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Effects of Nitrogen Rates on Yield, and Yield Components of Improved Sorghum Varieties in the lower watersheds of Habru District, Northern Ethiopia

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ABSTRACT

Nitrogen is the most limiting nutrient for the growth and development of sorghum; as in most Ethiopia soils, the soils of the study areas are deficient in nitrogen because of over cultivation of the land. Hence, this research was designed to study the effects of nitrogen rates on yield and yield components of improved sorghum varieties in the three lower watersheds of Habru district, northern Ethiopia. Factorial combinations of nitrogen rates (0, 46, 69, 92, and 115kg N ha^{-1}) and two sorghum varieties (Melkam and Girana 1) were arranged in a randomized complete block design with three replications. The experiment was conducted in three watersheds for two years. The analysis of variance showed that all the combined seasons and locations for the growth, yield, and yield-related traits of sorghum parameters were significantly ($p<0.05$) affected by the interaction of nitrogen rates and varieties except plant height which was significantly affected by the main effects of nitrogen and varieties only. Almost all the yield and yield-related parameters had shown a significant increase up to the rate of 92 kg N ha^{-1}. The partial budget analysis showed that the treatment combination of Melkam with 92 kg N ha^{-1} gave the highest marginal rate of return of 4321% followed by Melkam with 69 kg N ha^{-1}. Applying nitrogen to sorghum increased its productivity. Thus, the application maximizes yield of Melkam variety resulted in maximum profit and can be recommended for the study area.

Keywords: Fertilizer, Nitrogen, Sorghum, Varieties, Watersheds, Yield.

INTRODUCTION

Sorghum (*Sorghum bicolor* (*L*) Moench) is a vital cereal crop belonging to the Poaceae family. It can adapt to an area of low annual rainfall of 400-600 mm, in which it is too difficult for other cereals to survive (Dicko et al., 2006).

Sorghum is Africa's second most important cereal. In most West African countries, sorghum alone accounts for 50% of the total cereal cropland area. Therefore, true food security will be hard to achieve in those countries without a significant improvement in this major staple cereal's production, use, and marketing. The total national sorghum production was over 3,966 million metric tons (CSA, 2018). Sorghum is the most important cereal crop, which grows in the moisture-limited area of the country, and it serves as an insurance crop, especially in the north and northeastern parts of Ethiopia (Degu et al., 2009). It makes a great contribution to these areas economically, socially, and culturally.

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Despite the large-scale production and various merits, sorghum productivity has the potential to be far better. Currently, the average regional productivity is 2.1 t ha^{-1} but in the study area productivity is below 1.3 t ha^{-1}, which is very low as compared to other small grain cereals grown in Ethiopia (CSA, 2018). To feed the ever-increasing population and generate income, continuous land cultivation became common in major sorghum-producing areas, which eventually led to soil fertility decline and subsequent reduction of crop yields (Farré & Faci, 2006; Marsalis et al., 2010; Saberi, 2013). In Amhara region, north Wollo zone is the first in sorghum production. It is the first cereal crop in terms of area coverage and volume of production.

Nitrogen (N) is a major input for sorghum production, affecting both its yield and quality. Throughout Ethiopia, farmers use nitrogen fertilizer a blanket recommendation of 46 kg N ha^{-1} without considering the variability in fertility status of the soil from place to place. The problem has existed in eastern Amhara, which is one of the greatest sorghum-producing areas of the country. Therefore, this research aimed to identify suitable varieties and to determine optimum nitrogen rate for a particular soil type and specific agro-ecological location in eastern Amhara, particularly in Harbu district. Plant use efficiency of nitrogen depends on several factors including, rate of N, cultivar, and climatic conditions. Therefore, there is a need for site-specific recommendations for nitrogen rate because variations in climate, soils, and available nutrients differ greatly between areas. The farmers in the study area are using blanket recommendations of nitrogen fertilizer (46 kg N ha^{-1}). In addition, the farmers of the study area have limited information on sorghum varieties that enhance yield. Therefore, the study was conducted to evaluate the effect of nitrogen rate on yield and yield components of improved sorghum varieties in three lower watersheds sites of Habru district, north Wollo zone, Ethiopia.

MATERIALS AND METHODS

Field experiments were carried out in the lower parts of the three watersheds of Habru district in 2020 and 2021 main cropping seasons under rain fed conditions. The climatic characteristics of the experimental sites are indicated in Table 1.

Table 1: Description of the study area (Habru district)

Parameters	Description
Location	11°40′N-11°66.7′N latitudinal and 39°39.5′E-39°65′E longitudinal
Altitude	700-1900 m
Mean annual max. Temperature	28.5 ^{o}C
Mean annual min. Temperature	15 ^{o}C
Mean annual rainfall	750 - 1000 mm
Soil	Vertisol

Description of experimental materials:

The study used two improved sorghum varieties (Girana1 and Melkam) as test crops. The varieties were released from Srinka Agricultural Research Center (SARC). Nitrogen in the form of urea (46%) was used as a source of nitrogen for the experiment

Treatments, design, and experimental procedures:

Treatments consisted of two sorghum varieties (Melkam and Girana-1) and five rates of nitrogen (0, 46, 69, 92, and 115 kg/ha) arranged in factorial using randomized complete block design with three replications. The study was conducted in three watersheds for two years. The experiment was conducted under good agronomic practices that included soil tillage, weeding, and fertilizer applications. The spacings between block and plot were 1.5 m and 1 m, respectively. Each plot consisted of five rows spaced 75 cm apart while the spacing between plants was 15 cm. In each plot, one plant at both ends of each row was left to avoid the border effect and from each plot, the three central rows were considered for the determination of sorghum growth, yield, and yield-related traits of sorghum. Therefore, the net plot area was 2.25 m by 2.70 m (6.075 m^2). The urea was applied in split form (half at emergence and the remaining half at knee height).

Soil sampling and analysis method:

A surface soil sample (0-30 cm depth) was collected by using an auger from 5 spots of the experimental field before planting. These samples were composited into one sample and were air-dried and ground to allow them to pass through a 2.0 mm sieve before laboratory analysis.

The soil samples were analyzed at SARC for some parameters. Particle size distribution (texture), pH, cation exchange capacity (CEC), exchangeable bases (Ca, Mg, Na and K), organic matter content, total N, and available and total P contents were determined for the soil samples collected before planting. Soil pH was determined in a 1:2.5 soil water suspension using a glass electrode pH meter (Von Reeuwijk, 1992). Determination of particle size distribution (texture) was carried out using the hydrometer method (Day, 1965). Based on the oxidation of organic carbon with acid potassium dichromate, organic matter was determined using the Walkley and Black (1934) wet digestion method. Total nitrogen was analyzed using the Kjeldahl method as described by Bremner & Mulvaney (1982). Besides, available P was determined using the Olsen ($NaHCO_3$) extraction method (Olsen & Sommer, 1982) and the NaOH fusion method (Smith & Bain, 1982), respectively. The CEC was determined from ammonium-saturated samples that were subsequently replaced by sodium from a percolating sodium chloride solution. The excess salt was removed by washing with alcohol and the ammonium that was displaced by sodium was measured by the Kjeldahl method (Chapman, 1965). Exchangeable cations were extracted using the ammonium acetate method from which exchangeable Ca and Mg were measured with atomic absorption spectrophotometry while exchangeable K with spectrophotometry (Chapman, 1966)

Growth parameters of sorghum:

The height of five pre-tagged sorghum plants from the net area of each plot was measured from ground level to the main stalk. Their average height was taken as plant height per plant.

The heads of the five pre- tagged plants were harvested and weighed using sensitive balance and their average was expressed as head weight per plant.

Yield and yield components of sorghum:

Thousand grain weight: These were counted from the threshed bulk of each plot and weighed using sensitive balance and the weight was adjusted to 12.5% grain moisture content.

Head weight per plant: The heads of the five pre-tagged plants were harvested and weighed using sensitive balance and their average weight was-expressed as head weight per plan

Above-ground biomass yield: It was recorded from the net plot area after sun drying and separation into vegetative (stover) and grains, and the grain yield for each net plot area of each plot was recorded at 12.5% moisture content and converted to the hectare.

Grain yield: It was determined from the net plot area and adjusted to 12.5% grain moisture content and converted to yield per hectare.

Harvest index: The above-ground vegetative part was harvested and sun-dried, and the grains were separated. Harvest index was then calculated by the ratio of grain yield to above ground dry biomass and multiplied by 100.

Data analysis:

All the collected data were subjected to analyses of variance using statistical analysis system version 9.3. Combined analysis of the three sites' data for two years was performed after testing homogeneity of variance using the F-test (Gomez & Gomeze, 1984). Mean separation for treatments was done using least significant difference at 1% or 5% level of significance depending upon the result.

Economic analysis was performed following CIMMYT (1988) partial budget analysis methodology to identify the economically profitable variety and appropriate nitrogen rate. Percentage of marginal rate of return (MRR) can be calculated as the change in net benefit divided by the change in variable cost value indicates the best treatment in the economic aspect. Variable costs like labor, N fertilizer, adjusted grain, and stalk yield were used for doing the partial budget analysis.

RESULTS

The texture of the soil was subjugated by clay loam according to the particle size distribution of the separate from the sites 35.5% clay, 33.5% silt and 31% sand. The soil of the three experimental sites had CEC of 45.5, 39.15 and 37.04 cm (+) kg/ha for Libso, Mersa and Sirinka, respectively (Table 2). The sample also had organic matter content of 3.01%, 3.63%, and 3.56% for each sites, respectively and rated as moderate (EthioSIS, 2014). The pH of the experimental sites were 7.2, 6.8, and 6.3 for Libso, Mersa, and Sirinka, respectively. The soil analysis result of the experimental sites indicated that the available P of the soils were 17.8, 17.1, and 16.7 mg kg/ha. The soil samples were found to have a total N of

Table 2: Physico-chemical properties of soil before planting

Site	S	Particle size (%)			Texture	pH	OM%	N	P	CEC	Ca	Mg	K
		Sand	Silt	Clay									
Libso	3.8	31	33.5	35.5	Clay loam	7.2	3.01	0.11	17.8	45.33	23.62	11.79	0.39
Mersa	4.3	34.5	31.5	34	Clay loam	6.8	3.63	0.09	17.1	39.15	21.4	9.96	0.37
Srinka	5.1	35.5	27.5	37	Clay loam	6.3	3.56	0.07	16.7	37.04	20.38	12.08	0.32

S= slope**;** OM=organic matter; CEC= cation exchange capacity

Table 3: Combined yield and yield-related traits of sorghum varieties under different rates of nitrogen fertilizers

N rate (Kg/ha)	Varieties	Panicle length	1000 seed weight (g)	Head weight (g)
0	Melkam	0.26 ^{ef}	39.03 ^{ef}	111.98 ^{e}
	Girana-1	0.22 ^{g}	37.11 ^{f}	97.97 ^{f}
46	Melkam	0.29 ^{cd}	43.68 ^{cde}	114.79 ^{cd}
	Girana-1	0.25 ^{f}	37.5 ^{f}	109.09 ^{d}
69	Melkam	0.32 ^{c}	48.13 ^{bc}	117.92 ^{bc}
	Girana-1	0.27 ^{ef}	40.82 ^{def}	115.05 ^{cd}
92	Melkam	0.39 ^{a}	61.76 ^{a}	130.95 ^{a}
	Girana-1	0.29 ^{cd}	48.08 ^{bc}	119.62 ^{bc}
115	Melkam	0.35 ^{b}	53.19 ^{b}	121.29 ^{b}
	Girana-1	0.28 ^{de}	45.13 ^{cd}	118.47 ^{bc}
CV (%)		6.92	6.64	3.03
LSD (5%)		0.02	5.84	6.02

Values with different letters (abcdefg) are significantly different; N= Nitrogen; CV=coefficient of variance; LSD=list significance difference

0.11%, 0.09% and 0.07% for Libso, Mersa, and Sirinka, respectively.

The highest (1.9 m) and shortest (1.59 m) for both seasons and in the three lower parts of the watersheds were recorded from the application of 92 kg N/ha and unfertilized sorghum, respectively. From the two varieties, the higher plant height (2.19 m) for both seasons was obtained from Girana 1, whereas the shortest plant height was obtained from a variety of Melkam (1.3 m). Melkam with 92 kg N/ha recorded the highest panicle length (0.39 cm) while Girana 1 with zero nitrogen recorded the shortest panicle length (0.22 cm).

There was an increase in 1000 seed weight value for both varieties with increased nitrogen levels (Table 3). However, the maximum thousand seed weight for both seasons (61.76 g) was obtained from Melkam with the use of 92 kg N/ha whereas the minimum (37.1 g) was recorded from Girana 1 with the unfertilized plot.

There was an increase in the value of head weight for both varieties and nitrogen levels. 92 kg N /ha applied to variety Melkam gave maximum value in head weight per plant (130.95 g) whereas variety Girna1 showed the minimum value of head weight (97.97 g) in the controlled treatment.

The maximum above-ground biomass (41.61 ton) for both seasons and the three sites was recorded from Girana 1 under the use of 92 kg N/ha, which is statically at par with Girana 1 in the use of 115 kg N/ha and the lowest (14.88 ton) was recorded from zero nitrogen with Melkam, which is similar with 46 with Melkam.

Application of 92 kg/ha nitrogen with Melkam variety gave the maximum over season and locations combined grain yield (5.2 ton/ha) followed by 115 kg/ha with Melkam (4.15 ton), which was statically at par with 92 kg/ha with Girana1 while the lowest grain yield (2.15 ton) was recorded from unfertilized treatment with Girana 1 variety.

The maximum stalk yield (39.59 ton/ha) was obtained from the applications of 92 kg N/ha with Girana 1 variety while the minimum stalk yield (13.31 ton) was recorded from the control with Melkam variety, which is statically similar to 46 and 69 kg N/ha with Melkam variety (Table 4).

Table 4: Combined yield and yield-related traits of sorghum varieties under different rates of nitrogen fertilizer

N rate	Varieties	ABY	Stalk yield	Grain yield	HI
0	Melkam	14.88 [g]	13.31 [g]	2.56 [g]	17.3 [b]
	Girana-1	25.57 [cd]	23.42 [cd]	2.15 [h]	8.4 [c]
46	Melkam	17.76 [fg]	14.45 [fg]	3.31 [e]	19.78 [b]
	Girana-1	29.54 [bc]	26.79 [bc]	2.76 [fg]	9.37 [c]
69	Melkam	19.96 [ef]	16.25 [efg]	3.71 [cd]	19.73 [b]
	Girana-1	33.13 [b]	30.09 [b]	3.04 [ef]	9.53 [c]
92	Melkam	23.4 [de]	18.13 [ef]	5.28 [a]	23.93 [a]
	Girana-1	41.61 [a]	39.59 [a]	4.02 [bc]	9.79 [c]
115	Melkam	23.38 [de]	19.23 [de]	4.15 [b]	18.12 [b]
	Girana-1	40.13 [ab]	36.89 [a]	3.43 [de]	8.49 [c]
	LSD (5%)	4.48	4.29	0.39	2.96
	CV (%)	10.34	11.88	6.69	

Values with different letters (abcdefg) are significantly different; N= Nitrogen; ABY= above-ground biomass; HI=harvested index; CV=coefficient of variance; LSD=list significance difference

Table 5: Partial budget and dominance analysis of sorghum varieties' grain and stalk yield response to nitrogen fertilizer rates

Treatments	AGY (kg/ha)	AGY* price (birr)	ASY	ASY* price	TGB	TVC	NB		MRR (%)
Melkam*0	2473.1	61827.96	10967.10	2741.8	64569.7	0	64569.7		
Girana1*0	2178.5	54462.1	16873.50	4218.4	58680.5	0	58680.48	D	
Melkam*46	3070.7	76766.75	13402.20	3350.6	80117.3	1420	78697.30		994.9
Girana1 *46	2719.4	67983.68	21609.90	5402.5	73386.2	1420	71966.16	D	
Melkam*69	3451.7	86291.43	14359.20	3589.8	89881.2	2130	87751.23		1275.2
Girana1 *69	2944.0	73600.20	26211.00	6552.8	80153	2130	78022.95	D	
Melkam *92	4687.1	117177.4	16373.10	4093.3	121270.7	2840	118430.7		4321.1
Girana1 *92	3668.2	91704.26	32355.90	8089	99793.2	2840	96953.24	D	
Melkam *115	3730.4	93260.03	15940.80	3985.2	97245.2	3550	93695.23	D	
Girana1 *115	3204.2	80106.06	30506.40	7626.6	87732.7	3550	84182.66	D	

AGY= Adjusted grain yield; ASY= Adjusted straw yield; TGB= total gross benefit; TVC= total variable cost; NB= net benefit; MRR= marginal rate of return; D= dominance

The harvesting index revealed that the variation existed because of nitrogen and varieties. Applications of 92 kg nitrogen with Melkam variety was recorded as the maximum harvest index, whereas, the minimum one was recorded from no fertilizer with Girana 1variety, which is statistically at par with 46,69,92 and 115 kg nitrogen with Girana 1 variety

The maximum marginal rate of return of 4321.05% was obtained from the applications of 92 kg N ha^{-1} with Melkam variety (Table 5).

DISCUSSION

As per the soil textural class determination triangle, the soil of the experimental site was clay loam and it indicates the innate quality of the soil. Thus, the experimental site can be characterized by high water, and nutrient holding capacity, and high CEC. The high CEC may indicate the capacity of the soil to retain basic cations. According to Hazelton & Murphy (2007), top soil having CEC greater than 40cm (+) kg/ha is rated as very high while soils with CEC of 25-40 cm (+) kg ha^{-1} as high. Organic matter is both source and storage of plant nutrients and is a very good indicator of the fertility status of a given soil. The high amount of nutrients from organic matter accumulation in the lower parts of the watersheds might be due to it being carried there from the upper parts of the watersheds.

The pH of the experimental area was in the range of slightly acidic to neutral soil Tekalign (1991). The range of phosphorus was rated as below 5 mg kg/ha (very low), 5 - 9 mg kg/ha (low), 10 to 17 mg kg/ha (medium), 18 to 25 mg kg/ha (high), and greater 25 mg kg/ha as very high (Cottenie, 1980). Therefore, the soil of the three experiential sites was moderate in available P content which is satisfactory for optimum growth and yield of sorghum.

Total nitrogen was also rated as below 0.05% (very low), 0.05 to 0.12% as poor, 0.12 to 0.25 moderate and above 0.25% as high (Tekalign, 1991). As per this classification, the soil samples were found to have poor levels of total N (0.11, 0.09 and0.07%) at Libso, Mersa, and Sirinka, respectively. Thus, nitrogen is a limiting nutrient for optimum growth and yield of sorghum in the study area. The basic cation ions were very high in their rate. Nitrogen can encourage plant height and unfertilized sorghum was stunted in growth parallel with the application of 115 kg/ha, which is the maximum nitrogen level that couldn't give the maximum plant height of sorghum as compared with 92 kg/ha. This is due to experiment site being at the lower parts of the watersheds and it was expected that there might be a high accumulation of nutrients that was leached from the upper watersheds and when 115 kg/ha N was added leads the plant susceptible to disease and insects that leads to relative stunted growth of sorghum. Regardless of the significant effect, the available data showed that the most effective dose of nitrogen was between 92 and 115 kg/ha. The positive response of nitrogen on plant height is due to the important function of nitrogen of N as the most important element in the building blocks of plant organs. This result is in line with Khan et al. (2011), who reported with the increased N level the plant height increased. It is consistent with Maral et al. (2012) that obtained a significant increase in plant height of sorghum when supplied with higher N. Similarly, Adeniyan (2014) reported significant in various growth rates of maize when supplied with higher rates of N. This implies that using nitrogen can increase the height of sorghum and the reverse is true for the unfertilized one. The morphological variation among sorghum varieties might be the contributing factors for the difference in plant height.

The morphological difference between the two varieties with maximum panicle length was obtained at 92 kg/ha of N with the Melkam variety. The increments trend of panicle length concerning increased N application rate indicates maximum vegetative growth of the plants under higher N availability due to an increase in cell elongation as nitrogen is essential for plant growth. This result is consistent with Geberemariam & Dereja (2015), who reported that the application of nitrogen fertilizer on different sorghum varieties increases panicle length. Consistent with the result, the a positive correlation between the level of nitrogen and length of the ear was reported by Ahmad et al. (2018).

The maximum thousand seed weight obtained from 92 kg/ha with Melkam variety might be due to nitrogen having a great role in enzyme activity; the enzyme catalyzes chemical reaction which is important for the building of sorghum grain. On the other hand, using no fertilizer leads to leaf growth inhibition and the plant being unable to prepare its own food. Similarly, such a positive role of N in enhancing 1000 seed weight maize is also recorded by Arif et al. (2010) and Salam et al. (2010) who reported that yield-related traits increased with an increased rate of nitrogen. Thousand seed weight of sorghum increased with increased rates of N might be because application of nitrogen to the sorghum plants maintained greenness of leaves for a longer period which in turn helped in greater dry matter accumulation and this might have contributed much as a major source for the development of sink and thereby improved the yield attributes (Asaduzzaman et al., 2014).

When the nitrogen fertilizer increases from 0 to 92, the head weight also increases, however, no further increases were found after 92 kg N/ha. This is due to the optimum nutrient providing seed filling capacity of the head of sorghum. This result is in line with the finding of Berhane et al. (2015) who reported that optimum applications of N fertilizer significantly increase the head weight. The 1000 seed weight of plants in the unfertilized plot was light in weight because the stands in the unfertilized plot were not productive. Moreover, the morphological differences of the improved varieties of sorghum, and as nitrogen increases the head weight of varieties varies each other at the same time it was clear that N has a great role in dry matter accumulation.

The mean above-ground biomass was not varied in the three lower parts of the watersheds and two consecutive years of experimentation across the different watersheds. This implies that all the sites had similar fertility status during the experimentation years and N availability must be adequate at the vegetative stage of growth to ensure the maximum biomass yield of sorghum, in addition, biomass in the larger amount of nitrogen, investment of assimilates to leaves and stem increased and finally increased dry matter yield. The result is inconsistent with Habtamu (2015) who reported that the maximum biomass yield of maize was recorded at 90 kg N/ha. Considering the rate of nitrogen fertilizer the morphological difference between the two varieties might be also the reason for the variable response of above-ground biomass. The better availability of nitrogen to vegetative growth of sorghum which can contribute to higher biomass production was obtained from the optimum nitrogen fertilizer.

The combined over years and locations grain yield implies that the indigenous soil in the lower landscape of the three sites was similar over the two years of experimentations, resulting in similar N recommendations across the field. The application of nitrogen resulted in sharp increases in panicle length, thousand seed weight, and head weight per plant in both seasons and locations. This study showed that there were statically significant differences in the sorghum yield-related components by increasing nitrogen fertilizer from 0 to 92 kg/ha. As a result, increase sorghum grain yield was mainly associated with the increased basic yield-related traits like head weight, panicle length, and 1000 seed weight. Similarly, Uchino et al. (2013) reported that the yield of sorghum increased as the quantity of nitrogen fertilizer increased. Consistent with this, Buah & Mwinkara (2009) and Hugar et al. (2010) reported positive effects on grain yield and yield attributes of sorghum. This result was also confirmed by Ahmad (2018) and Mansour (2009) who reported that the application of nitrogen fertilizer can increase dry matter production, which leads to an increase in seed yield of maize varieties due to the increased leaf surface, which results to an increase the overall metabolic process. Both varieties with different levels of nitrogen produced significantly higher grain yield as compared to sorghum varieties without nitrogen fertilizer applications. Basically, there was a gradual increase in grain yield and significant variation was observed in all treatments compared to the control.

The treatment which gave maximum stalk yield (92 kg N/ha with Girana 1) had a very good functioning photosynthetic rate and a better percentage of the assimilatory surface. The increase in stalk yield of both varieties with increased N rate might be attributed to the enhanced availability of N for the vegetative growth of the crops. Added to nitrogen vegetative accumulation differences in the varieties have contributed to their stalk yield differences. Girana 1 with any fertilizer level even with no fertilizer was better in stalky yield due to the clear morphological and genetic differences between the two improved sorghum varieties.

Application of 92 kg nitrogen with Melkam variety had a very good translocation assimilates to economical yield (grain) more than vegetative growth, whereas, zero fertilizer, 46, 69, 92 and 115 kg/ha N with Girana 1 variety had inefficient translocations assimilates that leads the reduction in harvesting index. The harvest index value increased with increasing N level in Melkam variety. However, there were no significant variations in Girana 1 with any level of fertilizer, which indicates the genetic variation of the two sorghum varieties in partitioning assimilates.

Regarding the partial budget analysis, the objective of farmers in applying fertilizer is not limited to increasing yield alone but also making a profit out of it. Towards maximizing profit the cost of fertilizer, cost of grain, and stalk yield of sorghum varieties were determining factors. In the study areas, the demand and market price of sorghum is important, and therefore increasing both grain yield and biomass yield can increase the income of the farmers. A partial budget analysis was done to identify the most feasible nitrogen fertilizer rate and sorghum varieties. The maximum net benefit of 118430 Ethiopian birr (ETB)/ha was obtained in the treatment that Melkam variety received 92 kg N/ha. Both seasons and the three lower sites of the watersheds showed that application of 92 kg/ha with Melkam variety was economically viable as it gave the rate of return with 4321% MRR. This implies that for each ETB additional investment on fertilizers, farmers can earn a return of 43 ETB. However, the dominant treatments were rejected from further economic analysis to distinguish farmers with the optimum return to farmers' practice.

In conclusion, sorghum is one of the major staple crops in Ethiopia, particularly in study areas in terms of production and consumption. Even though it is such an important crop in Ethiopia and in the study area, it is giving low yield due to many production constraints such as identifying better-improved sorghum varieties and low soil fertility. From the results of this experiment, it is possible to conclude that nitrogen fertilizer rates had a significant effect on all growth, yield, and yield-related parameters of sorghum varieties except the phenological parameters for both seasons and in the lower parts of the three watersheds. Application of 92 kg/ha with Melkam varieties gave the maximum yield and also produced maximum profit which can be decisively recommended for the study areas and areas which have similar agro-ecologies.

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COMPETING INTERESTS

The authors have declared that they have no competing interest.

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