Agricultural mechanization indicators and power requirements of farming operations in Ethiopia

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Abstract: Ethiopian agriculture is dominated by a smallholder farming system, where the farmers rely on traditional farming method, which is labor-intensive and prone to drudgery. Appropriate mechanization should replace human labor in agriculture, but there is a low level of mechanization in the country. Based on this, the study aimed at evaluating agricultural mechanization indicators and power required for farming operations in the Hitosa district, Ethiopia. In this study, a total of 104 (80 farmers and 24 agricultural experts) were selected using multistage sampling techniques. Interviews, observations, and semi-structured questionnaires were used to collect the required data. The agricultural mechanization status of the study area was determined by the degree, level, and capacity of mechanization. The level of mechanization in the study area was 0.2098 kW ha^{-1} and, to reach 1.1186 kW ha^{-1}, 264 tractors would be required. The aggregate degrees of mechanization carried out by motorized, human and draught animal power for wheat were 0.1964 0.0487 and 0.1270 kW-hr ha^{-1}, respectively. The work done by all the power sources, as quantified mechanization indices, were 52% and 64% for wheat and barley respectively. This implies that the levels of agricultural mechanization in the study area are low. Therefore, appropriate use of mechanization input by the farmers in Hitosa district is highly encouraged for high agricultural productivity. Hence, the government and different stakeholders should facilitate the mechanization inputs to mechanized farming systems in Hitosa district to ensure food security.

Keywords: agricultural mechanization, mechanization indicators, mechanization index, Ethiopia

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1 Introduction

Agriculture is a backbone of Ethiopian economy. It contribute over 40% of the Gross Domestic Product (GDP) , accounts over 75% of the labor force and earn over 90% from export (Eshetu and Mehare, 2020) and largely dominated by smallholdings farming that powered by humans and/or animals (Baudron et al., 2015). Aware of this fact, the government of the country made one of the priority agendas in transforming the Ethiopian agricultural sector (Deribe et al., 2021). The source of farm power in the country predominantly relies on draught animal power. In general, the majority of small farm holders have been cultivating their lands manually except for some parts of the wheat-growing regions of Arsi and Bale highlands (Baudron and Gerard, 2013). This indicates that the country's agriculture is characterized by low level of mechanization.

Agricultural mechanization is a crucial input for

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agricultural production which has been neglected in the context of developing countries (Fadavi et al., 2010). Farm machinery utilization level in Ethiopia is low due to lack of mechanization policy (Amare and Endalew, 2016). A mechanized input in agriculture has a direct and significant effect on land and labor productivity, profitability, and sustainability (Olaoye and Rotimi, 2010). The power availability and mechanization indicators (mechanization index, consumed power and mechanization level), can be selected to assess the agricultural mechanization input (Singh, 2006).

According to Asfaw et al. (2012), attaining increased productivity and growth among smallholder farmers is impossible without developing and disseminating improved agricultural technology. Improving productivity, profitability, and sustainability of smallholder farming is the main pathway to getting out of poverty (Estrella et al., 2022).

In Ethiopia, agricultural mechanization is being encouraged to boost agricultural production as the country is characterized by a high growth rate of population. In such conditions where the population of the country grows at an alarming rate, the role of mechanization in agricultural production should stands out more than before. Therefore, agricultural mechanization should be applied to enhance agricultural productivity and achieve sustainable development.

Even with significant improvement in productivity in recent years, Ethiopia is still a net wheat importer. Determining mechanization status could be used as input for government policymakers for the decision-making process related to agricultural structure and service providers. Therefore, the main objective of the study was to determine the status of agricultural mechanization and power required for farming operations using agricultural mechanization parameters in the Hitosa district, Ethiopia. Such information should assist the policy formulation and planning of appropriate mechanization practices for smallholder farmers in Hitosa district specifically and Ethiopia in general.

2 Materials and method

2.1 Study location

The study was conducted in the Oromia Regional State Hitosa district, Ethiopia. The district lies between 7° 53' 0"–8° 14' 0" N latitude and 39° 9' 30"–39° 23' 30" E longitude with an elevation of 2430 m. The altitude of the district ranges from 1500 m to 4170 m above mean sea level. The temperature of the district varies between 20.5°C to 27°C with a minimum annual rainfall of 800 mm. The study area was more convenient for mechanization than other areas in the country (Hassena et al., 2000). Therefore, farmers in this area are relatively better in terms of agricultural mechanization level.

2.2 Data collection methods

The data were collected and organized from primary and secondary sources. The methods used to collect the data were questionnaires, interviews, observation, document analysis, and literature review. Agricultural mechanization indicators such as level, degree, and capacity of mechanization were computed to determine the status of agricultural mechanization practices among smallholder farmers.

A multistage sample procedure was adopted to collect the data. Using stratified random sampling. The kebeles were stratified into three strata: traditional farming, semi-mechanized farming (draught animal and engine power as motive power sources), and mechanized farming (engine power as motive power sources). In total, 104 respondents (80 farmers and 24 experts) were selected using systematic random sampling.

2.3 Determination of agricultural mechanization indicators and power requirements

In different countries, the three indices that used to study and evaluate mechanization are degree, level, and capacity of mechanization (Zangeneh and Banaeian, 2014).

2.3.1 Degree of mechanization

It used to evaluate the extent of different agricultural operations performed by humans, animals, or engine-powered (Almasi et al., 2000). The degree of farm mechanization is the ratio of mechanized operations to total operations (Ghadiryanfar et al., 2009). It can be also expressed as the average energy input of work provided exclusively by human power (labor) per hectare (Olaoye and Rotimi, 2010). According to Nowacki (1974) and Ortiz-Canavate and Salvador (1980), three degrees of farm mechanization were established and they are as sated below**.**

Degree of Mechanization M1: indicates operations carried out exclusively by human power and determined by:

$$L_{MH} = \frac{0.1 \times N_H \times T}{A} \quad (1)$$

Where, LMH =Work outlay of human beings (kW-h ha-1);

0.1 = Human power (male/female) in (kW);

NH = Number of persons working;

T = Time devoted to farm work (hr);

A = Area of land (ha).

Degree of Mechanization M2: indicates operations carried out by man and animal-drawn machines and estimated by:

$$L_{MK} = \frac{Z \times N_A \times T}{A} \quad (2)$$

Where, LMK =Work outlay of draft animal pulling implements (kW-hr ha-1);

Z = Single animal power in (kW);

NA = The number of animal working.

Degree of Mechanization M3: indicates operations carried out by motorized machinery and estimated by:

$$L_M = \frac{0.2 \times RP \times N_t \times T}{A} \quad (3)$$

Where, LM =Average energy input or work per hectare by motorized machine (kW-hr ha-1);

0.2 =Corrector co-efficient of the tractor-powered machine;

RP =Rated working power of the tractor (kW);

Nt =Number of power units;

T =Working time of the motorized energy source (hr);

A =The area worked in hectares by motorized machines (ha).

According to (Gebrselassie, 2012), the estimated power for men, women, and children were 0.1614 , 0.1319, and 0.1066 kW, respectively, and according to (Rasooli Sharabiani and Ranjbar, 2008), the estimated power for ox, donkey, mule, horse and cow were 0.5966, 0.3729, 0.5966, 0.7457, and 0.5966 kW, respectively,

2.3.2 Mechanization index

It represents the ratios of total work done by the tractor to total of human, animal and machinery (Singh, 2006). It also used to measure the assessment and grading of the different levels of mechanization practiced in a particular area and estimated by (Olaoye et al., 2017);

$$MI = \frac{P_M}{P_H + P_A + P_M} \quad (4)$$

Where, MI = Mechanization index;

PM = Total mechanical power (kW);

PH = Total human power (kW);

PA = Total draught animal power (kW).

2.3.3 Level of mechanization

It can be determined in terms of farm power availability per hectare (kW ha^{-1}), the number of tractors/1000 ha, ha/tractor, mechanical power/total power, and equipment weight/tractor (Canakci et al., 2005). According to (Pishbin, 2013; Almasi et al., 2000).

$$Level\ of\ Mechanization (kWha^{-1}) = \frac{Total\ power\ of\ tractors}{Cultivated\ area} \quad (5)$$

2.3.4 Mechanization capacity

It is amount of energy consumed in a unit area. Use to describe the potential of farm machine availability in an area. According to Iran Consulting (2000), Animal, Human and Mechanical energy: the energy produced by the animal, human and mechanical during a working day respectively, and computed by:

$(Animal\ energy\ (kWhr)) = (Total\ existing\ animal\ power) \times$

(*Animal functional animal hours*) (6)

(*Human energy (kWhr)*)=(*Total existing labor power*)×(*Animal functional labor hours*) (7)

(*Mechanical energy (kWhr)*)=(*Total existing mechanical power*)×(*Animal functional mechanical hours*) (8)

Table 1 Energy produced by animals during a working day

Animal	Horse	Donkey	Mule	Working cow	Bull
Corresponding power (kW)	0.7457	0.3729	0.5966	0.5966	0.5966

Note: Source (Rasooli and Ranjbar, 2008)

2.3.5 Determination of power requirement

The power required for farm operation is based on the number of tractors and combined harvesters available for use. The major way to measure the capacity of machinery is by workdays required to complete field operations. This depends on the land size, performance of machinery, machine size, and the availability of labor. According to (Rasooli and Ranjbar, 2008), the number of tractors and combines required:

$$\left(Necessary\ tractor\ power\left(kW\right)\right)=\frac{Determined\ Mechanization\ level^{a}\times Cultivated\ area\ (ha)}{Conversion\ Coefficient(0.75)} \tag{9}$$

$$\begin{pmatrix}\text{Required number}\\ \text{of combines}\end{pmatrix}=\begin{pmatrix}\text{Necessary number}\\ \text{of combines}\end{pmatrix}-\begin{pmatrix}\text{Existing active}\\ \text{combines}\end{pmatrix} \tag{10}$$

According to (Iran Consulting, 2000; Rasooli and Ranjbar, 2008), the determined mechanization level for developing countries is 1.1186 kW ha^{-1}.

2.4 Data analysis

The quantitative and qualitative primary and secondary data were collected, processed, and analyzed by tabulating, figures, and graphs. Analyzing the data, interpreting the results, and reporting the findings of the research were done by using SPSS version 26 software. Descriptive statistics such as mean, median, standard error, frequency and percentage were applied to describe the characteristics of the respondents and the results. Collected data were analysed and interpreted in the form of a table, pie charts, bar graphs and regression graphs. This was used to describe and analyze the smallholder farmer's characteristics including, farm activity and related entities of the sample smallholder farmers.

3 Results and discussion

3.1 Demographic and socioeconomic characteristics of smallholder farmers

The selected respondents were interviewed to find their background which is related to age, sex, education, marital status, household head, family size, accessibility to tractors and combine harvesters, cluster farming, crop protection methods, farm distance, and source of income. In total, 80 sample households' heads of smallholder farmers and 24 agricultural experts were considered in the study. Table 2 implied that most respondents (47.5%) were a productive age, which could result in a positive effect on crop production.

Among the total respondents, 96.3% of the farmers were engaged in agriculture, while only 3.7% were engaged in other businesses. According to Berhanu et al. (2019), smallholder farming in Ethiopia was dominated by mixed farming. In contrast, this study revealed that most of the respondents in the study areas were more engaged with crop production than mixed farming. Hence, the study area seemed to be more favourable for crop production than animal rearing.

Most of the farmers (76%) in the study area can read and write, which is crucially important to maximize their production. According to (CSA, 2021), the largest category of the household under the national level was illiterate which accounted for 49.62%. The result showed that the percentage of educated farmers was higher than the national level. This implied that awareness of smallholder farmers in the study area was higher than at the national level.

The study found that, farmers who have a better farming experience have a better engagement with farming than non-experienced ones. Similarly, Chiremba and Masters (2003) reported a similar idea, as farming experience is a better predictor of good farming performance.

Table 2 Socio-demographic characteristics of the sample of smallholder farmers

Variables	Categories	Frequency	Per cent
Age of farmers	Below 38	24	30
	38-50	38	47.5
	Above 50	18	22.5
Marital status	Single	2	2.5
	Married	78	97.5
Household head	Male	71	88.8
	Female	9	11.2
Family size	Less than 3	26	32.5
	4 to 6	30	37.5
	Greater than 6	24	30.0
Source of income	Crop production	62	77.5
	Mixed farming	15	18.8
	Other business	3	3.7

3.2 Land use and crop production patterns

The land is one of the important inputs for smallholder farmers. Owning land is considered a matter of life and death in smallholder farming. One of the determinant factors for agricultural mechanization is the size of the land, which is a mainstay for farmers. Ethiopia is the second-most populous nation in Africa. This makes it more difficult to own land and has resulted in smaller farm sizes. The size of the farm becomes decreased with the increased population, and the cropland has been fragmented among more people. These are some of the constraints of using farm mechanization input to sustain agricultural production in the country (Elias et al., 2013). But the country as well as the study area has great potential for agriculture because of fertile land, diverse climate, adequate rainfall, and a large labor pool. Besides that, the topography and awareness of the smallholder farmers in the study area made the farmers to use mechanization inputs such as machinery, improved seeds, and fertilizers. The total area of the landholdings of the sample households is 134 hectares.

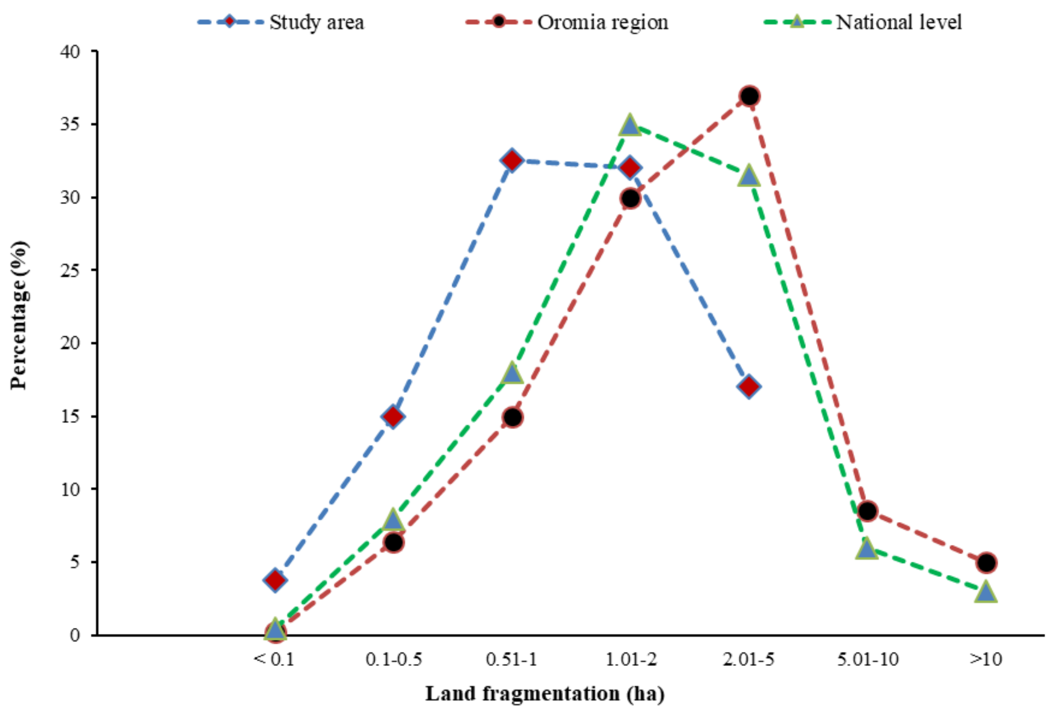

Figure 1 Comparison of national, regional, and the study area of landholding size

The result showed that in the study area there was high fragmentation of land among the farmers. The proportion of fragmented lands was very high, which has negative implications for farm mechanization. When the land is fragmented, irregular shapes of land have occurred. This led to difficulty in machinery use, waste of time, capital and labor, loss of soil and productivity, and arising land conflicts.

The total sample area of the land (95%) was a plane field while 5% of the land is sloppy (irregular). Because of the aforementioned facts, the study area is convenient for mechanization. In the study area, the aggregate level, and average yield of the first five major crops; wheat, barley, bean, maize, and *Teff* were 3.494, 2.84, 2.715, 3.284, and 1.293 ton ha^{-1}, respectively, in the 2021 *Meher* (long rain season June to October) season.

3.3 Farm power use and constraints in the study area

3.3.1 Sources of farm power

Agricultural mechanization in Ethiopia can be divided into three levels of technology based on farm power: hand-tool technology, draught animal technology, and engine-powered technology (Kelemu, 2015). Due to financial problems in the study area as well as in the country level, smallholder farmers cannot access farm machinery appropriately. In the area where service providers are available, the farmers use agricultural technology through rent. Even though many farmers rented tractors and combine harvesters, seed coverage and subsequent tillage operations in the study area were performed using draught animal power. This showed that in the study area, a shortage of modified technologies that were used to improve production as an alternative to tractor-drawn implements existed.

3.3.2 Rental-based farm power use for pre and postharvest operations

In the study area as well as at the national level, many farmers have been using both draught animal and farm machinery by renting. This reveals that, there was no full mechanization in the study area. Mixed use of tractor and animal power was also there. During primary tillage operation, most of the farmers (72%) used tractors for first plowing, while some farmers (13%) used draught animals, and 15% both draught animals and tractors together (farmers use animals and/or tractors power). In contrast to 1st plowing, most of the farmers in the study area used draught animals or oxen for the second plowing (47%), harrowing (70%) and seed covering (88%) (Figures 1 and 2).

As illustrated in Figure 2, the majority 70% and 88% of the farmers in the study area used draught animal power for harrowing and sowing operations, respectively, while some of the farmers (25%) ignored harrowing operations and operate the subsequent ones. This showed that the farmers had awareness of minimum tillage operation and cost minimization. Only 6% of smallholder farmers cover their seeds using tractors (planters). This implied that the farmers neither have any awareness of planting crops with planters nor that the equipment or planters were not available in the study area.

As indicated in Figure 3, most of the farmers (61%) in the study area used the mechanized ways of weed control method, while 6% of them used manual weeding and 33% of them used both manual weeding and chemical. In total, 94% and 96.25% of smallholder farmers used chemical and combine harvesters to control weeds and harvest their crops respectively. According to Agricultural Transformation Agency [ATA] (2021) in the Oromia region, farmers who used combine harvesters for wheat and barley crops were about 58.93%. Similarly, Berhane et al. (2017) reported that 14.5% and 30% of farmers in the Arsi and Bale zones, respectively used combine harvesters for harvesting wheat.

A comparative study conducted by Hassena et al. (2000) in a similar district showed that 41% of the farmers were using manual harvesting. Similarly, Koroso (2016) in the same study area showed that 7.78% of the farmers used manual harvesting. This time, the percentage of the farmers who were using manual harvesting in a similar district (where the study was conducted) was only 3.75%. This showed that the farmers' awareness increased from time to time and the usage of mechanization increased drastically.

3.3.3 Constraints of smallholder farmers and mechanization service provider

In the study area, most of the farmers (80%) agreed on the shortage of farm machinery during normal and peak operational times. These, delayed farm operation especially in planting and harvesting decreases crop productivity. The majority of Agricultural Mechanization Service Providers (AMSPs) agreed that the working environment (85%) that is topography, farmers' awareness, climatic conditions, etc. were convenient for delivering the services. However, the road access is not convenient (83.4%). This indicated that the government's role in providing infrastructure was not fulfilled. Not only that, the skilled human power for operating (66.6%) and maintaining (95.8%) farm machinery was very low especially, for mechanics.

This might increase the downtime of farm machinery.

3.3.4 Cluster farming in the study area

The study found that, farmers who were organized in cluster farming had better access than unorganized farmers in agricultural inputs and government/professional follow-ups, so that the productivity was increased. This is also supported by Hussen and Geleta (2021) finding that smallholder farmers participating in cluster farming have better access to machinery, improved seeds, and fertilizer.

3.4 Model development in agricultural mechanization

The study used three models: model-1) the traditional farming model which uses the draught animals as a source of power; model-2) the semi-mechanized farming model which uses draught animals and machines as a motive power, and model-3) the mechanized farming model which uses engine power as a source of power (Koroso, 2016).

Table 3 Input values of a wheat farm operation for the three models on a hectare

	Operation / Parameters	Primary and Secondary operations			Planting and managing		Harvesting operation			Total
		1st plow	2nd plow	Harrowing	Seed covering	Weed control	Harvesting	Threshing	Transporting and storage	
Model-1	No of oxen required	8	6	6	8	-	-	18	8	54
	Required days for oxen	4	3	3	4	-	-	2	2	18
	Required hour for oxen	24	18	18	24	-	-	144	64	292
	No of labor required	4	3	3	8	20	16	10	6	70
	Required hour for labor	24	18	18	48	160	128	80	48	524
	Cost for oxen (Birr)	2400	2200	2000	2000	-	-	-	800	9400
	Cost for labor (Birr)	-	-	-	600	3000	2400	1500	900	8400
	Total operation cost (Birr)	2400	2200	2000	2600	3000	2400	1500	1700	17800
Model-2	Required hour for tractor	1:30	-	-	-	-	30min	-	1	3
	Required days for oxen	-	3	3	4	-	-	-	-	10
	Required hour for oxen	-	18	18	24	-	-	-	-	60
	No of labor required	1	3	3	8	6	1	-	2	24
	Required hour for man	1:30	18	18	48	48	30min	-	16	150
	Cost for tractor (Birr)	2500	-	-	-	-	3200	-	-	5700
	Cost for oxen (Birr)	-	2200	2000	2000	-	-	-	-	6200
	Cost for labor (Birr)	-	-	-	600	900	-	-	320	1820
	Total operation cost (Birr)	2500	2200	2000	2600	900	3200	-	320	13720
Model-3	Tractor hour required	1:30	-	30min	1	-	30min	-	1	4:30
	No of man required	1	-	1	2	2	1	-	2	9
	Man-hour required	1:30	-	30min	2	4	30min	-	16	24.5
	Cost for tractor (Birr)	2500	-	2000	2300	-	3494	-	-	10294
	Cost for labor (Birr)	-	-	-	150	300	-	-	350	800
	Total operation cost (Birr)	2500	-	2000	2450	300	3494	-	350	11094

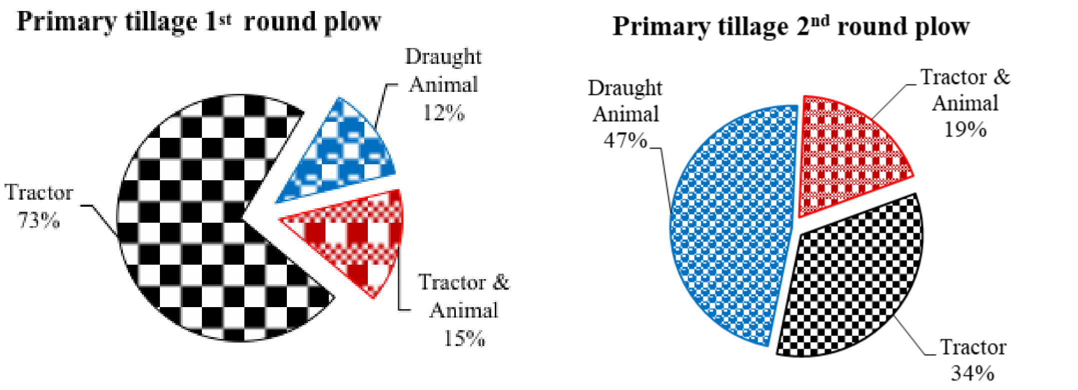

Figure 2 Sources of farm power for primary tillage operations

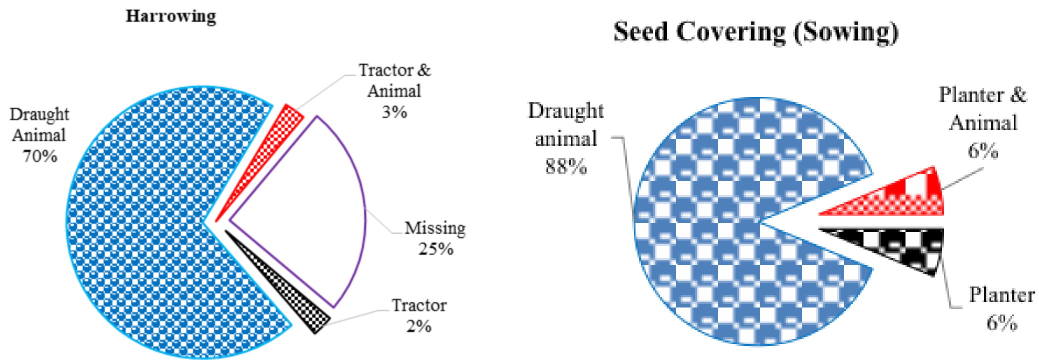

Figure 3 Sources of farm power for secondary tillage operations

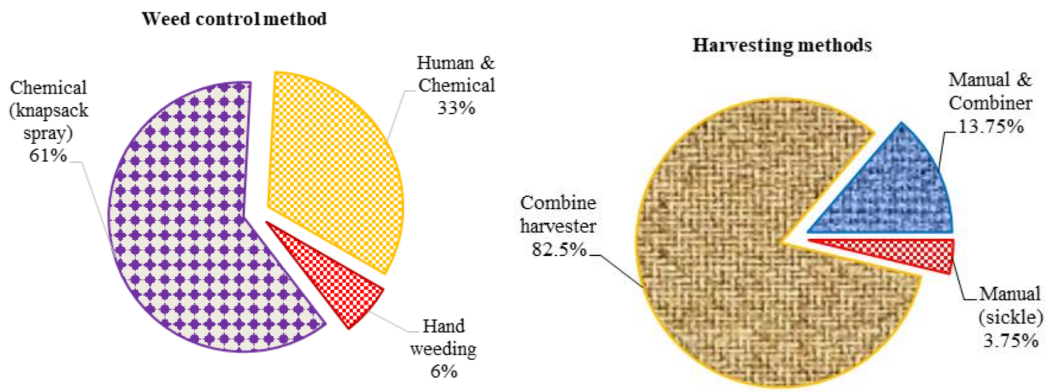

Figure 4 Sources of farm power for weed control and harvesting operations

3.5 Mechanization indicators in the study area

3.5.1 Farm machinery population

The mechanization indicators describe the mechanization status of the smallholder farming system in terms of the proportion of farming activities covered by machine work to the total power sources (Diao et al., 2016). There were about 112 registered farm machinery in the study area, out of which tractors and combine harvesters accounted for 73.2% and 26.8% respectively.

A comparative study conducted by Koroso (2016) in a similar district showed that 22, registered farm machinery were in the study area. This time, the number of farmers who were using farm machinery in a similar district (where the study was conducted) was 112. This showed that the usage of farm machinery in the Hitosa district increased by fivefold. This implied that the number of tractors and combine harvesters increased drastically in the study area.

3.5.2 Level of mechanization

The level of mechanization is the extent of use of mechanical power sources and equipment on a farm. It can be measured by the tractor and combine harvester availability in an area. To investigate the mechanization level in terms of kW ha^{-1}, it was necessary to determine the number of all kinds of active tractors in the study area which is used as the source of draft power. Therefore, the total power of all tractors and combine harvesters in the study area was shown in Table 5.

Table 4 Input values of a barley farm operation for the three models on a hectare

	Operation / Parameters	Primary and secondary operations			Planting and managing		Harvesting operation			Total
		1st plow	2nd plow	Harrowing	Seed covering	Weed control	Harvesting	Threshing	Transporting and storage	
Model-1	Required no of oxen	8	6	-	8	-	-	12	6	40
	Required days for oxen	4	3	-	4	-	-	2	2	15
	Required hours for oxen	24	18	-	24	-	-	96	48	210
	No of labor required	4	3	-	6	16	16	9	6	60
	Hours for man required	24	18	-	36	128	128	72	48	454
	Cost for oxen (Birr)	2400	2200	-	2000	-	-	-	600	7200
	Cost for labor (Birr)	-	-	-	300	2400	2400	1500	900	7500
	Total operation cost (Birr)	2400	2200	-	2300	2400	2400	1500	1500	14700
Model-2	Tractor hour required	1:30	-	-	-	-	30min	-	1	3
	Required days for oxen	-	3	-	4	-	-	-	-	7
	Required hour for oxen	-	18	-	24	-	-	-	-	42
	No of labor required	1	3	-	8	5	1	-	2	20
	Required hours for labor	1:30	18	-	48	40	30min	-	16	124
	Cost for tractor (Birr)	2500	-	-	-	-	2400	-	-	4900
	Cost for oxen (Birr)	-	2200	-	2000	-	-	-	-	4200
	Cost for man (Birr)	-	-	-	600	750	-	-	240	1590
	Total operation cost (Birr)	2500	2200	-	2300	750	2400	-	240	10390
Model-3	Required hour for tractor	1:30	-	-	1	-	30min	-	1	4
	No of labor required	1	-	-	2	2	1	-	2	8
	Required hours for labor	1:30	-	-	1:30	2	30min	-	16	21.5
	Cost for tractor (Birr)	2500	-	-	2300	-	2840	-	-	7640
	Cost for labor (Birr)	-	-	-	150	300	-	-	285	735
	Total operation cost (Birr)	2500	-	-	2450	300	2840		285	8375

Table 5 The total power and number of active farm machinery in the study area

	Type	Mean nominal power in hp	Number of tractors	Conversion coefficient	Total power (hp)	Total power (kW)
Tractors	Belarus	103	3	0.75	231.75	172.8160
	Case IH	125	11	0.75	1031.25	769.0031
	Cherry	97.5	8	0.75	585	436.2345
	Swift	80	1	0.75	60	44.742
	Foton	90	2	0.75	135	100.6695
	John Deere	132.86	7	0.75	697.52	520.1407
	Landini	128.33	29	0.75	2791.18	2081.3830
	Massey Ferguson	122.625	8	0.75	735.75	548.6488
	New Holland	130	10	0.75	975	727.0575
	YTO	100	3	0.75	225	167.7825
	Total tractor power	-	82	-	7467.44	5568.4700
Combine harvesters	Class	130	22	0.75	2145	1599.5265
	New Holland	160	3	0.75	360	268.452
	John Deere	145	1	0.75	108.75	81.0949
	Massey Ferguson	130	2	0.75	195	145.4115
	Nova	169	2	0.75	253.5	189.0350
Total combine harvester power		-	30		3062.25	2283.5199
	Total mechanical power				10,529.69	7851.9899

According to Table 5 and Equation 5, since the total cultivated area of the Hitosa district is 26582 hectares, the mechanization level in the study area was 0.2098 kW ha^{-1}. This simply means that the average nominal power of one tractor in the study area works for 324.17 hectares. According to Seccatore et al. (2014), a low level of mechanization can be characterized by a low level of production without considering other factors. In contrast to this, higher levels of mechanization are preferred by farmers to ensure timeliness, increase productivity, and reduce the cost of cultivation. Therefore, an increased level of farm power increases production.

3.5.3 Required farm power

The level of mechanization can be determined by the number of farm machinery (tractors) in the study area (Rasooli and Ranjbar, 2008). By using Equation 9, the required number of tractors showed that the necessary tractor power was 39644.3948 kW, of which 7398.8354 kW existed in the study area and so 32245.5594 kW was required. In this study, the average nominal power of the tractor was 93.2125 kW. Finally, 346 tractors of the same nominal power were estimated to meet the requirements of the study area. This means that to reach the 1.1185 kW ha^{-1} level of mechanization in the study area, 346 tractors would be needed, while 82 tractors existed. Therefore, additional 264 tractors with a nominal power of 93.2125 kW per tractor are required.

Based on Equation 10, and the result shown in landscape, the required number of combine harvesters indicated that 95% of the landscape was a plane field which was convenient for mechanization and the total cultivated area of wheat and barley were 21189 hectares in the study area in 2021 *Meher* season. That is an overall 20130 hectares of land were harvestable by combine harvesters. According to the operational calendar of the district from October 1 to December 30, in which November is peak time, the allotted time or workable days for harvesting is 30 days in the district. The maximum hectare harvested by one combine harvester of Hitosa Farmers' Cooperative Union at study area from October 1 to December 30, 2021, (workable period) was 295 hectares. Extensive studies show that the mean performance of Combine harvesters is 10 hectares per day (Kiani and Houshyar, 2012). Therefore, the performance of each Combine harvester's workable period in the study area is 300 hectares. So, using Equation 10 the number of combine harvesters needed was 67 of which only 30 combines existed. Therefore, the remaining 37 combine harvesters were required.

3.5.4 Mechanization capacity

Mechanization capacity is the consumed kW-hr in crop production via three energy resources (human, draught animal and mechanical) Rasooli and Ranjbar (2008). As shown in Tables 6 and 7, the consumed human energy by traditional farming (model-1) was higher than semi-mechanized and mechanized farming (model-2). This implied that traditional farming consumed more human power than the others. Based on Equations 6, 7, and 8, the total consumed energy via human, draught animal, and mechanical power sources by wheat and barley crops were calculated and summarized in Tables 7 and 8.

According to Table 7, the total consumed kW-hr in the sample area by model-1, model-2, and model-3 were 264449.4462, 48193.6992, and 47039.4529 kW-hr, respectively. In the sample cultivated area of 134 hectares, the total consumed kW-hr ha^{-1} by the wheat crop were 1974.8614, 359.7125, and 350.8179 kW-hr ha^{-1} for model-1, model-2, and model-3, respectively.

Table 7 revealed that the consumed kW-hr ha^{-1} (mechanization capacity) of wheat crops by energy-producing sources; human and animal energy comprised for model-1 was 29% and 71%, respectively. Similarly, for model-2 the kW-hr expenditure per hectare via human, animal, and mechanical was 5.3%, 29.7%, and 65% while for model-3 0.13%, 0%, and 99.87% of the energy was consumed, respectively. The result showed that as traditional farming was changed to mechanized farming, the human energy expenditure would be decreased while the mechanical energy increased.

As shown in Table 7, human energy consumed by model-1 was higher than that of model-2 and model-3 by 89% and 99.7%, respectively. Similarly, the consumed mechanical energy by model-3 was higher than that of model-2 by 34.9%, and the consumed animal energy by model-1 was higher than that of model-2 by 58.2%.

Table 7 revealed that the total consumed horsepower-hour (kW-hr) in the sample area for barley crops by model-1, model-2, and model-3 were 134645.083, 37708.5576, and 41800.4372 kW-hr, respectively. The total consumed horsepower-hour per hectare was 1004.8308, 281.4272, and 311.9263 kW-hr ha^{-1} for model-1, model-2, and model-3, respectively. Accordingly, for model-1, the horsepower-hour per hectare (kW-hr ha^{-1}) expenditure by energy-producing sources; human, animal, and mechanical energy were 36.2%, 63.8%, and 0%, respectively. Similarly, for model-2, the consumed hp-hr ha^{-1} was 4%, 13%, and 83% while for model-3, it was 0.1%, 0%, and 99.9% of the total consumed hp-hr ha^{-1} via human, animal, and mechanical, respectively. This showed the vital importance of mechanical aids in crop production. As shown in Table 8, the consumed hp-hr ha^{-1} of human energy by model-1 was higher than model-2 and model-3 by 89% and 99.7%, respectively. Similarly, consumed mechanical energy by model-3 was higher than model-2 by 17%.

Table 6 Consumed kW-hr ha^{-1} of the wheat crop in mechanization models

	Type	Consumed kW-hr	Consumed kW-hr per hectare	Share of resource (%)
Model-1	Human energy	76600.9885	571.6536	29
	Animal energy	187873.448	1402.0651	71
	Mechanical energy	0	0	0
	Total	264474.436	1973.71876	100
Model-2	Human energy	2577.1392	19.2391	5.3
	Animal energy	14317.44	106.8588	29.7
	Mechanical energy	31319.4	233.7024	65
	Total	48213.9792	359.8003	100
Model-3	Human energy	59.4323	0.44742	0.13
	Animal energy	0	0	0
	Mechanical energy	46979.1	350.5536	99.87
	Total	47038.5323	351.0010	100

Table 7 Consumed kW-hr ha^{-1} of the barley crop in mechanization models

	Type	Consumed kW-hr	Consumed kW-hr per hectare	Share of resource (%)
Model-1	Human energy	48740.1451	363.7525	36.2
	Animal energy	85904.64	641.0783	63.8
	Mechanical energy	0	0	0
	Total	134645.083	1004.8308	100
Model-2	Human energy	1478.2757	11.0364	4
	Animal energy	4910.8819	36.6884	13
	Mechanical energy	31319.4	233.7024	83
	Total	37708.5576	281.4272	100
Model-3	Human energy	41.23721	0.2983	0.1
	Animal energy	0	0	0
	Mechanical energy	41759.2	311.6280	99.9
	Total	41800.4372	311.9263	100

As shown in Figure 4, the consumed horsepower-hour of human and draught animals would decrease as the farming system changed from traditional farming (model-1) to mechanized farming (model-3), while the consumed horsepower-hour of mechanical energy would increase. In mechanized farming, the consumed horsepower-hour of human energy would be very small, and that of the animal energy zero.

3.5.5 Degree of agricultural mechanization

It used for determining the extent of different operations carried out by farm power sources (humans, animals, or machinery) (Almasi et al., 2000). It also indicates the extent to which a given operation in the crop production system is mechanized.

Based on Equation 1, the degree of mechanization operations carried out exclusively by human power for the wheat crop was 0.1317, 0.0135, and 0.0008 kW-hr ha^{-1} for model-1, model-2, and model-3, respectively, while the aggregated degree of mechanization carried out by human power (human energy) was 0.0510 kW-hr ha^{-1}. Similarly, the degree of mechanization carried out by the human energy for barley crop in model-1, model-2 and model-3 were 0.1025, 0.0093, and 0.0006 kW-hr ha^{-1}, respectively, while the mean of human energy in the three models was 0.0375 kW-hr ha^{-1} (Table 8).

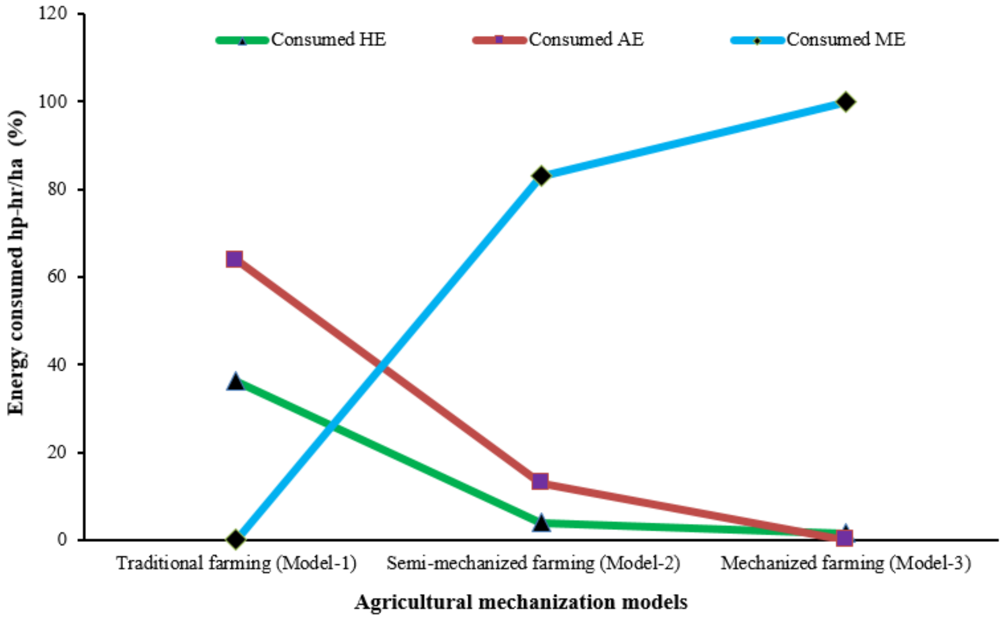

Figure 5 Energy (kW-hr ha^{-1}) consumed in agricultural mechanization models

Table 8 Summary of the degree of mechanization for the three models

	Wheat			Barley		
	HE	DAE	ME	HE	DAE	ME
Model-1	0.1766	0.4749	0	0.1375	0.2531	0
Model-2	0.0181	0.0362	0.3161	0.0125	0.0177	0.3161
Model-3	0.0011	0	0.4742	0.0008	0	0.4215

Note: HE- Human Energy, DAE-Draught Animal Energy, and ME-Mechanical Energy

Similarly, based on Equation 2, the degree of mechanization operations carried out by draught animals for the wheat crop was 0.3541, 0.0270, and 0 kW-hr ha^{-1} for model-1, model-2, and model-3, respectively; while the aggregated degree of mechanization of operations carried out by animals was 0.1270 kW-hr ha^{-1}. Likewise, the degree of mechanization carried out by draught animal energy for barley crop in model-1, model-2 and model-3 were 0.1887, 0.0132, and 0 kW-hr ha^{-1}, respectively, while the mean of draught animal for the three models was 0.0906 hp-hr ha^{-1}. In mechanized farming, the source of power was human and motorized; therefore, the work outlay by draught animals was zero kW-hr ha^{-1}.

The degree of mechanization operations carried out mainly by motorized machinery power based on Equation 3, for the wheat crop was 0, 0.2357, and 0.3536 kW-hr ha^{-1} for model-1, model-2, and model-3, respectively, while the aggregated degree of mechanization carried out by machine power (mechanical energy) was 0.1964 kW-hr ha^{-1}. Likewise, for the barley crop, the mechanical energy of mode1-1, model-2, and model-3 was 0, 0.2357, and 0.3143 kW-hr ha^{-1}, respectively, while the aggregate degree of mechanization for mechanical energy for the three models was 0.1833 kW-hr ha^{-1}. In traditional farming, the source of power was humans and draught animals, and the work outlay by motorized was zero kW-hr ha^{-1}.

As shown in Figure 5, the degree of mechanization for work outlay by human and draught animals decreased from traditional to mechanized farming for both wheat and barley crops. In contrast, the degree of mechanization of work outlay by motorized increased from traditional to mechanized farming for both crops. This implied that while the farming systems changed from traditional to mechanized operations the drudgery of work was decreased, that is, activities done by humans and draught animals were replaced by machines.

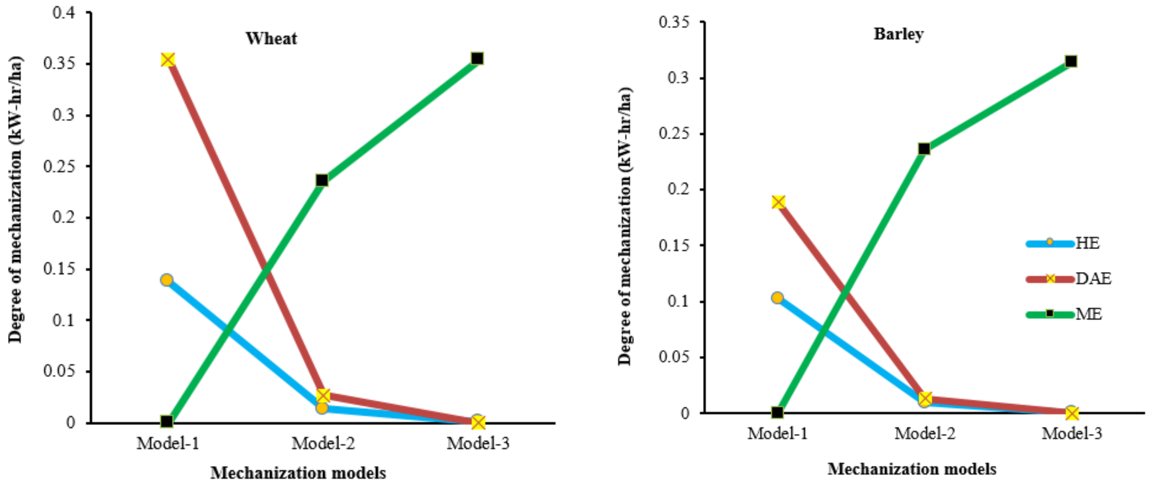

Figure 6 Operations carried out by farm power sources in the mechanization models

3.5.6 Agricultural mechanization index

It indicate the share of the work performed using mechanical power as related to the total work done using all the power sources in that particular season (Singh, 2007). A high level of mechanization index indicates a relatively high level of activities covered by machines (Olaoye and Rotimi, 2010). Based on Equation 4, mechanization indices for wheat and barley were 52% and 64%, respectively. According to the ATA (2021), mechanization indices of wheat and barley at the national level were 6.67%, and 1.13%, respectively. This showed that mechanization indices in the study area were higher than at the national average level by 87.2% and 98.2% for wheat and barley crops, respectively.

4 Conclusion

Agricultural mechanization practices in smallholder farming systems have a significant contribution to productivity. In the study area, the level of mechanization was 0.2098 kW ha^{-1}, and to reach 1.1185 kW ha^{-1}, 264 additional tractors and 37 combine harvesters would be required. The study found that while the farming systems were changed from traditional to mechanized farming, the operational costs, consumed energy, and drudgery of work decreased. Smallholder farmers should practice agricultural mechanization to upgrade their farming systems to mechanized farming. So, the role of mechanization in agriculture should be more intensified than before and more attention should be given to enhancing productivity and achieving sustainable development. This is important for policymakers and service providers. In general, the use of mechanization input for the smallholder farmers in the study area as well as at national level is essential. Therefore, the government and different stakeholders should facilitate the upgrading of the current traditional farming systems to mechanized farming systems. Strengthening the existing of clustered farming system, establishment of linkages between stakeholders and smallholder farmers and developing mechanization policy and strategy for the nation are very essential. In addition, the government should encourage service providers, supply adequate mechanization input, provide conducive environments, and institutionalize repair, maintenance, and training centres.

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