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Response of Sorghum (*Sorghum bicolor* L. Moench) to Nitrogen and Phosphorus Fertilizer Rates in Omo Nada District of Jimma Zone, Southwestern Ethiopia

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Abstract: Soil fertility is one of the major production constraints in Ethiopia. The deficiency of nitrogen and phosphorus is the main factor that severely reduces the yield of sorghum. As a result, a field experiment was carried out at Omo Nada in 2015/2016 during the cropping season to evaluate the response of various levels of nitrogen (N) and phosphorus (P) fertilizer using sorghum. The treatments consisted of factorial combinations of four rates each of N (0, 23, 46, and 69 kg N ha^{-1}) and P (0, 11.5, 23, and 34.5 kg ha^{-1} P_2O_5) laid down in a randomized complete block design (RCBD) with three replications. For data analysis, the correlation coefficient and ANOVA were used. The result showed that the yield and yield components of the sorghum crop were a highly significant response to the impacts of inorganic N-P fertilizer nutrients. Parameters such as plant height, head weight, grain yield, biomass yield, stover yield, and harvest index were statistically significantly different for nitrogen and phosphorus at different fertilizer rates. In addition, highly significant and positive correlations of grain yield with yield components were observed, especially for plant height (r=0.57**), head weight (r=0.85***), biomass yield (r=0.89***), and stover yield (r=0.75***). This result revealed that the maximum value of grain yield (3916.7 kg ha^{-1}) was obtained from 69/11.5 kg ha^{-1} NP fertilizer, while the minimum value of grain yield (2286.2 kg ha^{-1}) was obtained from the control. Compared to the control treatment, the highest rate of N/P (69/11.5 kg ha^{-1}) increased sorghum grain yield by nearly 71.32%. It is concluded that nitrogen and phosphorus at the rates of 69 kg ha^{-1} N and 11.5 kg ha^{-1} P_2O_5 have the best performance in obtaining the maximum grain yield of the sorghum crop. Therefore, the application of 69/11.5 N P kg ha^{-1} fertilizer rate was recommended for better sorghum production and economic return in Nitisols of Omo Nada district southwestern Ethiopia.

Keywords: Fertilizer, Grain Yield, Nitrogen, Phosphorus, Sorghum, Response, Rate

1. Introduction

Sorghum (Sorghum bicolor (L.) Moench) is the fifth most important cereal after rice, wheat, maize, and barley. It is one of the most important cereal crops cultivated in arid and semi-arid regions of the world, and it originated in semi-arid tropical Africa, India, and China, where it is now a major food grain. It is the crop of choice for dry regions and locations with low rainfall levels because of its drought resistance and a wide variety of ecological adaptations [19]. Sorghum is typically planted between 900 to 1,500 masl in most of East Africa, particularly Ethiopia; but the crop is cultivated throughout the region in a variety of agroecology, from high elevations with abundant rainfall to low plains with little rainfall [10, 19]. In Ethiopia, 4.3 million tons of grains are produced each year, and 1.8 million acres of land are designated for the production of sorghum, according to the report [5].

The crop is being used as a raw material in sectors other than animal feed and food for humans. It is gaining commercial value in the malting and brewing industries, which indicates that the crop has multiple purposes in the lower and mid-latitude regions of Ethiopia, and it is not only a staple food crop in the rural areas but also used primarily to prepare local foods (injera, bread, thick porridge). This crop makes up one-third of Ethiopia's total acreage used for producing cereal crops and occupies 16.36% of the country's total cultivated land [4]. Productivity is still relatively low; in areas where sorghum is the dominant crop, nil fertilizer yielded 11289 kg ha^{-1} [8]; while above 5100 kg ha^{-1} yield was observed from intensive management in Ethiopia [10]. The major problem with low productivity is a decline in soil fertility due to high soil erosion. Blanket application of NP fertilizer is among the major limiting factors for sorghum production.

Soil fertility is one of the major production constraints in Ethiopia. A deficiency of nitrogen and phosphorus is the main factor that severely reduces the yield of sorghum [1]. Among the major constraints on decreased production of sorghum are poor soil fertility, a limited supply of production inputs, low prices for the produce, and undeveloped markets [14]. The application of inorganic P fertilizer increased the efficient utilization of inorganic N fertilizer by the plants in grain yield and total biomass production; also, the P nutrition of soils is critical for the efficient use of inorganic N fertilizer, so a deficiency in soil P limited the efficient use of applied N by the plant [2]. However, there has been limited research conducted concerning fertilizer rates. As a result of this fact, the farmers rely on traditional practices. Most of the farmers at the experiment site do not use the NP combination above the blanket recommended rate. Therefore, there is a need to study the response of different NP rates on the yield and yield components of sorghum and the economic profitability of sorghum production in the study area.

2. Materials and Methods

2.1. Description of the Study Area

A field experiment was conducted on maize during the 2015/2016 cropping seasons in the Omo Nada district of southwestern Ethiopia. Geographically, the district lies between latitudes of 7°17' to 7°49'N and 37°00' to 37°28'E, with an altitude of 1650–2200 meters above sea level. The rainfall in the area is bimodal, with unpredictable short rains from March to April and the main season ranging from June to September. The minimum and maximum annual rainfall range from 1066 to 1200 mm, with a mean annual temperature ranging from 18 to 25°C [18]. The dominant soils of the area were reported [6] as nitisols and moderately to strongly acidic. Soils have a clayey texture and are strongly to moderately acidic in reaction.

2.2. Description of the Experimental Materials

Plant materials: In the present study, the sorghum variety Abamelko, which adapted to the agroecology of the area, was used. The variety, Abamelko, is the most promising Jimma Agricultural Research Center release. It is more adaptable and grows well at elevations ranging from 1740 to 2660 meters above sea level, with annual rainfall ranging from 1,200 to 2,800 mm.

2.3. Experimental Design and Plot Management

The experiment was conducted in the Omo Nada district of southwest Ethiopia in the 2015/2016 cropping seasons. The treatments consisted of four N levels (0, 23, 46, and 69 kg N ha^{-1}) and four P levels (0, 11.5, 23, and 34.5 kg P_2O_5 ha^{-1}). The experiment was arranged in a randomized complete block design (RCBD) with three replications in a factorial arrangement. The plot size was 16.2 m^2 (3.6 m x 4.5 m) and consisted of 6 rows. A distance of 0.5 m and 1 m were left between plots and blocks, respectively. The spacing of 75 x 25 cm was used between rows and plants, respectively, and there were 14 plants planted per row with a total of 86 plants per plot. Urea and Triple supper phosphate (TSP) were used as nitrogen and phosphorus fertilizers. Nitrogen fertilizer was applied in the form of urea, half at planting and the remaining 45 days after planting. Phosphorus was applied once in the form of TSP at the time of planting. Agronomic practices such as weeding and cultivation were done uniformly for all treatments as needed.

2.4. Data Collection and Measurement

Plant height (cm): Plant height was measured at physiological maturity from the ground level to the tip of the head of ten randomly taken plants and averaged on a per-plant basis.

Head weight (g): Samples of ten heads were weighed after harvesting and sun drying to determine the weight per head.

Grain and stover yields (kg ha^{-1}): Grain yields were determined by harvesting the entire net plot area and converted into kilogram per hectare. Grain yield was adjusted to a 12.5% moisture level, whereas stover yield was weighed after leaving it in the open air for 7 days.

$$\text{Adjusted yield}=\text{Actual yield} \times 100\text{-}M/100\text{-}D$$

where M is the measured moisture content in grain and D is the designated moisture content (12.5%). D is the designated moisture.

Total Biomass Yield (kg ha^{-1}): The total biomass yield was calculated as the sum of the grain and stover yields, and finally the biomass yield was converted to the hectare and expressed in kg ha^{-1}.

Stover yield (kg ha^{-1}): After threshing and measuring the grain yield, the straw yield was measured by subtracting the grain yield from the total above ground biomass yield.

Harvest Index (%): The harvest index was calculated as HI (%)=GY/BY × 100, where HI is the harvest index, GY is grain yield, and BY is above-ground dry biological yield.

2.5. Economic Analysis

Economic analysis was made following the CIMMYT methodology [3]. A partial budget analysis was done to see the economic feasibility. The costs include fertilizer and the price of sorghum collected from the study areas.

2.6. Statistical Analysis

All the collected data were subjected to an analysis of variance following the procedure described by the research [11] using SAS software version 9.3 [16]. A Least Significance Difference (LSD) test at a 5% level of significance was used to separate the treatment means that showed significant differences.

3. Results and Discussion

3.1. Growth Parameter

Plant height (cm):

NP fertilizer had highly significant effects on sorghum height ($p \leq 0.001$). The combination of 69 kg ha^{-1} N and 23 kg ha^{-1} P_2O_5 produced the highest mean value (192.3 cm), while the treatment that received no fertilizer produced the lowest mean value (160 cm), but was at par with the rates of 46/23, 46/11.5, 69/34.5, 46/34.5, 69/11.5, 23/34.5, 23/23, 46/0, and 69/0 kg ha^{-1} of N-P_2O_5 that responded linearly (Table 1). In comparison to unfertilized plots, the treatment improved the mean value of plant height by roughly 20.19%. Plant height is significantly and positively correlated with biomass and stover yield (Table 3). This finding indicates that plant height rose as NP fertilizer application rates were increased. The present finding is similar to that [17], who found that 69 kg ha^{-1} nitrogen and 46 kg ha^{-1} phosphorus fertilizer produced the highest plant height. Accordingly, the rise in plant height caused by nitrogen application could be attributed to nitrogen's effect on cell division and elongation, which resulted in growth and increased stem and leaf height [15].

3.2. Yield and Yield Components of Sorghum

Head weight (g):

Different NP application rates exhibited a significant ($p \leq 0.0001$) effect on head weight (Table 1). The results showed that head weight rose linearly with increasing amounts of NP fertilization, ranging from 0/0 to 69/23 kg ha^{-1} N-P_2O_5. The maximum head weight (101.27 g) was recorded from the application of 69/23 kg ha^{-1} N-P_2O_5, whereas the minimum (54.69 g) was obtained from the unfertilized treatment. However, statistically, it was at par with the rates of 69/11.5, 69/34.5, 46/34.5, 46/23, and 46/11.5 kg ha^{-1} of N-P_2O_5. Thus, the combination of N and P at 69/23 kg ha^{-1} resulted in about 85.17% higher head weight compared with the application of no fertilizer (Table 1). The current is in agreement with the finding [9], who reported that the combination of N and P at 69/23 kg ha^{-1} resulted in nearly 219.7% higher head weight compared to no fertilizer application. Furthermore, this current result is consistent with the findings [13], which discovered that applying nitrogen and phosphorus at 92 and 30 kg ha^{-1} yielded maximum plant head.

Grain yield (kg ha^{-1}):

Results showed that NP fertilizer rates had a highly significant ($p \leq 0.0001$) influence on the grain yield of sorghum. The data showed that the maximum value of grain yield (3916.7 kg ha^{-1}) was obtained from 69/11.5 kg ha^{-1} NP fertilizer and the minimum value of grain yield (2286.2 kg ha^{-1}) was obtained from the control, but, statistically, it was at par with the rates of 69/34.5, 69/23, 46/34.5, 46/11.5, 23/34.5, 23/23, and 0/34.5 kg ha^{-1} of N-P_2O_5 (Table 1). The application rate of 69/11.5 kg ha1 NP fertilizer was 71.32% higher than the treatment that did not receive any fertilizer. In addition, highly significant and positive correlations of grain yield with yield components were observed, especially for plant height (r=0.57**), head weight (r=0.85***), biomass yield (r=0.89***), and stover yield (r=0.75***) (Table 3). The findings are consistent with those of the research [13, 17], who found that applying NP fertilizer boosts sorghum grain yield. Another recent study done [9] at Kersa woreda in southwest Ethiopia is in agreement with the current findings.

Total Biomass Yield (kg ha^{-1}):

Results indicated significant ($p \leq 0.0001$) effects of NP fertilizer rate on total biomass yield (Table 2). The result also shows that there is an increase in the total biomass yield of sorghum with an increase in the application rates of nitrogen and phosphorus fertilizers. Similarly, the largest value (11483.3 kg ha^{-1}) was recorded from the application of 69/23 kg ha^{-1} NP fertilizer, while the lowest value (6150 kg ha^{-1}) was obtained from the control. Nevertheless, statistically, it was on par with the rates of 69/34.5, 69/11.5, 46/34.5, 46/23, and 46/11.5 kg ha^{-1} of N-P_2O_5. The current result indicated that NP fertilizer increased the biomass yield by 86.72% over control treatment. This present study is similar to those findings [9, 13, 17], who found that applying NP fertilizer increases sorghum's total biomass yield.

Stover yield (kg ha^{-1}):

The result of the analysis of variance revealed a highly significant ($P \leq 0.0001$) difference in the stover yield of sorghum (Table 2). Similarly, the maximum stover yield (7666.8 kg ha^{-1}) of sorghum was recorded from the application of 69/23 kg ha^{-1} NP inorganic fertilizer, while the lowest stover yield (3863.8 kg ha^{-1}) of sorghum was obtained from the unfertilized plot. Conversely, statistically, it was at par with the rates of 69/34.5, 69/11.5, 46/34.5, 46/23, and 46/11.5 kg ha^{-1} of N-P_2O_5. The application of 69/23 kg ha^{-1} NP fertilizer rates gave a stover yield advantage of 98.43% compared to unfertilized plots. The present study is supported by the [9] results, which indicated that the application of 69/23 kg ha^{-1} NP fertilizer rates gave a stover yield advantage of 124.86% compared to unfertilized plots. Moreover, this result is in agreement with the authors [17, 2], who reported that combining nitrogen with phosphorus increases plant height, grain yield, and biomass yield of sorghum, maize, and sorghum.

Table 1. *Influence of Nitrogen and Phosphorus Rates in Combination on Mean Plant Height, Head Weight, and Grain Yield of Sorghum.*

Treatments (NP kg ha^{-1})	Plant height (cm)	Head weight (gm)	Grain Yield (kg ha^{-1})
0/0	160.7^{f}	54.69^{f}	2286.2^{f}
0/11.5	168.3^{ef}	74.94^{ed}	2512.3^{ef}
0/23	174.3^{bcdef}	66.98^{ef}	2746.5^{def}
0/34.5	171.5^{cdef}	69.15^{ef}	3615.2^{ab}
23/0	169.7^{def}	68.57^{ef}	2720.8^{def}
23/11.5	166.7^{ef}	76.10^{de}	2824.3^{edf}
23/23	181.2^{abcde}	82.18^{bcde}	3601.2^{ab}
23/34.5	185.8^{abc}	81.31^{cde}	3627.5^{ab}
46/0	173.3^{bcdef}	70.32^{e}	2946.2^{cde}
46/11.5	190.8^{a}	89.99^{abcd}	3466.7^{abc}
46/23	192.0^{a}	91.73^{abc}	3172.2^{bcd}
46/34.5	183.7^{abcd}	86.52^{abcd}	3497.8^{abc}
69/0	179.3^{abcde}	67.71ef	2930.5^{cde}
69/11.5	183.5^{abcd}	97.22^{ab}	3916.7^{a}
69/23	192.3^{a}	101.27^{a}	3816.5^{a}
69/34.5	186.2^{ab}	89.41^{abcd}	3746.5^{ab}
LSD (0.05)	14.661**	15.491***	633.36***
CV (%)	4.920	11.721	11.82

Values followed by the same letter within a column are not significantly different at $P \leq 0.05$.

Harvest index (%):

The harvest index is calculated as the ratio of grain yield to the above-ground dry biomass weight. The harvest index of sorghum showed a highly significant ($p \leq 0.0001$) difference due to the treatment effect (Table 2). Given that, the highest value (41.8%) had been observed from the application of 0/43.5 kg ha^{-1} NP fertilizer rate, while the lowest value (30.7%) was observed from the treatment received at 46/23 kg ha^{-1} NP fertilizer rate. The present result is consistent with the findings [12], who found that the harvest index varied significantly due to different levels of phosphorus. Also, the author [20] found that the values of the harvest index showed an increasing trend in the harvest index values with the application of phosphorus.

Table 2. *Influence of Nitrogen and Phosphorus Rates in Combination on Mean Stover, Biomass, and Harvest Index of Sorghum.*

Treatments (NP kg ha^{-1})	Stover yield (kg ha^{-1})	Total Biomass Yield (kg ha^{-1})	Harvest index (%)
0/0	3863.8^{h}	6150.0^{g}	37.7^{b}
0/11.5	5237.7^{defg}	7750.0^{fg}	32.4^{def}
0/23	5053.5^{efg}	7800.0^{f}	35.2^{bcd}
0/34.5	5034.8^{efg}	8650.0d^{ef}	41.8^{a}
23/0	4912.5^{gh}	7633.30^{fg}	35.6^{bcd}
23/11.5	6259.0^{bcd}	9083.30^{cdef}	30.9^{ef}
23/23	6048.8^{cde}	9650.0^{bcde}	37.4^{b}
23/34.5	6022.5^{cdef}	9650.0^{bcde}	37.5^{b}
46/0	5403.8^{edfg}	8350.0^{ef}	35.2^{bcd}
46/11.5	6816.7^{abc}	10283.3^{abc}	33.7^{cdef}
46/23	7144.5^{ab}	10316.7^{abc}	30.7^{f}
46/34.5	6702.2^{abc}	10200.0^{abcd}	34.3^{bcde}
69/0	4952.8^{fgh}	7883.3^{f}	37.2^{bc}
69/11.5	7033.3^{abc}	10950.0^{ab}	35.9^{bcd}
69/23	7666.8^{a}	11483.30^{a}	33.2^{def}
69/34.5	6903.5^{abc}	10650.0^{abc}	35.1^{bcd}
LSD (0.05)	1090.6***	1614.4***	3.5366***
CV (%)	11.0	10.6	6.0184

Values followed by the same letter within a column are not significantly different at $P \leq 0.05$.

3.3. Correlation Between Growth Parameters, Yield, and Yield Components of Sorghum

On the farm of Omo Nada farmer, Table 3 gives a summary of the correlation coefficients for the correlations between specific growth factors like yield and yield components of sorghum. Accordingly, the result indicates all selected parameters of sorghum had a significant and positive correlation with one another except the harvest index. Hence, this result suggests that sorghum grain yield, plant height, head weight, total biomass yield, and stover yield are highly influenced by NP inorganic fertilizer. Stover had a significant and negative correlation with the harvest index. Harvest index had a negative correlation with stover, plant height, head weight, and biomass but a positive and nonsignificant correlation with grain yield. According to the research [7], there is a strong and positive link between grain yields, head weight, and 1000-grain mass, while there is a significant but negative correlation between panicle count and panicle length. Furthermore, the report [9] validates the current research investigation.

3.4. Economic Analysis

The results of the economic analysis for the response of sorghum to nitrogen and phosphorus fertilizer rates are indicated in Table 4. Application of 69/11.5 N P kg ha-1 gave the highest (14787.30 ETB) net benefit, whereas the 0/0 N P kg ha-1 gave the lowest (10105.00 ETB) with the highest marginal rate return of 501.3% with values to the cost ratio of EB 5.9 profit per unit investment for sorghum production in Omo Nada.

Table 3. *Pearson Correlation Coefficients Between Selected Sorghum Plant Parameters.*

Sorghum plant parameters	Plant height	Head wt.	Grain yield	Stover	Biomass	Harvest index
Plant height	1					
Head wt.	0.63***	1				
Grain yield	0.57**	0.85***	1			
Stover	0.68***	0.92***	0.75***	1		
Biomass	0.68***	0.95***	0.89***	0.97***	1	
Harvest index	-0.21^{ns}	-0.18^{ns}	0.24^{ns}	-0.45**	-0.23^{ns}	1

***=P ≤ 0.0001; **=≤ 0,001; *=P ≤ 0.05; ns=nonsignificant.

Table 4. *Sorghum Production Partial Budget Analysis.*

Treatments (NP kg ha^{-1})	Adjusted Yield (kg ha^{-1})	Gross Benefits (ETB)	TVC (ETB)	NB (ETB)	MRR (%)	VCR
0/0	2286.2	10105.0	0	10105.0	--	--
0/11.5	2512.3	11104.4	725.0	10379.4	37.9	14.3
0/23	2746.5	12139.5	1449.9	10689.6	42.8	7.4
0/34.5	3615.2	15979.2	2174.9	13804.3	429.6	6.3
23/0	2720.8	12025.9	599.8	11426.1	151.0	19.0
23/11.5	2824.3	12483.4	1324.8	11158.6	-36.9	8.4
23/23	3601.2	15917.3	2049.8	13867.5	373.7	6.8
23/34.5	3627.5	16033.6	2774.7	13258.8	-84.0	4.8
46/0	2946.2	13022.2	1199.7	11822.5	91.2	9.9
46/11.5	3466.7	15322.8	1924.6	13398.2	217.3	7.0
46/23	3172.2	14021.1	2649.6	11371.5	-279.6	4.3
46/34.5	3497.8	15460.3	3374.6	12085.7	98.5	3.6
69/0	2930.5	12952.8	1799.5	11153.3	59.2	6.2
69/11.5	3916.7	17311.8	2524.5	14787.3	501.3	5.9
69/23	3816.5	16868.9	3249.4	13619.5	-161.1	4.2
69/34.5	3746.5	16559.5	3974.4	12585.1	-142.7	3.2

ETB= Ethiopian birr, MRR= Marginal Rate of Return, TVC= Total variable cost, NBT= Net benefit, VCR=value cost ratio.

4. Conclusion

The present study showed that the yield and yield components of the sorghum crop responded significantly to the impacts of inorganic nitrogen and phosphorus fertilizer nutrients. Parameters such as plant height, head weight, grain yield, biomass yield, stover yield, and harvest index were statistically significantly different for nitrogen and phosphorus fertilizer rates. In addition, these parameters showed significant and positive correlations with each other, excluding the harvest index. As a result, N and P fertilizers are very vital nutrients in limiting the growth, development, and production of the sorghum in the study area.

The result revealed that the application of 69/11.5 N P kg ha^{-1} gave the highest (14787.30 ETB) net benefit, whereas the 0/0 N P kg ha^{-1} gave the lowest (10105.00 ETB) net benefit with the highest marginal rate return of 501.3% with values to the cost ratio of EB 5.9 profit per unit investment for sorghum production in Omo Nada. Therefore, the application of 69/11.5 N P kg ha^{-1} fertilizer rate was recommended for better sorghum production and economic return in Nitisols of Omo Nada district, southwestern Ethiopia.

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