Estimation of Mechanization Index and Farm Power Density: A Case Study of Smallholder Farmers in Bure District, Ethiopia

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Abstract

The mechanization index and farm power density are the most significant parameters that highlight the extent of mechanization, and they are estimated using data collected through questionnaires from smallholder farmers and machinery service providers in the Bure district, Amhara Region, Ethiopia. The insights obtained from the data reveal the current availability of various machinery for a range of farming activities, along with the methods farmers adopt to fit their land's size, topological features, elevation, crop types, and the reasons for the inadequate use of machinery. The cost data for different farm operations, categorized by animal, human, and mechanical power, are used to estimate the mechanization index and farm power density. The mechanization index indicates that threshing and cleaning have a rate of 19.01%, whereas land preparation and clearing stand at 1.94%. Crop-wise mechanization index for maize is 6.66%, 1.90% for wheat, and 0.69% for pepper, with an average index of 1.32%. The power density is estimated as 0.12 kW ha^{-1}, which is expected to reach 1 kW ha^{-1}, the goal set for 2024. Tillage is found to be the most power-intensive activity, with 32.12% of the total energy expenditure in crop production. The calculated tractor density is 17 tractors per 10,000 hectares of arable land, which is comparable to the continental average in Africa of 20 tractors per 10,000 hectares. The lower values of the mechanization index and farm power density identified from the survey indicate the need for support farmers in terms of subsidies and increased availability of machinery. Consolidation of land can boost farm mechanization, reduce the cost of production, and increase productivity. The present research contributes to the estimation of mechanization index, power density, and tractor density in comparison to the target set by the Ethiopian government, and the approach can be scaled up to other parts of the country as well.

Keywords: Agricultural mechanization, Combine harvesters, Crop production, Farm machinery, Tractor density

Introduction

Agricultural mechanization is crucial for Africa to achieve its growth and poverty reduction objectives as well as the broader developmental goals outlined in the African Agenda 2063, which correspond with the global Sustainable Development Goals (Daum, 2023; Kormawa *et al.*, 2018). Agricultural mechanization process involves the application of mechanical power throughout the agro-food system, encompassing pre-harvesting activities, post-harvest handling, storage, and processing (Daum *et al.*, 2024). In comparison to other continents, African farming systems are significantly under-mechanized, with only 10% of farmers utilizing tractors (Daum & Birner, 2020). This limited use of mechanization creates a heavy dependence on animal and human labor, which inhibits the potential productivity gains that could be realized through modern energy systems. As a result, both agricultural labor efficiency and crop productivity have remained stagnant. In Sub-Saharan Africa, human labor serves as the primary energy source for agricultural production (Daum, 2023; Kormawa *et al.*, 2018; Sims & Kienzle, 2017). The skilled tasks such as transplanting and weeding are effectively managed by humans, and animals predominantly assist with transporting products and performing processing activities.

The small size farms present a challenge for adoption of mechanization, as large machinery generally requires the economies of scale that smaller farms lack (Sims & Kienzle, 2017). Around the world, larger farm holders were among the first to adopt agricultural mechanization, benefiting from secure land rights, better access to resources, and the advantages of the economies of scale (Daum, 2023). In contrast, smallholder farmers who cultivate small and fragmented plots face substantial disadvantages. However, the smallholder farmers can still reap the benefits of appropriate technological solutions and mechanization designed to suit their specific needs through a different business models such as rental services ((Berhane, Dereje, Minten, & Tamru, 2017; Daum, 2023). A global study conducted over 106 countries revealed that a striking 84% of farmers are in the small holder category, even though they account for just 12% of the total crop land (Lowder, Skoet, & Raney, 2016). In Sub-Saharan Africa, the average size of a farm has diminished from 2.9 hectares in the past to just 1.6 hectares at present (Fan & Rue, 2020; Lowder, Sánchez, & Bertini, 2021). Despite receiving minimal policy support, these farmers play a crucial role in driving the economic development in Africa (Nxumalo, Antwi, & Rubhara, 2020). Like most developing countries, agriculture serves as the primary source of food and income in Ethiopia, supporting over 80% of the population (Assefa *et al.*, 2020; Workneh, Ujiie, & Matsushita, 2021), with smallholder farmers make up 90% of agricultural production in the country (Zerssa, Feyssa, Kim, & Eichler-Löbermann, 2021). Ethiopia has significant potential for agriculture due to its vast fertile land, diverse climate, abundant rainfall, and large workforce. Currently, 5.4% of agricultural power in Ethiopia comes from engine-driven sources, while 94.6% relies on human and animal power (Ayele, 2022). Notably, around 80% of farmers in Ethiopia still prepare their land using draft animals, indicating a limited adoption of mechanization (Begna, Kuma, & Yohannes, 2024). Furthermore, access to agricultural machinery in Ethiopia is lower than the Sub-Saharan region (Deribe & Getnet, 2021). Despite a steady increase in agricultural outputs, the sector has not yet reached its full potential, largely due to low mechanization use, which negatively impacts the agricultural productivity (Ayele, 2022).

Primary plowing with manual tools requires approximately 500 labor hours per hectare. In contrast, animal traction takes about 60 hours, while tractor usage can reduce this time to 2 hours (Sims & Kienzle, 2017). Families in Ethiopia that utilize tractors expend less than half the labor per hectare compared to those who do not use tractors (Berhane *et al.*, 2017). Ethiopia has developed an ambitious growth and development plan aimed to promote the use of agricultural tractors. The goal of this plan includes reducing post-harvest losses from 20% to 5%. It also aims to increase the power availability from a baseline of 0.13 kW ha^{-1} to 1 kW ha^{-1}, which will also improve the access to mechanization by 30% for smallholder farmers and cut their reliance on animal power to half by 2024 (Deribe & Getnet, 2021). At present, Ethiopia has low tractor density compared to other Sub-Saharan African countries with only 2 tractors available per 100 square kilometers of arable land, resulting in higher hire costs for tractors (Deribe & Getnet, 2021; Workneh *et al.*, 2021). Smallholder farmers are facing a critical shortage of farm power reaching only 0.75 kW ha^{-1}, which is half of the minimum recommended level of 1.5 kW ha^{-1} at national level in 2014 (Wako, 2016). This shortfall is causing significant delays in agricultural operations leading to substantial production losses.

The mechanization index and farm power density are the key indicators that indicate the level of mechanical power utilization in agricultural operations. Mechanization index represents the ratios of total work done by the machinery to total of human, animal and machinery (Singh, 2006).

However, there is scanty information, especially published scientific papers, in this regard. Although, few publications have addressed these key indicators, they are at the state level rather than at district level to relate to the specific features and peculiarities and the present study is aimed to fill this gap. No published research is available addressing the mechanization needs of Bure district, especially considering the rising need for farm machinery in view of the expected growth in demand driven by the industrial park in Bure district. The present research is focused to cover the farm machinery scenario in Bure district by estimating the mechanization index and farm power density to support the policy makers for the benefit of smallholder farmers.

For instance, Berhane *et al.* conducted surveys across five regions of Ethiopia: Amhara, Oromia, Tigray, the Southern Nations Nationalities and Peoples (SNNP), and the Somali region. Only 9% of households used machine power for activities such as plowing, harvesting, or threshing crops. A regional breakdown showed that mechanization rates were 11.5% in Oromia, 7.7% in SNNP, 7.4% in Amhara, and 9.1% in Tigray (Berhane, Hirvonen, & Minten, 2016). Moreover, Berhane *et al.*, have conducted their studies in 2013 and estimated that 7.4% of households in the West Gojjam Zone relied solely on tractor power (Berhane *et al.*, 2017).

A study was conducted by Yared and Bisrat in 2021 among 818 households in selected districts across the four regions of Ethiopia having high crop production. They estimated the mechanization index to be 12.1% in Oromia, 4.38% in SNNP, 4.35% in Amhara, and 3.48% in Tigray regions. The crop-specific mechanization indices in these regions are indicated as 9.93% for wheat, 5.20% for corn, 2.25% for sorghum, and 0.84% for *teff* (Deribe, Getnet, Kang, & Tesfaye, 2021).

There are limited number of studies on the status of mechanization at national and regional levels. The above studies have focused only on large areas and do not represent appropriately at the district levels. The studies conducted by Berhane *et al.*, in 2015 and those by Yared and Bisrat in 2021 indicate a decrease in agricultural mechanization over this period in all the regions, significantly in Amhara region (Berhane *et al.*, 2016; Deribe & Getnet, 2021). In the Amhara region of Ethiopia, efforts to consolidate small farms to accommodate large-scale machinery have encountered significant obstacles, particularly in persuading the smallholder farmers to implement land consolidation (Deribe *et al.*, 2021). This trend has propelled us to undertake this study, which seeks to identify the factors that contribute to the assessment of the current mechanization index and farm power density.

Understanding the level of mechanization is of paramount importance for assessing the current state of availability and identifying the factors that impede its effective use. It will also help the policy makers to plan and support farmers for wider utilization of farm machinery, thereby unlocking the full potential of crop productivity in the district. This research holds significant value as it develops a methodology utilizing questionnaires to gather data from smallholder farmers and machinery hiring services, allowing for an estimation of the mechanization index, power density, and tractor density in relation to the benchmarks established by the Ethiopian government for the 2014-2024 Growth and Transformation Plan. The present work is useful for conducting similar studies by any other researcher and can be scaled up to other parts of the country as well to find the status and propose intervention plans for the government. Therefore, the objective of this paper is to assess the level of mechanization in crop production among smallholder farmers, examining the mechanization index and farm power density in Bure district.

Methodology

A structured questionnaire is designed to collect information from smallholder in Bure district about the crop calendar, demography, types of crops produced, sources of farm power, the cost of different farm activities, and crop productivity. Information on the availability of different types of machinery, power capacity, place of availability, and their utilization is collected from machinery owners through another questionnaire. The data collected through questionnaire is analyzed and processed to extract suitable information for estimating the mechanization index, farm power density, and tractor density.

Description of the study area

Bure district is named after its largest town, Bure, which is located between latitude 10°17' - 10°49' north and longitude 37°00'- 37°11' east. Ethiopia has a hierarchical administrative system at four levels: kebeles (the smallest administrative units), districts, zones, and states (regions). A district encompasses multiple kebeles and functions as an intermediate administrative unit. Agriculture is the primary source of income for the vast majority of the inhabitants of this district. Almost all farmers in this district are smallholder farmers who primarily depend on rain-fed farming with limited farm inputs adopting poor crop management practices.

Bure district consists of 2 urban and 22 rural kebeles with different sizes, as indicated in Fig. 1. The topology of the district, with 21.77% of low altitude, 77.23% of mid altitude, and 1% of high altitude kebeles, makes it favorable to grow a variety of crops and raise animal breeds (Abay, 2010). As reported by the Bure District Office of Agriculture (2024), 35,112 hectares (46.07%) out of the total area of 76,216 hectares are designated for cultivation, as indicated in Table 1.

The dominance of 76% plain topography, combined with a favorable climate and fertile soils, offers substantial opportunities for the use of farm machinery, rendering Bure district ideal for enhancing crop production and livestock breeding (Zewdu, Agidie, & Sebsibe, 2003).

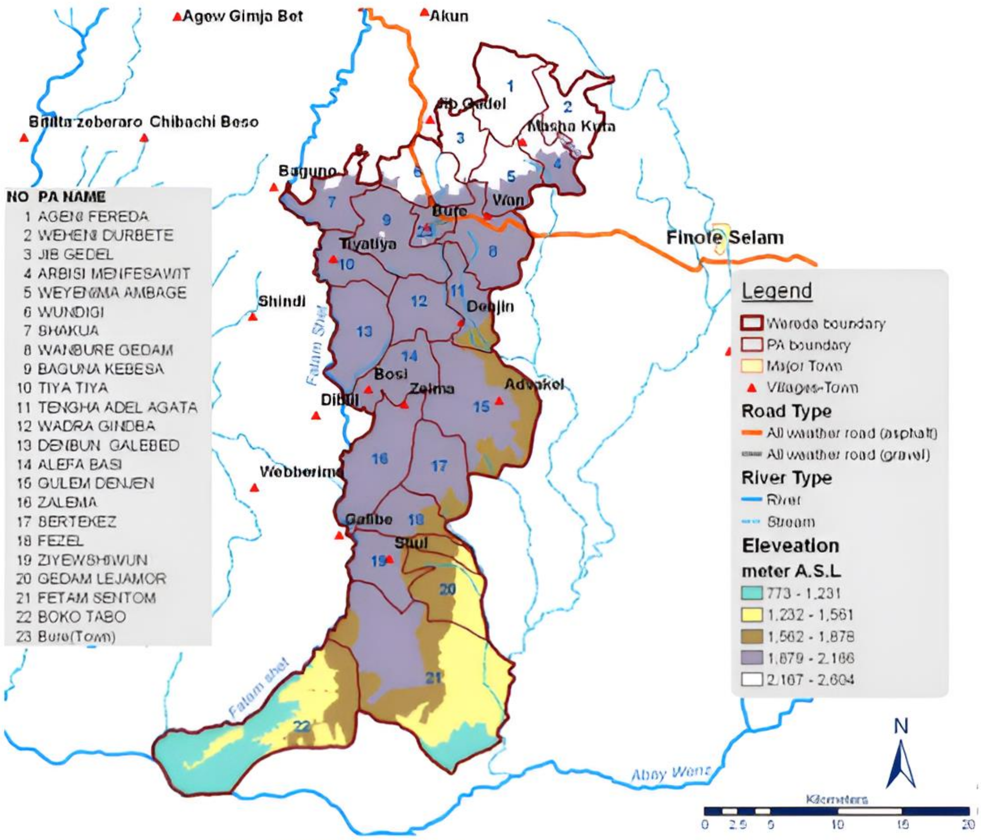


Fig. 1. Different kebeles in Bure district and respective elevation contour (Dessalegn, Hoekstra, Berhe, Derso, & Mehari, 2010)

Data collection

A structured questionnaire was designed to collect the data on demographic indicators, crop production, crop calendars, labor costs, mechanization services, and agricultural power use of farmers in Bure district during the 2022-23 crop season. It included both open- and close-ended questions along with scaled questions to assess the level of agricultural mechanization among smallholder farmers. The questionnaire was translated into Amharic, the language spoken by the local community, and underwent a pretest with 15 farmers from each of the Alefa-Basi and Baguna-Kebesa kebeles in the Bure district, both of which are part of this study's focus.

Bure district is purposely selected for its potential need for farm machinery utilization. The primary data was collected from all the 22 kebeles existing in the district to produce reliable results by equal representation in the survey. The survey was conducted by choosing a proportionate number of households by random sampling of the total households in each kebele. Reliability of the selection of the number of households was verified through site visits and discussions with experts in Bure District Office of Agriculture. Additional information on demography and land use was gathered from agricultural extension workers and Bure District Office of Agriculture.

The data collection took place from February to May 2024. Five enumerators were rigorously trained to administer the survey through interviews and interact with respondents to ensure genuineness and completeness of the data. The enumerators conducted face-to-face interviews since many of the farmers are illiterate and may have difficulty in filling the written questionnaires.

A snowball sampling technique was utilized to collect data from farm machinery owners in the Bure district on the types of farm machinery, brands, models, implements, and their technical information, such as rated power, etc. This approach was considered appropriate due to the lack of any responsible organization for registration and monitoring the types and numbers of farm machinery utilized in the district. For data collection, we initially contacted the farmers union to reach out to the private machinery owners in Bure and Kuch towns. At the outset, the survey should cover every machinery owner in the network without any form of exclusion.

Sample size

The sample size (n) should represent the characteristics of the entire population and is selected by considering four important factors: the level of confidence (Z), the margin of error (ε), the estimated proportion of population (p), and the total number of farm households (N). These factors inherently include the desired degree of precision, method of analysis, research objectives, as well as considerations of cost and time. The total number of households in each village serves as the sample frame. The sample size of households that best represents the entire study area is calculated using (Rahman & Chima, 2016):

$$n = \frac{NZ^2P(1-P)}{N\varepsilon^2 + Z^2P(1-P)} \quad (1)$$

where, N: total number of households (28,262), Z: confidence level (at 95% level, z = 1.96), p: estimated population proportion (0.5, this maximizes the sample size), and ε: error limit (5% or 0.05).

Data analysis

After collecting the responses to the questionnaire, the quantitative and qualitative data are organized and filtered to make it suitable for the analysis. The analysis utilized descriptive statistics incorporating percentages, ratios, and arithmetic mean to facilitate a comprehensive examination of the costs associated with crop production per hectare, and the distribution of various power sources. The findings from the survey and the costs analyzed are presented in graphs and tables. The results of the descriptive analysis were used for the calculation of mechanization index and power density.

To calculate the mechanization index related to crop and farm activities, a thorough examination of the cost per hectare alongside the total energy expenditure in the district is performed by multiplying the crop coverage from the 2022-23 season. Energy costs are classified as human, animal, or mechanical, with each category analyzed independently to estimate the mechanization index using the cost of energy approach. The farm power density and tractor density are calculated by considering the cost for utilization of farm machinery and the existing arable land in Bure district.

Mechanization index

Mechanization index (*MI*) evaluates the level of agricultural mechanization based on a combination of human, animal, and mechanical energy inputs. Although this can be measured in different ways, such as the actual energy utilized through humans, animals, and machinery sources, and also the costs associated with these sources for different farming activities. The current approach utilizes the costs expended on humans, animals, and machinery. The mechanization index is calculated by the ratio of the total cost of mechanical power to the overall cost of crop production expended on humans, animals, and machinery, as given by (Singh, 2006):

$$MI(\%) = \frac{C_M}{C_H + C_A + C_M} \times 100 \quad (2)$$

where, *MI*: the mechanization index,

C_M: the costs of employing machinery,

C_H: the costs of employing human labor, and

C_A: the costs of employing animal power.

Farm power density

The farm power density indicates the level of mechanization in terms of available power per unit of land area under cultivation as given by Eqs. (3)-(5) (Kumar & Tripath, 2019). This approach considers all types of machinery, such as tractors, combine harvesters, and shellers, utilized in crop production, ignoring the variation in the power capacity and types of machinery.

$$TRP_M(hp) = \sum_{i=1}^{n=NT} P_T + \sum_{i=1}^{n=NS} P_S + \sum_{i=1}^{n=NC} P_C \quad (3)$$

$$TAP_M(hp) = TRP_M(hp) \times C \quad (4)$$

$$PD(hp/ha) = \frac{TAP_M}{A_C} \quad (5)$$

where, *PD*: the power density ($hp\ ha^{-1}$),

A_C: area cultivated (*ha*),

TAP_M: total available power of machinery (*hp*),

TRP_M: total rated power of existing machinery (*hp*),

C: power use efficiency,

P_T, P_S, P_c: power of tractors, self-propelled shellers, and combine harvesters, respectively (*hp*), and

NT, *NS*, *NC*: number of tractors, self-propelled shellers, and combine harvesters, respectively.

The choice of the types of machines preferred by the farmers in carrying out different farm operations is also based on the time frame available in which the operations are to be completed. Hence, the power density based on Eq. (5) may not be applicable for all times.

Tractor density, proportion of tractor-covered area, and contribution of power

Tractor density is also another indicator of mechanization status and is expressed by Eq. (6). However, it has the drawback of not considering the number of tractors with variable capacity.

$$TD = \frac{NT}{LUC} \quad (6)$$

where, *TD*: tractor density,

NT: number of tractors, and

LUC: land under cultivation (in hectares or square kilometers).

Proportion of the tractor-covered area is given by Eq. (7), which is useful for calculating the data in Table 4.

Proportion of tractor-covered area (7)

$$= \frac{\sum_{i=1}^{n}(p_t A_t)_i}{\sum_{i=1}^{n}(p_t A_t)_i + \sum_{i=1}^{n}(p_h A_h)_i + (p_a A_a)_i}$$

where, n is 7 (the number of crop types),

p_t, p_h, p_a: total number of passes plowed by the tractor, human, and animal, respectively, for seedbed preparation as per data given in Table 9, and

A_t, A_h, A_a: area cultivated by tractor, human, and animal, respectively.

Contribution of power (CP_a) is given by Eq. (8), which can be used to calculate the average contribution of power (CP_a) given in the last column of Table 4.

$$CP_a = \frac{\sum_{i=1}^{n} P_i V_i}{\sum_{i=}^{n} 100 V_i} \quad (8)$$

where, n is 7 (the number of crop types),

V_i: volume of production of each crop type, and

P_i: percentage values of power.

Results and Discussion

Demography and land use pattern

The estimated population of Bure district as of July 2023 is 202,670 individuals, with a total of 28,262 households. Notably, 86.57% of these households are headed by males. Using Eq. (1), the sample size of households is estimated to be 380. These 380 households are distributed proportionately to different kebeles based on the number of households existing in each kebele. The average household size in the sample is seven individuals, with sizes ranging from one to twelve members. Approximately 90% of the sampled households have between three and nine members.

Following the fall of the Derg regime in 1997, the Ethiopian government has implemented a land reform policy in Amhara Region making the individuals aged 18 and above as eligible for allocation of farmland. Others who are not eligible at the time of allocation may own the land through inheritance or by gifts and this has led to the reduction of land holdings by individuals over a period of time. Currently, the average landholding per household is 1.25 hectares, calculated by dividing the total arable land by the total number of households, including those not having any land. Hence, the actual land holding may be higher if we consider only those households with land holding. During the government land allocation, based on soil fertility, the allocated land received was 3 to 9 plots for 91% of the households; 5.8% of households received more than 10 plots; and the remaining 3.2% of households received it as distributed over 1 to 2 plots. This indicates a fragmented nature of land holding by the smallholder farmers, which may not encourage them to utilize any mechanization technologies, leaving them with the choice of hiring human and animal labor, resulting in higher cost of crop production.

The land use pattern in Bure district is comprehensively outlined in Table 1. This table details the areas allocated for various purposes, including arable land for both annual and perennial crops, grazing land, water bodies, forests, bushes and shrubs, infrastructure, settlements, and unusable land. A comparative analysis of the current land use pattern with previous studies shows a steady increase in the land designated for crop production. This increase was due to the conversion of grazing lands and shrub areas into cropland, allocated to landless youth associations by different kebele administrations (Wonde, Tsehay, & Lemma, 2022; Zewdu *et al.*, 2003).

Table 1- Land use pattern in Bure district during the 2022-23 crop season

Land use	Area covered (ha (%))
Arable land	35,112 (46.07)
Annual crops	34,060 (44.69)
Perennial crops	1,052 (1.38)

Grazing land	3,201 (4.20)
Water bodies	183 (0.24)
Forest	7,164 (9.40)
Bush and shrubs	11,051 (14.50)
Infrastructure and settlement area	8,567 (11.24)
Unusable	10,937 (14.35)
Total	76,216 (100)

During the 2022-23 crop season, the tractor-plowed land in Bure district was 8,052 hectares, accounting for 22.86% of the total arable land. Among all the kebeles, Agni Fereda, Wehni Durbete, and Jib Gedele kebeles are found to have minimal usage of farm tractors for primary field preparation, since they are located in high-altitude areas, as depicted in Fig. 2. However, a higher utilization of farm tractors is noted in some of the kebeles located in mid-altitude areas, such as Gulm Denjin, Seretekeze, and Fetam Sentom kebeles, which are ranked in ascending order.

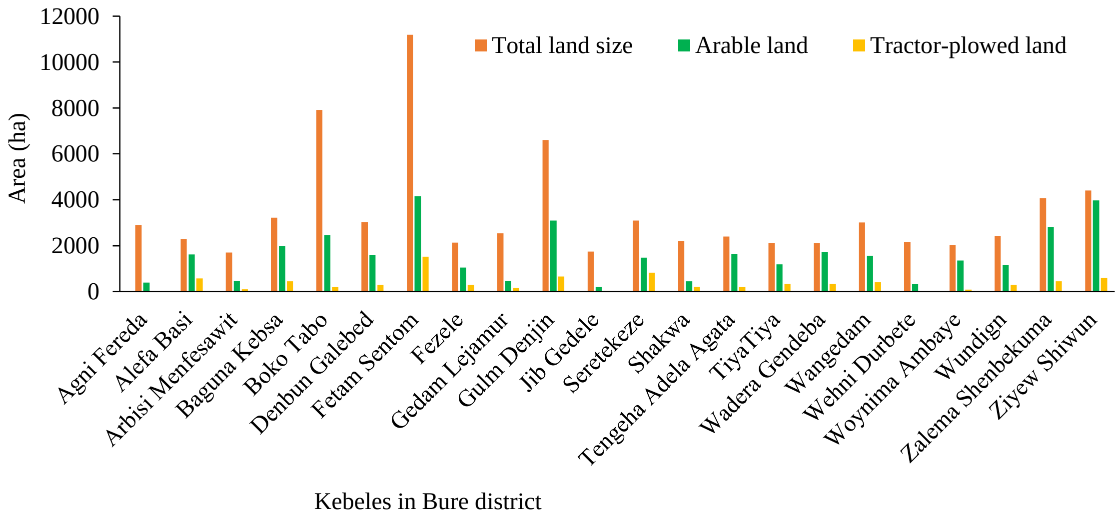


Fig. 2. Total land size, arable land, and tractor-plowed land in each kebele in Bure district during the 2022-23 crop season

Crop calendar

The crop calendar presented in Table 2 describes the agricultural practices observed among farmers in Bure district during the 2022-23 crop season. This crop calendar is set by the farmers, who primarily rely on traditional knowledge passed down through generations, making slight adjustments to adapt to changing climatic conditions. To meet the agricultural timelines and enhance crop productivity, the farmers perform various agricultural activities utilizing the available human and animal resources. The farmers with limited resources in terms of labor and animals tend to start their farming activities much in advance of the crop season and often work for longer hours compared to those with sufficient resources. They also prefer to employ mechanical power for primary tillage and threshing to mitigate the labor constraints within their households.

Commencing from March, the farmers engage in tilling the soil to prepare the seedbeds for most of the crops to make them ready for planting. The tilling period generally wraps up by the end of May, followed by the planting season during June and July, which coincides with the onset of rainfall. As the year progresses, the focus shifts to harvesting and threshing, which continues from October to February. During this period, the farmers are completely engaged in collecting their produce and preparing it for storage or sale.

Machinery utilization by the farmers will significantly diminish the drudgery, which enables them to engage in supplementary employment to enhance their income and also facilitate their participation in various social activities. Integration of farm machinery into various farming operations will not only increase the productivity but also reduce the post-harvest losses.

Table 2- Crop calendar in Bure district during the 2022-23 crop season

Crop type	Farm activity	Month											
		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Maize	Land preparation			■	■	■							
	Planting						■						
	Weeding												
	Harvesting										■	■	■
	Shelling	■	■										■
Wheat	Land preparation					■	■						
	Planting						■	■					
	Weeding								■	■			
	Harvesting											■	■
	Threshing	■											■
Teff (Red Soil)	Land preparation						■	■					
	Planting							■					
	Weeding												
	Harvesting										■	■	
	Threshing											■	■
Teff (Black Soil)	Land preparation							■					
	Planting								■				
	Weeding									■			
	Harvesting		■										
	Threshing			■	■								
Finger Millet	Land preparation				■	■	■						
	Planting						■	■					
	Weeding								■	■			
	Harvesting	■											■
	Threshing		■										
Barley	Land preparation			■	■	■							
	Planting					■	■						
	Weeding							■					
	Harvesting									■	■	■	
	Threshing										■	■	■
Pepper	Land preparation			■	■	■							
	Seeding pepper					■							
	Planting						■						
	Cultivation							■	■	■			
	Weeding										■		
	Harvesting											■	■
Potato	Land preparation			■	■								
	Planting					■	■						
	Weeding						■	■					
	Harvesting							■	■				

Crop production and productivity

Bure district is recognized as the leading surplus grain-producing region within Amhara region. The main crops, which include maize, wheat, *teff*, finger millet, barley, pepper, and potatoes, are cultivated over 93% of the arable land. The remaining 7% of the land is dedicated to vegetables, oil seeds, pulses, spices, and perennial crop production, as presented in Table 3.

Table 3- Types of crops, land coverage, and cosponsoring yields during the 2022-23 crop season in Bure district

Crop type	Cultivated land (ha)	Land coverage (%)	Crop yield (tn ha^{-1})	Total crop production (tn)	Crop production (%)
Maize	14,560	41.47	6.43	93,620.8	68.25
Wheat	4,557	12.98	3.0	13,671.0	9.97
Teff	3,800	10.82	1.25	4,750.0	3.46
Finger millet	1,621	4.62	2.18	3,533.8	2.58
Barley	1,036	2.95	3.0	3,108.0	2.27
Pepper	5,107	14.55	1.475	7,532.8	5.49
Potato	1,015	2.89	10.79	10,951.9	7.98
Pulses	1,362	3.88	*	*	*
Oil crops	958	2.73	*	*	*
Vegetables	37	0.11	*	*	*
Spices	7	0.02	*	*	*
Perennial crops	1,051	2.99	*	*	*
Total	35,111	100%			

* Data not available

It is identified that maize productivity is higher in mid- and low-altitude kebeles compared to high-altitude kebeles, which predominantly focus on cultivating wheat, barley, legumes, and potatoes. The Bure district is renowned as the “maize belt,” having substantial maize production of 68.25% of overall production with an average yield of 6.43 tn ha^{-1}, while the global average is only 5.8 tn ha^{-1}, and the national average is 4.5 tn ha^{-1}, (Erenstein, Jaleta, Sonder, Mottaleb, & Prasanna, 2022). The total production of maize in this district covers 41% of the total cultivated area during the 2022-23 crop season. Thus, the data indicate that maize is identified as the leading crop in terms of land coverage, production, and productivity.

Farmers grow red peppers for both commercial sales and household consumption. Red pepper is a significant cash crop primarily produced by smallholder farmers in this district, ranking second in crop coverage area next to maize (Abay, 2010). However, its productivity has declined over time due to widespread red pepper disease (Dessie, Koye, & Koye, 2019), which is further intensified by weather variability. Currently, the farmers lack access to chemicals that can control or eradicate this pest infestation. Consequently, many farmers are transitioning towards maize production due to its higher productivity and easier pest management compared to red pepper.

Farm mechanization in Bure district: scenario of cereal crop production

Table 4 provides the percentage contributions of human, animal, and mechanical power for different farm activities for producing various crops during the 2022-23 cropping season in Bure district. The percentage values given for each crop and activity indicate the proportion of utilization of human, animal, and mechanical power, which are obtained by consolidating the results of the questionnaire survey.

A total of 8,052 hectares of land were plowed using tractors for primary tillage, which accounted for 23.64% of the total crop-covered area. Considering the number of passes made by the tractor for the tractor-plowed land, and the number of passes made by animals and humans for the remaining land involved in subsequent tillage in seed bed preparation, the ratio of the land plowed by the tractor and the land plowed by the animals comes only to 5.43% which indicates a very low level of tractor utilization in the overall preparation of the land. The total tractor utilization rate of 5.43% is distributed among three major crops: red pepper at 2.44%, maize at 2.17%, and wheat at 0.82%. The utilization of animal power for land preparation in the district stands at 94.57%, surpassing the estimated national average of 80%, as indicated by previous studies (Behnke & Metaferia, 2011; Berhane *et al.*, 2017).

In the context of primary tillage, the power of tractors (p_t), power of humans (p_h), and power of animals (p_a) in Eq. (7), are each set to 1, resulting in a percentage of the area covered by the tractor calculated at 23.64. However, according to the total number of passes detailed in Table 9, this percentage is actually 5.43, as previously mentioned when derived from Equation (7).

The percentages values of power (P_i) given for each crop and activity indicate the proportion of utilization of human, animal, and mechanical power which are obtained by consolidating the results of the questionnaire survey.

The average contribution of power by human, animal, and mechanical sources for each farm activity, considering all types of crops, is presented in the last column of Table 4, which is obtained by taking the ratio of the sum of the volumes of production, considering the percentage of involvement of the respective type of power for each farm activity, and the total production of all varieties of crops. Eq. (8) is helpful in arriving at the average contribution of power (CP_a).

Table 4- Percentage of use of power for different activities and various crops in Bure district during the 2022-23 crop season

Farm activity/power source	**Crop type**							**Average contribution of power (CP_a)**
	Maize	***Teff***	**Wheat**	**Finger millet**	**Barley**	**Pepper**	**Potato**	
Land preparation and cultivation								
Hoe (Human)	0	0	0	0	0	40.88	50	11.69
Animals	95.1	100	92.63	100	100	50.10	50	83.19
Tractors	4.90	0	7.37	0	0	9.02	0	5.12
Harvesting								
Human	100	100	100	100	100	100	90	99.20
Animals	0	0	0	0	0	0	10	0.80
Machine	0	0	0	0	0	0	0	0
Threshing/shelling								
Hand	18.32	0	0	0	0	100	*	25.18
Animal	2.50	100	97.44	100	100	*	*	20.52
Sheller/stationary thresher/combine harvester	79.18	0	2.56	0	0	*	*	54.30

* Not applicable

Following the advice of the crop extension workers, the farmers usually employ tractors for plowing the same plot once every two to four years, and other times plow using the *Maresha* plow drawn by animals. Farmers adopt this practice to minimize the tillage expenses while sacrificing the full advantage of using tractors every year. Using the *Maresha* plow has setbacks such as being labor-intensive, time-consuming, and cutting only a shallow depth of 10-14 cm. This low depth of cut results in forming a hardpan, which reduces the rainwater runoff and prevents percolation of water sufficiently required for the crop (Guadie & Degu, 2018) However, this hardpan is broken when plowing is done by tractors.

As indicated in Table 4, hoes are exclusively used for cultivating potatoes and pepper. Farmers prefer to dig potatoes manually with hoes to prevent damage to the tubers, and only 10% of potato harvesting is done by animals using the *Maresha* plow. During the 2022-23 crop season, only 2.56% of the wheat crop was threshed using a combine harvester, and the rest was manually done using sickles. It is noted from the machinery owners that the limited use of combine harvesters is due to challenges of small land sizes, steep slopes, and presence of trees in the land. Land management practices such as consolidation, leveling, and tree removal can be considered to overcome these obstacles. Nearly 79.18% of the maize produced in Bure district is shelled using stationary shellers powered either by power take-off (PTO) of the tractor or self-propelled engines. Farmers prefer shellers driven by tractor PTO since these shellers have fans and sieves which enhance cleaning efficiency. The fans operate at higher speeds that improve separation of chaff from grain, leading to reduced labor and time. It has been noted from the survey that by implementing good land management practices and efficiently utilizing machinery, the smallholder farmers in Bure district have better chances of increasing their productivity and economic development.

Farm machinery and implements used in Bure district

The information gathered from a questionnaire detailing different tractor brands, models, their horsepower ratings, availability, ownership types, and locations within Bure district is presented in Table 5. Out of the 60 tractors available, 40 have a rated power above 80 hp and are in use for all farm operations. The remaining 20 tractors, which include 12 of the Belarus-805 model and 8 of the Cherry brand, are exclusively used to drive shellers. Although the 12 Belarus brand tractors have a rated power of 80 hp, they have served in regular farm operations for over 35 years, and presently they are confined only for shelling. It is essential to replace these inefficient and outdated tractors with new ones. Among the total number of 60 tractors, 10 are owned by Damot Union, 2 by governmental entities (Bure Polytechnic College), and the remaining 48 are owned by private individuals or agencies. Farmers and youth in the district do not own tractors; however, few of them own mule-pulled self-propelled shellers.

Table 5- Tractor brands providing service in Bure district during the 2022-23 crop season

S.N.	Tractor brand	Model	Rated power (hp)	Available quantity	Tractor ownership	Place of availability
1	Massey Ferguson	460 Xtra	110	5	Damot union	Bure
2	Massey Ferguson	460 Xtra	110	2	Private	Bure
3	Massey Ferguson	460 Xtra	110	2	Private	Kuch
4	Massey Ferguson	470 Xtra	120	5	Damot union	Bure
5	McCormick	G135 Max	127	5	Private	Kuch
6	McCormick	G135 Max	127	3	Private	Bure
7	Belarus	820	81	5	Private	Bure
8	Belarus	805	80	12	Private	Kuch
9	New Holland	T6080 Elite	155	1	Damot union	Bure
10	Claas	ARION 410	110	1	Government (Bure Polytechnic College)	Bure
11	Claas	ARION 420	120	1	Government (Bure Polytechnic College)	Bure
12	CaseIH	Maxxum 110	110	6	Private	Kuch
13	CaseIH	Maxxum 125	125	4	Private	Bure
14	Chery	RF400	40	3	Private	Kuch
15	Chery	RD300	30	5	Private	Kuch

All tractors located in Bure town provide hiring services exclusively for the Bure district. Those owned by Damot Union are utilized within the district to 35% of their capacity, and the remaining 65% of capacity is utilized for service in adjacent districts. From these results, it can be inferred that the role of private agencies is significant in promoting greater access and sustainable mechanization among smallholder farmers which also complies with the global findings (Ngoma, Simutowe, Matin, & Thierfelder, 2024).

Machinery service for seedbed preparation and shelling are predominantly provided by the private firms, which also own 80% of the tractors used in the district. Conversely, none of the private firms possess the combine harvester due to its high initial investment cost and limited applicability. Instead, the combine harvesters are owned by the union and the government entities, namely, Damot Union, Federal Mechanization Service, and Bure Polytechnic College.

The power range of tractors listed in Table 5 varies from 30 hp to 155 hp, and these tractors are stationed only in two towns, 33 in Kuch and 27 in Bure, to ensure proximity to their owners, access to fuel, and maintenance. Tractors stationed in each town provide service to their respective neighboring kebeles, while very few tractors from other districts occasionally crossing the kebeles in Bure district may offer additional hiring services, whose contribution is minimal.

According to the data presented in Fig. 3, Belarus, Massey Ferguson, and Case IH emerge as the three leading brands, each showcasing a diverse range of design complexities.

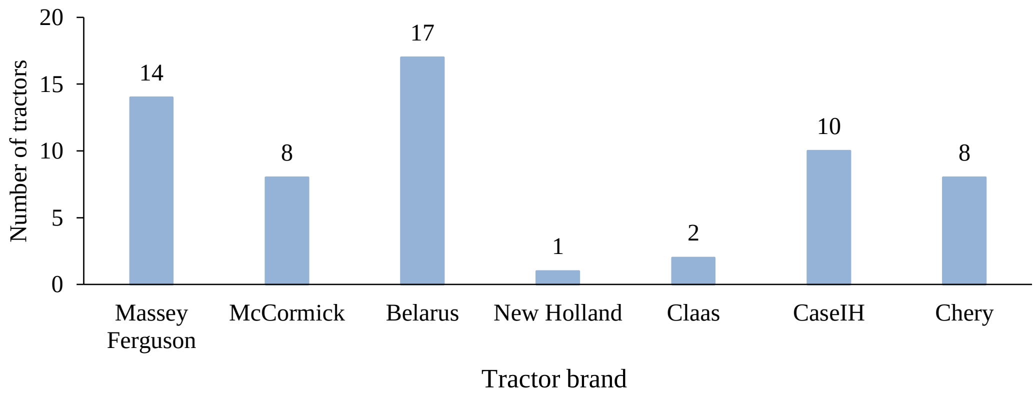


Fig. 3. Tractor brands available in Bure district during the 2022-23 crop season

Out of the 4 combine harvesters listed in Table 6, the New Holland brand owned by Damot Union provides its service to a limited capacity in Bure district, while the Claas brand models provide service only to commercial farms and smallholder farmers in neighboring districts who produce substantial amounts of wheat. The private ownership of combine harvesters is limited in the district due to the absence of a viable market and the high initial investment required.

Recent technological advancements have led to the development of increasingly complex systems for both tractors and combine harvesters, which poses challenges for operators due to their limited exposure to the new brands. Currently, there are no maintenance services or spare parts suppliers available in either Bure or Kuch town. Since the rain-fed crop farming system is time-sensitive in nature, it is essential to have the availability of experts in nearby towns who possess the necessary resources, skills, and training to offer prompt services (Wako, 2016).

It is recommended that both governmental and non-governmental organizations advocate for the establishment of maintenance workshops in Bure and Kuch towns to facilitate timely repairs of farm machinery. Furthermore, the machinery suppliers should also provide comprehensive after-sales service to ensure sustainable mechanization for smallholder farmers in the district. These initiatives will aid farming activities, ensuring adherence to timelines, enhancing worker productivity, increasing crop yields, and reducing post-harvest losses and labor intensity.

Table 6- Combine harvesters providing service in Bure district during the 2022-23 crop season

S.N.	Brand	Model	Power (hp)	Quantity	Ownership	Place of availability
1	New Holland	TC5.80	207	1	Damot union	Bure
2	Claas	Dominator 130	152	1	Government (Bure Polytechnic College)	Bure
3	Claas	Dominator 130	152	2	Government (Federal Mechanization Service)	Bure

Table 7 provides comprehensive data on a variety of implements used for different farming operations such as plowing, harrowing, and shelling. A total of 142 implements were identified, which include 3 harrows, 46 plows, and 93 shellers. The disc plow is the most widely used tool for primary tillage, while the disc harrow is commonly employed for secondary tillage. Disc plows are classified based on the number of discs or by their weight, as light-duty or heavy-duty. Tractor-driven shellers are more common than self-propelled shellers in this district. Five self-propelled maize shellers, pulled by mules, were discovered offering their services for hire to kebeles near the neighboring districts.

Table 7- Implements providing service in Bure district during the 2022-23 crop season

S.N.	Implement type	Model	Quantity	Ownership	Base town
1	Disc plow	3 Bottom	3	Private	Bure
2	Disc plow	4 Bottom	5	Damot union	Bure
3	Disc plow	4 Bottom	14	Private	Bure
4	Disc plow	4 Bottom	17	Private	Kuch
5	Disc plow	5 Bottom	5	Damot union	Bure
6	Mold board plow	6 Bottom	1	Damot union	Bure
7	Reversible mold boar plow	6 Bottom	1	Government (Bure Polytechnic College)	Bure
8	Disc harrow	22 Disc	1	Government (Bure Polytechnic College)	Bure
9	Disc harrow	24 Disc	1	Damot union	Bure
10	Disc harrow	28 Disc	1	Damot union	Bure
11	Sheller	PTO driven	3	Damot union	Bure
12	Sheller	PTO driven	31	Private	Kuch
13	Sheller	PTO driven	15	Private	Bure
14	Sheller	Self-propelled	39	Private (farmers)	Residing in kebeles in the district
15	Sheller	Self-propelled	5	Private (farmers)	Residing in adjacent kebeles from other districts

It can be identified from Figure 4 that the disc plow and sheller are the two most frequently used implements which is also evident from the data in Table 7.

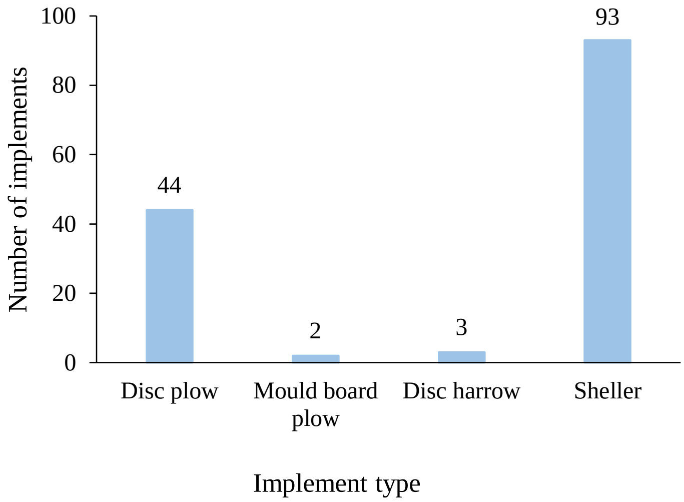


Fig. 4. Types and number of implements available in Bure district during the 2022-23 crop season

Tractor density

The tractor density is specified by the number of tractors employed for cultivating 10,000 hectares. For the cultivated land of 35,112 hectares with the available 60 tractors in Bure district, the tractor density is 17, as per Eq. (6). This value is derived from the assumption that every tractor possesses identical capacity and contributes uniformly across all kebeles.

The tractor density is the key parameter that indicates the progress and variation of agricultural mechanization between various countries in Africa (Mrema, Baker, & Kahan, 2008). Throughout Africa, the tractor density is 20, and it is 13 in Sub-Saharan Africa. In the present study region of Bure district, the tractor density of 17 is closer to that of Africa and much higher than the average tractor density of Ethiopia, which is equal to 4. In countries like Brazil and India, the tractor density is 11,600 and 12,800, respectively (Deribe & Getnet, 2021; Kumi & Taiwo, 2014). The calculation of tractor density using Eq. (6) is based on the assumption that all tractors have equal power capacity and perform all farm activities, which is not true. Hence, considering tractor density as the only indicator for farm mechanization will be misleading (Berhane *et al.*, 2017). The concentration of tractors is significantly higher in the vicinity of Bure and Kuch towns, while it noticeably decreases as we venture further from these areas.

The Bure district utilizes 40 tractors to plow a total of 8,052 hectares of land, as detailed in the respective sections on demography, land use patterns, and farm machinery within this manuscript. The actual tractor density comes to 50, which indicates a significant availability of tractor power. At present, 40 tractors are used for plowing just 8,052 ha, which means 200 ha $tractor^{-1}$ during the crop season. Considering the usual capacity of 10 ha day^{-1} and 60 days of plowing period as per the cropping calendar in Table 2 each tractor may plow up to 600 ha in the crop season. Comparing the present utilization of 200 ha $tractor^{-1}$ and the available capacity of 600 ha $tractor^{-1}$ during the crop season indicates a significant underutilization of the tractors, which leads to higher cost of mechanization services. It is necessary to investigate the reasons from the side of service providers and also from the farmers' side to identify the impeding factors for underutilization, although a maximum potential of plowing 24,000 ha is available for the 40 tractors at disposal.

Farm power density

For a comprehensive analysis, the consideration of the total power of all the tractors, combine harvesters, and self-propelled engines available in the district will provide greater insight for estimating the power per 100 sq. kilometers, rather than relying solely on tractor density. The maximum power generated by the farm machinery under ideal conditions is denoted as rated horsepower. In contrast, the available power refers to the actual power that may be utilized for farm activities, which is lower than the rated horsepower, due to factors such as soil conditions, load, and operating efficiency. The power density is determined using Eqs. (3)-(5). The calculation of power density is generally based on the assumption that all types of machinery are put to use simultaneously, although their application follows the crop calendar. However, the power density index remains valuable for farm power planning.

$$TRP_M\,(hp) = \sum_{i=1}^{n=60} P_T + \sum_{i=1}^{n=93} P_S + \sum_{i=1}^{n=4} P_C \qquad (9)$$

The total rated power (TP_M) of 7239.5 h*R*p is calculated by summing up the rated power of all the available number of tractors, shellers, and combine harvesters having 5,786 hp, 663 hp, and 790.5 hp, respectively, using Eq. (9). The total available power (TAP_M) of 5647 hp is obtained by applying a power use efficiency factor (*C*) of to 0.78 in Eq. (4). The power loss factor (*C*) outlined in Eq. (4) signifies how effectively the farm machinery operates. If the power is taken directly from the Power Take-Off (PTO) shaft, the power available will be higher than if it is taken through drawbar implements, and in such case, *C* is taken as 0.86; otherwise, it generally ranges from 0.6 to 0.7. In the present case, *C* is taken as 0.78, considering the arithmetic mean, since the power is drawn by both PTO as well as through drawbar.

$$PD = \frac{5647\,hp}{35112\,ha} = 0.161\,hp / ha = 0.12\,kW / ha \qquad (10)$$

The Bure district has a power density of approximately 0.12 kW ha^{-1}, closely approaching the national benchmark of 0.13 kW ha^{-1} established in 2014. The goal is to reach a target of 1 kW ha^{-1} within the next ten years, by 2024. The focus of this initiative is to advance mechanization, targeting a 50% reduction in animal power reliance for at least 30% of smallholder farmers (Deribe & Getnet, 2021).

Cost of crop production based on types power source

The energy sources utilized for these activities include the details of human, animal, and mechanical means for various farm activities along with their required numbers, cost, and the quantities of production for identified major crops such as maize, wheat, pepper, teff, finger millet, barley, and potato are presented in Table 8.

Table 8- Cost and quantity of farm power required per hectare of land

Type of farm activity	Source of power entity	Unit cost [ETB]	Number of humans, animals, and tractors (if not otherwise stated)						
			Maize	**Wheat**	**Pepper**	**Teff**	**Finger millet**	**Barley**	**Potato**
Land clearing	Human	300 day^{-1}	2	2	2	2	2	2	2
Plowing seedbed preparation	Human	400 day^{-1}	4	4	4	4	4	4	4
	Animal	900 pair of ox day^{-1}	4	4	4	4	4	4	4
	Tractor	8000 ha^{-1}	1	1	1	*	*	*	*
Plowing during seeding/ planting	Human	600 day^{-1}	2	2	2	2	2	2	2
	Animal	1650pair of ox day^{-1}	2	2	2	2	2	2	2
Land compaction and leveling (*Beray*)	Human	400 day^{-1}	*	*	*	2	2	*	*
	Animal	300 animal^{-1} day^{-1}	*	*	*	20	20	*	*
Seeding/planting and	Human	400 day^{-1}	8	2	32	2	2	2	12

fertilizing									
Weeding (chemicals)	Human	50 jar^{-1}	4	4	12	4	4	4	*
Weeding (hand)	Human	400 day^{-1}	*	*	12	*	8	*	*
Cultivation round (round 1, round 2, and round 3)	Human	400 day^{-1}	*	*	(22, 25, 25)	*	*	*	(18, 18, 20)
Harvesting (round 1, round 2, and round 3)	Human	400 day^{-1}	9	*	(24, 16, 4)	*	*	*	30
	Animal	900 pair of ox day^{-1}	*	*	*	*	*	*	2
Harvesting, threshing, cleaning, and packaging	Human	400 day^{-1}	*	24	*	*	*	24	*
Harvesting, collecting, and packing (*kimir*)	Human	400 day^{-1}	*	*	*	15	24	*	*
Watering	Human	300 day^{-1}	*	*	30 days	*	*	*	*
Transportation kernel	Human	40 trip^{-1} using cart	40 trips	*	*	*	*	*	*
	Animal	80 trip^{-1} using cart	40 trips	*	*	*	*	*	*
Dehusking	Human	400 day^{-1}	30	*	*	*	*	*	*
Shelling by hand	Human	400 day^{-1}	25	*	*	*	*	*	*
Animal trumping	Human	400 day^{-1}	4	*	*	*	*	*	*
	Animal	300 animal^{-1} day^{-1}	10	12	*	20	20	12	*
Threshing by sheller	Sheller	650 tn^{-1}	6.43 tn ha^{-1}	*	*	*	*	*	*
Threshing by combine harvester	Combine harvester	3000 tn^{-1}	*	3.0 t ha^{-1}	*	*	*	*	*
Feeding into sheller	Human	60 hr^{-1}	*	36	*	*	*	*	*
Feeding into combine harvester	Human	50 hr^{-1}	7	*	*	*	*	*	*
Grain cleaning and packaging	Human	400 day^{-1}	4	*	*	*	*	*	*
Transportation of grain	Human	200 tn^{-1}	6.43 tn ha^{-1}	3.0 tn ha^{-1}	1.47 tn ha^{-1}	1.25 tn ha^{-1}	2.18 tn ha^{-1}	3.0 tn ha^{-1}	10.79 tn ha^{-1}
	Animal	300 tn^{-1}	6.43 tn ha^{-1}	3.0 tn ha^{-1}	1.47 tn ha^{-1}	1.25 tn ha^{-1}	2.18 tn ha^{-1}	3.0 tn ha^{-1}	10.79 tn ha^{-1}
Drying	Human	400 day^{-1}	*	*	4 days	*	*	*	*
Guarding	Human	300 night^{-1}	*	*	16 days	*	*	*	*
Sorting out and packaging	Human	400 day^{-1}	*	*	8 days	*	*	*	*

* Not applicable

This study employs a cost-based approach to estimate the mechanization index, due to the non-availability of data and the difficulties associated with measuring the power consumption for various farm operations. The cost of production for each crop per hectare includes the costs of land clearing, plowing, seeding/planting, fertilizing, weeding, harvesting, threshing, and transportation. The farmers have exhibited a strong preference based on their perception that the tractors are suitable for primary tillage of land only for maize, pepper, and wheat crops.

The number of passes necessary for effective seedbed preparation is influenced by various factors such as crop rotation, soil type, availability of farm power, and primary tillage methods. The average number of passes of plowing and kernel transportation by human and animal power obtained from the survey are presented in Table 9. It is required to plow 2 to 5 times on average to prepare the land for sowing using the *Maresha* plow, which creates a trapezoidal furrow cross-section, resulting in gaps of un-tilled soil between adjacent furrows. Hence, each pass has to be made perpendicular to the previous one to cover every bit of soil in the field (Astatke, 1993). In traditional farming, oxen are restricted to seedbed preparation and threshing.

When primary tillage is done by tractors and subsequent passes are carried out by animals, the total number of passes required will be reduced by 2 for maize and pepper, and 3 for wheat, which reduces the total cost of seedbed preparation.

Table 9- The number of passes of farm activity for different crops using animal draft power

Type of farm activity	Source of power entity	Crop type						
		Maize	**Wheat**	**Pepper**	***Teff***	**Finger millet**	**Barley**	**Potato**
Average No. of plowing passes	Human	3.5	4.5	4	3	4.5	4	2
	Animal	3.5	4.5	4	3	4.5	4	2
Average No. of times kernels are transported	Human	40	*	*	*	*	*	*
	Animal	40	*	*	*	*	*	*

* Not applicable

The cost of farming utilizing different combinations of power sources, such as animal-human, animal-human-tractor, animal-human-sheller/thresher, and animal-human-tractor-sheller/thresher for different crops is presented in Tables 10-13 and a summary is presented in Table 14 and Fig. 5 for various crops during the 2022-23 crop season in Bure district. The cost of farming per hectare for animal-human power combination is presented in Table 10. This combination is widely prevailing among the smallholder farmers in Bure district.

Table 10- Cost of farming per hectare for animal-human power combination

Crop type	Cost of animal power [ETB]	Cost of human power [ETB]	Total cost of power [ETB]	Animal power (%)	Human power (%)
Maize	19,100	39,600	58,700	32.54	67.46
Pepper	18,142.5	95,087	113,229.5	16.02	83.98
Wheat	25,200	20,200	45,400	55.51	44.49
Finger millet	32,154	43,236	75,390	42.65	57.35
Potato	13,737	46,358	60,095	22.86	77.14
Teff	26,475	19,450	45,925	57.65	42.35
Barley	23,460	19,440	42,900	54.69	45.31

In the Bure district, the majority of smallholder farmers rely on both animal and human power for their agricultural activities. Notably, pepper production demands a considerable amount of human labor, making up 83.98% of the total effort, while draft animal power accounts for only 16.02%. Among all the crops, the pepper crop requires intensive human energy input, thereby escalating the cost by nearly three times compared to the cost of many other crops. The percentage of contribution of human energy for the total cost is only 42.35% for *teff*, which is the least among all other crops.

Table 11 gives the costs of animal, human, and tractor power for different crops and their contribution for the total cost in terms of respective percentages. Using tractors instead of animals for primary tillage minimizes the subsequent number of passes by the animals and reduces the overall cost of seedbed preparation. Introduction of tractor power has resulted in reducing the contributions of animal and human power for the total cost when compared to the percentage values of animal-human power combination presented in Table 10.

Table 11- Cost of farming per hectare for animal-human-tractor power combination

Crop type	Cost of animal power [ETB]	Cost of human power [ETB]	Cost of tractor power [ETB]	Total cost of power [ETB]	Animal power (%)	Human power (%)	Tractor power (%)
Maize	11,900	36,400	8,000	56,300	21.14	64.65	14.21
Pepper	10,942.5	91,295	8,000	110,237.5	9.93	82.82	7.26
Wheat	19,200	15,400	8,000	42,600	45.07	36.15	18.78
Finger millet	23,154	38,436	8,000*	69,590	33.27	55.23	11.50
Potato	10,137	44,758	8,000*	62,895	16.12	71.16	12.72
Teff	21,075	17,050	8,000*	46,125	45.69	36.97	17.34
Barley	17,460	14,640	8,000*	40,100	43.54	36.51	19.95

*This combination is not in practice and these values are presumptive.

The cost data presented in Table 12 shows that there is a reduction in the total cost of maize production and cost of human power, even though there is an additional cost for hiring the sheller. The cost of animal power is not affected, since it is not involved in shelling. Utilizing a combine harvester for wheat production significantly lowers costs associated with both animal and human labor, while still maintaining overall expenses similar to those of relying solely on the animal-human power combination, as illustrated in Table 10. It shows that using shellers for maize has reduced human involvement, while the combine harvester for wheat has reduced both animal and human drudgery without additional cost, which indicates the positive aspect of farm mechanization.

Table 12- Cost of farming per hectare for animal-human-sheller/combine harvester power combination

Crop type	Cost of animal power [ETB]	Cost of human power [ETB]	Cost of sheller/ combine harvester [ETB]	Total cost of power [ETB]	Cost of animal power (%)	Cost of human power (%)	Cost of sheller/thresher power (%)
Maize	19,100	31,760	4,179.5	55,039.5	34.70	55.70	7.60
Wheat	20,400	15,750	9,000	45,150	45.18	34.89	19.93

The data presented in Table 13 clearly indicates a significant reduction in the cost of animal and human power, and also the total cost for both maize and wheat when the tractor-sheller/combine harvesters are used simultaneously with animal and human power. The animal-human-tractor-sheller/combine harvester power combination indicates a significant reduction in the total cost as well as animal and human cost. Thus, it has both the benefits of reducing animal and human drudgery and cost reduction when compared to the cases presented in Tables 10-12.

Table 13- Cost of farming activities per hectare using animal-human-tractor-sheller/combine harvester power combination

Crop type	Cost of animal power [ETB]	Cost of human power [ETB]	Cost of tractor and sheller/combine harvester [ETB]	Total cost of power [ETB]	Cost of animal power (%)	Cost of human power (%)	Cost of tractor and sheller/combine harvester power (%)
Maize	11,900	25,360	121,79.5	49,439.5	24.07	51.30	24.63
Wheat	9,600	10,950	17,000	37,550	25.57	29.16	45.27

Table 14- Summarized cost of farm activities per hectare using various source of power combination

Crop type	Total cost for different power combinations			
	Animal-human-power [ETB ha^{-1}]	**Animal-human-tractor power [ETB ha^{-1}]**	**Animal-human-sheller/combine harvester power [ETB ha^{-1}]**	**Animal-human-tractor-sheller/combine harvester power [ETB ha^{-1}]**
Maize	59,500	57,100	55,839.5	50,239.5
Pepper	113,229.5	110,237.5	Not applicable	Not applicable
Wheat	45,400	42,600	45,150	37,550
Finger millet	75,390	69,590*	Not applicable	Not applicable
Potato	60,095	62,895*	Not applicable	Not applicable
Teff	45,925	46,125*	Not applicable	Not applicable
Barley	42,900	40,100*	Not applicable	Not applicable

*This combination is not in practice and these values are presumptive.

Although the total cost for the human-animal-tractor power combination for finger millet, potato, *teff*, and barley remains close to that of the animal-human power combination, farmers are reluctant to go for it since they do not know about the benefits of cost reduction. A significant factor contributing to the underutilization of mechanization is farmers' limited awareness, preventing them from effectively reducing the drudgery experienced by both animals and humans and consequently, the animal-human-tractor combination remains largely unpracticed.

The choice of animal-human-tractor-sheller/combine harvester power is better than other combinations since it has a significant contribution in reducing animal-human drudgery, overcoming the shortage of animal-human power, and also meeting the time lines, even if the cost reduction may not be as significant as usually perceived by the farmers.

Fig. 5 clearly indicates a gradual reduction in cost of maize production from the initial combination of animal-human power to the fourth combination of animal-human-tractor-sheller/combine harvester power. The cost of production for wheat also follows the same trend except for the increase in cost for animal-human-sheller/combine harvester combination. The increased cost of production by animal-human-sheller/combine harvester power combination can be related to the extra cost of hiring of the combine harvester and also the cost of human power for feeding the combine harvester during threshing. However, it reduced significantly when the tractor is introduced in the fourth combination. This is due to the introduction of tractor, which significantly reduced the cost of animal and human power in spite of a higher cost involved in using the combined harvester.

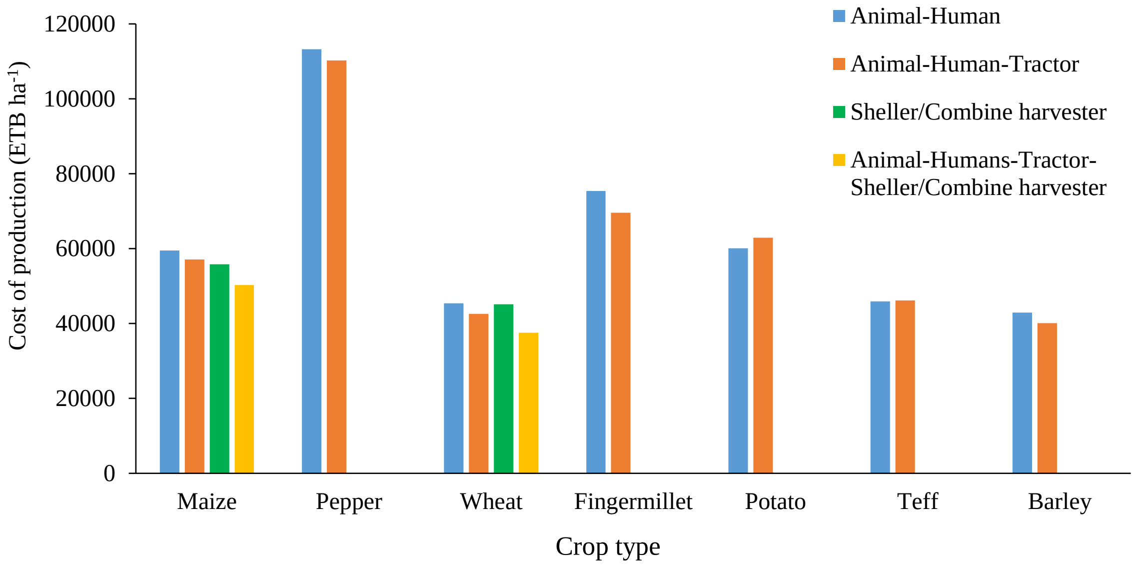


Fig. 5. Cost of crop production per hectare through different alternatives in Bure district during the 2022-23 crop season

Usually, the combine harvester could not be utilized to its full potential for simultaneous harvesting and threshing in the field due to unfavorable conditions of land size, its topology, road access, and obstacles like trees and stones in the field. For these reasons, use of combine harvester is not favored by both the service provider and the farmers. However, they are in limited service as stationary machines at convenient places, requiring extra cost for feeding the thresher.

Mechanization index for crop production

After analyzing and consolidating the responses by smallholder farmers and machinery owners, the cost involved for human, animal, and mechanical power in different farm activities for various crops in Bure district during the 2022-23 crop season is calculated, as presented in Table 15.

Table 15- Activity-wise cost of human, animal, and mechanical power, total cost of power for all farm activities, and the total cost of power for each crop

Farm activity	Source of power	Total cost of farm power [ETB]								
		Maize	Wheat	Pepper	Teff	Finger millet	Barley	Potato	Total cost	Grand total
Land clearing and tillage	Human	87,988,992	33,932,516	29,086,169	23,560,000	13,940,600	7,252,000	3,857,000	199,617,277	622425489
	Animal	178,319,232	70,196,210	40,160,631	63,840,000	35,986,200	14,918,400	7,308,000	410,728,673	
	Mechanical	5,707,520	2,686,807	3,685,211	*	*	*	*	12,079,538	
Planting and fertilizing	Human	64,064,000	9,114,000	71,498,000	7,600,000	3,242,000	2,072,000	6,090,000	163,680,000	26,827,6800
	Animal	48,048,000	15,038,100	16,853,100	12,540,000	5,349,300	3,418,800	3,349,500	104,596,800	
	Mechanical	*	*	*	*	*	*	*	*	
Weeding	Human	2,912,000	911,400	36,772,800	760,000	5,511,400	207,200	4,872,000	51,946,800	51,946,800
	Animal	*	*	*	*	*	*	*	*	
	Mechanical	*	*	*	*	*	*	*	*	
Cultivation	Human	*	*	147,081,600	*	*	*	14,616,000	161,697,600	161,697,600
	Animal	*	*	*	*	*	*	*	*	
	Mechanical	*	*	*	*	*	*	*	*	
Harvesting	Human	227,136,000	18,228,000	89,883,200	22,800,000	10,374,400	4,972,800	11,855,200	385,249,600	385,432,300

	Animal	*	*	*	*	*	*	182,700	182,700	
	Mechanical	*	*	*	*	*	*	*	*	
Drying and collecting	Human	*	*	45,963,000	*	5,187,200	*	*	51,150,200	51,150,200
	Animal	*	*	*	*	*	*	*	*	
	Mechanical	*	*	*	*	*	*	*	*	
Threshing and cleaning	Human	76,036,513	25,000,067	*	18,240,000	31,123,200	4,972,800	0	155372580	259,004,552
	Animal	1092000	13321022	*	22,800,000	9,726,000	7,459,200	*	54398222	
	Mechanical	48183817	1049933	*	*	*	*	*	49233750	
Transporting	Human	23296000	2734200	1,506,565	950,000	706,756	621,600	2,190,370	32005491	91,661,728
	Animal	46592000	4101300	2,259,848	1,425,000	1,060,134	932,400	3,285,555	59656236.5	
	Mechanical	*	*	*	*	*	*	*	*	
Watering	Human	*	*	45,972,000	*	*	*	*	45972000	45,972,000
	Animal	*	*	*	*	*	*	*	*	
	Mechanical	*	*	*	*	*	*	*	*	
Total cost of power for all farm activities	Human	481433505	89920183	467,763,334	73,910,000	70,085,556	20,098,400	20,098,400	43480570	
	Animal	274051232	102656632	59,273,579	100,605,000	52,121,634	26,728,800	26,728,800	14125755	
	Mechanical	53891337	3736740	3,685,211	0	0	0	0	0	
Grand total for each crop		809376074	196313555	530,722,124	174,515,000	122,207,190	46,827,200	46,827,200	57606325	

* Not applicable

The contribution of each type of power in different farm activities is illustrated in Fig. 6, and the mechanization index by farm activity for all the crops is calculated and presented in Table 16, using the data from the last two columns of Table 15. The data in Table 15 is also used to determine the contribution of each type of power for the total power required for various crops, as presented in Fig. 7, and the MI is calculated and presented in Table 17 for each crop using the cost data from the last two rows of Table 15.

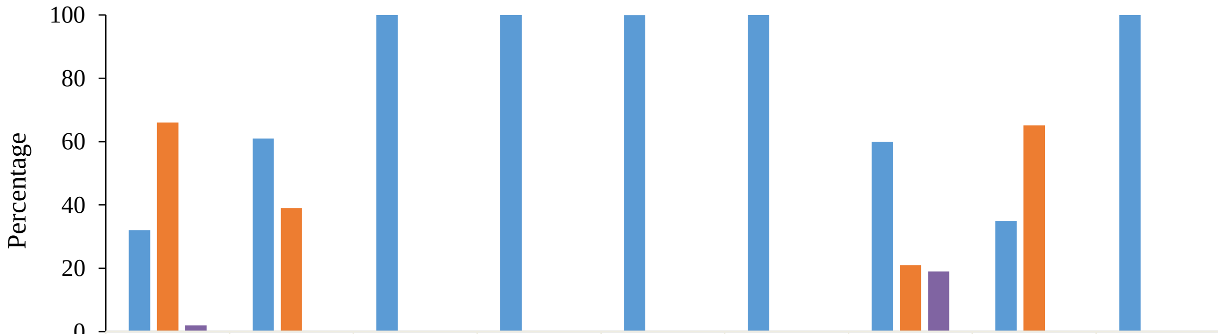
Mechanization index by farm activity

This study categorizes farm activities into nine groups: land clearing and tillage, planting and fertilizing, watering, weeding, cultivation, harvesting, drying and collecting, threshing and cleaning, and transporting. The analysis of mechanization associated with each farm activity examines the costs related to the seven main crops, organizing these expenses by major activities. The findings reveal that selective mechanization is implemented in the district. The use of mechanical power is predominantly confined to plowing and threshing, while crucial operations such as harrowing, planting, weeding, fertilizer application, and harvesting are carried out manually. The highest degree of mechanization was recorded in the threshing and cleaning category, reaching 19.01%, followed by land clearing and tillage at 1.94%. Human power is mainly employed for operating small tools and conducting stationary tasks, including plowing, seeding, cultivation, lifting, watering, harvesting, and winnowing. According to Table 15, a significant majority of agricultural activities depend heavily on human labor, supplemented by animal power. This dependence arises from poor working conditions for machinery and a lack of available equipment. The study highlighted that the underutilization of mechanical power, along with the reliance on outdated tractors with limited capabilities, has contributed to a low overall level of mechanization in the Bure district.

The utilization of mechanical power is significantly higher for threshing and cleaning compared to that of land clearing and tillage, while it is not used for the remaining activities as indicated in Table 16 and also illustrated in Fig. 6. The estimation of the mechanization index by farm activity is governed mostly by the machinery and implements available for tillage and threshing, presented in Tables 6 and 7. Disc harrows and combine harvesters are not in use due to limitations of land size and topology, road access, and obstacles in the field, although they are available. Furthermore, the sole combine harvester providing service in the district is used as a stationary thresher but not as a harvester and thresher, which projects its underutilization. The low level of mechanization prevailing in the district can be related to the lack of suitable machinery for the majority of the operations and the underutilization of the existing machinery.

Table 16- Mechanization index for various farm activity during the 2022-23 crop season in Bure district

Farm activity	MI (%)
Land clearing and tillage	1.94
Planting and fertilizing	0
Weeding	0
Cultivation	0
Harvesting	0
Drying and collecting	0
Threshing and cleaning	19.01
Transporting	0
Watering	0



	Land Clearing & Tillage	Planting & Fertilizing	Weeding (chemicals)	Cultivating	Harvesting	Drying & Collecting	Threshing & Cleaning	Transporting	Watering
Human power	32.07	61.01	100.00	100.00	99.95	100.00	59.99	34.92	100
Animal power	65.99	38.99	-	-	0.05	-	21.00	65.08	0
Mechanical power	1.94	-	-	-	-	-	19.01	-	0

Fig. 6. Components of power in different farm activities

Mechanization index by crop type

Table 17 provide a comprehensive evaluation of energy utilization from human, animal, and mechanical sources for various crops in rain-fed agriculture in Bure district during the 2022-23 crop season. The overall mechanization index for this season is 1.32%. Notably, it is 6.66% for maize which is the highest compared to that of all other crops. This not only signifies a substantial integration of mechanical power sources in maize production, but also its role in enhancing the local agricultural economy. Wheat is the second most mechanized crop, with a mechanization index of 1.9%, while pepper ranks the third with an index of 0.69%, indicating a limited mechanical power usage in its cultivation. The remaining four major crops indicate a large usage of traditional farming practices with negligible utilization of mechanical power. The values of MI presented in Table 17 indicates the levels of mechanization for each crop, projecting a significant adopt-ability for certain crops. The disparity of MI between different crops has an implication on the suitability of mechanization and the size crop production.

Table 17- Mechanization index for various crops during the 2022-23 crop season in Bure district

Crop type	**MI (%)**
Maize	6.66
Wheat	1.90
Pepper	0.69
Teff	0.00
Finger millet	0.00
Barley	0.00
Potato	0.00
Average MI	**1.32**

Fig. 7 indicates the percentages of contribution of human, animal, and mechanical power for the total power for each crop. It also indicates the variation between the average utilization of human, animal, and mechanical power for various crops. It is evident that for the majority of crops, human power plays the most significant role, followed by animal power, with mechanical power being the least utilized. This highlights the potential and necessity to enhance mechanical power use to reduce reliance on both human and animal labor. It also encourages the exploration of the underlying factors to find amicable solutions for better utilization of mechanical power.

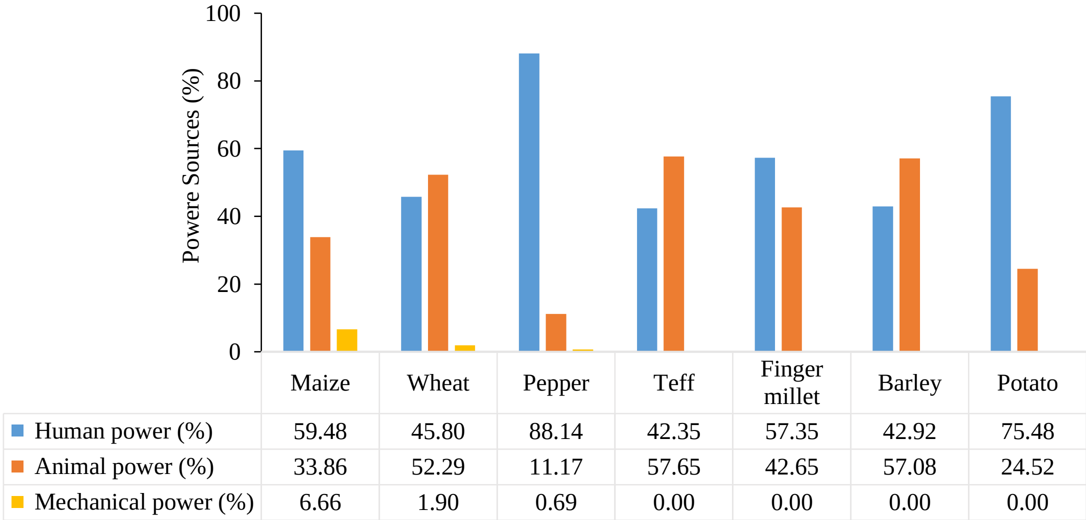


Fig. 7. Percentage utilization of different powers for various crops during the 2022-23 crop season

Rank of agricultural activity as per cost of energy

Due to limitation of measurements of energy required for different farm activities, the cost incurred for different sources of power is considered in the present study as an alternative to the cost of power for various farm activities. Table 18 presents the cost associated with each farm activity for all the crops cultivated in the Bure district during the 2022-23 crop season. The share of cost of each farm activity to the total cost can be noted from the 3rd column of Table 18, based on which the cost-wise ranking of different farm activities is placed in the 4th column of the same table. In order to reduce the cost of respective farm activities, and animal and human drudgery, and meet time lines of crop calendar, the ranking provided in Table 18 is extremely helpful to pinpoint those activities that require more intervention of farm mechanization. It can be noted that land clearing and tillage are the most energy-intensive tasks, making up 32.12% of the total cost of energy, which also confirms the findings of previous research (Patil, Salunkhe, Jadhav, & Patil, 2009; Perfect, McLaughlin, & Kay, 1997) that highlighted seedbed preparation as the major energy-intensive process in crop production.

The energy required for weeding has notably decreased due to the use of chemical methods with backpack sprayers, costing approximately 200 ETB ha^{-1} and taking less than two hours to complete. The energy spent on drying and collecting is negligible for most of the crops; but for crops like finger millet and pepper, the requirement of additional drying after harvesting incurs extra cost. Watering is necessary only for pepper, primarily during the initial growth of the seedling, which resulted in minimal costs of energy.

The cost-benefit analysis can be strategically used by policymakers to enhance productivity and reduce the cost of production, especially for crops like maize and wheat due to their high volume of production, and for pepper, which is highly energy intensive. This can also help to focus on farm activities to replace animal and human power with mechanical power, to reduce the drudgery and meet the timelines.

Table 18- Cost of different farm activities and their ranking for the 2022-23 crop season in Bure district

Farm activity	Cost of each activity for all the crops [ETB]	Cost of each activity (%)	Rank
Clearing and tillage	622,425,489	32.12	1
Planting and fertilizing	268,276,800	13.85	3
Weeding	51,946,800	2.68	7
Cultivation	161,697,600	8.35	5
Harvesting	385,432,300	19.89	2
Drying and collecting	51,150,200	2.64	8
Threshing and cleaning	259,004,552	13.37	4
Transporting	91,661,728	4.73	6
Watering	45,972,000	2.37	9
Total cost of all activities	1,937,567,469	100	

Conclusion and Recommendation

The analysis conducted through questionnaires targeting smallholder farmers in the Bure district, which examined the use of animal, human, and mechanical power across various farm operations for crops including maize, wheat, pepper, *teff*, finger millet, barley, and potato, has enabled the estimation of mechanization index (MI) based on crop type and farm activity. The mechanization index for selected crops is as follows: 6.6% for maize, 1.9% for wheat, and 0.69% for pepper. The MI by farm activity is 19.01% for threshing and cleaning and 1.94% for land clearing and tillage. The low MI value for land clearing and tillage suggests several implications regarding the size of the land, its topography, slope, and accessibility via roads. Currently, the estimated farm power density stands at 0.12 kW ha^{-1}, which significantly lags behind the Ethiopian government's target of reaching 1 kW/ha by the end of 2024. At present, only 8,052 ha are plowed by tractors, which amounts to 22.93% of the total arable land of 35,112 ha in the district. The estimated tractor density of 17 is significant as compared to its value of 20 for Africa. However, the survey revealed an underutilization of tractors due to the high cost of hiring by private enterprises, farmer unions, and government service providers. This underutilization also applies to the threshers and combine harvesters. On the contrary, demand consistently exceeds the supply during peak agricultural seasons despite their availability. This situation clearly indicates the need for intervention by government agencies to find ways and means to encourage farmers to adopt mechanization by providing subsidies for hiring, repair services, and spare parts. The present study has designed a methodology for estimation of the state of agricultural mechanization in Bure district in comparison to the 2014-2024 Growth and Transformation Plan of the Ethiopian government. This work lays the foundation for conducting similar studies, which can be scaled up to other parts of the country. It has been a matter of concern in most developing countries to support farmers for their sustainability, since they work to produce food grains under uncertainties and stand as the backbone of the country's economy. It is recommended that the government implement capacity-building initiatives, conduct awareness-raising demonstrations, and enhance access to financial loans for mechanization services. It is also recommended to identify the primary barriers from the supply side within the district.

Authors Contributions

Yonas Mitiku Degu: Conceptualization, Methodology, Text mining, Data pre and post processing, Manuscript preparation, Visualization.

D. K. Nageswara Rao: Supervision, Technical advice, Review and editing services.

Girma Moges Ketsela: Technical advice, Review and editing services.

Solomon Workneh Fanta: Technical advice, Review and editing services.

References

1. Abay, A. (2010). Market chain analysis of red pepper: the case of Bure woreda, west Gojjam zone, Amhara National Regional State, Ethiopia.
2. Assefa, T. T., Adametie, T. F., Yimam, A. Y., Belay, S. A., Degu, Y. M., Hailemeskel, S. T., Tilahun, S. A., Reyes, M. R., & Prasad, P. V. (2020). Evaluating irrigation and farming systems with solar MajiPump in Ethiopia. *Agronomy*, *11*(1), 17. https://doi.org/10.3390/agronomy11010017
3. Astatke, A. (1993). Research on the draught animal power systems in Ethiopia. *Recherche Pour Le Développement de la Traction Animale en Afrique de L'Ouest*, 199.
4. Ayele, S. (2022). The resurgence of agricultural mechanisation in Ethiopia: rhetoric or real commitment? *The Journal of Peasant Studies*, *49*(1), 137-157. https://doi.org/10.1080/03066150.2020.1847091
5. Begna, D., Kuma, T., & Yohannes, Z. (2024). The tendency of livestock growth in Ethiopia: A review. *Agricultural Reviews*, *45*(3), 502-507. https://doi.org/10.18805/ag.RF-291
6. Behnke, R., & Metaferia, F. (2011). The contribution of livestock to the Ethiopian economy–Part II. *IGAD LPI Working Paper 02-11*.
7. Berhane, G., Dereje, M., Minten, B., & Tamru, S. (2017). *The rapid–but from a low base–uptake of agricultural mechanization in Ethiopia: Patterns, implications and challenges* (Vol. 105). Intl Food Policy Res Inst.
8. Berhane, G., Hirvonen, K., & Minten, B. (2016). Agricultural mechanization in Ethiopia: Evidence from the 2015 feed the future survey. *ESSP Research Note 48*.
9. Daum, T. (2023). Mechanization and sustainable agri-food system transformation in the Global South. A review. *Agronomy for Sustainable Development*, *43*(1), 16. https://doi.org/10.1007/s13593-023-00868-x
10. Daum, T., Adegbola, Y. P., Kamau, G., Kergna, A. O., Daudu, C., Adebowale, W. A., Adegbola, C., Bett, C., Mulinge, W., & Zossou, R. C. (2024). Made in Africa–How to make local agricultural machinery manufacturing thrive. *Journal of International Development*, *36*(2), 1079-1109. https://doi.org/10.1002/jid.3845
11. Daum, T., & Birner, R. (2020). Agricultural mechanization in Africa: Myths, realities and an emerging research agenda. *Global Food Security*, *26*, 100393. https://doi.org/10.1016/j.gfs.2020.100393
12. Deribe, Y., & Getnet, B. (2021). Agricultural mechanization in Ethiopia: enabling policy,

suppliers and inter-regional heterogeneity. *Research Square*. https://doi.org/10.21203/rs.3.rs-478878/v1

13. Deribe, Y., Getnet, B., Kang, T. G., & Tesfaye, A. (2021). Benchmarking the Status of agricultural mechanization in Ethiopia. *Ethiopian Institute of Agricultural Research (EIAR). Research Report*(133).
14. Dessalegn, Y., Hoekstra, D., Berhe, K., Derso, T., & Mehari, Y. (2010). Smallholder apiculture development in Bure, Ethiopia: experiences from IPMS project interventions.
15. Dessie, A., Koye, T., & Koye, A. (2019). Analysis of red pepper marketing: Evidence from northwest Ethiopia. . *Economic Structures 8*(24). https://doi.org/10.1186/s40008-019-0156-0
16. Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K., & Prasanna, B. M. (2022). Global maize production, consumption and trade: trends and R&D implications. *Food Security*, *14*(5), 1295-1319. https://doi.org/10.1007/s12571-022-01288-7
17. Fan, S., & Rue, C. (2020). The role of smallholder farms in a changing world. *The Role of Smallholder Farms in Food and Nutrition Security*, 13-28. https://doi.org/10.1007/978-3-030-42148-9_2
18. Guadie, A. F., & Degu, Y. M. (2018). Design, Fabrication and Testing of Animal Drawn Multiple Mouldboard Plough. *International Conference on Advances of Science and Technology,* 206-224. https://doi.org/10.1007/978-3-030-15357-1_17
19. Kormawa, P., Mrema, G., Mhlanga, N., Fynn, M., Kienzle, J., & Mpagalile, J. (2018). Sustainable agricultural mechanization: a framework for Africa.
20. Kumar, M., & Tripath, A. (2019). Determination of agricultural mechanization parameters for Western Region of Uttar Pradesh, India. *International Journal of Current Microbiology and Applied Sciences*, *8*(9), 132-140. https://doi.org/10.20546/ijcmas.2019.809.018
21. Kumi, F., & Taiwo, A. (2014). Constraints to agricultural mechanization in sub-Saharan Africa. *International Journal of Applied Agriculture and Apiculture Research*, *10*(1-2), 75-81.
22. Lowder, S. K., Sánchez, M. V., & Bertini, R. (2021). Which farms feed the world and has farmland become more concentrated? *World Development*, *142*, 105455. https://doi.org/10.1016/j.worlddev.2021.105455
23. Lowder, S. K., Skoet, J., & Raney, T. (2016). The number, size, and distribution of farms, smallholder farms, and family farms worldwide. *World Development*, *87*, 16-29. https://doi.org/10.1016/j.worlddev.2015.10.041
24. Mrema, G. C., Baker, D., & Kahan, D. (2008). Agricultural mechanization in sub-Saharan Africa: time for a new look. *Agricultural Management, Marketing and Finance Occasional Paper (FAO)*(22).
25. Ngoma, H., Simutowe, E., Matin, M. A., & Thierfelder, C. (2024). Challenges and opportunities to scaling smallholder mechanization in Kenya, Malawi, Zambia, and Zimbabwe.
26. Nxumalo, K. K. S., Antwi, M. A., & Rubhara, T. T. (2020). Determinants of use of farm mechanization services amongst emerging farmers in North West Province of South Africa. *Journal of Agribusiness and Rural Development*, *2*. https://doi.org/10.17306/J.JARD.2020.01316
27. Patil, S., Salunkhe, S., Jadhav, S., & Patil, S. (2009). Evaluation for cost effective combination of different seed bed preparation implements with large size tractors. *International Journal of Agricultural Engineering*, *2*(2), 212-215.
28. Perfect, E., McLaughlin, N., & Kay, B. (1997). Energy requirements for conventional tillage following different crop rotations. *Transactions of the ASAE*, *40*(1), 45-49.
29. Rahman, S., & Chima, C. D. (2016). Determinants of food crop diversity and profitability in southeastern Nigeria: a multivariate tobit approach. *Agriculture*, *6*(2), 14. https://doi.org/10.3390/agriculture6020014
30. Sims, B., & Kienzle, J. (2017). Sustainable agricultural mechanization for smallholders: What

is it and how can we implement it? *Agriculture*, *7*(6), 50. https://doi.org/10.3390/agriculture7060050

31. Singh, G. (2006). Estimation of a mechanisation index and its impact on production and economic factors—A case study in India. *Biosystems Engineering*, *93*(1), 99-106. https://doi.org/10.1016/j.biosystemseng.2005.08.003
32. Wako, A. (2016). *Farm Mechanization of Small Farms in Ethiopia: A Case of Cereal Crops in Hetosa District* Seoul National University.
33. Wonde, K. M., Tsehay, A. S., & Lemma, S. E. (2022). Determinants of functionality level of farmers training centers in north-west Ethiopia. *Heliyon*, *8*(10). https://doi.org/10.1016/j.heliyon.2022.e10954
34. Workneh, W. A., Ujiie, K., & Matsushita, S. (2021). Farmers' agricultural tractor preferences in Ethiopia: a choice experiment approach. *Discover Sustainability*, *2*, 1-15. https://doi.org/10.1007/s43621-021-00021-2
35. Zerssa, G., Feyssa, D., Kim, D.-G., & Eichler-Löbermann, B. (2021). Challenges of smallholder farming in Ethiopia and opportunities by adopting climate-smart agriculture. *Agriculture*, *11*(3), 192. https://doi.org/10.3390/agriculture11030192
36. Zewdu, T., Agidie, A., & Sebsibe, A. (2003). Assessment of the livestock production system, available feed resources and marketing situation in Belesa woreda: A case study in drought prone areas of Amhara Region.". *Proceeding of the 10th annual conference of the Ethiopian society of Animal Production (ESAP) Held in Addis Ababa, Ethiopia*, 165-179.

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چکیده

شاخص مکانیزاسیون و سطح مکانیزاسیون مزرعه مهم‌ترین پارامترهایی هستند که میزان مکانیزاسیون را برجسته می‌کنند و با استفاده از داده‌های جمع‌آوری‌شده از طریق پرسشنامه از کشاورزان خرده‌پا و ارائه‌دهندگان خدمات ماشین‌آلات در بخش بوره، منطقه امهارا، اتیوپی تخمین زده می‌شوند. بینش‌های به‌دست‌آمده از داده‌ها شامل میزان فعلی در دسترس بودن ماشین‌آلات مختلف برای طیف وسیعی از فعالیت‌های کشاورزی است، همراه با روش‌هایی که کشاورزان متناسب با اندازه زمین، ویژگی‌های توپولوژیکی، ارتفاع، نوع محصول اتخاذ می‌کنند و دلایل استفاده ناکافی از ماشین‌آلات را نشان می‌دهد. داده‌های هزینه برای عملیات مختلف کشاورزی، که بر اساس توان دامی، انسانی و مکانیکی طبقه‌بندی شده‌اند، برای تخمین شاخص مکانیزاسیون و تراکم توان مزرعه استفاده می‌شوند. شاخص مکانیزاسیون خرمن‌کوبی و بوجاری نرخی معادل ۱۹/۰۱٪ دارند، در حالی که شاخص مکانیزاسیون آماده‌سازی و پاکسازی زمین ۱/۹۴٪ است. شاخص مکانیزاسیون محصولات زراعی برای ذرت ۶/۶۶٪، گندم ۱/۹۰٪ و فلفل ۰/۶۹٪ بوده و میانگین شاخص ۱/۳۲٪ است. سطح مکانیزاسیون ۰/۱۲کیلووات در هکتار تخمین زده می‌شود که انتظار می‌رود به ۱ کیلووات در هکتار، هدف تعیین‌شده برای سال ۲۰۲۴، برسد. خاک‌ورزی با ۳۲/۱۲٪ از انرژی کل صرف‌شده در تولید محصولات کشاورزی، پرمصرف‌ترین فعالیت از نظر انرژی است. تراکم تراکتور ۱۷ به‌دست آمد که نزدیک به شاخص ۲۰ در آفریقا است. مقادیر پایین‌تر شاخص مکانیزاسیون و سطح مکانیزاسین مزرعه که از این نظرسنجی مشخص شده است، نشان‌دهنده نیاز به حمایت از کشاورزان با اختصاص یارانه و افزایش دسترسی به ماشین‌آلات است. یکپارچه سازی لرلضی می‌تواند مکانیزاسیون مزرعه را افزایش دهد، هزینه تولید را کاهش دهد و بهره‌وری را افزایش دهد. تحقیق حاضر به تخمین شاخص مکانیزاسیون، سطح مکانیزاسیون و تراکم تراکتور در مقایسه با هدف تعیین‌شده توسط دولت اتیوپی کمک می‌کند و این رویکرد می‌تواند به سایر نقاط کشور نیز تعمیم داده شود.

واژه‌های کلیدی: تراکم تراکتور، تولید محصول، کمباین، ماشین آلات کشاورزی، مکانیزاسیون کشاورزی

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