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Nutrient Response Functions of Sorghum for Miesso District Central Rift Valley of Ethiopia

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Abstract

This study was executed to offer the basis for optimized profit from fertilizer use for sorghum yield and to determine robust crop nutrient response function and economic rate for the production of sorghum at Miesso Central Rift Valley of Ethiopia. Trails were conducted at six experimental sites, sorghum yield response to N and P fertilizers application and economically optimum rates of nitrogen (EONR) and phosphorus (EOPR) were evaluated on a vertisols within the semi-arid Miesso districts west Hararge zone of Oromia region. The nutrient rates in 2014 cropping season four levels of Nitrogen (N) alone, these levels with 20 $kg{\cdot}ha^{-1}$ Phosphorus (P) and without N, 69 $kg{\cdot}ha^{-1}$ N with three levels of P treatments including the zero control were evaluated. In 2015, cropping season similar rates of N alone, the same rate N with 20 $kg{\cdot}ha^{-1}$ P, 92 $kg{\cdot}ha^{-1}$ N with three rates of P including the zero control were evaluated. The treatments were arranged in a randomized complete block with three replications in factorial design. Nutrient responses of sorghum were determined using asymptotic quadratic plateau functions. The significantly highest nitrogen rate was 46 $kg{\cdot}ha^{-1}$ alone in 2014 season, which gave grain yield of 2.56 $Mg{\cdot}ha^{-1}$ with a maximum yield advantage of 43%. P rates in both seasons and combined (sites + seasons) were not significantly influenced sorghum yield. Nitrogen agronomic and partial factor productivity peaked at 23 kg N ha^{-1} but declined with increasing N rate. The EONR combined (sites + seasons) were 37, 45, 52 and 60 $kg{\cdot}ha^{-1}$ and for the profit to cost ratio (PCR) were 2.43, 3.65, 4.86 and 5.79 at difference cost to grain price ratios (CP) = 3.6, 2.3, 1.6 and 1.2 respectively at Miesso Ethiopia. Nitrogen application had economically profitable than P. The study concluded that the application of N at 37 or 60 kg N ha^{-1} to sorghum production could be economically profitable for those economically constrained farmers or economically not constrained farmers. Validation should be farther conducted on farmers' fields for refining the results obtained.

Keywords

Sorghum, Response Function, Economically Optimum Rates, Nutrient Use Efficiency, Cost to Grain Price Ratio, Ethiopia

1. Introduction

Cereals are the major food crops in Ethiopia both in terms of the area they are covered and amount of production obtained. They are produced in larger amount compared with other crops, because they are the major staple crops. Out of the total grain crop area, 79.38% was under cereals. Teff, maize, sorghum and wheat took up 24.31%, 16.08%, 13.52% and 12.94% of the grain crop area, respectively [1]. Among these sorghum was the third cereal produced in 2013/2014 cropping season. According to the CSA [1] report, the average grain yield of sorghum was 2465 kg·ha^{-1}.

Low mineral fertilizers use by smallholder farmers in developing countries commonly limits agricultural productivity. Most of farmers in this region do not have the budget to buy enough fertilizer to increase net benefit on their small investment per hectare. High mineral fertilizer costs and low market prices for agricultural production often reduce profit potential. Competing needs for money often take priority. Such farmers need high net returns on their investments to justify the application of fertilizers. Recommendations for non-finance constrained fertilizer use commonly strive to maximize mean net returns across all planted areas. These recommendations are infeasible for smallholders with limited financial capacities. Increasing net benefit needs the fertilizer investments focus on crop nutrient with the highest marginal returns until the budgeted financial resources are exhausted [2].

The economic consequences of soil fertility depletion are great with reduced farm production and food security. Also fertilizer use in Sub Sahara Africa (SSA) countries is low, partly because farmers do not recognize adequate profit opportunity with acceptable risk [3].

Optimization of fertilizer use by smallholders refers the maximization of net returns on the farmers' investment achieved through the best choice of crop-nutrient-rate combinations. Making decisions on choice of crop to fertilize and the amount of each nutrient to apply, however, is very complex. Crop responses to applied nutrients needs to be considered in addition to the farmer's land allocation to different crops, the value of the production, the costs of fertilizer use and the money available for fertilizer use [4].

For the other related and above mentioned constraints, the activity of Nutrient response functions of Sorghum and Nitrogen use efficiency was conducted at Miesso district of west Harerghe zone, Oromia Region. Therefore, this study was executed to offer the basis for optimized profit from fertilizer use for sorghum yield and to determine robust crop nutrient response function and economic rate for the production of sorghum at Miesso Central Rift Valley of Ethiopia.

2. Materials and Method

2.1. Study Area Description and Rainfall

Three on farm trials per season were conducted in two consecutive cropping seasons 2014 and 2015 G.C at Miesso district west Harerghe, Oromia region, the geographical locations of the study areas are 09˚13'35" Nothing, 40˚45'10" Easting 1339 masl, 09˚13'8.2" Northing, 40˚45'30" Easting with 1327 masl and 09˚13'32" Northing, 40˚45'23" Easting with the 1338 masl (Figure 1).

At Miasso rainfall distribution is bimodal. The Rainfall data for the 2014 were greater than the 2015 season as indicated in Table 1.

2.2. Materials

Twelve treatments were arranged in randomized complete block replicated three times in factorial design. In 2014 and 2015 cropping seasons the treatments arranged in the following table (Table 2).

The sources of N and P were urea and triple supper phosphate (TSP). Urea was applied in split, half at planting and the rest top-dressed at knee height. TSP was placed at planting in basal. Sorghum variety ESH-3 at the rate of 12 kg·ha^{-1} was planted in rows. Plot size was 4.00 m by 3.75 m (5 rows) and 3 harvestable

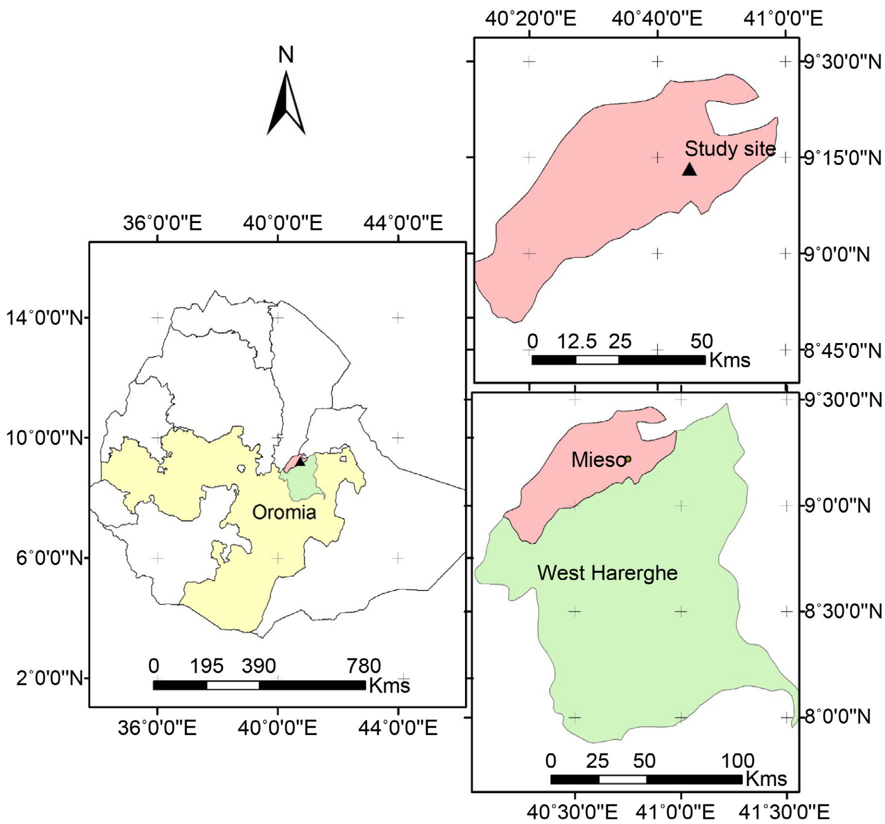

Figure 1. Map of the study site.

Table 1. Rainfall (mm) and temperature (˚C) data of Measo.

Year	Rainfall (mm)	Max Temp (˚C)	Min Temp (˚C)
2014	498.6	31.1	15.0
2015	424.8	32.1	15.5
	Main (Meher) season	**Minor (Belg) season**	
	Late Jun-Early Oct	**Mar-May 15**	
2014	390 mm	108.6 mm	
2015	318.8 mm	106 mm	

Table 2. Treatment arrangements in 2014 and 2015 cropping seasons.

Treatment	2014	2015
	kg·ha^{-1}	
1	0N, 0P	0N, 0P
2	23N, 0P	23N, 0P
3	46N, 0P	46N, 0P
4	69N, 0P	69N, 0P
5	92N, 0P	92N, 0P
6	0N, 20P	0N, 20P
7	23N, 20P	23N, 20P
8	46N, 20P	46N, 20P
9	69N, 20P	69N, 20P
10	92N, 20P	92N, 20P
11	69N, 10P	92N, 10P
12	69N, 30P	92N, 30P

rows, 0.75 m between rows and 0.20 m between plants.

2.3. Method

Following the standard soil sampling procedures, five representative sub-samples from each farmer field was taken at a depth of 0 - 20 cm before planting and made one composite sample. Then the samples were labeled and transported to Melkassa Agricultural research Center (MARC) soil laboratory.

At agronomic maturity, sorghum plants within the three central rows of each plot in a net plot area of 9.0 m^2 were harvested for Aboveground Biomass (AGB) Grain Yield (GY) determination. Sorghum grains were adjusted to 12.5% moisture content.

2.3.1. Laboratory Analysis

The soil samples were air-dried, crushed with mortar and pestle, passed through 2 mm wire sieve for various physico-chemical parameters analysis. Soil texture, bulk density, pH, EC, total nitrogen, available phosphorus and organic carbon were determined at Melkassa Agricultural Research Center (MARC) soil laboratory. Other chemical parameters of soil including Exchangeable cations (K, Na, Ca, Mg), Cation exchange capacity (CEC), and Zinc (Zn), Copper (Cu), Iron (Fe) and Manganese (Mn) were determined at Debrezeyit Agricultural Research Center soil laboratory.

Particle size distribution of the soil samples was determined by hydrometer method [5]. Soil bulk density was determined by the undisturbed core sampling method after drying the soil samples in an oven at 105˚C to constant weights.

Potentiometric method using a glass calomel combination electrode was used to measure pH of the soils in water suspension in a 1:2.5 (soil: water ratio) [6]. Electrical conductivity (EC) was measured using a conductivity meter from the same soil water suspension extract. The [7] wet digestion method was used to determine soil organic carbon (OC) content. Total nitrogen content of the soil was determined by wet-oxidation procedure of the Kjeldahl method [8]. Available P was determined using the standard [9] extraction methods. The absorbance of available P extracted was measured using spectrophotometer after colour development. Exchangeable cations (Ca, Mg, K and Na) were determined after extracting the soil samples by 1N neutral ammonium acetate (1N NH_4OAc) solution adjusted to a pH 7.0. Exchangeable Ca and Mg in the extract were measured by atomic absorption spectrophotometer (AAS) whilst K and Na were determined using flame photometer from the same extract [10]. Cation exchange capacity of the soils was determined from the ammonium acetate saturated samples through distillation and measurement of ammonium using the modified Kjeldhal procedure as described by [10]. Micronutrients (Fe, Mn, Zn, Cu) were extracted by Di-ethyl Tri-amine Penta-acetic acid (DTPA) as described by [11] and all these micronutrients were measured by AAS.

The values reported by FAO [12], Jones [13], Clements and McGowen [14], Bruce [15], Tekalign [16], Hazelton and Murphy [17], Landon [18] were used as soil analysis result guide for diagnosing nutrient status of the soil in the test sites.

2.3.2. Data Collection and Analysis

Two economically valuable parameters, AGB and GY of sorghum were measured and considered in this analysis. A linear modeling framework was used to determine variation in yield with the different levels of N and P by combining study sites and combining study sites and seasons. The linear modeling framework (in PROC LINEAR of the SAS system) was chosen for the different levels of analyses. The model was the following form:

$$Y = \mu + \text{Season} + \text{rate} + \text{Season} * \text{rate} + \text{Site} + \varepsilon \quad (1)$$

where μ is the grand mean yield ($Mg \cdot ha^{-1}$), season, rate is the rate of application ($kg \cdot ha^{-1}$) for the nutrient under study, site is the random component and ε is the error term.

The variations in yield with fixed effects were considered significant when P ≤

0.05. Least square estimates and their 95% confidence intervals were used for statistical inference. The means for two or more levels of a fixed effect were considered to be significantly different from one another only if their 95% CI were non-overlapping.

In order to determine the optimum rate of the nutrient in question, nutrient response functions were compared and used as deemed appropriate.

When significant nutrient rate effects occurred, the asymptotic quadratic-plateau grain yield response function was fitted to nutrient rates. This function gave an exponential rise to maximum yield or to a yield plateau. The asymptotic function was adjusted grain yield (AGY) ($Mg \cdot ha^{-1}$).

$$\text{AGY} = a - bc^N$$

where a is yield at the plateau or maximum yield, b is the gain yield obtained due to nutrient application, and c^N determined the shape of the quadratic response, where c is a curvature coefficient and N is the nutrient rate.

Statistical analyses were done by site-season and combined across site-seasons using SAS 9.0 computer program [19] and Statistix 10 (Analytical Software, Tallahassee, FL). The ANOVAs and regression analyses for N rate effects included treatments with and without P applied, but a separate yield response analysis combined across site-seasons was done for N response with no P applied. Similarly, the ANOVAs for P rate effects included treatments with and without N applied. There were no grain yield increases due to applied P. Differences and relationships were considered significant at the 5% level of probability [20].

In the second step of analyses, we focused on the assessment of the agronomic efficiency of N (AEN) because this measure production efficiency. AEN also answer a more direct question [21] "How much productivity improvement was gained by the use of this nutrient input". Therefore, AEN is more important for decision-making concerning fertilizer use. The PFPN is an aggregate efficiency index that includes contributions to crop yield derived from uptake of indigenous soil N, N fertilizer uptake efficiency, and the efficiency with which N acquired by the plant is converted to grain yield. AEN and NPFP (nitrogen partial factor productivity) were determined using the formulae following Dobermann [22]:

$$\text{AEN}\left(\text{kg} \cdot \text{kg}^{-1}\right) = \frac{\left(\text{YNf} - \text{YN0}\right)}{\text{Nr}} \quad (2)$$

$$\text{NPFP}\left(\text{kg} \cdot \text{kg}^{-1}\right) = \frac{\left(\text{YNf}\right)}{\text{Nr}} \quad (3)$$

where YNf is the grain yield of the fertilized plot (kg), YN0 is the grain yield of the unfertilized plot (kg) for each replicate, and Nr is the quantity of N fertilizer applied (kg).

Economically optimal nutrient rates (EORs) and Net returns to fertilizer use were determined using the OFRA/FOT (fertilizer optimization tool) developed by University of Nebraska. These were dependent on the grain yield, grain value (US\$0.23 kg^{-1}) and farm gate fertilizer (urea) value (US\$1.03 kg^{-1}) in 2015. Nonlinear regression analysis was also used to derive an equation to relate EONR to a different rate of fertilizer use cost to grain price ratios (CP). The EONR was determined at CP ratios of 1.2, 1.6, 2.3, and 3.6, with CP as the independent variable.

3. Result and Discussion

3.1. Soil Physicochemical Properties before Planting

The soil of the experimental site has medium bulk density, very low in salt content and slightly alkaline in reaction, adequate in available phosphorus with low total nitrogen and optimum organic carbon content. All exchangeable bases except sodium were high with high cation exchange capacity (CEC) and base saturation as the standard given by [12]. All micronutrients except zinc were low in these experimental sites as the standard given by [13] **Table 3**.

Table 3. Soil physicochemical properties and their standard value of Miesso site.

Location		Miesso	Rate	Source
Depth	cm	0 - 20		
Sand		550		
Clay	$g \cdot kg^{-1}$	180		
Silt		270		
T. Class		SL		
BD	g/cm^3	1.25		
pH		7.82	Slightly Alkaline	[13]
EC	dS/m	0.59	V. Low	[13]
AP	ppm	17.2	Adequate	[14]
TN	$g \cdot kg^{-1}$	1.5	Low	[15]
OC		29.2	Medium	[16]
Na		0.56	V. low	[12]
K		1.10	High	[12]
Ca	Cmol(+)/kg	19.63	High	[12]
Mg		8.38	High	[12]
CEC		34.00	High	[17]
BS	%	87.24	High	[18]
Cu		0.24	Low	[13]
Fe		1.59	Low	[13]
Mn	ppm	4.22	Low	[13]
Zn		4.56	High	[13]

3.2. Yield Parameters

The result of 2014 and 2015 cropping seasons and combined analysis (sites + seasons) of response of sorghum to nitrogen and phosphorus were presented in the following four Tables (Tables 4-7).

Table 4. Nitrogen application effect at rates of 0, 23, 46, 69 and 92 $kg \cdot ha^{-1}$ on sorghum grain and above ground biomass yield (AGB) for 0P levels in 6 trials conducted in Ethiopia.

(2014) (n = 3)	N-Rate ($kg \cdot ha^{-1}$)	0	23N	46N	69N	92N	F < P	CV (%)
GY	$Mg \cdot ha^{-1}$	1.79[c]	2.33[bc]	2.56[a]	2.43[ab]	2.20[bc]	*	8.57
AGB		7.69	7.42	7.99	7.47	7.55	ns	13.26
2015 (n = 3)								
GY	$Mg \cdot ha^{-1}$	2.03	2.23	2.26	2.34	2.69	ns	6.72
AGB		7.87	8.09	7.17	7.51	7.76	ns	14.71
Site + Season (n = 6)								
GY	$Mg \cdot ha^{-1}$	1.91[b]	2.28[ab]	2.41[ab]	2.38[ab]	2.45[a]	*	8.10
AGB		7.78	7.75	7.58	7.49	7.65	ns	13.99

Table 5. Nitrogen application effect at rates of 0, 23, 46, 69 and 92 $kg \cdot ha^{-1}$ on sorghum grain and above ground biomass yield (AGB) @ 20 P kg ha^{-1} level in 6 trials conducted in Ethiopia.

2014 (n = 3)	N-Rate ($kg \cdot ha^{-1}$)	0	23N	46N	69N	92N	F < P	CV (%)
GY	$Mg \cdot ha^{-1}$	2.38	2.39	2.39	2.47	2.54	ns	8.57
AGB		6.70	7.33	7.70	8.05	6.68	ns	13.26
2015 (n = 3)								
GY	$Mg \cdot ha^{-1}$	2.42	2.15	2.31	2.41	2.33	ns	6.72
AGB		7.11	7.42	8.14	7.32	7.27	ns	14.71
Site + Season (n = 6)								
GY	$Mg \cdot ha^{-1}$	2.40	2.27	2.35	2.44	2.44	ns	8.1
AGB		6.90	7.38	7.92	7.68	6.98	ns	13.99

Table 6. Phosphorus application effect at rates of 0, 10, 20 and 30 $kg \cdot ha^{-1}$ on sorghum grain and above ground biomass yield (AGB) @ 69 N kg ha^{-1} level in 3 trials conducted in Ethiopia.

2014 (n = 3)	$kg \cdot ha^{-1}$	0P	10P	20P	30P	F < P	CV (%)
GY	$Mg \cdot ha^{-1}$	2.43	2.18	2.47	2.38	ns	8.57
AGB		7.47	7.96	8.05	7.87	ns	13.26

Table 7. Phosphorus application effect at rates of 0, 10, 20 and 30 kg·ha^{-1} on sorghum grain and above ground biomass yield (AGB) @ 92 N kg ha^{-1} level in 3 trials conducted in Ethiopia.

2015 (n = 3)	kg·ha^{-1}	0P	10P	20P	30P	F < P	CV (%)
GY	Mg·ha^{-1}	2.69	2.71	2.33	2.25	ns	6.72
AGB		7.76	7.52	7.27	7.02	ns	14.71

3.2.1. Grain Yield (GY)

The mean table of GY showed that sorghum was significantly affected by the application of nitrogen fertilizer alone as compared to the zero control and to each other and hence a maximum yield 2.56 Mg GY obtained by the application of 46 kg N ha^{-1} and has 43% yield advantage over the control (0 kg ha^{-1}) at $p < 5\%$ level. This value also statistically the same as the yield obtained from the treatment received 69 kg N ha^{-1} (Table 4). This indicated that the application of nitrogen only at lower rate, improved the grain sorghum in 2014 cropping season.

However, in 2015 cropping season the sorghum GY consistently increased (2.03 - 2.69 Mg·ha^{-1}) by the application of nitrogen (0 - 92 kg·ha^{-1}) alone (Table 4). These increment of GY were not statistically different from the control at $P < 0.05$ level. But, the application of nitrogen alone had 10% to 32% yield advantage over the zero control. The combined analysis (sites + seasons) revealed that statistically significant yield differences were observed by the application of highest rate of nitrogen (92 kg·ha^{-1}) over the control at $P < 0.05$ level. GY of other nitrogen treated plot also greater than the zero control but statistically not different from the zero and to each other. The application of nitrogen had 19% - 28% yield advantage over the control. This was due to the soil of Miesso insufficient with total nitrogen (Table 3); thus, the application of nitrogen fertilizer improved the grain yield of sorghum at least by more than 25% when compared to the zero control. Nitrogen is the main component of most of the vital biomolecules, nucleotides, amino acids, proteins, and hormones related to the plants growth and development [23].

The same rates of nitrogen were also evaluated at 20 kg P ha^{-1} (Table 5). The mean table showed that statistical yield differences or advantages were not observed among the treatments of nitrogen rates in both seasons and combined (sites + seasons) at $p < 0.05$ probability.

The application of 69 or 92 kg·ha^{-1} to different rates of P (0 - 30 kg·ha^{-1}) at different seasons (2014 and 2015) showed that there were no statistical yield differences observed among P rates in the study sites at $P < 0.05$ level. The application of 92 and 69 kg N ha^{-1} gave the higher GY at 0P, 10P and 0P, 20P than the other P treated plots respectively (Table 6 and Table 7). This is due to the soil of the study sites adequate in AP content (Table 3).

3.2.2. Above Ground Biomass (AGB)

The mean table (Table 4) revealed that AGB were not significantly influenced by the treatment factors at $p < 5\%$ by the application of different rates nitrogen alone. AGB of sorghum in 2014 was 7.99 $Mg \cdot ha^{-1}$ by the application of 46 kg N ha^{-1} and 8.09 $Mg \cdot ha^{-1}$ by the application of small dose (23 kg N ha^{-1}) in 2015 cropping season. Other N rates in both seasons (2014 and 2015) were lower than the zero control 7.69 and 7.87 $Mg \cdot ha^{-1}$ respectively. The combined analysis (sites + seasons) revealed than the application of nitrogen at different rates weren't improved AGB yield. The highest AGB yield was observed at the zero control 7.87 $Mg \cdot ha^{-1}$.

The application of different rates of nitrogen at 20 kg P ha^{-1} improved AGB by about 20% by the application of 69 kg N ha^{-1} in 2014 cropping season, in 2015 and combined (sites + seasons) analysis showed that (**Table 5**) the application of 46 kg N at 20 kg P ha^{-1} gave the heights (8.14 and 7.92 $Mg \cdot ha^{-1}$) AGB yield respectively, though statistically not different with other treatments.

In 2014, the application of 69 kg N ha^{-1} to different rates of P as shown in **Table 6**, not significantly affected AGB at $P < 0.05$ level. The improvement of AGB was not more than 8% by the application of different rates of P. However, in 2015, the application of 92 kg N to different rates of P was not different from the yield obtained from the zero control. These may be due to the rain fall pattern during the seasons (**Table 1**).

3.3. Nutrient Response Curve

The effect of nitrogen, and phosphorus fertilizer application rates on the observed grain yield of sorghum during the 2014 season and combined (Sites + Seasons) are presented in **Table 4** and **Table 5**. The results indicated that the application of N fertilizer alone significantly ($p \le 0.05$) increased observed sorghum grain yields in the 2014 season and combined (Sites + Seasons). The application of N with P, however, did not have any significant effect on observed grain yield at ($p \le 0.05$) level. The average observed grain yield for N0 in 2014 season and combined (Sites + seasons) were 1.79, and 1.91 $Mg \cdot ha^{-1}$, respectively (**Table 4**). The response curves were steep increase in sorghum grain yield to N application alone up to 33 $kg \cdot ha^{-1}$ in 2014 season and 61 N ha^{-1} combined (sites + seasons), followed by a succeeding yield decline (**Table 4**). The grain yield of sorghum increased with increasing N rates till plateau were reached at 33 and 61 $kg \cdot ha^{-1}$ N application after which the grain yield stabilized (**Figure 2**) in estimated yields. The increases in observed grain yield with N application ranged from 0.41 to 0.77 and 0.37 - 0.54 $Mg \cdot ha^{-1}$, corresponding to relative increment of 23% to 43% and 5.8% to 16% over the control in the 2014 season and combined (sites + seasons) respectively. The resulting yield response functions with respect to N application were as follows:

$$\text{Yield} = 2.39 - 0.60 \times 0.89^{N} \left(\text{2014 season}\right) \tag{4}$$

$$\text{Yield} = 2.43 - 0.52 \times 0.95^{N} \left(\text{all sites} + \text{seasons}\right) \tag{5}$$

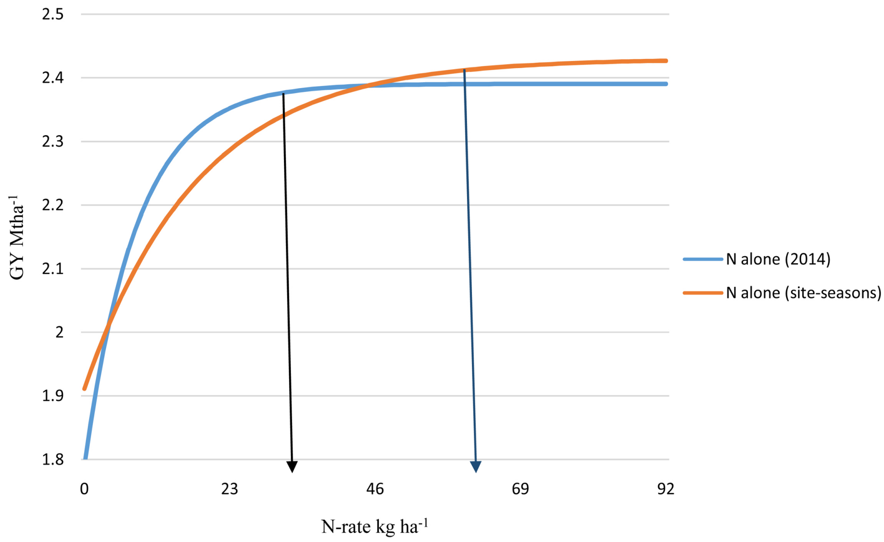

Figure 2. The nutrient response curve of Sorghum as influenced by N rates alone in 2014 and combined site-seasons at Miesso.

Results of the predicted asymptotic quadratic-plus-plateau yield functions in relation to nutrient rate effects are presented in **Table 8**. The predicted maximum sorghum grain yields were 2.39 and 2.43 Mg·ha^{-1} with an average grain yield increase of 0.6 and 0.52 Mg·ha^{-1} resulting from N application in 2014 cropping season and combined (sites + seasons) respectively. The expected yield increases for N following elemental nutrient rate change from 0 to 23, 23 to 46, 46 to 69, and 69 to 92 kg N ha^{-1} were 0.56, 0.04, 0.002, and 0.0, in 2014 season 0.38, 0.1, 0.03 and 0.01 combined (sites + seasons) Mg·ha^{-1}. The results revealed that yield increased by the application of nitrogen rate change commonly decreases with increasing rates. The nutrient rate change from 46 to 69 kg N ha^{-1} resulted in an insignificant yield increase of 0.002 Mg·ha^{-1} whereas a further increment in N application from 69 to 92 kg N ha^{-1} did not lead to any yield escalation. In agreement to this study similar occurrence in sub-Saharan Africa were reported by [24] [25] and [26] in maize trials in Kenya, Tanzania and Gahanna respectively.

3.4. Nutrient Use Efficiency (NUE)

Agronomic efficiency of nitrogen (AEN) is the amount of increased yield obtained in kg from addition of a kg of nutrient [27]. **Figure 3** revealed that the highest nitrogen use efficiency was recorded for plots treated with 23 and the lowest treated with 92 kg N ha^{-1} respectively in both 2014 cropping season and combined (site + seasons), the application of lowest dose of N 23 kg (23.48 and 16.09 kg·kg^{-1}) and the highest dose 92 kg (4.46 - 5.87 kg of sorghum kg^{-1}) **Figure 3**. Therefore, a unit kg of N application caused increase in sorghum grain yield by 23.48 and 16.09 kg from plots treated with 23 kg N ha^{-1} and 4.46 and 5.87 kg from plot treated 92 kg N ha^{-1}. In line with this study some scholars reported

Table 8. Asymptotic nonlinear regression coefficients (a, b, and c) for grain yield in N levels and economically optimal N rates (EONR) for sorghum with fertilizer N use cost/grain price ratios (CP).

	a	b	c		1.2CP	1.6CP	2.3CP	3.6CP
N alone	2.39	0.60	0.89	2014	34	32	29	25
N alone	2.43	0.52	0.95	(Site-Seasons)	60	52	45	37
				2014_PCR	13.13	10.41	7.81	5.40
				(Site-Seasons)_PCR	5.79	4.86	3.65	2.43

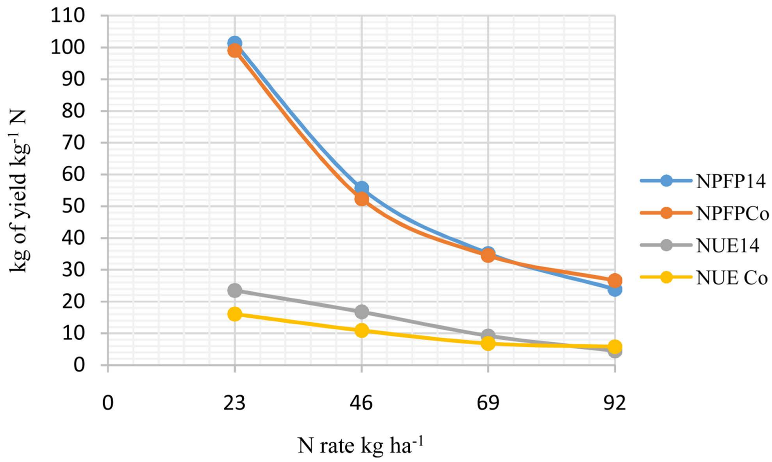

Figure 3. Nutrient use efficiency of sorghum in 2014 cropping season.

that mean agronomic efficiency of N decreased with increasing N rate for maize in Uganda [28], wheat in Ethiopia [29].

The PFPN is an aggregate efficiency index that includes contributions to crop yield derived from uptake of indigenous soil N, N fertilizer uptake efficiency, and the efficiency with which N acquired by the plant is converted to grain yield [22]. **Figure 3** showed that the highest PFP of N 101/99 kg grain kg^{-1} N at the smallest dose 23 kg N and the smallest 23.9/26.6 kg grain kg^{-1} N at the highest dose 92 kg N ha^{-1} in 2014 season/combined (all sites and both seasons). These results are higher than the world average 70 kg grain kg^{-1} N as described by [22]. The higher the PFPN may be due to the adequate soil organic carbon pool of the study site (**Table 2**). Bell [30] and Kolberg [31] described higher indigenous N source from decomposition of the organic N pools, which can reduce N fertilizer requirements to maintain yields and thereby increase PFPN.

3.5. Net Returns to Fertilizer Use

From the results obtained, the 2014 season and combined (all sites + both seasons) farmers with low financial ability can take benefit of the high earnings (320.09 and 481.01 US $ ha^{-1}) gathered from using low nitrogen application rates 25 and 37 kg·ha^{-1} respectively at CP 3.75, (**Figure 4**) revealed that, the gentler the slope of the response curve, the higher the net returns to nutrient use.

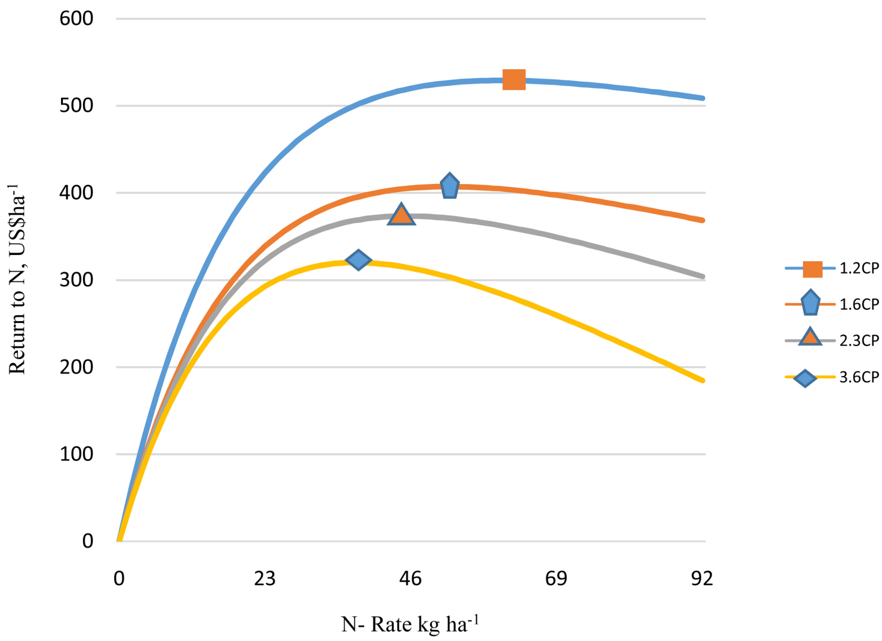

Figure 4. Net returns of sorghum to fertilizer N application to at varying N rates and fertilizer cost to grain price ratios (CP) Combined (Sites + seasons). The EONR with each CP is indicated by a specific symbol at the peak of each curve.

Hence, as the purchasing fertilizer expense increases, the slope decreases until it reaches a plateau and finally drops leading to profit deterioration. In general, the N application rate exceeded the EONR the net returns to N fertilizer use diminished. In line with this study, Benedicta [26] reported that in semi-deciduous forest zone of Ghana who recognized that net return and value cost ratio decline as nutrient application rates get further away from the optimum. Different scholars in sub-Saharan Africa have reported higher net returns to fertilizer use. Gittinger [32] reported that a benefit cost (BC) ratio greater than 1 is profitable because the benefits exceed the cost of investment. Net return is dependent on the cost of the nutrient applied and therefore, may vary from place to place. High net returns accounting for high BC ratios were also reported by [33] Ethiopia.

3.6. Economically Optimal Nutrient Rates for N Fertilizer Use Cost to Grain Price Ratios

The EONR in this study combined (site + seasons) were 37, 45, 52 and 60 kg·ha^{-1} and for the PCR were 2.43, 3.65, 4.86 and 5.79 for CP = 3.6, 2.3, 1.6 and 1.2 respectively. The semi-arid area is generally characterized by receiving low average annual rainfall less than 500 mm this caused the crop may have resulted in lower nutrient dissolution and this hindered N uptake. From the estimated results, net returns of US$ 528.89, 407.32, 373.44 and 320.09 for CP 1.2, 1.6, 2.3 and 3.6 could be obtained at the EONR of 60, 52, 45 and 37 kg·ha^{-1} respectively. Financially constrained smallholder farmers can be benefited at lowest EONR (37 kg N ha^{-1}) (**Table 7** and **Figure 3**) this was supported by other study with curvilinear to plateau responses [34].

Sorghum grain yield were not significantly affected by application of phosphorus for all N rate at 20P and for all P rate at 69 and 92 kg N ha^{-1} thus effect of P did not fit a response function (**Tables 4-6**). Liben [35] investigated that application of fertilizer P in sorghum production is not economically feasible at the Melkassa and Miesso sites.

4. Conclusion

Application of different rates of nitrogen and phosphorus treatments was tested at Miesso District West Hararghe zone of Oromia Region, lower doses of nitrogen economically feasible for the sorghum production. AEN and NPFP of also showed the smaller doses gave more intense yield per kg of nitrogen. This study also revealed application of phosphorus was not economically feasible for sorghum production in this study area. Therefore, at Miesso application of more than 60 kg N ha^{-1} (EOR) could not be economically important; rather smaller doses improve the PCR and net return. Validation should be farther conducted for EONR on farmers' fields for refining the results obtained from this study.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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