Optimizing Inter-row Spacing and Blended NPS Fertilizer to Boost Production of Sorghum (Sorghum bicolor (L) Moench) and Ensure its Economic Feasibility

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Abstract

Due to varietal variation in architecture, the conventional inter-row spacing of 75 cm is not always applicable to all varieties in sorghum production. Similarly, the blanket fertilizer recommendation assumes equal fertility levels across all soil types, making it unsuitable. Thus, a field experiment was conducted to find the optimum rate of blended NPS and inter-row spacing for sorghum in Southeast Ethiopia. The experiment consisted of a factorial combination of five NPS levels (0, 50, 100, 150 and 200 kg NPS ha^{-1}) and three inter-row spacing (55, 65 and 75cm). The treatments replicated thrice with randomized complete block design. The results showed that NPS fertilizer and inter-row spacing had significant ($P<0.05$) effect on various parameters, but their interaction effect had no significant effect ($P>0.05$) on all parameters. Increased inter-row spacing and NPS rate prolonged days to flowering and maturity. The increase in the rate of NPS and inter-row spacing significantly increased leaf area, leaf area index, panicle weight, and 1000-kernel weight. Similarly, plant height increased with increasing rate of NPS but decreased with increasing inter-row spacing. The maximum grain yield (3336.81 kg ha^{-1}) and biomass weight (7900.01 kg ha^{-1}) were recorded with a rate of 150 kg NPS ha^{-1}, while the lowest grain yield (1730.21 kg ha^{-1}) and biomass (5660.44 kg ha^{-1}) were obtained under nil-treated plots. The highest grain yield (2734.27 kg ha^{-1}) and biomass (7490.12 kg ha^{-1}) were recorded with spacing of 65 cm. The partial budget analysis showed that the highest net benefit of 85,913 birr ha^{-1} with maximum marginal rate of return (2534.22%) was obtained in the treatment that received 150 kg NPS ha^{-1} with 65 row-spacing. Therefore, 150 kg ha^{-1} blended NPS with 65 cm inter-row spacing is recommended in the study area and in dry and semi-arid regions with similar agro-ecological conditions.

Key words: blended NPS fertilizer, marginal rate of return, sorghum, spacing, yield

Introduction

Sorghum (*Sorghum bicolor* (L.) is a crucial drought-resistant grain crop that is cultivated in dryland areas of the world (Agrama and Tunstra, 2003; Kumara et al., 2011). It is a staple crop in arid and semi-arid parts of Africa and Asia (Hariprasanna and Rakshit, 2016). Thus, it is the second most important cereal (after maize) in sub-Saharan Africa (Prajapati et al., 2018).

In East Africa, sorghum is primarily produced in altitude ranging from 900 to 1,500 m (Terefe, 2017). The crop is grown in Ethiopia's multiple agro- ecological zones. However, it is predominantly produced in dry areas that cover nearly 66% of the total area of Ethiopia (Geremew et al., 2004). Because of its drought resistance, sorghum is the crop of choice for dry regions and areas with unreliable rainfall (Terefe, 2017).

Grain yield of sorghum differs across the various parts of the world. From 2001 to 2020, the average sorghum grain yield in the world was 2.5 t ha^{-1} (Khalifa and Eltahir, 2023). However, it was 4.5 t ha^{-1} in developed countries. In sub-Sahara countries, except for South Africa (which achieved a maximum grain yield of 4.0t ha^{-1}), the yield of sorghum was significantly lower. For instance, in Ethiopia the average sorghum grain yield was 2.0 t ha^{-1} (Khalifa and Eltahir, 2023). A major problem for the low productivity of sorghum is the decline in soil fertility accompanied by a lack of appropriate agronomic practices like proper plant spacing.

In dryland areas, optimizing plant spacing and fertilizer application based on crop architecture and resources (Frantová et al., 2024) is effective strategy for maximizing yields and minimizing the potential for crop failure (Haarhoff and Swanepoel, 2022) due to limited water availability. Adjusting rows spacing and fertilizer management are key measures to avoid competition, reducing soil evaporation (Mupangwa and Wegary, 2018), enhance light interception and increase photosynthesis (Khan et al., 2017), and ensure productivity (Piao et al., 2022). According to Zheng et al. (2019), fertilization, plant density, row spacing, and a variety of other factors all have a favorable effect on grain yield.

Row spacing plays an important role in determining plant density under dry land conditions (Mashiqaa et al., 2022). Optimizing planting density improves light capture, air circulation, and resource usage, resulting in uniform growth, decreases nutrient competition, and supports sustainable weed management, leading to higher yields (Tang et al., 2025). Although drought tolerant and early maturing sorghum varieties have been developed and disseminated to the community, the majority of the developed varieties were not widely adopted in the Southeastern Ethiopia since they were not preferred by agro-pastoralists. Most agro-pastoralists preferred landraces and late maturing variety for their biomass apart from the grain yield. These varieties are drought-susceptible, low yield, and long maturity. Thus, due to the recurrent drought and climate effect, the community was convinced to adopt early maturing variety with smaller biomass. In Ethiopia, the recommended spacing for sorghum is 75 cm between rows and 20 cm between plants. The spacing was set based on the morphology of tall and late maturing sorghum varieties. But, the community in the semi-arid area of Southeastern Ethiopia applies this spacing for early maturing sorghum varieties either. Therefore, it is advisable

to determine the right spacing for early and short sorghum varieties which have relatively small canopy.

In Ethiopia, for the last few decades nitrogen and phosphorous containing fertilizers (in the form of urea and DAP) had been used for all crops. Such unbalanced application of plant nutrients may aggravate the depletion of other important nutrient elements in soils such as K, S and micronutrients (Zn and B) (EEA, 2005). Application of blended fertilizer (19% N, 38% P_2O_5 and 7% S) is crucial to increase production and productivity of crops. The Sulfur in blended NPS makes it different from the DAP. Plant tissue requires similar amount of sulfur as that of P (Narayan et al., 2022) because they are building block of protein. Crops cannot produce their maximum amount of protein or yield without adequate sulfur (Zhao et al., 1996). Application of sulfur also decreases soil pH which is very essential in study area where the soil is calcareous. In response to these challenges, blended NPS fertilizer has been recently introduced in market of study area. However, there is little information about the optimum rate of blended NPS in the study area. Therefore, this study was designed to assess the effect of blended NPS fertilizer and inter-row spacing on productivity of sorghum in Southeastern Ethiopia.

Materials and Methods

Description of the Study Area

The study was conducted at Upper Fafen Sub-Basin, Somali Regional State, Ethiopia. Fafen is located 9° 20’ N latitude and 45° 56’ E longitude and has an elevation of 1,650 m above sea level (Degefu et al., 2011). Distance of the sites is 596 km from Addis Ababa to the East and 35 km from Jigjiga town to the west. The area has bi-modal rainfall pattern (from March to early June (Gu’) and the main rainy season from July to late November). With an average yearly rainfall of 400–600 mm, the region is primarily semi-arid and arid (Keskes et al., 2013). According to NMSA (2004), the average annual minimum and maximum temperatures are 16–20 °C and 28–38 °C, respectively.

Planting Materials

Meko-1 is sorghum variety which is released by Melkassa Agricultural Research Centre in 1998. It is an open pollinated variety (OPV) that can withstand drought. Blended fertilizer NPS (19% N, 38% P_2O_5 and 7% S), and urea (46% N) was used as source of fertilizer. Two separate applications of urea were made at the sowing and knee-height growth stages.

Treatment and Experimental Design

Five rates of blended NPS (0, 50, 100, 150, and 200 kg NPS ha^{-1}) (supplemented with 100 kg urea) and three inter-row spacings (55, 65, and 75 cm) comprised the treatments. A randomized complete block design with three replications was used to conduct the experiment. Thus, there were 5x 3 = 15 treatment combinations constituting 15 x 3 = 45 plots or experimental units. The size of each plot in the experiment was $15m^2$ (4m x 3.75 m), 13 m^2 (4 m x 3.25 m) and 13.2 m^2 (4 m x 3.3 m) for 75 cm, 65 cm and 55 cm inter-row spacing, respectively. All the required data were collected from the middle rows leaving the outer most rows in both sides and some distance at both ends to avoid edge effects. The net harvestable area was 2.25m x 3.6m, 1.9m x 3.6 m, and 1.65 m x 3.6 m for 75 cm, 65 cm and 55 cm row spaced plots, respectively. Each experimental plot

and blocks were separated by 1 m and 1.5 m spacing, respectively. The recommended intra-spacing of 20cm between plant was used.

Table 1. *Nutrient composition of blended NPS fertilizer and urea in each treatment*

S/N	Fertilizer rate at planting (kg NPS ha^{-1})	N, P and S applied at planting (kg N, P_2O_5, S ha^{-1})	100 kg urea (kgN ha^{-1})	Total N, P and S (kg N, P_2O_5, S ha^{-1})
1	0	0	0	0 kg N, 0 kg P_2O_5, 0 kg S
2	50 kg NPS	9.5 kg N, 19kg P, 3.5 kg S	46kg N	55.5 kg N,19 kg P_2O_5,3.5 kg S
3	100 kg NPS	19 kg N, 38 kg P,7 kg S	46kg N	65 kg N, 38 kg P_2O_5, 7 kg S
4	150 kg NPS	28.5 kg N,57 kg P,10.5kg S	46kg N	74.5 kgN,57kg P_2O_5,10.5 kg S
5	200kg NPS	38kg N, 76 kg P, 14kgS	46kg N	84 kg N, 76kg P_2O_5, 14kgS

Experimental Procedures

Before planting, the land was prepared thoroughly, cleaned, leveled and made suitable and available for planting. While conducting the experiment, all the recommended agronomic practice was kept constant except the different levels of inter-row spacing and NPS rates used as treatment in the study. Sorghum seeds (*Meko-1* variety) were planted at rate of two seeds per hill then, after emergence it was thinned to one seedling per hill. At time of planting, all plots received a basal application of different rate of blended fertilizer (NPS) (19% N, 38% P_2O_5 and 7% S) and 50% of the recommended value of N in the form of urea. Urea was applied at time of planting and the remaining 50%of the urea used as a side dressing at knee height stage. The N was placed about 5 cm away from the plant base during knee height. Supplementary irrigation was applied based on the soil moisture. Plants in the two outer rows were not considered for data collection.

Data Collection

Days to 50% flowering was recorded as the number of days from the date of planting to the date at which 50% of the plants in a plot flower. Days to Maturity was taken as the time from the date of planting until the grains from the main shoot reached to the black layer stage. Plant height, leaf area and leaf area index data were taking from five representative sample plants at 50% flowering. Plant height (cm) was measured from the ground level to the base of the panicle. The leaf length and width of representative plants' sample were taken and then the leaf area (cm^2) was determined by using the method developed by Sticker et al. (1961) as: $LA=L*W*0.75$ where, LA: Leaf Area, L: Leaf Length, W: Maximum Width of the leaf, 0.75: correction factor for sorghum. The leaf area index (LAI) was calculated as the ratio of the leaf area to the area of land occupied by the plant. Number of productive tillers was determined as the number of productive tillers counted for ten sampled plants from each net plot area. Five plants were selected from each plot, and the length of the panicle (cm) was measured from the base to the tip at maturity. Panicle weight (g) was determined by weighing of all harvested panicles from

each net plot. Thousands kernel weight (g) was determined by counting 1000 kernel and adjusting to 12.5% moisture level before weighing them using sensitive balance. Above ground dry biomass weight was determined by weighing the sun dried plants taken from the net plot at harvesting time. The grain yield was determined by weighing the grains collected from net plot, then adjusting to 12.5% moisture level, and converting them to per hectare bases. Harvest index (HI) was determined by taking the ratio of grain yield to the total biomass yield

$$HI=\frac{Grain\ yield}{above\ \ ground\ biomass}X100$$

Soil Analysis

Before planting, a composite soil sample at a depth of 0-20cm, representing each plot was taken for determining the physiochemical parameters of the soil of the experimental site.

Economic analysis

The economic analysis was performed based on CIMMYT (1988) in which the local market prices for inputs at planting and for outputs at harvesting were used. In this analysis, all the costs and benefits were computed on hectare basis in Ethiopian Birr. The concepts used in the partial budget analysis were the mean grain yield, the gross benefit (GB) ha^{-1} (the mean yield for each treatment) and the field price of fertilizers. Marginal rate of return refers to net income obtained by incurring a unit cost of fertilizer and its application. Unadjusted grain yield (UGY) (kg ha^{-1}) refers to an average yield of each treatment. Adjusted grain yield (AGY) (kg ha^{-1}) refers to the average yield adjusted down ward by a 10% to show the difference between the experimental yield and yield of farmers. Adjusted yield multiplied by farm price was used to determine gross field benefit (GFB) (ETB ha^{-1}). GFB = AGY × farm price for the crop. Total variable cost (TVC) ETB ha^{-1}) was calculated by summing up the costs that vary, including the cost of NPS fertilizer, urea and the average open price of sorghum at Jigjiga market and labor cost. To calculate the net benefit (NB) the difference between the gross benefit (GFB) and the total cost that vary (TCV) was taken. i.e. NB= GFB– TCV. Each pair of ranked treatments, % marginal rate of return (MRR) was calculated using the formula:

$$MRR\% = \frac{changeNB(NBb - NBa)}{Change\ inTVC(TCVb - TCVa)}x100$$

Where, NB a=immediate lower, NB b=next higher, TVC a=immediate lower TCV, TCV b=next higher TCV, the treatment with highest net benefit and Higher MRR was considered for recommendation.

Statistical Data Analysis

Using SAS software, the acquired data was put through an analysis of variance (ANOVA) appropriate for the design. The mean separation was performed using LSD at 0.05 level of probability. Pearson correlations were done to determine linear associations between selected agronomic parameters.

Results and Discussion

Weather and Physio-Chemical Properties of the Experimental Site

The experiment was conducted during the main cropping season under rain-fed condition. The annual of rainfall for the crop growth duration was 240.9 mm and the annual rainfall was 441.3 mm. But the crop requires an average annual precipitation of 455-800 mm (Balasubramaniyan and Palaniappan, 2004). It shows that the pattern of rainfall of research area during the growing period was below the water requirement of the crop. Thus, this rain-fed experiment was supplemented with irrigation. During the crop growth period the mean temperature was 21.35^0c with the mean minimum and maximum temperature of 14.25^0c and 28.1^0c, respectively.

The soil analytical results indicated that the soil pH is 7.8 showing mildly alkaline nature of soil (Hazalton and murphy, 2007). The soil pH falls in the optimum range of pH requirement sorghum (Espinazo and Kelley, 2005), implies soil pH of the experimental site was suitable for sorghum production. The result of the soil analysis also shows that the soil of the research area can be classified as sandy clay loam that contain total N of 0.10% which falls in the low range (0.05-0.15), 6 ppm available phosphorus also falls in the low range (5-10 ppm) and 1.50% organic carbon which is in the low range (1.0-1.71%) (Hazelton and Murphy, 2007). It indicates that the soil in the study area is low in total N, available P, and organic carbon. Therefore, application of fertilizer rich in N, P and organic C is recommended.

Crop phenology and Growth of Sorghum

The result indicated that days to flowering and days to physiological maturity were significantly ($P < 0.01$) influenced by NPS fertilizer and inter-row spacing (Table 2). Days to 50% flowering was significantly affected by NPS with the longest day to flowering (74.67days) was recorded for the plots received the highest rate (200 kg NPS ha^{-1}), while the earlier flowering (65days) was registered under nil-treated plots (Table 2). Amjad et al. (2005) also reported the days to flowering increased with the increase rate of fertilizer .This is attributed to the nitrogen fertilizer that enhanced vegetative growth and thus delayed flowering (Bilekudari et al., 2005).

Likewise, days to flowering was significantly affected by inter-row spacing with the prolonged days to flowering (70 days) was observed with inter-row spacing of 75cm (Table 2). This is because widely spaced plants may have experienced luxurious vegetative growth due to ample growth resources which resulted in delayed flowering.

As the rate of NPS increased the days to physiological maturity delayed. The longest days to maturity (116.3 days) was recorded for the plants treated with 200kg NPS ha^{-1}, while the earlier maturity (103.4 days) was recorded for nil-treated plots (Table 2). The higher application of nitrogen could enhance vegetative growth and thus increased days to maturity (Dawadi and Sah, 2012; Hussein and Leitch, 2007). This would have a negative impact on study area where moisture deficit is a serious issue.

Thus, optimizing the rate of fertilizer is essential to cope with such challenges. Similarly, increasing inter-row spacing increased the days to maturity (Table 2). The longest days to maturity (113 days) was recorded at 75 cm inter-row spacing while the earliest days to maturity (107 days) was recorded at 55cm inter-row spacing (Table 2).

Negash et al. (2017) also found that compared to plants produced at broader row spacing, sorghum plants planted at 55 cm row spacing had noticeably shorter days to maturity. The early physiological maturity due to narrow-row spacing might be due to the intense inter-space competition which led to the depletion of the available nutrients and as result plants tended to mature earlier.

The results showed a significant influence of NPS and inter-row spacing on growth parameters such as on plant height and leaf are per plant. Plant height increased progressively with the increase in rate of NPS, from values of 156.02 to 170.08 cm with NPS increasing from 0 to 200 kg ha^{-1}. This could be the contribution of nitrogen and sulfur promotes the formation of chlorophyll for photosynthetic activity (Rao et al., 2001) and phosphorous enhances the shoot and root development which in turn resulted in vigorous vegetative growth.

The tested inter-row spacing predominantly influenced the height of plants, where increasing inter-row spacing decreased plant height. The tallest plant (164.20cm) was measured from 55 cm inter-row spacing and the shortest plant (161.82cm) was recorded with the conventional spacing of 75cm (Table 2). Plants in the higher planting density become taller as a result of competition of plant for light (Miko and Manga, 2008).

As the rate of NPS rose, the leaf area grew as well. The maximum leaf area (1988 cm^2) was measured for plants received 200 kg NPS ha^{-1} which is in parity with rate of 150kg NPS ha^{-1}. Whereas, the lowest leaf area (1543.01 cm^2) was recorded from nil-treated plots. This result is in conformity with the work of Chimdessa (2016) and Berhane et al. (2015) who reported that application of fertilizer increased the leaf area. This could be the increased NPS resulted in vigorous growth of the crop and leaf expansion in length and width. Leaf area increased with the increase in inter-row spacing, from value of 1689.66 to 1706.19 and 1963.40cm with spacing increasing from 55 to 65 and 75cm, respectively.

The lowest leaf area for the crop grown with the narrower spacing could be due to interplant competition for light and mineral nutrients among highly populated plants. As the rate of NPS increased, the leaf area index rose as well. The highest Leaf area index (1.44) was recorded for 200 kg NPS ha^{-1} treated plots, while the lowest (1.13) was recorded for nil-treated plots. Our findings were supported by Addai and Alimiyawo (2015) who reported that the application of NP fertilizers to the sorghum significantly increased leaf area and LAI. The increase of LAI could be attributed to more production of expanded leaves in response to nitrogen.

Table 2. *Effect of NPS and inter-row spacing on crop phenology and growth of sorghum*

Treatment	Days to flowering	Days to maturity	Plant height (cm)	Leaf area per plant (cm^2)	Leaf area index
NPS rate (kg ha^{-1})					
0	65.78d	103.40c	156.02d	1543.01c	1.13c
50	67.22c	106.84bc	159.54c	1697.45bc	1.15c
100	69.33bc	107.81b	162.21b	1813.17ab	1.21bc
150	70.67a	114.34a	169.70a	1938.11a	1.32ab
200	74.67a	116.33a	170.08a	1988.00a	1.44 a
P value	**	**	**	**	*
$LSD_{(0.05)}$	1.094	1.968	1.120	187.6	0.1523
Inter-row (cm)					
55	67.87b	107.41b	164.20a.	1689.66b	1.20a
65	67.87b	108.82b	163.83b	1706.19b	1.34a
75	70.80a	113.01a	161.82c	1963.40a	1.22a
P value	**	**	**	**	NS
$LSD_{(0.05)}$	0.848	1.968	0.868	145.3	NS
CV	1.6	2.4	0.7	10.9	12.6

LSD = least significant difference; CV= coefficient of variation (%). Means in the same column followed by the same letter(s) are not statistically significantly different at a 5% probability level.

Yield and Yield Components of Sorghum

The findings demonstrated that inter-row spacing and blended NPS had a substantial impact on sorghum production and yield components (Table 3).The tiller number increased significantly ($P<0.01$) with the increased in NPS rates. The maximum number of tiller (13.09) was recorded under application of 200 kg NPS ha^{-1}; while the lowest number of tiller (8.31) was recorded for the nil-treated plots. The added N and P might have played a vital role in cell division. The tested inter-row spacing predominately influenced the tiller number of plants, where the significantly highest tiller number (12.1) were found in the row spacing of 75cm while the lowest tiller number (8.88) in the row spacing of 55 cm. Higher number of tillers for wider row-spacing, most likely related to

better access to space, nutrients, water, and light in wider spacing. Mosavi (2009) also reported that decrease in number of tillers with increasing plant population per unit area.

When the rate of NPS was increased from 0 to 150 kg NPS ha^{-1}, the panicle length increased significantly. However, this parameter reduced when the rate of NPS was increased above 150 kg NPS ha^{-1}. Application of 150 kg NPS ha^{-1} had resulted in about 26.28% higher panicle length over control treatment (Table 3). Our results supported by findings of Weldegebriel et al. (2018) and Gebrekorkos et al. (2017) who reported that increase NPS fertilizer increased panicle length. Similarly, increasing inter-row spacing significantly ($P<0.01$) increased panicle length. The maximum panicle length (23.51cm) was measured for the widest inter-row spacing (75 cm), while the minimum (21.53 cm) was measured for the narrowest (55 cm) spacing. The widely spaced plants have higher number of panicle length because they are more effective in mobilizing photosynthetic for panicle length and grain filling compared to closely spaced plants (Hasanuzzaman et al., 2009).

Apart from panicle length, the panicle weight is one of yield components that determine the grain yield of sorghum. In response to increasing the rate of NPS, the panicle weight increased significantly. It shows that the impact of the essential nutrients in enhancing the seed holding capacity of the panicle. It was also observed that the panicle weight increased with the increase in inter-row spacing. Rajput et al. (1983) also reported that heavier panicle was obtained from widely spaced (less populated) plants than the densely populated plants. The higher panicle weight due to wider row spacing was probably caused by greater availability of growth resources with less inter competition.

The thousands kernel weight is very important measure of seed quality, indicating application of the optimum amount of fertilizer and keeping the right plant row-spacing is crucial for better seed quality. Thousand kernel weights were significantly ($P<0.01$) affected by NPS with the highest values registered for the plants grown under highest rates (200 kg ha^{-1}); however there were no statistical significant differences in this parameter due to the three higher NPS rates (100, 150 and 200kg ha^{-1}). Chimdessa (2016) also reported a significant difference on thousand-kernel weight of maize due to the effect of blended fertilizer. The more kernel weight could be due to contribution of the nutrients in photosynthesis process and translocation of the assimilates to storage organs (seeds). Similarly, thousand kernel weights were significantly ($P<0.01$) affected by inter-row spacing with the highest values were obtained (39.92g) with a row spacing of 75cm, while decreases of 5.83% and 7.01 % were observed with spacings of 65 and 55cm, respectively. The higher thousands kernel weight noted in wider-rows might be due to a more efficient utilization of water, nutrients, and light due to minimal inter-row competition and lower plant population.

The result showed that grain yield of sorghum was highly significantly ($P\leq0.001$) influenced by the main effect of blended NPS fertilizer and inter-row spacing. The maximum grain yield (3336.81 kg ha^{-1}) was recorded under rate of 150 kg NPS ha^{-1} which was statistically in parity with 200kg NPS $ha^{-}1$, while the lowest grain yield (1730.21 kg ha^{-1}) was obtained for the control (Table 3), representing an increase of 98.82% compared to the nil-treated plots. Chimdessa (2016) also found that application of

blended significantly increased grain yield as compared the control. This is due to combined application of N with S fertilizers increases the net photosynthetic rate in crop plants, which in turn increases their grain yield of the plants (Fegeria et al., 2011). Likewise, grain yield was significantly (P≤0.001) affected by inter-row spacing with the highest grain yield (2734.27 kg ha^{-1}) was obtained with a row spacing of 65cm, while decreases of 7.99% and 19.27 % were observed with spacings of 75 and 55cm, respectively. The increase in grain yield due to intermediate row spacing might be due to the ability of closely spaced plants to trap most of the photo synthetically active radiation, more leaves per plant that resulted in more surfaces for photosynthesis and assimilates production.

Table 3. *Effect of blended NPS rate and inter-row spacing on yield & yield component parameters*

Treatment	Number of tillers	Panicle length (cm)	Panicle weight (g)	Thousand kernel weight(g)	Grain yield (kg ha^{-1})
NPS (kg ha^{-1})					
0	8.31c	20.24c	57.66d	34.95c	1730.21d
50	8.27c	21.30bc	63.02c	36.77b	2454.41c
100	11.36b	22.2b	67.22b	39.55a	2661.01b
150	11.43b	25.56a	73.33a	39.63a	3336.81a
200	13.09a	24.96a	75.98a	40.15a	3324.68a
P value	**	**	**	**	***
$LSD_{(0.05)}$	2.39	1.07	4.02	0.99	1497.04
Inter-row (cm)					
55	8.88b	21.53b	65.40b	37.12b	2207.14c
65	11.09a	22.51ab	66.85b	37.59b	2734.27a
75	12.11a	23.51a	70.08a	39.92a	2515.74b
P value	*	**	**	**	***
$LSD_{(0.05)}$	1.853	0.827	3.116	0.770	115.9
CV	23.2	4.8	6.2	2.7	7.0

LSD = least significant difference; CV= coefficient of variation (%). Means in the same column followed by the same letter(s) are not statistically significantly different at a 5% probability level

The positive correlation of grain yield with leaf area (r= 0.575**), leaf area index (r=0.440**), panicle length (r=0.818**), panicle weight (r=0.658***), and thousands kernel weight (r=0.772*) (Table 4) showed that NPS and spacing are the main factors that influence growth, yield components which in turn grain yield. The result agreed with the findings of Gebreyes (2008) who reported that grain yield was positively and highly significantly associated with other growth and yield related -traits.

Table 4. *Correlation coefficients analysis among crop phenology, growth, yield and yield components of sorghum*

Traits (phenology & growth)	GY	DF	DM	PH	LA	LAI
Grain Yield, GY	1.00					
Days to flowering, DF	-0.055**	1.00				
Days to maturity, DM	0.825**	0.037*	1.00			
Plat height, PH	0.674**	-0.045	-0.184	1.00		
Leaf area, LA	0.575**	-0.026	0.698	0.378	1.00	
Leaf area index, LAI	0.440***	-0.184	0.422**	0.506**	0.350*	1.00
Traits (yield & related traits)	GY	PL	PW	TKW	BM	HI
Grain yield, GY	1.00					
Panicle length, PL	0.818**	1.00				
Panicle weight, PW	0.658***	0.641**	1.00			
1000-kernel weight, TKW	0.772*	0.658**	0.573**	1.00		
Biomass, BM	0.808**	0.729**	0.496**	0.740**	1.00	
Harvest index, HI	0.825**	0.625**	0.581**	0.575*	0.404*	1.00

Sorghum biomass was significantly ($P<0.01$) affected by blended NPS (Table 5). The maximum biomass weight (7900.01 kg ha^{-1}) was obtained from the application of 150 kg NPS ha^{-1} which statistically in parity with 200 kg NPS ha^{-1}, whereas the minimum biomass (5660.44 kg ha^{-1}) was obtained for nil-treated plot (Table 5). This result was in conformity with the findings of Demissie et al. (2017) also reported that application of 150 kg ha^{-1} NPS blended fertilizer increased the crop biomass. The adequate supply of N and P application and their assimilation might have played an important role in tillering and overall plant growth. Likewise, inter-row spacing also had significant effect ($P<0.01$) on biomass weight of sorghum. The highest biomass yield (7490.12 kg ha^{-1}) was recorded with inter-row spacing of 65 cm; however the other spacing had statistically similar effect on biomass (Table 5). Ali et al. (2017) also showed that higher above ground dry biomass yield of hybrid maize were obtained due to intermediate and closer spacing. This could be due to the ability of the plant to use soil nutrients, water and light efficiently and effectively at 65 cm inter-row spacing.

The result showed that harvest index was highly significantly ($P<0.01$) influenced by blended NPS rate but inter-row spacing had no significant effect on harvest index (Table 5). The highest value of harvest index (43.68%) was recorded due to the highest rate 200 kg NPS ha^{-1} whereas the lowest (30.68%) was obtained due to the control treatments (Table 5). This result corroborates with the findings of Abera et al. (2018) who reported that harvest index was significantly affected by blended NPS. The increment in harvest index at higher rates of blended NPS might be due to higher transfer of assimilates to the grain that maximized the harvest index.

Table 5. *Effect of blended NPS rate and inter-row spacing on biomass & harvest index*

Treatment	Grain yield (kg ha^{-1})	Biomass (kg ha^{-1})	Harvest index
NPS (kg ha^{-1})			
0	1730.21d	5660.44d	30.68d
50	2454.41c	6406.70c	38.33c
100	2661.01b	6838.82b	39.25c
150	3336.81a	7900.01a	42.41b
200	3324.68a	7672.47a	43.68a
P value	***	**	**
$LSD_{(0.05)}$	1497.04	419.63	3.72
Inter-row (cm)			
55	2207.14c	6514.54b	39.39a
65	2734.27a	7490.12a	39.33a
75	2515.74b	6682.65b	38.31a
P value	***	**	NS
$LSD_{(0.05)}$	115.9	726.7	NS
CV	7.0	6.3	8.7

LSD = least significant difference; CV= coefficient of variation (%). Means in the same column followed by the same letter(s) are not statistically significantly different at a 5% probability level

Economic Analysis

The interest of producers in applying fertilizer is not limited to increasing grain yield alone, but also to make profit out of it. Towards maximizing profit, the amount and type of fertilizer application as well as costs of fertilizer are determining factors. The demand and market price of sorghum in study area is important.

Due to this fact increasing grain yields can increase farmers‟ income. As indicated in the Table 6, the partial budget analysis showed that the highest net benefit of 89127 birr ha^{-1} with maximum marginal rate of return (2533.2%) was obtained in the treatment that received 150 kg NPS ha^{-1} with 65 row-spacing which was superior when compared to the other treatments. This implies that for every one birr invested in urea and blended fertilizer application, farmers can expect to obtain 25.33-birr ha^{-1} (Table 5).

Table 6. *The economic (Dominance and MRR) advantages of different blended fertilizer on Yield and yield components of sorghum*

Treatment		Yield (kg ha^{-1})	Adjusted yield kg ha^{-1}	Gross Filed Benefit (EB ha^{-1})	Total Cost (EB ha^{-1})	Net Benefit (EB ha^{-1}	Marginal Rate of Return (%)
NPS	Inter-row						
0	55	1688.5	1519.2	45576	1450	44126	-
0	65	1782.7	1603.8	48114	1650	46464	1169
0	75	1833.2	1649.7	49491	1850	47641	588.5
50	55	2223.3	2000.7	60021	2250	57571	2482.5
50	65	2458.4	2212.2	66366	2550	63716	2048.3
50	75	2680.7	2412	72360	2850	69610	1964.6
100	55	2435.3	2191.5	70128	2650	67378	D
100	65	2615.4	2353.5	75312	2950	72512	1711.3
100	75	2966..1	2669.4	80082	3250	76832	1440
150	55	3393..8	2783.7	83511	3150	80261	D
150	65	3219.7	2897.73	92727.3	3500	89127	2533.2
150	75	3396.0	3056.4	91692	3850	87842	D
200	55	3251.1	2925.9	87777	4000	83777	D
200	65	3258.5	2932.6	93844.8	4450	89394.8	1786
200	75	3463.4	3116.7	93501	4600	89001	D

Conclusion

Due to its drought resistance, sorghum is the crop of choice for dry regions and areas with unreliable rainfall. However, its productivity is considerably low which is attributed to low soil fertility and inappropriate agronomic management like improper spacing. Thus, applying the appropriate rate of fertilizer and spacing is crucial. The results showed that 150 kg ha^{-1} blended NPS with 65 cm inter-row spacing is the optimum rate and spacing for higher sorghum productivity in the study area. The partial budget analysis also showed that the highest net benefit of 89,127 birr ha^{-1} with a maximum marginal rate of return of 2533.2% was obtained in the treatment that received 150 kg NPS ha^{-1} with 65 cm inter-row spacing. This shows that for every one birr invested in input costs, farmers can expect to obtain one birr and 25.33-birr ha^{-1}. It showed that intermediate inter-row spacing (65cm) can boost grain yield by improving plant density and resource utilization. Simultaneously, applying 150 kg NPS ha^{-1} rate is crucial for providing essential macronutrients such as nitrogen, phosphorous, and sulfur, resulting in higher yields and profitability. Therefore, it is suggested that application 150 kg ha^{-1} blended NPS with 65 cm inter-row spacing is recommended in the study area and regions with similar agro-ecological conditions.

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