RESEARCH ARTICLE

Response of improved sorghum varieies to nitrogen ferilizer rates in the middle scope of Habru district, Northeastern Ethiopia

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Hussen M, Tadesse M, Molla A. Response of improved sorghum varieties to nitrogen fertilizer rates in the middle scope of Habru district, Northeastern Ethiopia. AGBIR.2024;40(2):988-992.

Sorghum, a vital staple food crop cultivated by subsistence farmers in Ethiopia, is traditionally grown with minimal or no fertilizer inputs. To evaluate the response of improved sorghum varieties to varying nitrogen fertilizer rates, a field experiment was conducted in three locations within the Habru district (Sirinka, Mersa and Libso) during the 2019/2020 and 2020/2021 cropping seasons. The study employed a randomized complete-block design with three replications, combining five nitrogen levels (0, 46, 69, 92 and 115 kg ha^{-1}) with two improved sorghum varieties (Melkam and Girana-1). Significant (P<0.05) variations were observed in all parameters due to the interaction effects of nitrogen and sorghum varieties. Grain yield and yield-related characteristics of the sorghum varieties exhibited an increasing trend as nitrogen levels increased from 0 to 92 kg ha^{-1}. Remarkably, the application of 92 kg ha^{-1} nitrogen fertilizer rate resulted in the highest sorghum grain yield, reaching 4.77 tons/ha. The partial budget analysis revealed that the Melkam treatment, with an application rate of 92 kg N/ha, yielded the highest marginal rates of returns (3666.47%). These findings strongly indicate that utilizing the Melkam variety along with 92 kg N/ha can significantly enhance sorghum production, both in terms of quality and economic viability. Consequently, it is highly recommended for adoption not only in the study area but also in regions sharing similar agro ecological characteristics.

Key Words: *Nitrogen fertilizer; Marginal rate of returns; Partial budget analysis; Varieties; Yield*

INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is an important cereal crop grown in various regions of Ethiopia, including the Habru district in the northeastern part of the country. It is a staple food for many communities and plays a crucial role in food security and livelihoods. Sorghum is extensively cultivated in the highlands, lowlands and semiarid regions of Ethiopia, particularly in areas with limited moisture where most other crops struggle to thrive [1].

Although sorghum production and its numerous advantages have been substantial, the actual productivity falls considerably short of its potential due to low soil fertility, poor management of land and lack of improved sorghum varieties [2]. Currently, the average regional productivity stands at 2.1 tons per hectare, whereas the productivity in the study area is less than 1.3 tons per hectare.

Tailoring fertilizer recommendations based on soil fertility status and understanding the interaction between nitrogen levels, sorghum varieties and local environmental conditions can significantly improve agricultural practices. It sounds like the research aims to address critical issues in sorghum production in Ethiopia, specifically focusing on the use of nitrogen fertilizer and the selection of suitable sorghum varieties for different soil types and agro-ecological locations. By conducting this study, the goal is to provide site-specific recommendations that consider variations in climate, soils and available nutrients, ultimately aiming to enhance crop productivity. The study's objectives to assess the impact of nitrogen fertilizer rates on yield and yield components of improved sorghum varieties in the Habru district of Northeastern Ethiopia are crucial.

MATERIALS AND METHODS

Descriptions of the experimental sites

The study was conducted in the Habru district (Sirinka, Mersa and Libso) of Northeastern Ethiopia, during the main rainy season from July to November in 2019/2020 and 2020/2021. Geographically, the district is located between 11°40'N and 11°66.7'N latitude and 39°39.5'E and 39°65'E longitude, at an altitude ranging from 800 to 1,200 meters above sea level. The area experiences a bimodal rainfall pattern, with a short (Belg) rain period from February to April and the main rainy (kiremt) season from June to September, characterized by erratic rainfall distribution. The mean annual temperature in the district ranges from 15 to 28.50 degrees celsius, while the mean annual rainfall ranges between 700 and 1000 mm. Agriculture serves as the primary source of income and livelihood for the community. Based on information from the Ethiopian Mapping Agency, the study site consists of several soil types, including Vertisols, Lithosols, Cambisols and Regosols.

Experimental materials

In this experiment, two sorghum varieties, namely Melkam and Girana-1, were utilized. These varieties were released by the Sirinka Agricultural Research Center and are specifically adapted to lowland areas. They are early maturing types and are widely cultivated in the study area. Urea, with a nitrogen content of 46%, was employed as the nitrogen source for the experiment.

Treatments, design and experimental procedures

The study used a factorial experiment following a Randomized Complete Block Design (RCBD) with three replications and a total of 10 treatments. The treatments included two sorghum varieties (Girana-1 and Melkam) and different rates of N fertilizer (0, 46, 69, 92 and 115 kg/ha). The experiment followed good agronomic practices, including proper soil tillage, weeding and fertilizer applications. There were a total of 30 plots, with a spacing of 1.5 m between blocks and 1 m between plots. Each plot consisted of five rows spaced 75 cm apart, with plants spaced 15 cm apart within each row. To avoid border effects, one plant was left at both ends of each row in each plot. The three central rows of each plot were used to determine the growth, yield and yield-related traits of sorghum. The net plot area was calculated as 2.25 × 2.70 (6.075 m^2). The N fertilizer was applied in two split forms, with half applied at emergence and the remaining half applied at knee height.

Soil sampling and sample preparations

Surface soil samples (0-30 cm depth) were collected from five designated spots within the experimental field prior to planting. An auger was utilized to extract these samples. To facilitate laboratory analysis, the collected samples were combined into a single composite sample. Subsequently, the composite sample underwent an air-drying process and was subsequently ground until it

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Received: 16-Feb-2024, Manuscript No. AGBIR-24-127686; **Editor assigned:** 19-Feb-2024, Pre QC No. AGBIR-24-127686 (PQ); **Reviewed:** 04-Mar-2024, QC No. AGBIR-24-127686; **Revised:** 11-Mar-2024, Manuscript No. AGBIR-24-127686 (R); **Published:** 18-Mar-2024, DOI:10.35248/0970-1907.24.40.988-992

was able to pass through a 2.0 mm sieve. This prepared the sample for further examination and testing in the laboratory.

Soil sample analysis

The soil samples collected before planting were subjected to analysis for various parameters relevant to the study. These analyses were conducted following standard procedures at the Sirinka Agricultural Research Center. The parameters examined included particle size distribution (texture), pH, Cation Exchange Capacity (CEC), exchangeable bases (Ca, Mg, Na and K), organic matter content, total nitrogen (N) and total phosphorus (P) contents. Soil pH was determined using a glass electrode pH meter in a 1:2.5 soil water suspension. The particle size distribution (texture) was determined using the hydrometer method [3]. Organic matter content was assessed using the Walkley and Black wet digestion method as described by Olsen [4], which involves the oxidation of organic carbon with acid potassium dichromate. Total nitrogen was analyzed using the Kjeldahl method.

For available phosphorus, the Olsen ($NaHCO_3$) extraction method was employed. Cation Exchange Capacity (CEC) was determined by saturating the soil samples with ammonium and subsequently replacing the ammonium ions with sodium ions from a percolating sodium chloride solution. The excess salt was removed by washing with alcohol and the displaced ammonium ions were measured using the Kjeldahl method [5]. The extraction of exchangeable cations was performed using the ammonium acetate method. Exchangeable Calcium (Ca) and Magnesium (Mg) were measured using atomic absorption spectrophotometry, while exchangeable Potassium (K) was determined using spectrophotometry [5].

Vegetative growth, yield and yield related characteristics

The height of five pre-tagged sorghum plants in each plot was measured by determining the distance from ground level to the main stalk. The average height of these plants was calculated to determine the plant height per plant. Additionally, the heads of the five pre-tagged plants were harvested and weighed using a sensitive balance. The average weight of the heads was considered as the head weight per plant. To assess the weight of a thousand grains, a sample was taken from the threshed bulk of each plot. The grains were counted and weighed using a sensitive balance, with the weight adjusted to account for a grain moisture content of 12.5%. Furthermore, the above-ground biomass of each plot was recorded after sun drying. The biomass was then divided into vegetative (Stover) and grain components. The grain yield for each plot's net area was measured at a moisture content of 12.5% and converted to yield per hectare. To calculate the harvest index, the above-ground vegetative parts and grains were dried separately and their weights recorded. The harvest index was determined by dividing the grain yield by the above-ground dry biomass, multiplying by 100.

Data management and statistical analysis

After collecting the data, they were subjected to Analysis of Variance (ANOVA) using Statistical Analysis System (SAS) version 9.3. To combine the data from the three sites over a period of two years, homogeneity of variance was tested using the F-test [6]. Following the ANOVA result, mean separation for treatments showing statistical differences was conducted using Least Significant Difference (LSD) at a significance level of 1% or 5%. Moreover, to determine the economically viable variety and appropriate nitrogen rates for the study, an economic analysis was carried out using the International Maize and Wheat Improvement Center (CIMMYT) partial budget analysis method. The calculation of Marginal Rate of Return (MRR) was employed, which involves dividing the change in net benefit by the change in variable cost value. This analysis aimed to identify the treatment that yielded the best economic results. The partial budget analysis utilized variable costs such as labor, N fertilizer, adjusted grain and stalk yield. These factors were considered to evaluate the economic implications of the different treatments.

RESULTS AND DISCUSSION

The results of the analysis of variance showed that both nitrogen levels and sorghum varieties had significant effects ($P<0.05$) on plant height in the three middle parts of the watershed. However, there was no interaction between the two factors (Figure 1 and Table 1). Increasing the nitrogen rate from 0 to 92 kg/ha significantly increased the plant height of sorghum varieties. The tallest plant height (1.78 m) was observed with the application of 92 kg/ha N fertilizer, which was statistically similar to the application of 115 kg/ha N fertilizer. On the other hand, the shortest plant height (1.52 m) was recorded in the untreated plot.

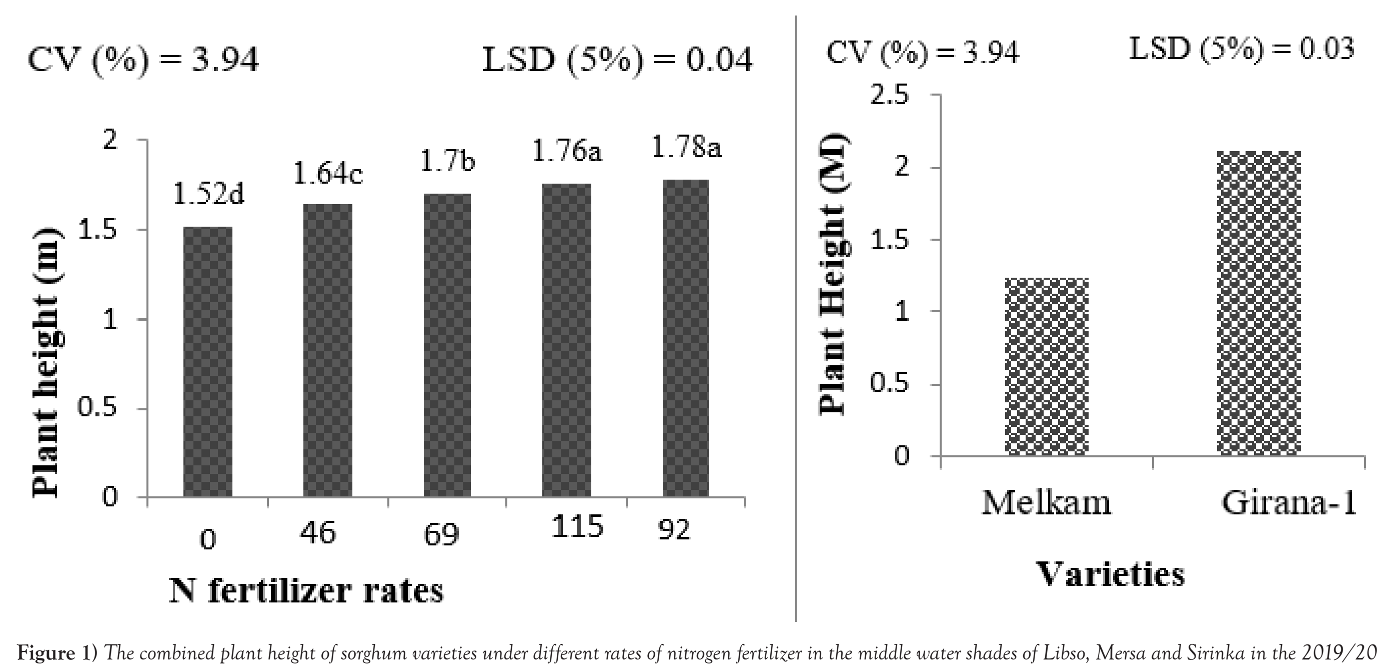

Figure 1) *The combined plant height of sorghum varieties under different rates of nitrogen fertilizer in the middle water shades of Libso, Mersa and Sirinka in the 2019/20 and 2020/21 cropping seasons*

TABLE 1

Major soil physico-chemical characteristics of the three middle watersheds

Experimental sites	Slope	Particle size distribution (%)			Textural class	Soil pH	OM%	TN%	Av.P ppm	CEC cmolc/ kg	Ca cmolc/ kg	Ca cmolc/ kg	K cmolc/ kg
		Sand	Silt	Clay									
Libso	6.3	34	35.5	35.5	Clay loam	7.5	3.02	0.098	18.3	38.33	20.62	11.79	0.35
Mersa	9.5	34.5	31.5	34	Clay loam	7.1	3.00	0.09	15.10	33.15	20.08	9.9	0.33
Sirinka	8.3	35.5	27.5	37	Clay loam	6.7	2.99	0.08	11.70	30.04	19.2	9.4	0.30

Note: OM: Organic Matter; TN: Total Nitrogen; Av.P: Available Phosphorus; CEC: Cation Exchange Capacity; Ca: Calcium; Mg: Magnesium; K: Potassium.

The observed increase in plant height of the Girana-1 sorghum variety with higher nitrogen fertilizer levels can be attributed to multiple factors like nutrient availability and protein synthesis, genetic variation and environmental factors.

Higher nitrogen levels likely enhance the availability of nutrients that aid in protein synthesis. This availability could contribute to cell enlargement in plants, thereby leading to increased plant height. Genetic differences among sorghum varieties could also play a role in their response to nitrogen levels. Hussain et al., [7] highlighted how genetic makeup influences plant height, implying that certain varieties may respond differently to nitrogen availability. Both genetic makeup and environmental conditions can influence plant height. Moraditochaee et al., [8] supported this by showing that varying nitrogen levels affect sorghum plant height, indicating the interplay between genetics and environment.

While the response to nitrogen may be similar in increasing plant height for both sorghum and maize, each crop may exhibit unique characteristics in their growth patterns.

Abera et al., [9] demonstrated that higher nitrogen application resulted in taller sorghum plants, possibly due to increased cell elongation supported by nitrogen's role in fundamental plant growth processes, including chlorophyll formation and vigorous vegetative growth.

Overall, these studies collectively suggest that nitrogen availability influences plant height in sorghum, likely through various mechanisms such as protein synthesis, cell enlargement and chlorophyll formation. The specific responses observed might be influenced by both genetic factors inherent to the sorghum variety and the environmental conditions in which they are grown.

The interaction effects of nitrogen and varieties significantly influenced panicle length in both seasons and the three middle locations ($P<0.05$). Melkam variety with 92 kg/ha N application had the longest panicle length (0.36 cm), while Girana-1 variety without nitrogen application had the shortest panicle length (0.17 cm) (Table 2).

TABLE 2

The combined panicle length measurements of sorghum varieties under different nitrogen fertilizer rates across three locations (Libso, Mersa and Sirinka) during the 2019/2020 and 2020/2021 cropping seasons

Nitrogen (kg/ha)	Varieties	Panicle length (m)
0	Melkam	0.23e
	Girana-1	0.17g
46	Melkam	0.26d
	Girana-1	0.21f
69	Melkam	0.29c
	Girana-1	0.23e
2	Melkam	0.36a
	Girana-1	0.26d
115	Melkam	0.33b
	Girana-1	0.25ed
3.02	-	0.02
Coefficient of variation (%)	-	6.82

The observed increase in panicle length with the increment in nitrogen application rates, especially noted at 92 kg/ha with the Melkam variety, suggests several underlying factors:

- The increment in nitrogen rates positively influences sorghum's vegetative growth, potentially enhancing nutrient uptake.
- This stimulation contributes to overall vegetative development, possibly explaining the increased panicle length in both sorghum varieties.

On the other hand, nitrogen's role in promoting healthy, vigorous growth in sorghum likely leads to longer panicles. This healthy growth might be a result of increased nitrogen availability, enhancing overall crop assimilation.

Higher nitrogen rates might also prolong the life of leaves, leading to rapid leaf area development. This extended leaf lifespan could contribute to increased overall crop assimilation, as supported by findings from Halvorson et al., [10].

Variations in panicle length among sorghum varieties could be attributed to genetic disparities. Genetic differences, as noted by Sarmiso [11], influence physiological qualities like viability, germination power and vigor, potentially affecting the development of panicle length in response to nitrogen levels.

The synergy of nitrogen's stimulating effects on vegetative growth, the resulting healthy and vigorous plant development and genetic disparities among sorghum varieties collectively contribute to the observed differences in panicle length in response to varying nitrogen application rates.

The interaction between varieties and N fertilizer rates also had a significant impact on 1000 seed weight ($P<0.05$) across seasons and the middle parts of the three watersheds. The application of 92 kg/ha N fertilizer with Melkam variety resulted in the highest 1000 seed weight (57.65 g), whereas the untreated plot with Girana-1 variety had the lowest 1000 seed weight (32.64 g), which was statistically similar to the no nitrogen application with Melkam variety (Table 3).

TABLE 3

The combined data on yield-related traits of sorghum varieties under various nitrogen fertilizer rates across three locations (Libso, Mersa and Sirinka) during the 2019/2020 and 2020/2021 cropping seasons

N fertilizer rate (Kg/ha)	Varieties	1000 seed weight (g)	Head weight (g)
0	Melkam	33.68d	92.58de
	Girana-1	32.64d	90.17e
46	Melkam	42.77bc	104.89bc
	Girana-1	34.85cd	102.13cd
69	Melkam	44.34b	110.43bc
	Girana-1	40.43bcd	108.18bc
92	Melkam	57.65a	123.37a
	Girana-1	46.18b	111.74bc
115	Melkam	45.25b	115.08ab
	Girana-1	40.57bcd	110.16bc
Least significant difference (5%)	-	8.63	10.86
Coefficient of variation (%)	-	9.21	4.69

The Melkam variety exhibited its heaviest sorghum grains at 92 kg/ha N, possibly due to enhanced nitrogen utilization, resulting in robust seed sizes. Additionally, the higher 1000 seed weight in Melkam varieties highlighted distinct seed weight differences between the two varieties. Studies on maize yield attributes, such as those by Gosavi et al., [12] and Prodhan et al., [13] consistently show increased yields, particularly in green cob yields, with higher nitrogen application, impacting both vegetative and reproductive growth.

In the three middle watersheds of the district, the interaction effects of sorghum varieties and N fertilizer rates significantly influenced the head weight per plant in both seasons (P<0.05). It was observed that both varieties and nitrogen levels contributed to an increase in head weight. The highest head weight per plant (123.37 g) was obtained with 92 kg/ha N application in Melkam variety, while the lowest head weight (90.5 g) was observed in Girna-1 variety without fertilization, which was similar to the no fertilization treatment in Melkam variety (90.17 g).

The rise in head weight under higher nitrogen levels may be attributed to the augmented metabolic rate induced by nitrogen, leading to increased carbohydrate synthesis. This, in turn, potentially extends the grain-filling phase, resulting in enhanced crop head quality. This finding resonates with the observations made by Miao et al., [14] and Oktem et al., [15], who noted that increased nitrogen levels correlated with higher maize head weights.

Furthermore, variations in head weight per plant were evident regardless of nitrogen levels, indicating varietal distinctions in the translocation of nitrogen from vegetative growth to grain. These differences likely stem from inherent variances in yield components related to head weight between the two sorghum varieties.

The interaction between Nitrogen (N) fertilizer and sorghum varieties had a significant impact (P<0.05) on the Above-Ground Biomass (ABY) of sorghum across seasons and locations. The Average Grain Yield (AGY) varied significantly due to different levels of fertilization and the use of improved sorghum varieties. Among the treatments, the application of 92 kg/ha of N fertilizer with the Girana-1 variety resulted in the highest ABY, reaching 37.1 tons/ha. In contrast, the lowest ABY of 13.09 tons/ha was observed in plants treated with no fertilizer and the Melkam variety. This lowest yield was statistically similar to the yields obtained from plots treated with 46 kg/ha and 69 kg/ha of N fertilizer in combination with the Melkam variety (Table 3). The analysis of variance indicated a significant difference (P<0.05) in the interaction effects of N fertilizer and varieties on grain yield across the combined years and locations. Specifically, the highest grain yield of 4.77 tons/ha was achieved with the application of 92 kg/ha of N fertilizer to the Melkam variety, while the lowest grain yield of 1.9 tons/ha was recorded in the untreated plots with the Girana-1 variety.

As nitrogen levels increased in this study, both varieties showed an uptick in aboveground biomass. This rise can be linked to the nitrogen rate's potential to boost plant vegetative growth and the accumulation of photo-assimilates, particularly as plants reach maximum maturity. This accumulation results in a higher overall crop dry matter. This finding aligns with Ali et al., [16], who observed the highest biomass yield at the highest nitrogen application rate.

Notably, treatments with elevated fertilizer rates exhibited significantly increased head weight per plant, 1000 seed weight and panicle length compared to those without fertilizer or the control, leading to substantial biomass accumulations. The distinct morphological characteristics observed might be attributed to variances in aboveground biomass between the two varieties. For instance, Girana-1 demonstrated superior vegetative growth, consequently yielding higher aboveground biomass, as expected with nitrogen influence.

Kaizzi et al., [17] also support these findings, reporting a significant enhancement in sorghum biomass and grain yield with nitrogen fertilizer application.

Similarly, variations in stalk yield were observed due to the interaction effects of N fertilizer and sorghum varieties in both seasons and the three experimental locations. The highest stalk yield of 33.26 tons/ha was obtained when applying 92 kg/ha of N fertilizer with the Girana-1 variety, while the lowest stalk yield of 10.72 tons/ha was recorded in the control group with the Melkam variety. This lowest yield was statistically similar to the yields obtained from plots treated with 46 kg/ha and 69 kg/ha of N fertilizer in combination with the Melkam variety (Table 4).

The analysis of the Harvesting Index (HI), which represents the crop's ability to efficiently convert photosynthetic material into economic yield, revealed variations influenced by the interaction of N fertilizer and sorghum varieties. The maximum HI of 23.93% was observed when applying 92 kg/ha of N fertilizer with the Melkam variety.

Partial budget analysis

A partial budget analysis was conducted to determine the most viable nitrogen fertilizer rate and sorghum varieties. Table 5 indicates that the highest net benefit of 106935.6 EB/ha was achieved when the Melkam variety received 92 kg N/ha. Across both seasons and the three intermediate watershed sites, it was evident that applying 92 kg/ha with the Melkam variety proved economically advantageous, yielding a rate of return of 3666.47% MRR. This implies that for every additional birr invested in fertilizers, farmers could gain a return of 36 Ethiopian birr. However, the predominant treatments were excluded from further economic analysis to differentiate and identify the optimum return for farmer's practices.

TABLE 4

The combined yield and yield-related traits data of sorghum varieties under different nitrogen fertilizer rates across three locations (Libso, Mersa and Sirinka) during both the 2019/2020 and 2020/2021 cropping seasons

N fertilizer rate (Kg/ha)	Varieties	Above-ground biomass	Stalk yield	Grain yield	Harvesting index
0	Melkam	13.09f	10.72f	2.37h	18.76b
	Girana-1	19.81d	17.82d	1.99i	14.49c
46	Melkam	14.41f	11.39ef	3.01fg	21.03b
	Girana-1	26.21c	23.44c	2.76g	10.75c
69	Melkam	16.14ef	12.59ef	3.55cd	22.31ab
	Girana-1	30.99b	27.84b	3.15ef	10.25c
92	Melkam	19.01de	14.24e	4.77a	23.93a
	Girana-1	37.1a	33.26a	3.84bc	10.39c
115	Melkam	18.45de	14.49de	3.96b	21.46b
	Girana-1	34.08ab	30.71ab	3.37ed	9.91c
Least significant difference (5%)	-	3.21	3.37	0.34	3.74
Coefficient of variation (%)	-	7.85	9.18	6.47	14.32

TABLE 5

The partial budget and dominance analysis of the two sorghum varieties' grain and stalk yield responses under various nitrogen fertilizer rates across three locations (Libso, Mersa and Sirinka) during the 2019/2020 and 2020/2021 cropping seasons

TRTS No's	ADJTGY (kg/ha)	ADJTGY* Price (birr)	ADJSY* Price	TGB	TVC	NB	Dominance	MMR
Melkam* 0	2068.5	51712.54	2245.5	53958.04	0	53958.04	-	0
Girana* 0	1887.33	47183.33	3537	50720.33	0	50720.33	D	-
Melkam* 46	2813.77	70344.35	2862	73206.35	1420	71786.35	-	1255.51
Girana* 46	2403.17	60079.35	4713.75	64793.1	1420	63373.1	D	-
Melkam* 69	3193.37	79834.2	3199.5	83033.7	2130	80903.7	-	1284.13
Girana* 69	2809.03	70225.7	5573.25	75798.95	2130	73668.95	D	-
melkam* 92	4253.23	106330.9	3444.75	109775.6	2840	106935.6	-	3666.47
Girana* 92	3492.11	87302.81	6984	94286.81	2840	91446.81	D	-
Melakm* 115	3380.2	84504.92	3546	88050.92	3550	84500.92	D	-
Giranan* 115	3036.69	75917.28	6016.5	81933.78	3550	78383.78	D	-

Note: ADJTGY: Adjusted Grain Yield; ADJSY: Adjusted Straw Yield; TGB: Total Gross Benefit; TVC: Total Variable Cost; NB: Net Benefit; MRR: Marginal Rate of Returns.

CONCLUSION

Various sorghum varieties and nitrogen levels demonstrated significant impacts on both the yield and yield components of sorghum. The highest yield and its components, as well as the MRR, were observed under the application of 92 kg N ha^{-1} and with the Melkam variety. This study's implication suggests that utilizing the Melkam sorghum variety with 92 kg N ha^{-1} ensures the maximum economic grain yield per production area. Therefore, the unequivocal recommendation for areas resembling the study's agro-ecological conditions would be the application of 92 kg/ha of nitrogen with Melkam varieties, ensuring not only the maximum yield but also optimal profitability.

ACKNOWLEDGEMENT

We, the authors duly acknowledge Woldia University and Sirinka Agricultural Research Center for providing funds and different research inputs, respectively.

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