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Constraints and Opportunities for Improving *Tef* Productivity: Evidence from On-Farm Demonstration

Abate Bekele*, Solomon Chanyalew, Tebkew Damte, Nigussu Husien, Yazachew Genet, Kebebew Assefa, Demeke Nigussie, Dominik Klauser and Zerihun Tadele

Abstract

Tef [Eragrostis tef (Zuccu). Trotter] is the most important food crop in Ethiopia where it is annually cultivated on about three million hectares of land. This is equivalent to 30% of the total area allocated to cereals. Compared to other cereal crops, such as wheat and maize, tef has higher tolerance to unfavorable environment conditions which include both biotic and abiotic stresses. Since the inception of tef improvement program in Ethiopia in the late 1950s, 42 improved varieties have been released by the national research system. However, overall economic benefits derived from tef farming are poorly understood. To assess economic benefit of recently released improved tef varieties, a field study was carried out with 40 lead farmers in four districts in central Ethiopia. Varieties used in the study and year of their release were Tesfa(2017), Dagim (2016) and Boset (2012). The average grain yield of the three varieties were comparable (Tesfa = 2.31, Dagim = 2.24 and Boset = 2.12 hectare^{-1}). The average variable production cost for the three varieties was 23,756.09 Birr ha-1. Given the input and output prices that prevail in the selected districts, farmers obtained on average a gross income of 36,673.25 Ethiopian Birr(ETB) hectare^{-1}. Analysis of the variable production cost structure revealed that the highest share of production costs across the 40 lead farmers was for labor (63.2%) and fertilizer (18.2%). From the total labor costs used in tef production, the lion's share went to harvesting (57.1%) followed by weeding (24.8%). Thus, technologies that either replace labour or improve labour productivity in tef production should be sought.

Key words: *Eragrostis tef*, gross margin, productivity, improved variety, *tef*, variable cost

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*Debre Zeit Agricultural Research Center, Ethiopian Institute of Agricultural Research, Ethiopia; E-mail: abatebekele98@gamil.com.Abate Bekele was the presenter as well as the corresponding author.

1. Introduction

Tef [Eragrostis tef (Zucc.) Trotter] is a small-grain cereal native to Ethiopia, grown in many parts of the country. It is annually cultivated on about three million hectares of land which is equivalent to about 30% of the total cereal area (CSA 2016). The cultivation and production of *tef* in Ethiopia increased in recent years due to high demand of the grain by consumers.

In addition to the long list of nutritional and health related benefits (Baye 2014), *tef* is resilient to both the conditions of excessive and scarce moisture, which are prevalent in the Ethiopian highlands where the crop is dominantly cultivated. For instance, *tef* is a crop of choice on poorly drained vertisols which is a dominant soil type in the country (Abate et al. 2012), especially in areas receiving high rainfall. Similarly, in vast areas in the country which are prone to drought, *tef* is widely cultivated as its short maturing period, offers additional benefit than other cereals.

At present, it becomes difficult to grow *tef* at scale because planting it in wet fields and harvesting the lodged *tef* with farm machinery is ineffective. Due to this, large proportion of labour in *tef* husbandry goes to harvesting and threshing (Abate et al. 2017).

The time series data collected for more than ten years at Bishoftu (Debre Zeit) market in central Ethiopia indicated that the prices of both the grain and straw had increased steadily (Gezahegn et al. 2005, DZARC Annual Research Report 2012). Both the grain and straw of *tef* fetch higher price than other cereals. However, variations in the price of the grain are observed depending on location and time of year. Major factors which affect the *tef* prices are quality related characteristics which include grain color, grain size, purity, age and brand name Some of the quality characteristics are believed to be either cryptic or evident qualities that manifest themselves in various ways in the market (Ibid.).

In order to satisfy future domestic and potential international demand, we have to sustainably intensify *tef* production to improve both the livelihoods of smallholder farmers and provide secure food sources to a growing population (Piccinin 2010).

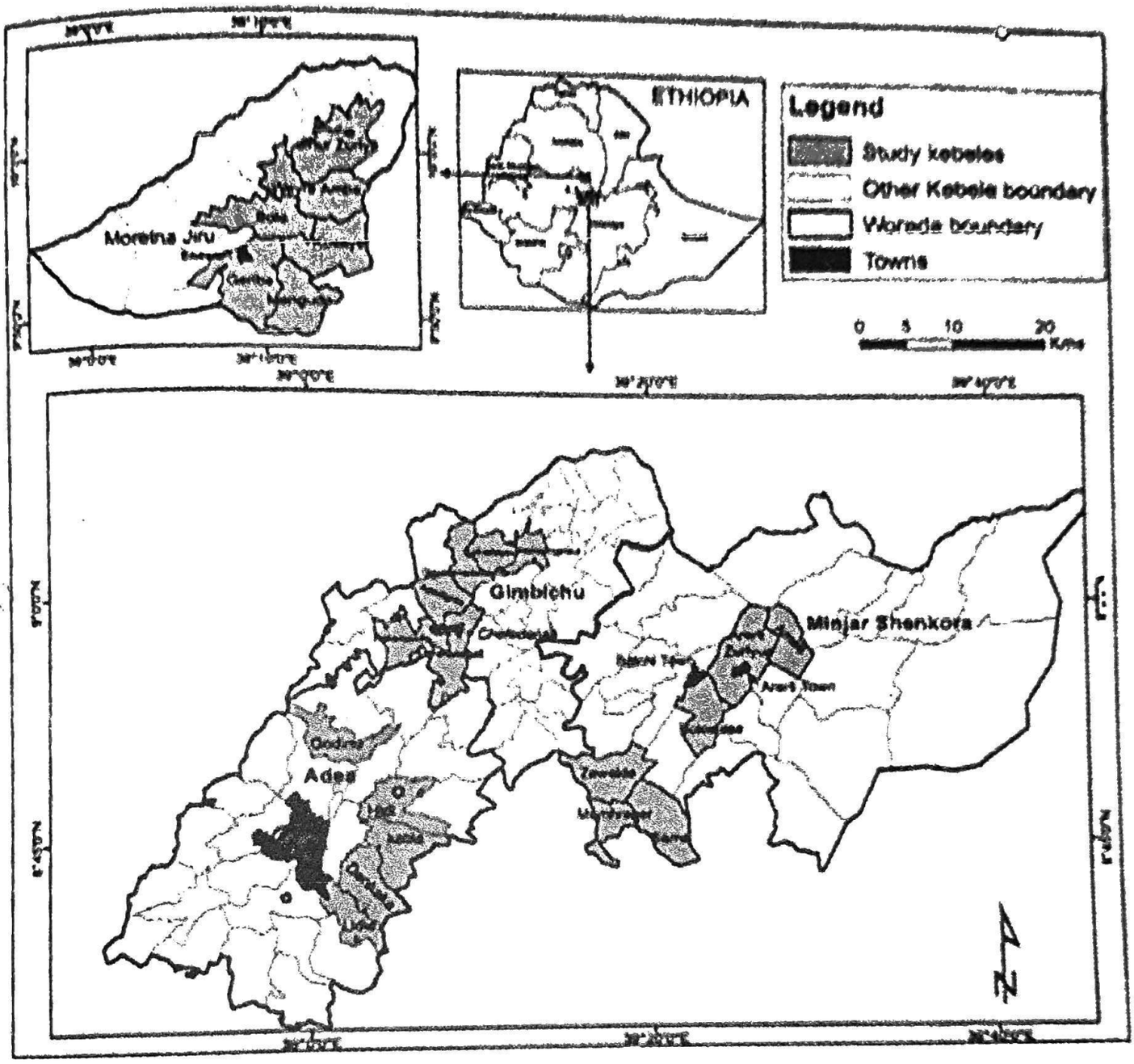

Figure 1: Location map of the study area

ii) Design and sampling

Forty (40) farmers were randomly selected from 92 lead farmers. Lead farmers refer to smallholder farmers who are ready to test new farming technologies including improved varieties in their fields(Chabata and Judith de Wolf 2013). Three improved *tef* varieties were used for the study. These are *Tesfa* (released in 2017), *Dagim* (2016) and *Boset* (2012). Based on their preference, each farmer was given two of the three varieties. While 26 farmers grew *Tesfa* and Dagim varieties, 14 farmers chose *Tesfa* and *Boset* varieties. The varieties were planted side by side

on the same field and at the same sowing date each on about 0.25 hectare land in order to compare results. The seed rate of both varieties was 16-20 kg ha^{-1}, while farmers individually decided on all other agronomic management practices which include the frequency of ploughing, time of sowing, time of hand weeding, and type, time and rate of fertilizer application. Moreover, except for the seed, farmers used their own inputs and they were also responsible for managing the trials, while researchers and the extension agents were responsible for facilitating and providing guidance. They also assisted the lead farmers to ensure that the trials were done uniformly at all sites.

iii) Data collection and analysis

Relevant physical and cost data were collected from the primary sources. Data on grain yield, labor and oxen use, and use of seeds and fertilizers were recorded. The data were coded and entered into the SPSS Computer Software Package for analysis. Data were initially analyzed using descriptive statistics such as frequency, percentages, minimum, maximum, means and standard deviations.

Physical and economic information on the demonstration trials, as a resource, for development is only just beginning to gain ground in Ethiopia. Policy makers, planners, researchers and extension agents are increasingly recognizing the fact that physical and economic information is indispensable to the development process. One serious constraint to agricultural development is the limited access to financial information on the demonstration trials/plots so far done for a number of years. The current study attempted to collect both physical and economic data on the demonstration trials as well as to express the results in both physical and monetary terms.

Gross margin was calculated as the difference between gross revenue and variable costs. Gross revenue refers to the value of total grain and straw in monetary terms. Performance indicator is the ratio between the total output and the total input.

All costs and revenues were initially quantified for the 0.25 hectare land of each farmer in the current study which were later extrapolated to the hectare basis.

3. Results and Discussion

i) Socio-economic characteristics of *tef* farmers

The findings from key parameters are briefly presented below:

Age: The result of the analysis shows that 45% of the respondents were between the ages of 41-50 years, 22.5% were between 31-40 and 17.5% were older than 50 years(Table 1).

Education: Table 1 shows that there is high level of education among the respondents as 65% attended primary school and the other 25% completed secondary school. This shows that the majority of the respondents are literate. This relatively higher level of literacy is expected to enhance innovativeness of farmers.

Farm size: Over one third (35%) of the respondents possessed a land size larger than 2.5 hectares while 22.5% of the respondents had a land between 2.1-2.5 hectares. This result indicated that the majority of the *tef* farmers belong to small-scale category in terms of land holdings. This is in agreement with earlier report which classified the majority of *tef* farmers as small landholders (Abate et al. 2005).

Farming experience: Slightly over half of the respondents (52.5%) had more than 10 years of farming experiences. The implication of this finding is that the majority of the respondents were experienced farmers who are considered to be responsible and rational in taking farm related decisions.

Table 1: Socio-economic characteristics of the selected *tef* farmers (n = 40)

Variables	Frequency	Percentage
Age (years)		
21-30	6	15.0
31-40	9	22.5
41-50	18	45.0
>50	7	17.5
Education level		
Illiterate	4	10.9
Primary school	26	65.0
Secondary school	10	25.0
Farm size (ha)		
<1	2	5.0
1.1-1.5	7	17.5
1.6-2.0	8	20.0
2.1-2.5	9	22.5
>2.5	14	35.0
Farming experiences (years)		
1-5	10	25.0
4-10	9	22.5
>10	21	52.5

ii) Level of awareness of *tef* production technology

Farmers were asked to indicate their awareness of *tef* production technology from five recommended technologies available for the crop which include improved seed, fertilizer and pest and disease control measures.

The results showed that farmers have low awareness about the major recommended technologies (18%) (Table 2). Low awareness of released improved varieties was flagged by 37.5% of the farmers. The proportion of farmers for low awareness of seed rate and fertilizer rates were 25% and 15%, respectively. The implication of this finding indicates the farmers who are not aware of the technology will not certainly adopt the technology easily.

Table 2: Respondents' awareness of recommended *tef* production technology (n = 40)

Technology	Awareness			
	Yes	%	No	%
Recently released improved varieties	15	37.5	25	62.5
Seed rate(kg/ha)	10	25.0	30	75.0
Fertilizer rate(kg/ha)	6	15.0	34	85.0
Control of pests and diseases	3	7.5	37	92.5
Improved harvesting technologies	2	5.0	38	95.0

iii) Constraints to utilization of *tef* production technology

The potential to improve *tef* productivity is limited by multiple constraints. Among these, inadequate supply of quality seed and farm machinery are critical barriers to increasing *tef* productivity. Compared to other cereal crops, *tef* is labour intensive because of low level of mechanization.

Farmers were asked to rate the constraints in *tef* technology. The results of the study presented in Table 3 revealed that the constraints to the utilization of *tef* production technology, as rated by the farmers, is shortage of improved varieties(23.5%), followed by lack of farm machinery for harvesting. Shortage of cash to pay for labour at harvesting (20%) and lack of information on input supply (18.2%) were also other constraints to the utilization of *tef* production technology.

Table 3: Constraints to utilization of *tef* production technology (n=40)

Constraints	Respondents	
	N	Percent
Shortage of seeds of improved varieties	40	23.5
Shortage of capital to pay for labour at harvesting	34	20.0
Lack of harvesting technology	38	22.4
Lack of information on input supply	31	18.2
Inadequate extension contacts	27	15.9
Total	170*	100

* Respondents exceed 40 because they gave multiple responses.

iv) Farmers' perceptions of the improved varieties

In this study, the common criteria farmers used to assess new *tef* varieties were grain yield, maturity period, quality and quantity of straw for livestock feed, shoot fly (*Atherigona hyalinipennis*) tolerance and frost escape. In fact, substantial variability exists in temperature, rainfall, soil type and length of growing period in the four districts and 40 farmers' fields. Due to these variabilities in the agro-ecology of experimental sites, the performance of *tef* varieties also differs from location to location. For instance, *Tesfa* and *Boset* varieties yielded well in *Minjar-Shenkora* and *Ada'a* districts because of shorter rainy seasons and high

Tesfa and *Dagim* because of adequate and extended rainfall which is ideal for the late-maturing *Dagim*variety.

Enumerating farmer's selection criteria, the overall farmers' evaluation of the new varieties is presented in Table 4. In terms of grain yield and tolerance to shoot fly, all the three varieties received similar and high score indicating the high preference of the varieties tested by farmers from diverse agro-ecological conditions. Compared to *Tesfa* and *Boset* varieties, the late maturing *Dagim* variety is less preferred by farmers due to its late grain filling period and little chance to escape frost. This shows that, in general, farmers prefer for early maturing *tef* varieties since it enables farmers to harvest ahead of other crops especially during the critical period of grain shortage.

According to farmers' evaluation, in semi-arid areas like *Minjar* and *Ada'a*, *Boset* and *Tesfa* are preferred by farmers whereas in wet areas like *Moretna-Jirru* and *Gimbichu Tesfa* and *Dagim* are preferred.

Table 4: Overall farmers' evaluation for the three *tef* varieties in 2016/17 cropping year using 1(least preferred) to 5 scale (most preferred by farmers)

Tef variety	Grain yield	Maturity (grain filling)	Plant Height	Shoot fly tolerance	Frost escape	Mean	Rank
Tesfa	4.75	4.78	4.70	4.75	4.93	1.78	1.00
Dagim	4.60	3.53	4.75	4.78	3.35	4.20	3.00
Boset	4.58	5.00	3.78	4.90	4.98	4.65	2.00

v) Agronomic data

In this study, equal seeding rates, for the three varieties, was used for sowing at all sites but plant population across the selected locations exhibited variability. Thus, at maturity, the plant mean population ranged between 1163 and 1532 per square meter. The variability in plant populations might be associated with differences in seed bed preparation, sowing date, soil moisture state and soil packing at planting. The higher plant population usually has a direct and positive correlation with high plant biomass(or straw) which is vital as a livestock feed.

Small amount of grain yield difference was observed among the three varieties. On average, 15t ha^{-1} obtained at two locations in *Moretna-Jirru* districts. This low yield was obtained partly due to shoot fly (*Atherigona hyalinipennis*) infestation and poor soil moisture conditions during the grain filling period. With additional supplemental precipitation, this soil packing practice might support the plant in conserving enough moisture around the root zone of *tef* plant and enable the plant to provide some harvest in even bad season. It is observed that higher soil moisture condition at planting and grain filling stages increase yield per hectare. As indicated in Table 5, the average shoot biomass, grain yield and harvest index for the three varieties were comparable. This narrow differences among the three varieties were: for shoot biomass from 8.8 t ha^{-1} (*Boset*) to 10.0t ha^{-1} (*Dagim*).

Table 5: Agronomy-related parameters determined from harvesting samples of the demonstration trials

Variety	Number of sites	Plant pop. (No m^{-2})	Plant height (cm)	Shoot biomass (t ha^{-1})	Grain yield (t ha^{-1})	Harvest indes (%)
Tesfa	40	1359.31	107.17	9.99	2.31	23.12
Dagim	26	1531.67	112.72	10.01	2.24	22.38
Boset	14	1162.67	81.08	8.79	2.12	24.11

vi) Production costs of the demonstration trials

Production costs of the demonstration trials play an important role in the decision of the farmers. Explicitly or implicitly most of the farmers keep in mind the cost of producing additional units of output from improved varieties.

In a competitive market, *tef* prices are not in the control of an individual farmer because there are large number of farmers who are individually producing very small proportions of total production of a commodity. Individual farmer's production must, therefore, sell at the same or even lower prices, even though additional production might involve higher costs. The second alternative is to reduce the cost of production through rationalization of resource-use with low cost of production factors. Thus, cost minimization is the second alternative that directly adds to the gross margin or profit of the farmers who hosted the demonstration trials.

Costs of production often become a policy issue and farmers complain that the prices they receive for their products do not cover the cost of production. In the context of this paper, costs of production here mean the expenses incurred per unit of output that include the variable and fixed costs. In the production of one unit of *tef*, for example, there are different costs involved. The major cost items involved in *tef* production are seed, fertilizers, labour and oxen traction. In order to make a rational choice amongst alternatives, the major costs involved in the demonstration trials should ideally mirror actual production systems as appropriately as possible.

The cost of production was estimated from farmers' records of input use. Producing *tef* requires substantial amounts of labour and oxen-hours, averaging 854.70 man-hours and 459.90 oxen-hours ha^{-1}, respectively (Table 6). Categorically, higher proportion of labour was allocated to harvesting and weeding. The results of the study revealed that the lead farmers used variable rates of DAP and urea fertilizers. This indicates that farmers did not apply the recommended

dose of fertilizer to *tef*. The mean amount of DAP and urea fertilizers applied by farmers were 215 and 140 kg ha^{-1}, respectively.

Table 6: Amount of inputs, labour and oxen time used for demonstration trials as recorded by the farmers (n = 40)

Parameters	Seed (kg ha^{-1})	Fertilizer (kg ha^{-1})		Labour (man-hour ha^{-1})	Oxen (Oxen-hour ha^{-1})
		DAP*	Urea**		
Minimum	16.00	200	100.00	772.00	408.00
Maximum	20.00	260	200.00	956.00	504.00
Mean	18.30	215.00	140.00	854.70	459.90
St. Deviation	2.00	26.31	41.12	46.05	25.06

*DAP contains 16% nitrogen and 46% P_2O_5

** Urea contains 46% nitrogen

vii) Estimates of variable costs

Given the input prices that prevail in the selected districts, cost of variable inputs of 40 lead farmers are summarized in Table 7. The major inputs considered in *tef* production were seed, fertilizers, and labour for seedbed preparation, sowing, weeding, harvesting and threshing as well as oxen time for plowing, planting and threshing. Product transport from the farm to the homestead (threshing ground), stacking, winnowing and cleaning costs were not included in the total variable costs.

On average, the total variable costs were *Birr* 23,765.09 per $hectare^{-1}$ out of which the mean labour cost was 15,046.66 *Birr* $hectare^{-1}$. This means, 63% of the total cost is incurred by labour (Figure 2). Farmers were asked about costing procedures and methods of labour payment. Eighty (80) percent of the farmers reported that hourly labor payment for harvesting remains higher due to the overlap of different farm operations across crops and the fact that harvesting for *tef* should be done within short period of time (one to two weeks). Farmers further

explained that neither migrant nor family labor fulfill the labor demand for harvesting. Thus, to perform harvesting and threshing in a given period of time, they indicate their need for mechanized solution. Hence, introducing farm machinery offers an opportunity to improve the productivity of *tef* farming in the future.

Table 7: Variable input costs of *tef* demonstration trials (n = 40)

Parameters	Seed cost (Birr/ha)	Fertilizer cost (Birr/ha)	Labour cost (Birr/ha)	Oxen cost (Birr/ha)	Total cost (Birr/ha)
Minimum	400.00	3,750.00	13,235.00	3,550.00	20,517.55
Maximum	500.00	5,610.00	16,880.00	4,440.00	25,708.05
Mean	457.50	4,372.50	15,046.66	4,009.00	23,756.09
St. Deviation	20.06	757.92	714.23	208.40	1336.18

Source: Researchers' computation.

A reasonable amount of cost also went to oxen-hour whereas the seed cost was insignificant. This shows that small-scale *tef* farming absorbs labor and oxen cost. It is, therefore, arguable that small-scale farmers should either use labour effectively or use farm machinery to increase *tef* production per unit area. Harvesting with sickles, oxen-stamping to dislodge the seeds during threshing and cleaning the seeds using pitchfork and manual winnowing will not meet high demand from both domestic and foreign markets as *tef* is not only a popular grain in Ethiopia but also becoming a life-style crop in Europe and North America.

a) Labour cost structure

In developing countries, the bulk of the labor force is concentrated on agriculture. However, labour becomes very scarce at the time of harvesting. The situation gets worse when small rains appear during the harvesting period of *tef* as the demand for labour gets high and then the wage for *tef* harvesting increases. This means, labour supply fails to keep pace with demand during harvesting. As a consequence,

labour prices tend to rise. Due to these constraints in labor shortage and unexpected rise in harvesting costs, introducing farm machinery is the most important breakthrough in order to overcome this critical shortage of labour during harvesting. Farm machinery reduces the drudgery of farm work and facilitates optimum period for *tef* harvesting and threshing. The current study indicated that 57% of the total labour cost was allocated for *tef* harvesting (Figure 2). Investment in technology which reduces the shortage of labour and improves the flow of agricultural labour to industrial development need to be promoted (Norton and Alwang 1993, Mijinadadi and Njoku 1995, Agwu etal. 2008).

b) Oxen cost structure

In many developing countries like Ethiopia, oxen are the principal source of power as they are used in several activities including plowing, planting and threshing. Oxen traction is indispensable in diverse types of terrains and soil types including those difficult to work with. From the total oxen-hours, 61% was allocated to threshing while 28% to plowing (Figure 2). Normally, farmers hire labour and increase numbers of oxen to perform threshing in a short period of time before untimely rain spoils their harvest.

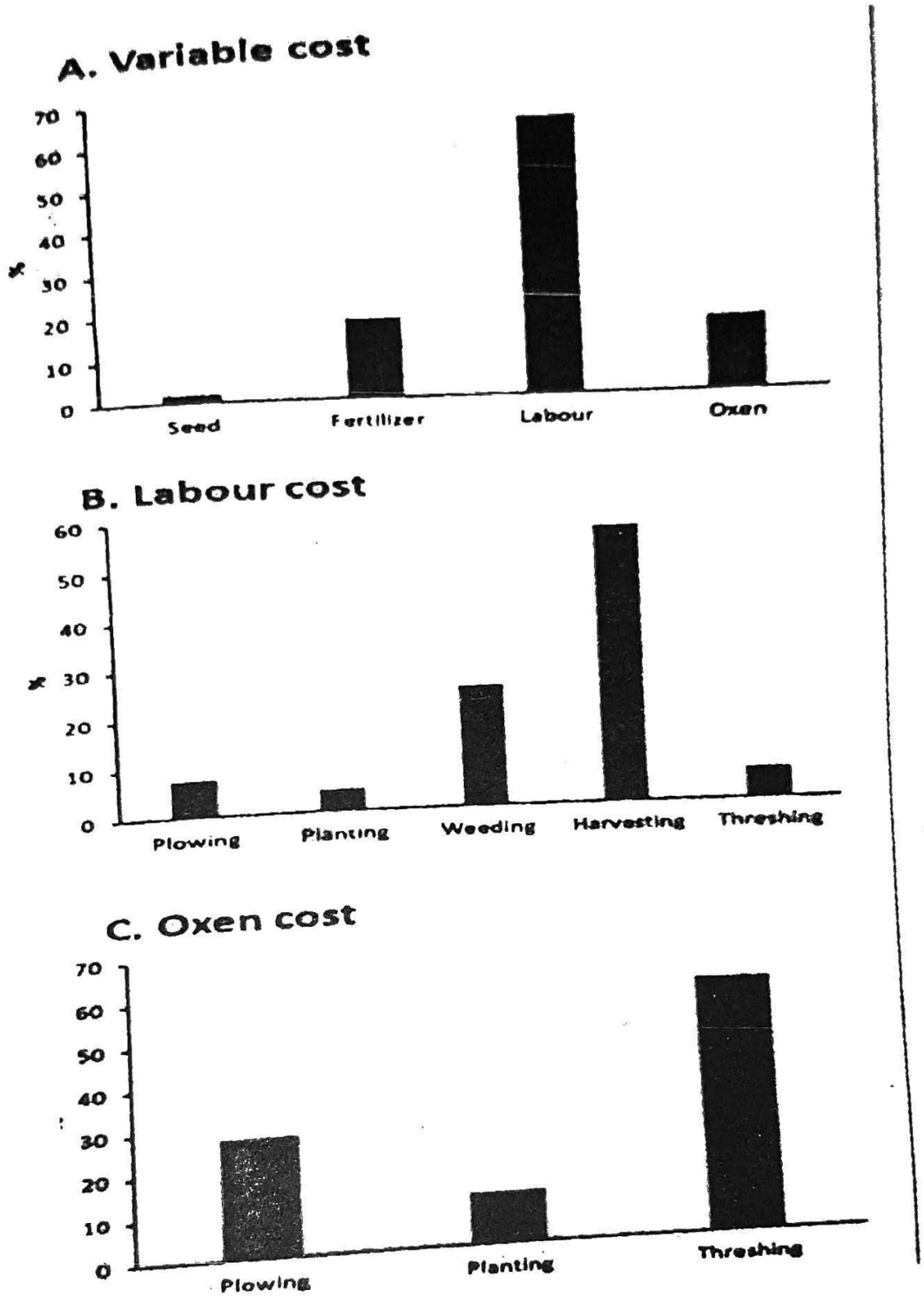

Figure 2: Major costs incurred in *tef* farming: (A) variable costs, (B) costs of labour, and (C) costs for oxen.

c) Estimates of gross margin or revenue

Given the input and output prices that prevail in the selected districts, the mean revenue and mean variable costs were estimated to determine the mean gross margin (Table 8).

The mean gross margins were 38,736.88 ETB hectare-1for *Tesfa*, 37,345.59 ETB hectare-1 for *Dagim* and 33,937.27 ETB hectare-1 for *Boset*. The additional gross margins of *Tesfa* and *Dagim* compared to *Boset* were 4,799.61 and 3,408.32 ETB hectare-1, respectively. The mean variable costs were slightly more in high yielding varieties since they required additional labour for harvesting and threshing but they produce more output per unit of land. *Tef* straw value was considered because farmers believe that they stay profitable if the straw is either fed to their cattle or sold to the market for different purposes (Feed, house plastering and bedding). Straw prices were collected from the four study districts to estimate the gross revenue obtained from the straw. Accordingly, the total revenue was the sum of revenues obtained from grain and straw. Finally, benefit cost ratio of each variety was determined to obtain the value of benefit from a unit of investment.

Table 8: Mean revenue, variable costs and gross margin by farmers growing the three improved *tef* varieties

Parameters	Improved varieties		
	Tesfa (n = 40)	*Dagim* (n = 26)	*Boset* (n = 14)
Grain yield (t hectare^{-1})	2.31	2.24	2.12
Straw yield (t hactare^{-1})	9.99	10.01	8.79
Total revenue* (ETB hectare^{-1})	62,808.00	61,292.00	57,188.00
Variable costs (ETB hectare^{-1})	24,071.12	23,946.41	23,250.73
Gross margin (ETB hectare^{-1})	38,736.88	37,345.59	33,937.27
Additional gross margin (ETB hectare^{-1})	4,799.61	3,408.32	-
Benefit- cost ratio	1.61:1	1.56:1	1.46:1

* Grain and straw priced at 22.0 and 1.2 ETB kg^{-1}, respectively.

Source: Researchers' computation.

viii) Performance indicators of the varieties

Growth in *tef* output per unit of area and per worker is generally recognized as a necessary condition for economic development. The benefits of improved *tef* technology in small-scale farming are realized in terms of an increase in farm output, higher income and improved living standard (Hart et al. 2005). Smallholder farmers are characterized by the difference in relative endowments of improved technologies, land and labour. Substantial differences in *tef* productivity are closely associated with changes in the supply of improved technology, land and labour.

Performance indicators for *tef* vary based on farm size, effective use of improved technologies and labour. Compared to other cereal crops, *tef* is labour intensive because of low productivity per unit of labour and per unit of land. This can be partly explained by the fact that smallholder farmers cannot afford to purchase improved technologies. Grain yield per hectare, return per unit of fertilizer, labour and oxen were the most important performance indicators in *tef* production. The growth of crop performance by small-scale producers depends on the need to improve productivity of inputs used. It is evident that productivity growth may be achieved through technological progress or efficiency improvement, such as improved farmer education, to ensure that farmers use the existing resources more efficiently. The need to improve total productivity of inputs (land, seed, fertilizer, labour and oxen) as to raise the level of output would be a coherent and fundamental issue. As indicated on Table 9, seed multiplication ratio refers to the average *tef* yield divided by the average seed used per hectare. In other words, it is the amount seed multiplied from a unit of seed used or the amount of seed produced per unit of seed used. In our study, there was no significant difference among the varieties. *Tef* grain return per unit of DAP and urea were used to produce a unit of *tef* grain. In the same way, labour and oxen productivity means what unit of *tef* grain produced per unit of hour. This low labour productivity in *tef* indicates low level of mechanization. The variable production cost incurred to produce a kilogram of *tef*.

Table 9: Performance indicators of improved *tef* varieties disseminated to lead farmers in 2018 cropping year

Performance indicators	Varieties		
	Tesfa (n=40)	*Dagim* (n = 26)	*Boset* (n = 14)
Average *tef* yield (kg/ha)	2,307.81	2,237.78	2,116.67
Average variable production cost (*Birr*/ha)	24,071.12	23,946.41	23,250.73
Seed multiplication ratio	128.01	125.04	124.67
Tef grain return per unit of DAP (kg)	10.79	10.49	10.15
Tef grain return per unit of urea (kg)	19.17	18.17	17.80
Labour productivity in *tef* (kg/man-hour)	2.55	2.46	2.29
Oxen productivity in *tef* (kg/oxen-hour)	5.05	4.92	4.66
Variable production cost (Birr/kg)	10.43	10.70	10.98

Source: Researchers' finding.

4. Conclusions

On the basis of the field trials, the following conclusions were made:

The grain yields from the three *tef* varieties are comparable (*Tesfa* = 2.31, *Dagim* = 2.24 and *Boset* = 2.21 t ha^{-1}). Despite this reality, each variety has its own merits and demerits.

The average variable production cost for the three varieties was 23,756.09 *Birr* hectare^{-1}. Given the input and output prices that prevail in the selected districts, the lead farmers obtained, on average, a gross income of 36,673.25 ETB hectare^{-1}.

To this end, the average variable cost to produce a kg of *tef* was estimated at Birr 10.70, whereas, the average current price farmers received per kilogram of *tef* is *Birr* 21.00. This indicates that small-scale *tef* farming is not only a financially viable venture, but it has also significantly contributing towards generating income for farmer households.

Analysis of the variable production cost revealed that the highest proportion of the production costs across the 40 lead farmers were for labor (63%) and fertilizer (18%). These findings suggest that small-scale farmers should use farm machinery for harvesting and threshing in order to minimize cost of labour and post-harvest losses in *tef* production.

Unless improved method of farming is implemented in *tef*, the existing practices in harvesting, threshing and winnowing do not make in the long-run *tef* production profitable.

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Address:

Unity University
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