Refining fertilizer recommendations for bread wheat production in South Wollo of Amhara Region

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Abstract

Bread wheat (Triticum aestivum L.) is among the most important crops produced in the highlands of Ethiopia. However, declining soil fertility due to poor management practices have resulted in low crop yield. Among the poor soil fertility management practices, a very general crop-specific guideline or more often, a blanket recommendation for all crops (100 kg DAP (18-46-0) and 100 kg Urea (46-0-0) was practiced in most parts of the country. Accordingly, this study was conducted to examine the optimum rate of nitrogen, phosphorus and sulfur fertilizers for bread wheat under balanced fertilizers in Jamma district of South Wollo Zone, Amhara region in 2015 and 2016. The study was comprised of six levels of N, P and S studied independently under specified balanced fertilizers. The combined analysis of variance over years indicated that there was significant response of wheat grain and straw yields to the application of nitrogen fertilizer. Application of 115 kg ha^{-1} and 138 kg ha^{-1} nitrogen gave similar yield which has grain yield advantage of 156%, 53%, 50.6% and 15.8% over the control, 46 kg N ha^{-1}, 69 kg N ha^{-1} and 92 kg N ha^{-1} respectively. The economic optimum rate of nitrogen for wheat grain and straw yield is the application of 115 kg/ha while it gives similar and higher agronomic optimum yield compared to the application of 138 kg/ha nitrogen in Jamma district. There is also a significant yield response for phosphorus fertilizer rate for wheat yield and the economically profitable yield response was recorded from the application of 20 kg/ha phosphorus. Whereas there was no significant yield response to sulfur fertilizer rates in Jamma district.

Keywords: Economically profitable, optimum fertilizer, wheat, yield response.

Introduction

Wheat (*Triticum aestivum* L.) is one of the major global cereal crops, ranking second after paddy rice both in area and production, and provides more nourishment than any other food crop (Curtis *et al.*, 2002). Bread wheat is one of the most important cereal crops in Ethiopia and used both as a source of food and income. It is the fourth most widely grown crop after Teff, maize, and sorghum (Motsara and Roy, 2008). Ethiopia produces 3.8 million tons of wheat per year, making it the second largest wheat producer country in Sub-Saharan Africa (SSA) next to South Africa. However, the amount of wheat produced is insufficient to meet the domestic needs, which is compelling the country to import about 25 to 35% of the annual wheat grain required for consumption (CSA, 2014).

The national annual mean wheat yield of Ethiopia was estimated at about 2.2 t/ha (CSA, 2014). Global Agricultural Information Network Number ET1401. Addis Ababa Ethiopia However, by international standards such yields are considered to be low. The Government of Ethiopia (GOE) estimates that over 4.5 million households are involved annually in wheat production, but that still does not satisfy the country's annual domestic demand. Hence, a large quantity of wheat is imported every year to meet the rising domestic consumption demand (CSA, 2014). The declining of soil fertility is a fundamental impediment to agricultural development and the major reason for the slow growth rate in food production and food insecurity in Ethiopia (Gebrekidan, 2005).

Wheat production in the country is adversely affected by low soil fertility and suboptimal use of mineral fertilizers in addition to diseases, weeds, erratic rainfall distribution in lower altitude zones, and water-logging in the Vertisols areas (Gorfu *et al.*, 2003). The root causes of the current low soil fertility problem of the country are soils of inherent low fertility; continual nutrient mining due to continues cropping without replacement of nutrients taken together with WKH KDUYHVW DQG WRSVRLO UHPRYDO WKURXJK ZDWHU HURVLRQ $VQDNHZ :ROGHDE (W fertilizer sub-

Current fertilizer recommendation in Ethiopia is also based on very general crop-specific guidelines or more often, a single recommendation for all crops (100 kg DAP (18-46-0) and 100 kg Urea (46-0-0). This blanket recommendation often fails to take into consideration differences in resource endowment (soil type, labor capacity, climate risk) or make allowances for dramatic changes in input/output price ratio, thereby discouraging farmers from fertilizer application. Moreover, the nutrients in the blanket recommendation are not well balanced agronomically and its continued use will gradually exhaust soil nutrient reserves. Nutrient mining due to suboptimal fertilizer use in one hand and unbalanced fertilizer use on other have favored the emergence of multi-nutrient deficiency in Ethiopian soils (Astatke *et al.*, 2004) that in part may contribute to fertilizer factor productivity decline experienced over recent past.

Therefore, neither yields nor profits can be sustained using imbalanced application of fertilizers, as the practice results in accelerating deficiencies of other soil nutrients. Since the absence of one or more nutrients besides N and P can depress yield significantly. This could explain, in part, the modest crop yield improvements observed over the last few decades in contrast to significant increases in fertilizer use and investment made in the country. Today, in addition to Nitrogen and Phosphorus fertilizers, S, B and Zn deficiencies are widespread in Ethiopian soils and some soils are also deficient in K, Cu and Mn (Astatke *et al.*, 2004; Asgelil *et al.*, 2007). To overcome the constraint of low nutrient recovery and optimize fertilizer use, there is a need to replace such general and over-simplistic fertilizer recommendations with those that are rationally differentiated according to agro-ecological zones (soils and climate), crop types, nutrient uptake requirements and socio-economic circumstances of farmers. Better matching fertilizer application recommendations to local climate, soil, and management practices help ensure that production can be intensified in a cost-effective and sustainable way and, thereby, enhance regional food security. In view of this, the present study was carried out to determine optimum Nitrogen, Phosphorus and Sulfur fertilizers response curve under balanced fertilization and to establish economic mixes of blended fertilizers for wheat.

Materials and Methods

Description of study site

The study was carried out in 2015 and 2016 main cropping seasons in Jamma District of South Wollo Zone of the Amhara Region in Ethiopia. The District is situated within the geographical boundaries of 10^{o} ¶ - 10^{o} ¶ODWLWXGHVDQG ^{o} ¶ - 39^{o} ¶ORQJLWXGHV and altitudinal ranges of 1428 - 2752 meters above sea level. Based on the last ten years (2008-2017) meteorological data obtained from Ethiopian Meteorological Agency, Kombolcha station, the district receives a mean annual rainfall of 873.0 mm with mean minimum and maximum temperatures of 10.3 and 21.6 ^{o}C, respectively. The range of the physico-chemical properties of surface soil (0-30 cm) of the study districted is presented in Table 1. The dominant soil type of the study District is Vertisols, and the area is characterized by poor drainage and water-logging, difficulty to work in but has a high potential for the production of wheat and Teff.

Treatments and Experimental Design

The study was conducted using six levels of Nitrogen, Phosphorus and Sulfur fertilizers each independently with balanced fertilizers rate of 69/80/30/2/1 P_2O_5/K_2O/S/Zn/B kg ha^{-1} for Nitrogen trial, 92/90/30/2/1 N/K_2O/S/Zn/B kg ha^{-1} for Phosphorus trial and 92/69/90/2/1 N/P_2O_5/K_2O/Zn/B kg ha^{-1} for Sulfur-trial for all treatments (Table 2). The treatments were laid out in a randomized complete block design (RCBD) with three replications on three UHSUHVHQWDWLYHIDUPHUV¶ILHOGVLQHDFKHDU DQG 7KHH[SHULPHQWDO SORW KDG D JU plot size of 4 m x 3.2 m; while, the harvestable plot area was 4 m x 1.6 m.

Table 3. Range of physico-chemical properties of surface soil (0-30 cm) of Jamma District

Soil Properties	Values
pH (H_2O)	6.10-6.80
Organic matter (OM) (%)	1.36-1.92
Total Nitrogen (TN) (%)	0.09-0.31
Available P (mg kg^{-1} soil)	7.05-21.05
Exchangeable Ca (cmol$_C$ kg^{-1})	30.60-46.30
Exchangeable Mg (cmol$_C$ kg^{-1})	9.90-12.90
Exchangeable K (cmol$_C$ kg^{-1})	0.60-0.70
Cation exchange capacity (CEC) (cmol$_C$ kg^{-1})	52.00-61.70
Percent base saturation (PBS) %-	82.50-97.61
Bulk density (gm cm^{-3})	1.30-1.50
Sand %	16.3-17.5
Silt %	20.0-21.3
Clay %	62.5
Textural class	Clay

Table 4. Rates of Nitrogen, Phosphorus and Sulfur fertilizers.

Treatments	N-rates	P-rates	S-rates
1	0 N	0 P	0 S
2	46	10 P	10 S
3	69	20 P	20 S
4	92	30 P	30 S
5	115	40 P	40 S
6	138	50 P	50 S

Experimental Materials and Procedures

Bread wheat variety *Dinknesh* was used as a test crop. The test crop was planted in a row with a spacing of 20 cm between rows and seeding rate of 150 kg ha^{-1} on pre-prepared broad bed furrow which had a 0.8m bed and 0.4m furrow. The beds were used for planting of wheat and the furrows were used for draining excess water from the experimental area. Phosphorus, Potassium, and Sulfur fertilizers were applied as triple super phosphate (TSP), muriate of potash (KCl) and calcium sulfate ($CaSO_4$) straight fertilizers, respectively, in a row all at planting. Nitrogen fertilizer was applied as urea in split, half at planting and the remaining half side dressed at 45 days after planting. The micronutrients Zn as $ZnSO_4$ and B as Borax weighed in plot-level were each dissolved in tap water in a plastic container and poured into 16 liters volume spraying knapsacks and filled up with tap water up to the mark. Thereafter, water dissolved Zn and B micronutrients were applied as foliar application 50 and 60 days after planting, respectively.

Data Collection

Fresh biomass yield was measured by weighing the total above ground biomass of the entire harvestable area. The dry biomass weight was measured by taking a straw sample with the seed spikes, drying in an oven at 105 ^oC for 24 hours and adjusting the fresh biomass weight in to dry weight basis. While grain yield was measured by weighing the seed harvested from the 6.4 m^2 harvestable area and adjusted with a moisture correction factor. The straw yield was calculated by subtracting the grain yield from the dry biomass. Harvest index was calculated by dividing the grain yield by total biological yield.

Data analysis

The collected data were subjected to analysis of variance (GLM procedure) using SAS software version 9.00 (SAS, 2004). The mixed model procedure was used for the combined analysis over the testing sites in which the only N was used as a fixed variable while site and replication were used as random variables. Since experimental sites were not fixed in the two years, the year was neither considered as a fixed or random variable. A significant difference between treatment PHDQV ZDV GHOLQHDWHG E\XQFDQ¶V 0XOWLSOH 5DQJH WHVW at $P<0.05$. Simple nonlinear regression analysis was run using SAS to determine the goodness of fit of yield response curves. The farm gate prices of 12.00, 31.50, 62.50 Ethiopian Birr (ETB) kg^{-1} for Wheat grain, Nitrogen and Phosphorus fertilizer, respectively, were used for partial budget analysis following the CIMMYT procedure (CIMMYT, 1988). The mean grain yields used in the partial budget analysis were adjusted to 90% of the actual yield.

Results and discussion

I. Response of wheat to N fertilizer

The study showed that there were significant grain and straw yield responses to nitrogen fertilizer from three testing sites and there was also a similar trend of treatments with three sites in Jamma District in 2015 (Table 3). Thus, the combined analysis of grain yield by applying 115 kg ha^{-1} was found biologically maximum compared to the other treatments. Similarly, the combined analysis of wheat grain and straw yields in 2016 showed that application of 115 kg ha^{-1} and 138 kg ha^{-1} nitrogen gave higher yield compared to other treatments (Table 4). From Table 5, the interaction of treatments and location over the two years on grain and straw yield was insignificant. Thus, the result revealed that nitrogen fertilizer applied in the three sites could be discussed as a combined analysis over 2015 and 2016. Accordingly, application of 115 kg ha^{-1} and 138 kg ha^{-1} nitrogen gave similar grain yield which have 156%, 53%, 50.6% and 15.8% grain yield advantage over the control, 46 kg N ha^{-1}, 69 kg N ha^{-1} and 92 kg N ha^{-1} respectively. Similarly, application of 115 kg ha^{-1} and 138 kg ha^{-1} nitrogen gave 151%, 63%, 26.3% and 16% straw yield advantage over the control, 46 kg ha^{-1}, 69 kg ha^{-1} and 92 kg ha^{-1} nitrogen respectively.

The response of wheat to nitrogen fertilizer in this study was accredited to the low total nitrogen (0.09-0.31%) in the surface soil of the study district (as shown in Table 1), according to the ratings by Tekalign Tadese, 1991. This low amount of nitrogen led to the inadequacy of crop-available nitrogen which is likely to be stored in organic matter and clay minerals (Birkeland, 1984). Many nutrient response studies in Ethiopia also revealed that wheat responds positively to nitrogen fertilizer especially in Vertisols (Harfe, 2017; Solomon and Anjulo, 2017). The findings of this study are also similar to the finding by Allam (2003) who reported that increasing nitrogen levels increased grain yield (Figure 1).

Table 5. Response of wheat to nitrogen fertilizer in 2015 from three locations of Jamma District and combined analysis of the three sites.

	Grain yield (kg ha^{-1})				
Treatment	Yedo	Gebreguracha	Faji	combined	Straw yield (kg/ha)
0N+BF	1411.7b	1080.8d	1285c	1262.8c	1927.8d
46 kg N ha^{-1} + BF	3228.8a	2718.8c	1789.8bc	2579.1b	4486.9c
69 kg N ha^{-1} + BF	3847.5a	4091.3ab	1865.2bc	3268ab	5847b
92 kg N ha^{-1} + BF	3237.4a	3885.3b	2241.9ab	3121.5ab	6062.5b
115 kg N ha^{-1} + BF	3958a	4509.4a	2697a	3721.5a	7250.5a
138 kg N ha^{-1} + BF	4031a	4017.3ab	2564a	3537.4a	6653.6ab
CV (%)	14.09	9.18	17.5	28.5	22.5
Trt*Loc				NS	NS
Loc				NS	NS

Means followed by the same letter are no significantly different at $p > 0.05$. * and **- significant at 0.05 and 0.01 probability levels, respectively. ns = non-significant at $p > 0.05$.

Table 6. Effect of different rates of N fertilizer on wheat yield over sites and combined in 2016

	Grain Yield(kg/ha)				Straw
Treatments	Meja	GebreGuracha	Yedo	Combined	yield (kg/ha)
0 N+BF	902e	1228e	862.8d	997.6e	2265.4d
46 kg N ha^{-1} + BF	1342.2de	1368.6de	1339.2c	1350d	2261.1d
69 kg N ha^{-1} + BF	1526.4cd	1663.7cd	1875.9b	1688.7c	2871.5c
92 kg N ha^{-1} + BF	1977.2bc	1956bc	2289.5ab	2074.3b	3411.8b
115 kg Nha^{-1} + BF	2185.4b	2170b	2531.8a	2295.8b	3757.8b
138 kg Nha^{-1} + BF	2907.4a	2501.7a	2680a	2696.4a	4386.9a
CV (%)	18.2	9.5	12.9	14.6	16.2
Trt*Loc				NS	NS
Loc				NS	NS

*Means followed by the same letter are no significantly different at $p > 0.05$. * and **- significant at 0.05 and 0.01 probability levels, respectively. NS = non-significant at $p > 0.05$.*

Table 7. Effect of different rates of N fertilizer on wheat yield combined over 2015&2016 at Jamma.

Treatments	Grain Yield(kg/ha)	Straw yield (kg/ha)
0N+BF	1174.7d	2193.6d
46 kg N ha^{-1} + BF	1964.6c	3373.9c
69 kg N ha^{-1} + BF	2478.3b	4359.1b
92 kg N ha^{-1} + BF	2597.9b	4737.2b
115 kg N ha^{-1} + BF	3008.6a	5504.1a
138 kg N ha^{-1} + BF	3116.9a	5520.3a
CV (%)	19.54	20.18
Trt*Loc	NS	NS
Loc	NS	NS

*Means followed by the same letter are no significantly different at p > 0.05. * and **- significant at 0.05 and 0.01 probability levels, respectively. NS = non-significant at p > 0.05.*

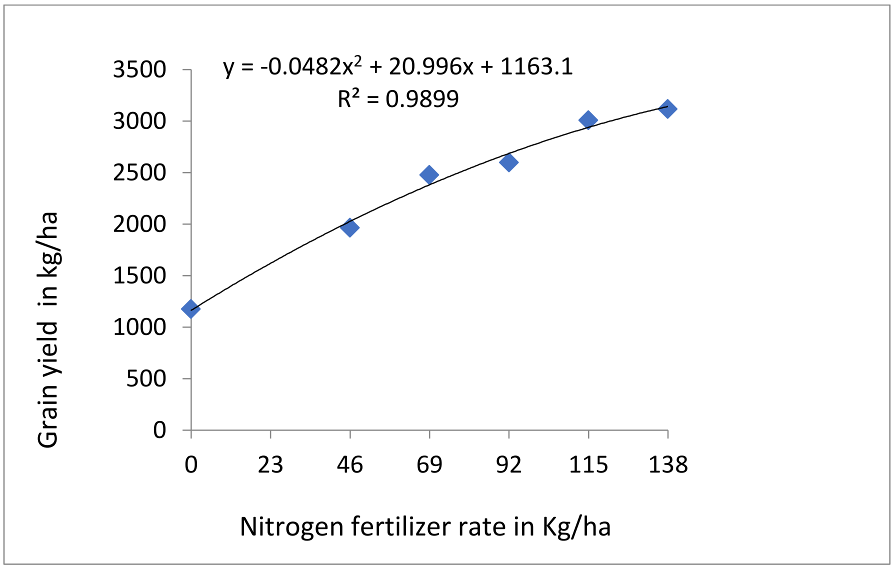

Figure 8. The effect of different nitrogen fertilizer rates on the grain yield of wheat on Jamma district.

Partial budget analysis of Nitrogen fertilizer

The partial budget analysis (Table 6) shows that all nitrogen rates except 92 and 138 kg/ha gave an acceptable marginal rate of return (i.e., MRR greater than 100%). Accordingly, the partial budget analysis stripped that the highest MRR is 610 from the application of 69 Kg nitrogen/ha with a net economic return of 27552.3 Ethiopian Birr per hectare. But according to CIMMYT (1988), when there are two and more treatments with MRR greater than 100%, the treatment with greater net benefit should be selected for recommendation. Therefore, application of 115 kg/ha nitrogen which gave 32574.5 Ethiopian Birr per hectare while possessing MRR of greater than 100% is economically viable in Jamma district.

Table 8. Partial budget analysis of the variable costs on mean grain and straw yields of wheat in Jamma district for nitrogen fertilizer

N	AGY	GYP	ASY	SYP	TR	FC	TFC	LC	TVC	NB	MRR
0	1040.5	12	2193.6	1	14679.5	31.5	0	0	0	14679.5	
46	1768.2	12	3373.9	1	24591.6	31.5	1449	1200	2649	21942.6	270
69	2230.6	12	4359.1	1	31125.8	31.5	2173.5	1400	3573.5	27552.3	610
92	2338.1	12	4737.2	1	32794.5	31.5	2898	1600	4498	28296.5	80
115	2707.7	12	5504.1	1	37996.9	31.5	3622.5	1800	5422.5	32574.5	460
138	2805.2	12	5520.3	1	39182.8	31.5	4347	2000	6347	32835.8	30

All costs are expressed in Ethiopian birr (ETB). N = Nitrogen fertilizer rates AGY=Adjusted grain yield (kg ha^{-1}); GYC=Grain yield price kg-1 (ETB), ASY=Adjusted straw yield (kg ha^{-1}), SYP=Straw yield pricekg-1 (ETB), TR=Total revenue (ETB), FC=Fertilizer cost kg-1 (ETB), TFC= total fertilizer cost (ETB), LC=Labor cost (ETB), TVC=Total variable cost, NB=Net benefit (ETB); MRR=Marginal rate of return(%).

II. Response of wheat to Phosphorus fertilizer

The analysis of variance showed that there was no significant difference in wheat grain yield among the phosphorus rates including the control (Table 7) at Jamma. The reason for the no wheat grain yield response to phosphorus fertilizer may be attributed to the higher available phosphorus content of the soil of the experimental site and the pH of the soil was neutral and no P fixation. However, the difference in straw yield was significant among the P rates and the highest straw yield was obtained from the application of 50 kg P ha^{-1} which was at par with the straw yield obtained from 20 ± 40 kg P ha^{-1}.

Table 9. Effect of Phosphorus rates on bread wheat yield combined over years (2015 and 2016)

Treatments	Grain Yield (kg/ha)	Biomass wt. (kg/ha)
0 P +BF	2242	5538.2c
10 P + BF	2181	5934.6bc
20 P + BF	2294.1	6333.9ab
30 P + BF	2346.6	6591.4ab
40 P + BF	2427.3	6481.5ab
50 P + BF	2369.9	6649.3a
CV (%)	11.97	13.76
LSD (0.05)	NS	NS

*Means followed by the same letter are no significantly different at p > 0.05. * and **- significant at 0.05 and 0.01 probability levels, respectively. ns = non-significant at p > 0.05.*

Partial budget analysis of Nitrogen fertilizer

The partial budget analysis (Table 10) showed that the highest MRR (*i.e*., 200%) was obtained from the application of 20 kg P ha^{-1} which brought about a net benefit of 27,285.4 Ethiopian Birr (ETB). This study is similar to the finding of Abreha *et al.* (2008) which indicated that application rates of 10 and 20 kg P/ha is feasible in Enderta, Ethiopia. Similarly, Fisseha Hadgu (2008) reported that 20 Kg P ha was economically feasible and recommended to be applied as maintenance.

Table 11. Partial budget analysis of the variable costs on mean grain and straw yields of wheat in Jamma district for phosphorus

P	AGY	GYP	ASY	SYP	TR	FC	TFC	LC	TVC	NB	MRR (%)
0	2017.8	12	2193.6	1	26407.2	62.5	0	0	0	26407.2	
10	1962.9	12	3373.9	1	26928.7	62.5	625	500	1125	25803.7	-50
20	2064.7	12	4359.1	1	29135.4	62.5	1250	600	1850	27285.4	200
30	2078.3	12	4737.2	1	29676.6	62.5	1875	700	2575	27101.6	D
40	2190.5	12	5504.1	1	31790.2	62.5	2500	800	3300	28490.2	D
50	2133.0	12	5520.3	1	31116.3	62.5	3125	900	4025	27091.3	D

All costs are expressed in Ethiopian birr (ETB). N = Nitrogen fertilizer rates AGY=Adjusted grain yield (kg ha^{-1}); GYP=Grain yield price kg^{-1} (ETB), ASY=Adjusted straw yield (kg ha^{-1}), SYP=Straw yield price kg^{-1} (ETB), TR=Total revenue (ETB), FC=Fertilizer cost kg^{-1} (ETB), TFC= total fertilizer cost (ETB), LC=Labor cost (ETB), TVC=Total veriable cost, NB=Net benefit (ETB); MRR=Marginal rate of return(%).

III. Response of wheat to Sulfur fertilizer

Combined ovJEBh

Table 12. Effect of Sulfur fertilizer rates on wheat grain yield at three testing sites in 2015 at Jamma District

	Grain yield (kg ha^{-1})		
Treatment	Meja	Gebreguracha	Yedo
0 S + BF	2946.9ab	2591.0	2547.3

Conclusions and Recommendations

Application of different rates of nitrogen fertilizer significantly affected wheat grain and s traw yields in Jamma district. The combined analysis over years indicated that there was significant difference in wheat grain and straw yields to nitrogen fertilizer rates. Thus, application of 115 kg N ha^{-1} and 138 kg N ha^{-1} (with equal yield) gave 156%, 53%, 50.6% and 16% grain yield advantage over the control, 46 kg N ha^{-1}, 69 kg N ha^{-1} and 92 kg N ha^{-1} respectively. Similarly, 115 kg N ha^{-1} and 138 kg N ha^{-1} gave 151%, 63%, 26% and 16% straw yield advantage over the control, 46 kg N ha^{-1}, 69 kg N ha^{-1} and 92 kg N ha^{-1} respectively. Therefore, 115 kg N ha^{-1} and 138 kg N ha^{-1} were recommended for wheat for Jamma district and similar agro-ecologies for they gave similar agronomic and economic yields. Similarly, 20 kg P ha^{-1} was economically feasible and recommended for Jamma district and similar agro-ecologies. There was no significant wheat yield difference to sulfur fertilizer rates. Hence, 115 kg N ha^{-1} nitrogen and 20 kg P ha^{-1} are economically feasible and recommended for Jamma district and similar agro-ecologies.

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