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Original Paper

Determination of Nitrogen and Phosphorus Fertilizer Rates for Sorghum (*Sorghum bicolor L. Moench*) Production in Wag-Lasta, Ethiopia

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***Abstract*— The decline in soil fertility due to topsoil loss caused by erosion, leaching, and continuous crop residue removal is a major challenge for crop production in the Wag-Lasta areas of Ethiopia. To address this issue, a field experiment was carried out in Lasta and Sekota districts, Eastern Amhara, Ethiopia, during the main rainy season in 2014 and 2016. The purpose of the experiment was to determine the optimal nitrogen and phosphorus fertilizer rates for Sorghum bicolor production. The experiment involved four nitrogen rates (0, 23, 46, 69 kgha^{-1}N) and three phosphorus rates (0, 23, 46 kg kgha^{-1} P_2O_5) arranged in a randomized complete block design with three replications in a factorial arrangement. Soil samples were collected from 0–20 cm to determine selected soil properties, and agronomic data were collected following standard procedures. The data were then analyzed using SAS software version 9.0, and significant treatment means were separated using the least significant difference at 5% significance level. The results showed that nitrogen and phosphorus rates significantly affected sorghum yield and yield components at both locations. Specifically, applying 23 kg ha^{-1} N and 46 kg ha^{-1} P2O5 increased sorghum yield by 60% compared to the control at Sekota, while 23 kg ha^{-1} N and 23 kg ha^{-1} P_2O_5 gave a 125% yield increment over the control at Lalibela. Therefore, it was recommended to apply 23 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5 for sorghum production in Sekota and 23 kg ha^{-1} N and 23 kg ha^{-1} P_2O_5 in Lalibela.**

Keywords: Fertility, Production, Yield

I. Introduction

The agricultural sector in Ethiopia, particularly in areas prone to degradation and drought, faces significant challenges in achieving high productivity. Factors such as drought, low soil fertility, diseases, insects, and weeds have led to low crop productivity, particularly in sorghum production [1]. Sorghum is an important cereal crop globally, ranking fifth after maize, rice, wheat, and barley [2]. In Ethiopia, it is the second most produced staple food crop after maize. Despite its significance, sorghum production and productivity are currently below their potential, with average regional sorghum productivity at 2.4 t ha-1 and even lower in specific zones due to poor soil fertility [3]. To address this, there is a need to maximize sorghum production and productivity to ensure food security and generate income. Research has highlighted the critical role of inorganic fertilizer in increasing crop yield, and it has been suggested that fertilizer levels should be optimized to meet the growing food demand [4]. However, many farmers in the Wag-lasta region do not apply fertilizer, and those who do use blanket recommendations that may not be suitable for their specific sites. As a result, this research aims to determine the optimal rates of nitrogen and phosphorus fertilizers to improve the yield and yield components of sorghum in the Wag-Lasta areas.

II. Material And Method

A. Study Area Description

The research was conducted in the Lalibella and Aybra districts, located in the Lasta and Sekota Weredas, respectively, within the Amhara Regional State in the years 2014 and 2016. The study sites were located at 11° 58' 50.15" North latitude and 38° 59' 03.22" East longitude, and 12° 43' 52.82" North latitude and 39° 12' 22.01" East longitude. They were at altitudes of 1966 meters and 1915 meters above sea level, respectively "Fig. 1."

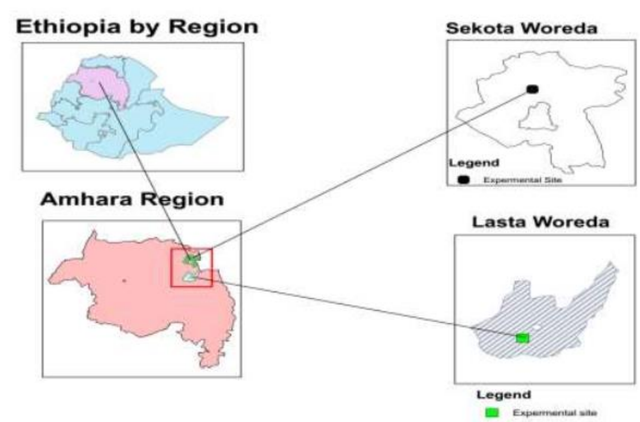

Fig. 1. the experimental locations

B. Experimental Design and Treatments

The experiment was conducted in the Wag-Lasta areas of the Amhara Region during the main cropping seasons. It included four different levels of nitrogen (0, 23, 46, and 69 kg ha-1 N) and three levels of phosphorus (0, 23, and 46 kg ha^{-1} P_2O_5). The experiment followed a randomized complete block design with three replications in a factorial arrangement. Each plot measured 14.25 m2 (3.75 m x 4 m) and consisted of five rows, with a net plot size of 9 m2. There was a distance of 0.5 m between plots and 1 m between blocks. The spacing between rows was 75 cm and between plants was 15 cm. Each plot contained 26 plants per row, totaling 133 plants per plot. Urea and TSP were used as nitrogen and phosphorus fertilizer sources, respectively. The nitrogen fertilizer was applied in two splits, with half at planting and the remaining later.

C. *Data Collection And Analysis*

The heights of the plants, lengths of their heads, weights of the heads, grain yields, and above-ground biomass of sorghum were measured for each plot. The data was analyzed using SAS statistical software version 9.0, and treatment effects were compared using Fisher's Least Significant Differences test at the 5% level of significance.

D. *Partial Budget Analysis*

The economic feasibility was assessed using the manual developed by CIMMYT (1988) through a partial budget analysis. Costs, including fertilizer cost and the price of sorghum, were collected from the study areas.

E. *Soil Analysis*

The soil samples were collected from a depth of 0–20 cm before planting. They were air-dried and passed through a 2 mm sieve to determine soil parameters, except for total nitrogen and organic carbon, which were determined from soils passed through a 0.5 mm sieve. Soil pH was determined from the filtered suspension of a 1:2.5 soil-to-water ratio using a glass electrode attached to a digital pH meter. The organic carbon of the soils was determined following the wet digestion method as described by [5]. The percentage of organic matter in the soils was determined by multiplying the percent organic carbon value by 1.724. Total nitrogen was determined by the micro-Kjeldahl digestion, distillation, and titration method.

III. RESULTS AND DISCUSSION

A. *Soil Analysis Results At Aybra And Lalibela*

The soil analysis showed that the textural class for both sites was clay loam (Table I). The pH of the surface soil at Aybra was 5.96, and at Lalibela, it was 6.3. The soil reaction at Aybra was classified as moderate, while Lalibela was classified as slightly acidic [6]. According to [6], the organic matter and total nitrogen contents in the surface soil were low for both sites.

TABLE I. SOIL ANALYSIS OF THE STUDY AREA

Site	pH	EC Dec/m	Om%	TN%	Texture			Textural class
					Sand	*Silt*	*Clay*	
Lalibella	6.23	1.3	1.06	0.07	39	27	34	Clay loam
Aybra	5.96	1.8	1.09	0.084	33	32	35	Clay loam

B. *Effects of Nitrogen and Phosphorus Rates on Sorghum Yield and Yield Components at Aybra Plant Height*

The analysis of variance showed a highly significant ($P \leqslant 0.001$) difference in plant height between the fertilizer rates and the control. However, there was no significant difference among the fertilizer rates (Table II). Over the years, the highest mean plant height was recorded with 23 $kgha^{-1}$ of nitrogen (140.01 cm) and 23 $kgha^{-1}$ of P_2O_5 (140.08 cm) (Table III). Our findings are consistent with those of [7], who found that 18 kgha-1 of nitrogen and 46 kgha-1 of phosphorus with tie-ridge had a significant effect on plant growth in southern Ethiopia. Similarly, based on [8], reported that nitrogen and P_2O_5 at a rate of 18 $kgha^{-1}$ and 46 $kgha^{-1}$ with in situ moisture conservation resulted in higher plant height.

TABLE II. COMBINED ANOVA FOR THE IMPACT OF N AND P FERTILIZERS ON THE YIELD COMPONENT PARAMETERS AT SEKOTA (AYBRA).

Source of variation	DF	Mean square values				
		Plant height (cm)	*head length (gm)*	*Head weight (gm)*	*Grain Yield (gm)*	*Biomass Yield (gm)*
N	3	1879.41**	3.96^{ns}	922.14**	3463406.69**	246540773**
P	2	1460.56**	3.61^{ns}	667.37***	2959677.33**	223566291**
N*P	6	186.92*	7.34*	310.57***	373721.83**	50981317**
Year	1	1305.00**	580.26**	9480.64**	509325.21*	13230964**

TABLE III. EFFECT OF NITROGEN AND PHOSPHORUS ON GROWTH PARAMETERS OF SORGHUM AT SEKOTA (AYBRA)

Treatment	Plant height (cm)			head Length (cm)			head weight (gm)		
N kg ha^{-1}	*1st year*	*2nd year*	*combined*	*1st year*	*2nd year*	*combined*	*1st year*	*2nd year*	*combined*
0	122.48^{b}	115.86^{b}	119.17^{b}	14.68^{b}	20.35^{ab}	17.94	13.84^{c}	20.83^{c}	17.33^{b}
23	130.56^{a}	149.46^{a}	140.01^{a}	15.53^{ab}	21.77^{ab}	18.23	17.12^{b}	46.33^{ab}	31.72^{a}
46	135.47^{a}	142.85^{a}	139.16^{a}	15.87^{ab}	20.82^{ab}	18.35	19.18^{a}	43.33^{b}	31.25^{a}
69	132.42^{a}	146.82^{a}	139.62^{a}	16.12^{a}	21.97^{a}	19.05	16.21^{b}	47.66^{a}	31.94^{a}
LSD (0.05)	6.49	9.42	7.17	1.21	1.60	ns	1.49	3.90	10.16
P2O5 $kgha^{-1}$									
0	120.47^{b}	130.69^{b}	125.58^{b}	15.49^{ab}	21.05	18.27	15.47^{b}	32.25^{b}	23.86^{b}
23	137.59^{a}	142.56^{a}	140.08^{a}	16.34^{a}	21.31	18.82	17.21^{a}	50.75^{a}	33.98^{a}
46	132.65^{a}	143.00^{a}	137.82^{a}	14.83^{b}	21.33	18.08	17.08^{ab}	35.62^{b}	26.35^{ab}
LSD (0.05)	5.62	8.16	6.21	1.05	ns	ns	1.29	3.38	8.79
CV (%)	5.12	6.98	7.99	8.01	7.75	18.72	9.24	10.14	14.29

C. *Effects of Nitrogen and Phosphorus Rates on Sorghum Grain Yield*

The grain yield was significantly affected by nitrogen and phosphorus fertilizer rates ($P < 0.05$) (Table VI). Increasing the rates of N/P_2O_5 fertilizers from 0/0 to 23/46 kg ha^{-1} increased the crop yield from 1172 to 2959.2 kg ha^{-1}. The highest grain yield was obtained from 23 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}, resulting in a 60.4% increase over the control. The yield from the control treatment was significantly lower ($P \leq 0.05$) than the yields obtained from the various rates of NP fertilizers (Table IV). This suggests that without inputs such as inorganic and organic fertilizer addition, the grain yield of sorghum was very low. The findings of this study align with those of [7;8], who found that applying 18 kg ha^{-1} of nitrogen fertilizer and 46 kg ha^{-1} of phosphorus significantly increased the grain yield of sorghum. Similarly, research by[9], observed that applying 46 kg ha^{-1} P_2O_5 and 18 kg ha^{-1} N with tie-ridge increased the grain yield of sorghum by 15–38% in the moisture-stress areas of Eastern Ethiopia.

TABLE IV. EFFECT OF NITROGEN AND PHOSPHORUS ON GRAIN YIELD (KGHA^{-1}) OF SORGHUM AT SEKOTA (AYBRA) COMBINED OVER YEAR

N level (kg ha^{-1})	P level (kg ha^{-1})		
	0	23	46
0	1172.5^{e}	1507.1^{de}	1559.0^{d}
23	2104.0^{c}	2293.8^{bc}	2959.2^{a}
46	1480.2^{de}	2404.9^{bc}	2111.3^{c}
69	1656.5^{d}	2546.2^{b}	2301.2^{bc}
LSD (5%)		348.99	
CV (%)		15.04	

TABLE V. EFFECT OF NITROGEN AND PHOSPHORUS ON BIOMASS YIELD (KGHA^{-1}) OF SORGHUM AT SEKOTA (AYBRA)

N level (Kg ha^{-1})	P level (kg ha^{-1})		
	0	23	46
0	5086.3^{g}	7126.6^{f}	7433.2^{f}
23	9048.0^{e}	10810.9^{cd}	12018.8^{bcd}
46	10679.4^{d}	13407.4^{ab}	11382.2^{cd}
69	9058.6^{e}	13731.5^{a}	12151.0^{ab}
LSD (5%)		1410	
CV (%)		12.01	

D. *Biomass Yield*

The biomass yield of sorghum (Table 5) was significantly affected ($P < 0.05$) by the application of different rates of nitrogen and phosphorus fertilizers. Biomass yield increased with the application of NP fertilizers. The highest biomass yield (13731.5kg ha^{-1}) was recorded at a rate of 69 kg ha^{-1} N and 23 kg ha^{-1} phosphorus fertilizer, while the lowest biomass yield (5086.5 kg ha^{-1}) was recorded in the control treatment (Table VI). This indicates that NP fertilizer increased the biomass yield by 37.07% over the control. Biomass yield is particularly important as the leaves and stems are used for cattle feed during the long dry season [8].

E. *Partial Budget Analysis*

The partial budget analysis indicates that applying 46 kg ha^{-1} N and 23 kg ha^{-1} P_2O_5 resulted in the highest net benefit of 16523.46 birr ha^{-1}, with a MRR of 1349%. Following closely is the application of 23 kg ha^{-1} N and 23 kg ha^{-1} P_2O_5, which yielded a net benefit of 13086.94 birr ha^{-1} and an MRR of 714%. This means that for every Ethiopian birr invested in this technology, farmers can gain an additional 13.49 birr.

F. *Plant height at Lalibela location*

Nitrogen and phosphorus had a significant effect ($P \leq 0.001$) on the height of sorghum. The application of 69 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5 fertilizers resulted in the tallest plants compared to the control. The sorghum plants were 18.21 cm taller with 69 kg ha^{-1} N and 4.33 cm taller with 46 kg ha^{-1} P_2O_5compared to the control. The increase in plant height due to nitrogen application is attributed to its effect on cell division and elongation, leading to stem and leaf growth [10]. This finding is consistent with the results of previous studies by [11], as well as [7], who also found significant effects on sorghum plant height with the application of 69 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5.

G. *Effect of Nitrogen and Phosphorus Rates on Grain Yield*

The grain yield was significantly affected by the application of nitrogen and phosphorus fertilizers ($P < 0.05$). The highest grain yield (3888.3 kgha^{-1}) was recorded from 69/23 N/P_2O_5 kgha^{-1}, and the lowest (1698.4 kgha^{-1}) was recorded from the control (Table II). The highest grain yield of sorghum, 46/23 N-P_2O_5 kg ha^{-1}, was significantly higher than the lower rate but was at par with the rates of 23/23, 46/23, and 69/23 kgha^{-1} of N-P_2O_5 that responded linearly. The grain yield of sorghum was greater by 2190.4 kgha^{-1} and 2148 kgha^{-1} at 69/23 and 46/23 kgha^{-1} N and kgha^{-1} P2O5 compared with the control. The yield was increased by 56.33% and 28.93% and 55.88%. The result is in agreement with the findings of [12], who reported that the application of NP fertilizer increases the grain yield of sorghum. Similarly, due to [13], the reported that an increasing rate of nitrogen and phosphorus had increased the grain yield of sorghum in Kenya.

TABLE VI. PARTIAL BUDGET ANALYSIS AT SEKOTA (AYBRA)

N	P2O5	Adjusted grain yield (kg ha^{-1})	Gross benefit	Variable cost	Net benefit	MRR%
0	0	1055.25	7386.75		7386.75	
0	23	1893.6	13255.2	608.5	9256.52	3.07
0	46	1332.18	9325.26	1217	8108.26	D
0	69	1490.85	10435.95	1825.5	8610.45	D
23	0	1356.39	9494.73	755.5	8739.23	D
23	23	2064.42	14450.94	1364	13086.94	7.14
23	46	2164.41	15150.87	1972.5	13178.37	0.15
23	69	2291.58	16041.06	2581	13460.06	0.46
46	0	1403.1	9821.7	1511	8310.7	4.81
46	23	2663.28	18642.96	2119.5	16523.46	13.49
46	46	1900.17	13301.19	2728	10573.19	D
46	69	2071.08	14497.56	3336.5	11161.06	D

TABLE VII. COMBINED ANOVA FOR THE EFFECT OF N AND P FERTILIZERS ON THE PLANT HEIGHT, SORGHUM HEAD LENGTH, HEAD WEIGHT, GRAIN YIELD AND BIOMASS AT LALIBELLA

Source of variation	DF	Mean square values				
		Plant height (cm)	Head length (cm)	Head weight (gm)	Grain yield (gm)	Biomass yield (gm)
N	3	1185.19^{**}	10.99^{*}	318.59^{***}	10591267.03^{***}	140261599.0^{**}
P	2	152.80^{**}	0.84^{ns}	15.75^{ns}	1267516.55^{**}	1058796.5^{*}
N*P	6	170.91^{**}	2.46^{ns}	422.81^{***}	1010479.64^{**}	7253023.4^{**}
Year	1	4402.58^{**}	14.35^{**}	375.63^{*}	23109478.2^{**}	483484.8^{*}

H. *Biomass Yield of Sorghum*

The biomass yield of sorghum was significantly affected ($P < 0.05$) by applying different rates of nitrogen and phosphorus fertilizers. The highest biomass yield (24924kg ha^{-1}) was recorded with the application of 69/23 N-P^2O^5 kg ha^{-1}, and the lowest (8993 kg ha^{-1}) was recorded in the control treatment (0N, 0P). The application of fertilizer increased the biomass yield of sorghum by 36.08%.

TABLE VIII. EFFECT OF NITROGEN AND PHOSPHORUS ON GRAIN YIELD (KGHA^{-1}) OF SORGHUM AT LALIBELLA

Treatment	Plant height (cm)			Head length (cm)			Head weight (gm)		
N kg ha^{-1}	1st year	2nd year	comb	1st year	2nd year	comb	1st year	2nd year	comb
0	140.80^{b}	156.69^{d}	149.17^{d}	19.11^{b}	18.63^{c}	18.87^{b}	40.12^{c}	44.60^{b}	42.96^{b}
23	146.78^{b}	161.73^{c}	156.50^{c}	19.51^{ab}	20.42^{b}	19.96^{a}	55.48^{a}	47.28^{b}	50.39^{a}
46	154.44^{a}	171.07^{b}	163.97^{b}	19.46^{ab}	21.11^{ab}	20.28^{a}	42.92^{bc}	54.60^{a}	48.74^{a}
69	154.46^{a}	179.26^{a}	167.38^{a}	19.95^{a}	21.44^{a}	20.70^{a}	44.13^{b}	56.37^{a}	49.11^{a}
LSD 0.05	6.48	3.43	2.73	0.83	0.93	0.73	2.94	4.04	4.96
P_2O_5 kg ha^{-1}									
0	146.86^{b}	165.88^{b}	157.84^{b}	19.35	20.18	19.76	45.74^{b}	47.49^{b}	46.28
23	147.93^{ab}	168.94^{a}	157.96^{b}	19.66	20.54	19.96	49.27^{a}	53.71^{a}	49.56
46	152.57^{a}	168.41^{a}	162.17^{a}	19.51	20.76	20.14	41.98^{c}	50.94^{ab}	45.39
LSD 0.05	5.61	1.33	2.37	ns	ns	ns	2.54	3.5	ns
CV (%)	4.46	8.91	5.23	4.41	5.19	5.49	6.61	8.19	15.64

I. *Partial Budget Analysis*

The partial budget analysis indicates that applying 23 N kg ha^{-1} and 23 kg ha^{-1} P_2O_5 resulted in the highest net benefit (23447.23birr ha^{-1}) with an MRR of 983%. This was followed by 23 N kgha^{-1}, which had a net benefit of (16269.97birr ha^{-1}) and an MRR of 952%.

TABLE IX. EFFECT OF NITROGEN AND PHOSPHORUS ON GRAIN YIELD (KGHA^{-1}) OF SORGHUM AT LALIBELLA

N level (kg ha^{-1})	P level (kg ha^{-1})		
	0	23	46
0	1698.4^{d}	2160.2^{dc}	1718.9^{d}
23	2607.7^{bc}	3822.6^{a}	3319.6^{ab}
46	2790.0^{bc}	3846.4^{a}	2887.6^{bc}
69	2454.4^{dc}	3888.3^{a}	3293.4^{ab}
LSD 0.05		800.16	
CV (%)		7.09	

TABLE X. EFFECT OF NITROGEN AND PHOSPHORUS ON SORGHUM BIOMASS YIELD (KGHA^{-1}) AT LALIBELLA

N level (kg ha^{-1})	P level (kg ha^{-1})		
	0	23	46
0	8993^{d}	10387^{cd}	9786^{d}
23	12452^{bcd}	18253^{ab}	18156^{ab}
46	12493^{bcd}	17212^{bc}	18628^{ab}
69	12184^{bcd}	24924^{a}	17554^{b}
LSD 0.05	-	6983	-
CV(%)	-	18.55	-

TABLE XI. PARTIAL BUDGET ANALYSIS AT LALIBELLA

P_2O_5	N	Adjusted kgha^{-1}	Gross benefit	Variable cost	Net benefit	MRR%
0	0	1528.56	10959.77	-	10959.77	-
0	23	2346.93	16827.48	557.5	16269.97	952
0	46	2511	18003.87	1115	16888.87	111
0	69	2208.96	15838.24	1672.5	14165.74	D
23	0	1944.18	13939.77	662.5	13277.27	D
23	23	3440.34	24667.23	1220	23447.23	1083
23	46	3461.76	24820.81	1777.5	23043.31	-72
23	69	3499.47	25091.19	2335	22756.19	D
46	0	1547.01	11092.06	1325	9767.06	D
46	23	2987.64	21421.37	1882.5	19538.87	D
46	46	2598.84	18633.68	2440	16193.68	D
46	69	2964.06	21252.31	2997.5	18254.81	D

IV. RECOMMENDATION

The findings indicate that nitrogen and phosphorus fertilizers can significantly increase sorghum production and profitability in the studied areas. The average sorghum grain yield was notably influenced by the combination of NP fertilizer rate. Both N and P fertilizers are crucial for plant growth, development, and land productivity in the study area. The application of 23 kg ha^{-1} P_2O_5 and 46 kg ha^{-1} N is recommended as the optimal rate for sorghum productivity in Sekota woreda at Aybra kebele and similar agro-ecological zones. In contrast, the application of 23 kgha^{-1} N and 23 kgha^{-1} P_2O_5 is suggested for optimal sorghum productivity in Lalibella (Shumsha) and similar agro-ecological zones.

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