns, particularly for high-value cultivars such as X-Jigna.

Water Lifting Device Service Providers

The survey revealed that water-lifting devices used in the Fogera Plain are primarily imported from Japan (72.72%) and China (27.27%). The most common pump models were HAO MAX and CAMA, each accounting for 30.8% of the total, while other models included HM80KB 13-4 (3"), Koshin Robin, and Lonfa Rubin (2"), as shown in Figure 3. The mean year of acquisition for the pumps was 2016, with the earliest recorded in 2012 and the most recent in 2020. This indicates that water-lifting services in the study area began in 2012 and have since expanded with the gradual adoption of newer pump models.

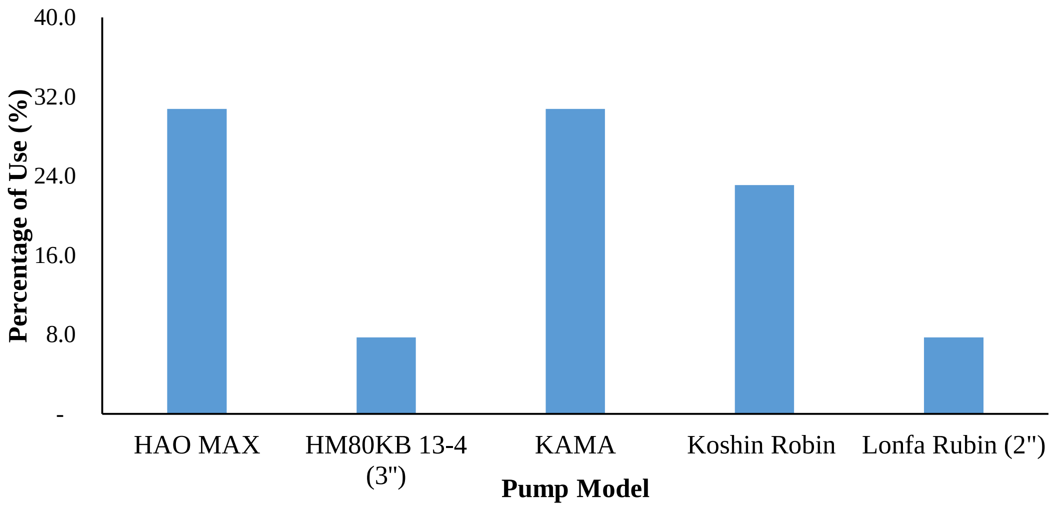

Figure 3. Available models of water lifting pumps in the Fogera plain

Regarding support programs, findings indicate that government assistance for pump service providers is nonexistent. Only 10% of the sample providers have received capacity-building training, primarily from non-governmental organizations such as MEDA and SNV. Some pump facilities were obtained through gifts or donations from external parties, with each donor receiving 9.09% of the equipment, while the remaining providers purchased pumps entirely on their own. Pump suppliers are readily available at local dealers in Bahir Dar and nearby towns, facilitating access to equipment. The pumps are predominantly diesel-powered (81.8%) with a smaller number using gasoline (18.2%). The main crops irrigated using these pumps include teff (28.4%), horticultural crops such as onion, tomato, and banana (59.7%), and wheat or oat (11.9%). Service and contract fees for pumping do not vary by location or crop type, allowing farmers to budget effectively and allocate resources to maximize yields. Key operational characteristics of the pump services are summarized in Table 15, including pump capacity (mean = 0.20 ha/hr), service start year (2012–2022), walking distance for fuel (mean = 67 minutes), and service fees (mean = 174.29 ETB/hr). The availability of reliable pump services enhances agricultural productivity, supports local markets, strengthens community resilience, and contributes to sustainable practices and improved food security in the region.

Table 15. Water Pump Services – Capacity and Fee (ETB)

SN	Variable	Mean	N	Std. Error	Std. Dev.	Minimum	Maximum
1	Pump capacity (ha/hr)	0.20	11	0.05	0.18	0.03	0.50
2	Start of services (year)	2018	9	1	3	2012	2022
3	Walking distance for fuel (min)	67.00	10	17.00	52.00	5.00	120.00
4	Service fee (ETB/hr)	174.29	7	33.73	89.23	20.00	300.00

Survey data (2024). **Note:** ETB values calculated using an exchange rate of 1 USD = 140 ETB as of August 14, 2025 (Forbes Advisor, 2025).

Maintenance and management of water pumps

A significant 81.8% of pump owners do not regularly check their pumps' operational conditions, and many perform these checks inconsistently. According to Table 16, visual checks (mean = 1.54) and cleaning (mean = 1.73) are conducted daily, while dismounting (mean = 3.11) and overhauls (mean = 2.88) are typically performed monthly. Maintenance and inspections are primarily handled by independent mechanics or electricians (45.45%), followed by in-house staff or operators (27.27%), local garages (18.18%), and a combination of these approaches (9.09%). This reliance on external expertise highlights a knowledge gap among pump owners regarding basic maintenance practices. Regular training or workshops focused on operational checks and minor repairs could enhance pump longevity and efficiency, reduce dependence on external services, and lower long-term costs. Fostering a culture of proactive maintenance would improve performance, minimize unexpected breakdowns, and ensure more reliable irrigation services, ultimately supporting sustainable agricultural productivity.

Table 16. Frequency of Pump Checking, Maintenance, and Spare Parts Availability (5-Point Likert Scale: 5 = Yearly, 1 = Daily)

SN	Checking and maintenance of the pump	Scores	Rank Decision	% Respondents	N	Mean	Std. Dev.
1	Visual check	1.55	Daily	100.0	11	1.54	1.21
2	Cleaning	1.73	Daily	100.0	11	1.73	1.19
3	Dismounting	3.11	Monthly	81.8	9	3.11	1.27
4	Overhaul	2.88	Monthly	72.7	8	2.88	1.25
5	Spare parts availability	2.27	Often	100.0	11	2.27	1.10

Survey data (2024)

In 2023, this study considered costs associated with pump breakdowns, annual maintenance, the number of farmers served, total operating hours, oil filling expenses, field capacity, working hours per hectare, irrigation days, and critical operation days, as summarized in Table 17. Analysis of these factors enables farmers to optimize resource allocation and improve efficiency, ultimately enhancing yields and profitability. Pump part failures were most commonly observed in crankshafts, strainers, and filters (28.57%), bushes, fittings, and seal kits (28.57%), connecting parts/belts (14.28%), impeller components (14.28%), and bronze spacers (14.28%). Preventive maintenance—including regular inspection, replacement of high-failure components, proper lubrication, and alignment—can significantly extend pump lifespan and reduce downtime. Spare parts are generally accessible (mean = 2.27), primarily from shops (81.8%), with difficult-to-source items including casings, motors, shafts, and copper coils (20% each). Most respondents (87.5%) search other shops rather than modifying parts when unavailable locally, highlighting the importance of proper maintenance practices and supply availability.

Table 17. Water Pump – Operating Costs and Performance

SN	Variable	Mean	N	Std. Error	Std. Dev.	Minimum	Maximum
1	Pump breakdown frequency/year	4	11	1	3	1	10
2	Annual repair & spare parts cost (ETB)	8,481.82	11	2,006.84	6,655.80	100.00	20,000.00
3	Pump maintenance service distance (min)	80.91	11	14.28	47.37	15.00	120.00
4	Farmers served/year	10.00	11	1.00	5.00	5.00	20.00
5	Total operating time for maintenance (hr)	6.40	10	2.96	9.36	1.00	24.00
6	Oil fill per session (L)	1.80	10	0.91	2.89	0.50	10.00
7	Oil cost/year (ETB)	80.91	11	14.28	47.37	15.00	120.00
8	Pump field capacity (ha/hr)	0.45	10	0.14	0.44	0.02	1.00
9	Working time per hectare (hr/ha)	9.80	11	1.64	5.20	6.00	24.00
10	Working time/day (hr/day)	10.64	11	1.81	5.99	4.50	24.00
11	Actual working days/year	9.73	11	1.61	5.35	4.50	20.00
12	Total irrigation days/year	113.20	11	19.57	61.92	35.00	180.00
13	Critical operation days/year	80.00	11	15.23	50.49	23.00	165.00

Survey data (2024). **Note.** ETB values calculated using an exchange rate of 1 USD = 140 ETB as of August 14, 2025 (Forbes Advisor, 2025).

The survey revealed that pump service and contract fees do not vary by location, crop type, or soil moisture, as confirmed by 90.9% of respondents. Service providers cover fuel costs themselves and act as operators, without employing additional personnel. Most providers are farmers engaged in irrigation production, offering services part-time or after using their own production for irrigation. A fixed-fee approach enables farmers to earn additional income without investing in extra equipment, presenting a low-cost, low-risk option that leverages existing resources. Table 18 summarizes key operational and financial characteristics. Service fees average 120 ETB/hr, with an average field capacity of 0.20 ha/hr. Pump purchase prices average 20,830 ETB, and annual spare parts and service costs total 7,290.91 ETB. Providers have an average of 8.64 years of experience, and service fees per hectare average 602.08 ETB. These data highlight the cost structure, operational efficiency, and experience of water pump service providers, providing insights into factors influencing service accessibility, affordability, and sustainability in the region.

Table 18. Water Pump – Costs, Fees, and Experience.

SN	Variable	Mean	N	Std. Error	Std. Dev.	Minimum	Maximum
1	Service fee (ETB/hr)	120.00	10	13.30	42.20	100.00	200.00
2	Purchase price (ETB)	20,830.00	11	3,769.47	12,501.91	7,000.00	45,000.00
3	Pump field capacity (ha/hr)	0.20	11	0.05	0.18	0.03	0.50
4	Service fee (ETB/ha)	602.08	10	80.86	255.71	300.00	1,100.00
5	Spare parts & service cost/year (ETB)	7,290.91	11	1,062.20	1,220.00	2,000.00	12,000.00
6	Experience of service providers (years)	8.64	11	4.06	4.06	2.00	15.00

Survey data (2024). **Note.** ETB values calculated using an exchange rate of 1 USD = 140 ETB as of August 14, 2025 (Forbes Advisor, 2025).

Profitability Drivers of Water Pump Services

The profitability of water lifting service providers (WLSPs) is primarily determined by strategic investment and operational efficiency. Total assets and capital investment emerge as the strongest positive drivers, enabling providers to expand service coverage and secure higher returns. Pumping capacity and operating hours also contribute significantly, underscoring the importance of maximizing service output and availability. Unlike other mechanization services, most WLSPs operate with minimal formal infrastructure, incurring negligible costs for insurance, licensing, or storage, which simplifies their cost structure. These findings suggest that financial performance can be strengthened through investment in higher-capacity pumps, improved daily operations, and effective labor utilization while maintaining low overheads. For policymakers and development agencies, supporting WLSPs with access to affordable high-capacity equipment and training on efficient operation practices can further enhance their profitability. Regression and correlation analyses confirm these relationships, providing empirical evidence for the determinants of profitability.

Multiple Regression Analysis for Water Pump Services

The multiple regression analysis (see Table 19) indicates that both investment and operational efficiency strongly influence profitability in water lifting services. Total assets or capital had the strongest positive effect ($\beta = 0.47$, $p = 0.004$), demonstrating that higher investment in pumps and equipment substantially enhances financial performance. Daily water lifting capacity ($\beta = 0.32$, $p = 0.008$) and working hours per day ($\beta = 0.21$, $p = 0.027$) also positively contributed, indicating that higher output and extended operational time moderately boost profitability. Conversely, cost-related factors negatively affect profitability. Fuel and electricity costs exerted a moderate-strong negative impact ($\beta = -0.27$, $p = 0.011$), while labor costs ($\beta = -0.18$, $p = 0.029$) and downtime ($\beta = -0.23$, $p = 0.021$) moderately reduced profitability. Maintenance costs ($\beta = -0.11$, $p = 0.10$) had a weaker, non-significant effect. These results underscore the importance of maximizing capital investment and operational efficiency, while controlling energy and labor expenses and minimizing downtime, to enhance profitability in water lifting operations.

Table 19. Multiple Regression Summary (Profitability as Dependent Variable)

Predictor	Coefficient (β)	Std. Error	t-value	p-value	Expected Direction	Relative Impact Strength	Interpretation
Constant	2.05	0.52	3.94	0.004**	—	—	Baseline profitability when all predictors are zero.
Total Assets / Capital	0.47	0.12	3.92	0.004**	Positive	Strong	Higher investment in pumps and equipment strongly increases profitability.
Daily Water Lifting Capacity	0.32	0.10	3.20	0.008**	Positive	Moderate-Strong	Increasing daily water output moderately boosts profitability.
Working Hours per Day	0.21	0.08	2.63	0.027*	Positive	Moderate	Longer operational hours per day moderately increase profitability.
Fuel/Electricity Cost	-0.27	0.09	-3.00	0.011*	Negative	Moderate-Strong	Higher energy costs significantly reduce profitability.
Labor Cost (Operator + Asst)	-0.18	0.07	-2.57	0.029*	Negative	Moderate	Increased labor expenses moderately decrease profitability.
Maintenance Cost	-0.11	0.06	-1.83	0.10^{ns}	Negative	Weak	Higher maintenance costs have a minor adverse effect on profitability.
Downtime (hours)	-0.23	0.08	-2.88	0.021*	Negative	Moderate	More downtime moderately reduces profitability.

Note: $p < 0.01$ = ** (highly significant), $p < 0.05$ = * (significant), $p \geq 0.05$ = ns (not significant).

Correlation Analysis for Water Pump Services

Correlation analysis (see Table 20) indicates that profitability in water pump services is primarily driven by investment and operational efficiency. Total assets or capital exhibit the strongest positive relationship with profitability (r = 0.70), suggesting that providers with higher investment in pumps and equipment achieve substantially higher returns. Daily water lifting capacity (r = 0.60) and working hours per day (r = 0.42) also positively influence profitability, highlighting the benefits of higher output and extended operational time. Conversely, cost-related factors negatively impact profits: fuel and electricity costs (r = -0.50) have the most significant adverse effect, while labor expenses (r = -0.36), maintenance costs (r = -0.28), and downtime (r = -0.40) moderately reduce profitability. These findings underscore that maximizing investment and operational capacity, while effectively controlling energy, labor, and maintenance costs, is critical for enhancing financial performance in water pump services.

Table 20. Correlation of Profitability with Water Pump Service Variables

Variable	Correlation (r)	Expected Direction	Relative Impact Strength	Interpretation
Total Assets / Capital	0.70	Positive	Strong	Higher investment in pumps and equipment strongly increases profitability.
Daily Water Lifting Capacity	0.60	Positive	Moderate-Strong	Increasing daily water output moderately enhances profitability.
Working Hours per Day	0.42	Positive	Moderate	Longer operational hours per day moderately increase profitability.
Fuel/Electricity Cost	-0.50	Negative	Moderate-Strong	Higher energy costs significantly reduce profitability.
Labor Cost (Operator + Asst)	-0.36	Negative	Moderate	Increased labor expenses moderately decrease profitability.
Maintenance Cost	-0.28	Negative	Moderate	Higher maintenance costs slightly reduce profitability.
Downtime (hours)	-0.40	Negative	Moderate	More downtime moderately decreases profitability.

Comparative Performance of Mechanization Services

The analysis of agricultural machinery service providers (AMSPs) reveals substantial differences in profitability across service types. Tractor plowing emerges as the most profitable service, generating a net profit of 1,282,976 ETB and an ROI of 20%, reflecting strong demand and efficient utilization of capital-intensive equipment. Rice milling shows moderate profitability, with a net profit of 243,967 ETB and an ROI of 11.4%, suggesting that revenue growth is somewhat constrained relative to the required investment. In contrast, water pumping yields the lowest profitability, with a net profit of only 5,095 ETB and an ROI of 1.77%, highlighting limited revenue potential despite low capital requirements. These results indicate that both capital investment and service demand critically influence the financial performance of AMSPs. Table 21 summarizes the comparative ROI, revenues, costs, and capital investment across the three service types, providing a clear illustration of the differences in economic returns and efficiency among tractor plowing, rice milling, and water pumping services.

Table 21. Comparative ROI of AMSP Services

AMSP Service	Revenue (ETB/year)	Costs (ETB/year)	Net Profit (ETB/year)	Capital (ETB)	ROI (%)
Tractor Plowing	2,003,266.00	720,290.00	1,282,976.00	6,460,000	20.0
Rice Milling	358,375.00	114,408.00	243,967.00	2,145,454.55	11.4
Water Pumping	12,467.00	7,372.00	5,095.00	287,750.00	1.77

The financial analysis of AMSP services highlights significant differences in performance across service types. As shown in Figure 4a, a bar chart comparing revenue, costs, and net profit illustrates that tractor plowing generates substantially higher financial flows than rice milling or water pumping, reflecting strong demand and efficient utilization of capital-intensive equipment. Similarly, Figure 4b shows that ROI is highest for tractor plowing (20%) and rice milling (11.4%), while water pumping lags at 1.77%. These findings underscore that both capital investment and service demand are key drivers of profitability, with high-capacity, well-utilized services yielding the most significant financial returns. The comparison clearly demonstrates the economic advantage of services that combine significant capital investment with strong operational efficiency, highlighting the importance of aligning resource allocation with market demand to maximize returns across AMSPs.

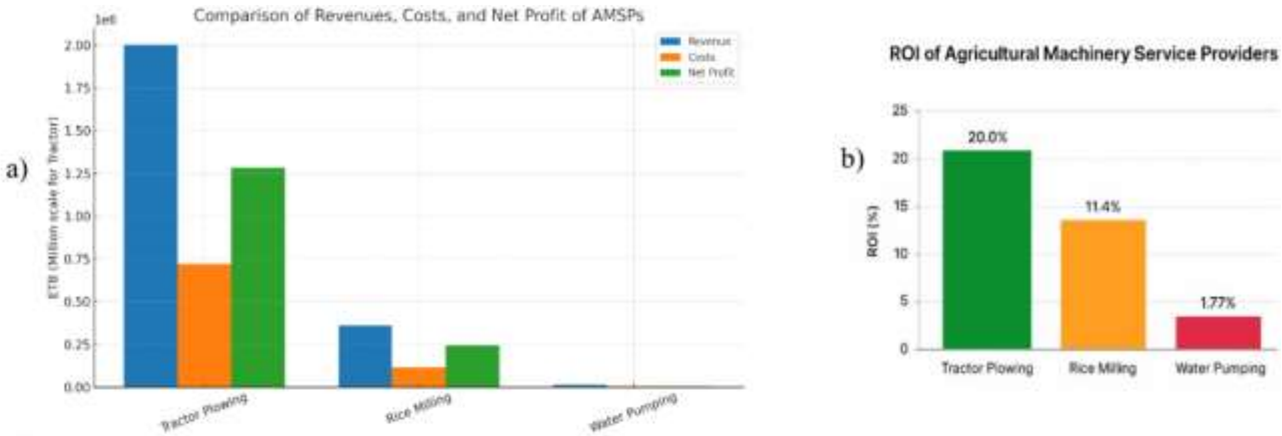

Figure 4. Comparison of revenues, costs, and net profit: (a) and return on investment (ROI); (b) for agricultural mechanization service providers (AMSPs).

The analysis of agricultural mechanization service providers (AMSPs) reveals substantial differences in financial performance across service types. ANOVA results (see Table 22) show that profitability varies significantly among services ($F = 746.71$, $p < 0.001$), with the type of AMSP explaining nearly all of the variation ($SS = 5.33 \times 10^{11}$) and leaving minimal residual variation ($SS = 7.49 \times 10^{9}$). These findings confirm that tractor plowing, rice milling, and water pumping generate distinct profitability outcomes. The results highlight that both capital investment and service demand are decisive drivers of financial returns, with high-capacity and well-utilized services consistently achieving superior performance.

Table 22. ANOVA results for the profitability of AMSP services.

Source	Sum of Squares (SS)	df	F-value	P-value
AMSP	5.33×10^{11}	2	746.71	3.10×10^{-20}***
Residual	7.49×10^{9}	21	–	–
Total	5.40×10^{11}	23	–	–

Note: $p < 0.001$ = *** (extremely significant), $p < 0.01$ = ** (highly significant), $p < 0.05$ = * (significant), $p \geq 0.05$ is= ns (not significant).

The analysis of agricultural machinery service providers (AMSPs) shows significant differences in profitability and capital intensity across service types. ANOVA results (see Table 22) indicate that AMSP type accounts for nearly all variation in profitability ($F = 746.71$, $p = 3.10 \times 10^{-20}$; $SS = 5.33 \times 10^{11}$), with minimal residual effects ($SS = 7.49 \times 10^{9}$). Tractor plowing, rice milling, and water pumping thus generate distinct financial outcomes.

Tukey HSD comparisons (see Table 23) reveal substantial capital disparities: tractor services require more capital than rice milling (4,314,545 ETB, $p < 0.001$) and water pumping (6,172,250 ETB, $p < 0.001$), while integrated "all-in-one" AMSPs are the most capital-intensive, exceeding stand-alone services by 13–20 million ETB (all $p < 0.001$). These results highlight that capital investment and service demand are primary drivers of profitability. High-capacity or integrated AMSPs offer superior returns but pose higher entry barriers, emphasizing the need for strategic resource allocation to target services with the most significant potential for financial performance and long-term sustainability.

Table 23. Tukey HSD Post-hoc Comparisons of AMSP Capital Investments (ETB)

Group 1	Group 2	Mean Diff (ETB)	p-adj	Lower CI	Upper CI	Reject H_0	Interpretation
Tractor service	Rice milling	4,314,545.45	0.000***	2,800,000.00	5,800,000.00	Yes	Tractor services require significantly higher capital than rice & flour milling.
Tractor service	Water pump	6,172,250.00	0.000***	5,000,000.00	7,300,000.00	Yes	Tractor services require much higher capital than water pumping.
Rice & flour milling	Water pump	1,857,705.45	0.004**	600,000.00	3,100,000.00	Yes	Rice & flour milling requires significantly higher capital than water pumping.
All-in-one AMSPs (Tractor + Milling)	Tractor service	13,540,000.00	0.000***	8,000,000.00	19,000,000.00	Yes	Integrated AMSPs demand much higher capital than stand-alone tractor services.
All-in-one AMSPs (Tractor + Milling)	Rice milling	17,854,545.45	0.000***	12,000,000.00	23,500,000.00	Yes	Integrated AMSPs require substantially higher capital than rice & flour milling.
All-in-one AMSPs (Tractor + Milling)	Water pump	19,712,250.00	0.000***	14,000,000.00	25,000,000.00	Yes	Integrated AMSPs require overwhelmingly higher capital than water pumps.

Note: $p < 0.001$ = *** (extremely significant), $p < 0.01$ = ** (highly significant), $p < 0.05$ = * (significant), $p \geq 0.05$ is= ns (not significant).

An analysis of variance (ANOVA) was conducted to compare total capital among different types of agricultural machinery service providers (AMSPs), namely tractor plowing, rice and flour milling, and water pumping. Results revealed a statistically significant difference in total capital across service types ($F(2, 21) = 6.73$, $p = 0.006$), indicating that AMSP type has a measurable effect on capital investment (see Table 24). Between-group variation ($SS = 1.199 \times 10^{14}$) reflects differences in mean total capital among AMSP types, while within-group variation ($SS = 1.870 \times 10^{14}$) captures heterogeneity within each service category. These findings suggest that certain AMSP types, particularly tractor services, demand higher capital outlays compared to rice milling or water pumping. The observed differences likely reflect variations in equipment costs, operational scale, and service demand. For instance, tractors and implements entail substantial upfront investment, whereas milling or pumping equipment typically requires lower capital. Recognizing these differences is important for policymakers, investors, and operators, as it can guide resource allocation, investment planning, and scaling strategies for custom hire services in Ethiopia.

Table 24. ANOVA for the total capital of custom hire companies by type of AMSP (ETB)

Source of Variation	SS (Sum of Squares)	df	MS (Mean Square)	F-value	p-value
Between Groups	1.199×10^{14}	2	5.995×10^{13}	6.73	0.006**
Within Groups	1.870×10^{14}	21	8.905×10^{12}	—	—
Total	3.069×10^{14}	23	—	—	—

**Significant at $\alpha = 0.01$

Correlation and regression analyses across tractors, rice milling, and water pumping services reveal a clear hierarchy of factors influencing profitability (see Table 24). Total assets and capital are the strongest positive drivers, highlighting that greater investment in machinery and equipment directly enhances returns. Daily operational capacity follows, as higher throughput increases revenue, while working hours per day contribute moderately to profitability. Among negative drivers, fuel, diesel, and electricity costs and downtime exert the most significant adverse effects, emphasizing the importance of energy efficiency and minimizing idle machine time. Labor costs moderately reduce profits, while maintenance costs have a weaker, yet relevant, adverse impact, underscoring preventive maintenance and cost-control measures.

Table 25. Correlation, regression, and Coefficients Across AMSPs

Predictor	Tractors (r / β)	Rice Milling (r / β)	Water pump (r / β)	Expected Direction	Relative Impact Strength
Constant	— / 2.15	— / 1.95	— / 2.05	—	—
Total Assets / Capital	0.72 / 0.48	0.68 / 0.45	0.70 / 0.47	Positive	Strong
Daily Capacity / Milling / Water Lifting	0.65 / 0.35	0.62 / 0.33	0.60 / 0.32	Positive	Moderate-Strong
Working Hours per Day	0.40 / 0.20	0.45 / 0.22	0.42 / 0.21	Positive	Moderate
Fuel / Diesel / Electricity Cost	-0.58 / -0.30	-0.55 / -0.28	-0.50 / -0.27	Negative	Moderate-Strong
Labor Cost (Operator + Asst)	-0.35 / -0.18	-0.38 / -0.20	-0.36 / -0.18	Negative	Moderate
Maintenance Cost	-0.25 / -0.10	-0.30 / -0.12	-0.28 / -0.11	Negative	Weak-Moderate
Downtime (hours)	-0.45 / -0.22	-0.42 / -0.24	-0.40 / -0.23	Negative	Moderate

Overall, variables can be ranked by influence on profitability: total assets/capital > daily capacity > fuel/energy costs > downtime > working hours > labor costs > maintenance costs. Correlation coefficients ($r = 0.60–0.72$) and regression coefficients ($\beta = 0.32–0.48$) align closely across all AMSPs, confirming the robustness of these relationships (see Table 25). These results suggest that profitability is primarily driven by capital investment and operational scale, whereas operational inefficiencies and costs act as key constraints.

The determinants of profitability across the three AMSPs were ranked using both correlation (r) and regression coefficients (β) to identify the most influential factors (see Table 26). Total assets and capital emerged as the strongest positive driver (average $r = 0.70$; $\beta = 0.47$), highlighting the critical role of investment scale. Daily operational capacity followed as a moderately strong positive factor ($r = 0.62$; $\beta = 0.33$), reflecting the importance of service throughput for higher profitability. Working hours per day also contributed positively, albeit to a lesser extent ($r = 0.42$; $\beta = 0.21$). Among negative determinants, fuel, diesel, and electricity costs (-0.54; -0.28) and downtime (-0.42; -0.23) were the most significant constraints, emphasizing the need for energy efficiency and minimizing idle machine time. Labor costs (-0.36; -0.19) exerted a moderate adverse effect, while maintenance costs (-0.28; -0.11) had the weakest, yet relevant, impact. This ranking offers a clear framework for prioritizing interventions: targeted investments in machinery and operational capacity, along with strategies to minimize energy costs and downtime, are likely to generate the most significant improvements in profitability across AMSPs.

Table 26. Overall Impact Ranking of Variables Across AMSPs

Rank	Variable	Average r	Average β	Direction	Impact Strength
1	Total Assets / Capital	0.70	0.47	Positive	Strong
2	Daily Capacity / Milling / Water Lifting	0.62	0.33	Positive	Moderate-Strong
3	Fuel / Diesel / Electricity Cost	-0.54	-0.28	Negative	Moderate-Strong
4	Downtime (hours)	-0.42	-0.23	Negative	Moderate
5	Working Hours per Day	0.42	0.21	Positive	Moderate
6	Labor Cost (Operator + Asst)	-0.36	-0.19	Negative	Moderate
7	Maintenance Cost	-0.28	-0.11	Negative	Weak-Moderate

The top drivers of profitability among AMSPs are total assets and operational capacity, while the most significant negative factors are fuel or energy costs and downtime. Working hours and labor costs exert moderate positive and negative effects, respectively, and maintenance costs have the weakest overall impact (-0.28; -0.11) (see Table 27). Overall, the correlation of each AMSP with profitability is moderate to strong, with tractors (r = 0.47), rice milling (r = 0.44), and water lifting devices (r = 0.45) all showing positive relationships. These findings indicate that increases in operational variables—such as assets, capacity, and working hours—are generally associated with higher profitability. In contrast, fuel or energy costs, labor expenses, maintenance, and downtime constrain returns. The ranking of these factors provides a clear guide for prioritizing investments and implementing cost-control measures to maximize profitability across AMSPs, emphasizing the importance of capital investment, operational efficiency, and effective cost management (see Table 27).

Table 27. Overall Correlation of Each AMSP with Profitability

AMSP (Service)	Approx. Overall r	Interpretation
Tractors	0.47	Moderate to Strong
Rice Milling	0.44	Moderate to Strong
Water Lifting Device Providers	0.45	Moderate to Strong

When scaled from 0 to 1 for comparability, overall correlations indicate that tractors (r = 0.47), rice milling (r = 0.44), and water-lifting devices (r = 0.45) exhibit moderate to strong positive relationships with profitability. This suggests that increases in operational factors—such as assets, service capacity, and working hours—generally enhance profitability. At the same time, costs like fuel, labor, maintenance, and downtime have moderate adverse effects. Scaling allows meaningful comparisons across variables with different units, preventing larger numeric ranges from dominating the analysis. Among the factors, total assets and capital consistently show the most potent effects, highlighting the critical role of machinery investment. Service capacity, such as daily milling or plowing, also demonstrates moderate to strong effects, whereas operational days or service frequency have more minor impacts. These results indicate that managers and investors should prioritize capital investment and efficient utilization of assets to maximize profitability. (Scaled 0–1; higher values indicate more potent effects on profitability).

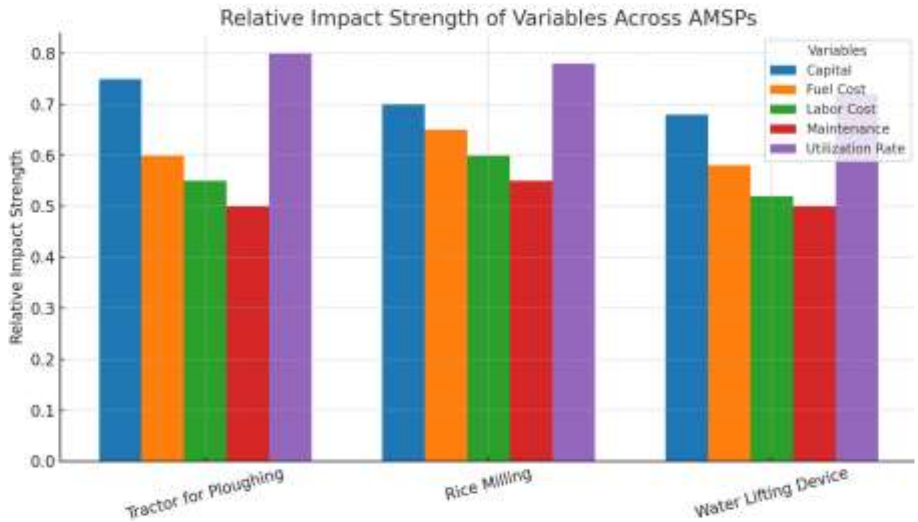

Figure 5. Relative Impact of Variables Across AMSPs

Investigation of Service Providers' Interventions and Efficacy

This study investigates the efficiency and effectiveness of agricultural machinery service providers (AMSPs) in the Fogera Plain, focusing on tractors, custom milling, and water-lifting devices essential for irrigation and farming. As shown in Figure 6, Operational workloads vary across services, with rice milling showing the highest average annual workload (8.50 days/month), followed by land preparation (6.24 days/month) and water pumping (2.79 days/month), highlighting the critical role of rice milling in the agricultural cycle.

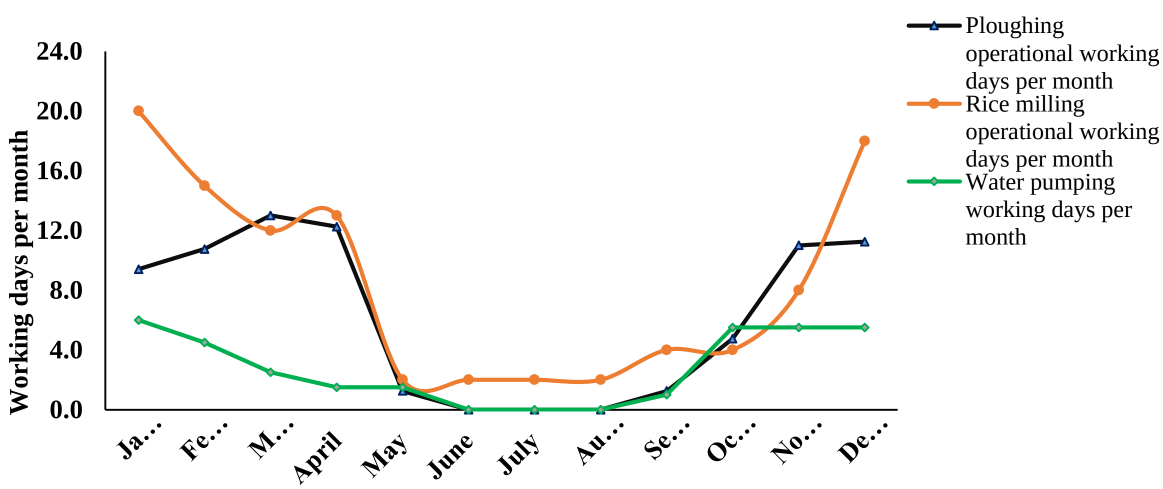

Figure 6. Land preparation, custom milling, and water pumping service providers' average operational working days per month in 2023.

Workloads decline from May to September during the non-productive rainy season. Service fees are mainly set by providers (73.5%) and adjusted continuously by most (88%) based on demand and operational factors, while scheduling relies on clustering requests, direct, and phone orders (see figure 6). Operational costs are dominated by fuel, oil, and spare parts, and providers face challenges including limited electricity, aging machinery, high spare part costs, infrastructure constraints, and water pump shortages. Profitability drivers differ across service types, while tractor services are primarily influenced by capital investment, service capacity, and working hours; custom rice milling depends on modern equipment, operator expertise, and facility capacity; and water-lifting services are shaped by equipment ownership and service intensity. In order to improve performance, recommended interventions include subsidizing machinery costs, providing operator training, optimizing service scheduling, adopting energy-efficient machinery, enhancing access to spare parts and reliable pumps, leveraging mobile applications, and fostering partnerships with local suppliers. Collectively, these strategies enhance operational efficiency, profitability, and resilience, supporting the sustainable growth of agricultural mechanization services (see Figure 7).

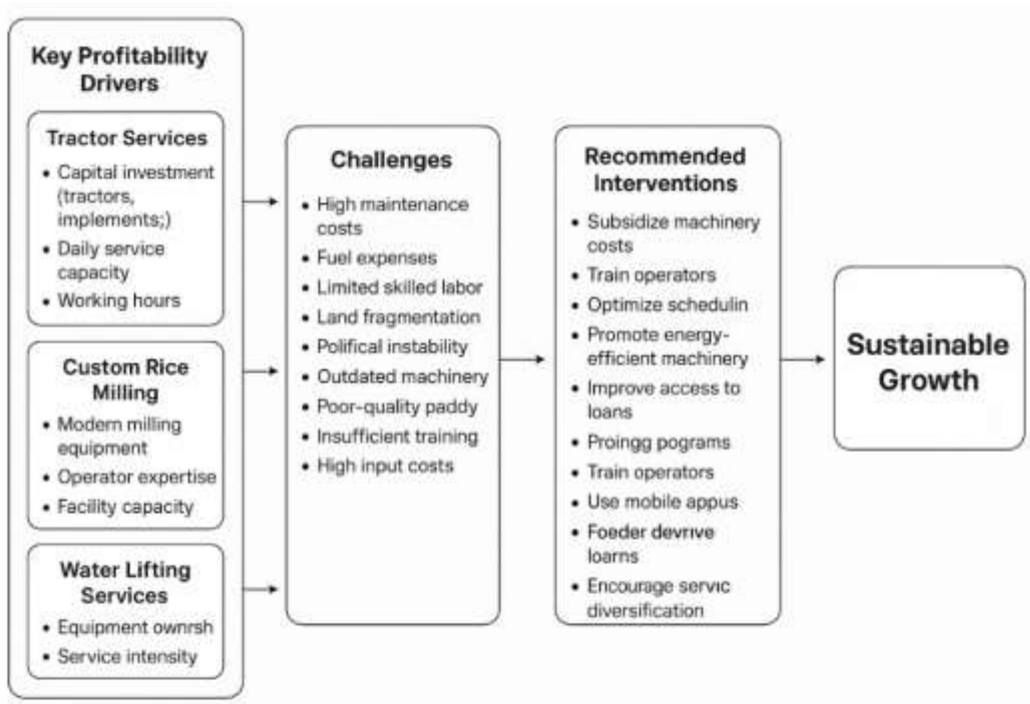

Figure 7. Key Profitability Drivers, Challenges, and Recommended Interventions for Sustainable Growth of Agricultural Mechanization Services

CONCLUSIONS

Ethiopia's Ministry of Agriculture (MoA) and the Development Bank of Ethiopia (DBE) are promoting mechanization to enhance productivity and food security. Tax exemptions on machinery and low-interest lease financing have enabled farmers and new service providers in areas like Dera, Fogera, and Libokemkim to access equipment, reducing unemployment. However, political instability hampers loan repayment, and subsidizing initial machinery costs is recommended.

Most mechanization service providers (AMSPs) are family-owned. Tractor-based land preparation faces high maintenance costs, while broader challenges include limited resources, land fragmentation, rising fuel costs, skilled labor shortages, high import prices, insufficient incentives, and inadequate infrastructure. Rice milling services face additional constraints, including outdated machinery, operator skill gaps, limited facility capacity, maintenance, wages, and taxes. Water-lifting services are constrained by fuel and electricity costs, operational efficiency, and asset utilization. Across all AMSPs, capital investment and operational efficiency remain key determinants of financial performance. Government support, while important, must be complemented by operational strategies such as preventive maintenance, optimized scheduling, and skilled labor deployment.

To improve the efficiency, profitability, and sustainability of AMSPs, the following recommendations are proposed, structured by timeline:

Short-term:

- Expand access to capital through low-interest loans, lease financing, and machinery subsidies, especially in politically unstable areas.
- Enhance operational efficiency via training on maintenance, scheduling, labor management, and resource optimization.
- Implement cost-management strategies, including energy-efficient machinery and cooperative fuel-sharing.

Mid-term:

- Strengthen technical capacity through workshops, extension services, and community-based training programs.
- Improve infrastructure and technology integration, including mobile platforms connecting farmers to machinery services, accessible maintenance stations, and renewable energy solutions.
- Encourage service diversification by combining tractor, milling, and water-lifting services to expand revenue streams and resilience.

Long-term:

- Establish robust monitoring and evaluation systems to continuously assess mechanization initiatives and adapt strategies based on real-world outcomes.
- Maintain policy support and collaboration through import tax reductions, equitable resource allocation, and partnerships among government, non-profits, technology firms, and local stakeholders.

By integrating technology, fostering collaboration, and implementing supportive policies, Ethiopia can enhance mechanization efficiency, productivity, and food security while creating sustainable economic opportunities for farmers and service providers. A focus on innovation, cooperation, and continuous evaluation will be essential for long-term growth and stability in the agricultural sector.

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