Soil Test Based Phosphorus Fertilizer Recommendation Equation for Bread Wheat (*Triticum aestivum* L) for North Gonder highlands

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Abstract

Soil test based fertilizer recommendation plays a vital role in ensuring balanced nutrition to crops and fertilizer schedules on the magnitude of crop response to applied nutrients at different soil fertility level. An experiment was conducted in north Gondar Zone, Ethiopia on soil test based phosphorus response to see the response of bread wheat. In the first phase of the experiment, determination of the optimum rate of P_2O_5 kg ha^{-1} was done keeping nitrogen fertilizer constant at 92 kg ha^{-1}. The experiment contains five treatments arranged in Randomized Complete Block Design with three replications. Five rates of phosphorous fertilizer (0, 46, 92, 138 and 184 P_2O_5 kg ha^{-1}) with the agronomic recommendation of Nitrogen fertilizer (92 N kg ha^{-1}) were used. In the second phase of the experiment, verification of soil test based P fertilizer recommendation equation model was tested on 10 m by 10 m plots. One plot for agronomic fertilizer recommendation and the other plot for the calibrated fertilizer recommendation. The results of the experiment showed that the equation was proven and verified that it can estimate the phosphorus fertilizer requirement of wheat in the highlands of North Gondar.

Key words: Nitrogen, Phosphorous, soil test, bread wheat, verification

Introduction

Ethiopia is the second largest wheat producer in sub-Saharan Africa, after South Africa. Wheat is mainly grown in the highlands, planted in the summer before the main rainy season, and harvested in October-November. Wheat is one of the major cereal crops in the Ethiopian highlands, which range between 6 and 16°N, 35 and 42°E, and from an altitude of 1500 to 2800 m.a.s.l. Soil types used for wheat production vary from well-drained fertile soils to waterlogged heavy Vertisols.

According to an estimate, the global grain demand would double by the year 2050 (Tilman et al., 2002). Cereal producers are under pressure to increase the yields and maintain their profitability despite several environmental restrictions and escalating fertilizer prices (Semenov *et al*., 2007). Due to inefficient agricultural production system, the yield of most agricultural crops like wheat is far below their demonstrated achievable potential. Numerous factors are responsible for low yields; amongst them improper use of fertilizers is the major one (Aslam *et al*., 2011a).

Proper nutrient management increases soil productivity and helps in sustainable crop production (Dilshad *et al*., 2010; Sarwar *et al*., 2012). Application fertilizer nutrients by the farmer without information on soil fertility status and nutrient requirement by crop affect soil and crop adversely Once existing nutrient levels are established, producers can use the data to best management what nutrients are applied, decide the application rate, and make decisions concerning the profitability of their operations while managing for impacts such as erosion, nutrient runoff, and water quality (Mallarino *et al*., 2000). However, in sub Saharan countries including Ethiopia, over the years blanket fertilizer recommendation have been applied for crops and crop mixtures. A study showed that Blanket recommendation gave a lowest cassava yield over soil test based recommendation (Fondufe, *et al*., 2001).

Modern soil testing was developed in the 1940s, and improvements in, and the use of, soil testing have increased in contemporary times (Watson and Mullen, 2007). Soil tests are developed to help producers predict their soil's available nutrient status in relation to crop production and fertilizer management program. Soil test based fertilizer recommendation plays a vital role in ensuring balanced nutrition to crops and fertilizer schedules should therefore be based on the magnitude of crop response to applied nutrients at different soil fertility level. Based on this concept, soil test based phosphorus response studies were undertaken in North Gondar zone, Ethiopia.

Materials and Methods

Geographic Location of the study Area

The study area is located in the Amhara National Regional State, in North Gondar zone at Dabat and Debark Woredas. The altitude of the experimental site of Dabat and Debark are 2580 m and 2770 m above mean sea level, respectively. It is located between 37.77'and 37.9' longitude 12.98' and 13.19' latitude, respectively. The maximum temperature of the areas was about 24.5 °C and 23.1°C. While the minimum temperature was about 4.6°C and 3.7, respectively. The mean annual rainfall in the area is about 1254 and 1231 mm, respectively.

Experimental design and procedures

The study was conducted in 2010–2012 cropping seasons on farmers' field in two phases.

Phase 1:

In the first phase of the experiment, determination of the optimum rate of P_2O_5 kg ha^{-1} was done. The experiment contains five treatments arranged in Randomized Complete Block Design with three replications. Five rate of phosphorous fertilizer (0, 46, 92, 138 and 184 P_2O_5 kg ha^{-1}) with the agronomic recommendation of Nitrogen fertilizer (92 N kg ha^{-1}) were used. Triple Super Phosphate (TSP), Di-ammonium phosphate (DAP) and Urea fertilizers were used as fertilizer source to supply phosphorous (P) and nitrogen (N). Split application of equal amount of nitrogen fertilizer was given to all plots. The gross plot size was 16 m^2 net plot size was 9 m^2. Improved bread wheat variety (TAY) was used with seed rate 125 kg ha^{-1} and planted in rows. Plots were kept weed free by hand weeding. All other agronomic practices were applied. Composite soil samples were collected before planting.

Soil Sampling and Analysis

Prior to planting surface (0 - 40 cm) soil samples, from five spots across the experimental field were collected to know the initial soil status of the soil. After three weeks from the day of planting and phosphorus fertilizer application, soil samples were collected from each treatment plot by replication for determination of available P. The soil samples were air dried, thoroughly mixed and grounded to pass 2 mm sieve to determine necessary soil physical and chemicals parameters. Available P was extracted with sodium bicarbonate solution at pH 8.5 following the procedure described by Olsen et al. (1954). Total nitrogen was determined by the micro-Kjeldahl digestion, distillation and titration method as described by Jackson (1958). Soil pH was measured potentiometrically in the supernatant suspension of a 1:2.5 soil:water mixture using a pH meter according to method outlined by Sahlemedhin and Taye (2000). Organic carbon was determined following the Walkley and Black wet oxidation method as described by Jackson (1958). The soil CEC was determined at pH 7 after displacement of the cations by using 1 N ammonium acetate; thereafter, the ammonium was estimated titrimetrically by distillation of ammonium that was displaced by sodium following the procedure of Sahlemedhin and Taye (2000). Total exchangeable bases were determined after leaching the soils with ammonium acetate; Ca^{2+}

Determination of Critical P levels

The Cate-Nelson graphical technique (Cate and Nelson, 1965) was used to determine the P critical level. It was determined from the relationship between relative yields (which is this yield x (100/ maximum yield)) and soil test P values of each replication. The maximum yield was taken from each site and for every replication to determine the relative yield.

Determination of P Requirement Factor

P requirement factor is the measure of the quantity of P nutrient per hectare required to raise the soil P level measured by selected P availability indices by 1 mg kg^{-1} (ppm).This was calculated from the difference between available P values in soil samples of the control plots and the plots that received fertilizer as indicated in Table 1.

Table1 P requirement factor

P fertilizer treatment (P_2O_5 kg ha^{-1})	Olsen and Bray II P levels after incubation (mg kg^{-1})	P level increase over the control by Olsen and Bray II methods (mg kg^{-1})	P requirement factor (Pf)
0	A	-	-
46	B	b-a	46/ (b-a)
92	C	c-a	92/ (c-a)
138	D	d-a	138/ (d-a)
184	E	e-a	184/ (e-a)
Mean	-	[(b-a)+ (c-a) + (d-a) + (e-a)]/4	[(46/(b-a))+ (92/(c-a)) + (138/(d-a)) + (184/(e-a))]/4

Developing the Equation

To develop the equation for calculating the P fertilizer requirement, three parameters were required. They were P critical level (P_c), Soil test value of P (P_0) and P requirement factor (P_f). P_c was determined from the Cate-Nelson graph, P_0 was the measurement of soil P and P_f is calculated according to Table 1. Therefore, P fertilizer requirement (P_r) was the amount of P required to raise the soil P from the existing level to the critical level. It was calculated by the formula:

$$P_r = (P_c - P_0) * P_f$$

Where P_r = P fertilizer requirement (kg ha^{-1})

P_c = Critical P level by Olsen or Bray=II methods (mg kg^{-1})

P_0 = Soil test value of P of the field (mg kg^{-1})

P_f = P requirement factor determined by the experiment

Phase 2:

The second phase of the experiment was verification of soil test based P fertilizer recommendation equation model. Bi-plot (10 m * 10 m) experimental area was used. One plot for agronomic fertilizer recommendation and the other plot was the calibrated fertilizer recommendation. Bread wheat response data from field experiments conducted in 2012 were used in the present investigation. Soil and fertilizer nutrient efficiencies for the amount of fertilizer required for specified bread wheat yield targets were computed from this data by two procedures, agronomic recommendation and calibrated recommendation using Cate-Nelson graphic technique.

Agronomic fertilizer recommendation was obtained in the first phase of this experiment which was 92 kg P_2O_5 ha^{-1} whereas the calibrated fertilizer recommendation was obtained based on the results of soil test P in the laboratory soil analysis.

Soil Sampling and analysis

Composite soil samples were collected for laboratory chemical analysis at the depth of 0-30cm from each field before planting and soil analysis for available P was done at Gondar Soil testing laboratory. The results of available P were calculated from the equation using the equation obtained from the model.

$$P_r = (P_c-P_0) * P_f$$

Statistical Analysis

The collected data was analyzed using SAS software (SAS V9.0, SAS Institute Inc., Cary, NC, USA). Whenever significant differences between treatments are detected, mean separation was done using least significant difference (LSD).

Results and Discussions

Physical and chemical Properties of the Soil

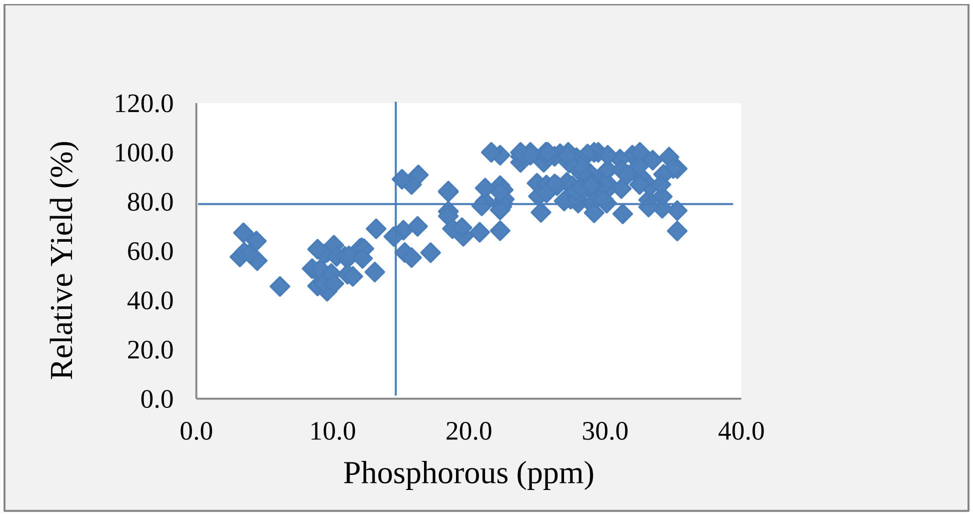
The analytical results indicated that the experimental soil was low in its organic matter content according to Landon (1991) ratings (> 20 % very high, 10-20 % high, 4-10 % medium, 2-4 % low and < 2 % very low) (Table 2). The low organic matter content of the soils in Ethiopian highlands has been attributed to factors such as sever soil erosion, continuous cultivation, frequent and complete removal of farm residues commonly carried out by farmers in the area which tends to destroy much of the organic materials that could have been added to the soil. The CEC of the soil was 58.18 $cmol_c\ kg^{-1}$ which is very high (Landon, 1991). According to Olsen *et al.* (1954) P rating (mg kg^{-1}), the available P content of < 3 is very low, 4 to 7 is low, 8 to 11 is medium, and > 11 is high. Thus, available P content the experimental site of is low to medium. The pH of the soil was 6.13, which is suitable for wheat production (Landon, 1991).

Table 2 Initial status of soil chemical properties of experimental site

Parameters	Soil analysis results
pH	6.13
Available P (ppm)	3.2- 8.98
Organic matter (%)	1.42
CEC cmol(+)kg^{-1}	58.16
Exchangeable Ca, cmol(+)kg^{-1}	41.52
Exchangeable Mg, cmol(+)kg^{-1}	25.19
Exchangeable k, cmol(+)kg^{-1}	2.21
Exchangeable Na, cmol(+)kg^{-1}	0.31

Phase 1:

The results of the combined analysis showed that there was highly statistically significant difference ($p < 0.01$) among the treatments (Table 3). Plant height, tiller number, biomass yield and grain yield were significantly ($P < 0.01$) influenced by the rates of phosphorous fertilizer application. 92 kg ha^{-1} P_2O_5 with 92 kg ha^{-1} nitrogen fertilizer gave the highest grain yield whereas the lowest grain 417 yield was obtained from 0 kg ha^{-1} P



Graph 1. Cate-Nelson graph

Determination of P Requirement Factor:

The results from Table 4 showed that the P requirement factor (P_f) was found to be 5.4 and the critical soil P concentration was 15.8 mg kg^{-1} (ppm). Therefore, the equation becomes:

$$Pr = (15.8 - Po) * 5.4$$

Where

P_r = P fertilizer requirement

P_o = Soil test value of P

Table 4 Determination of P requirement for the high lands of North Gondar

Treatment (P_2O_5 level)	P level after incubation	p increase	Pf
0	8.97	-	-
46	22.02	13.05	3.5
92	26.19	17.22	5.3
138	29.28	20.31	4.7
192	31.46	22.49	8.2
Mean			**5.4**

Phase 2: Verification

Results from the verification of the equation developed on soil test based P fertilizer recommendation for bread wheat showed that the Model gave better estimates of P fertilizer determined by Cate-Nelson graphic technique procedure. The differences in the predicted amounts of P fertilizer and the agronomic fertilizer recommendation were adequate to explain the variation indicating that this approaches can be followed for the amount of phosphorous required for specified yield targets (Figure 1 and 2).

The results in this model estimates the actual situation in the field in respect of the relationship between soil and fertilizer P availabilities and P uptake by the crop providing usefulness of this model for assessing the amount of P required for specified grain yield targets (Figure 1 and 2).

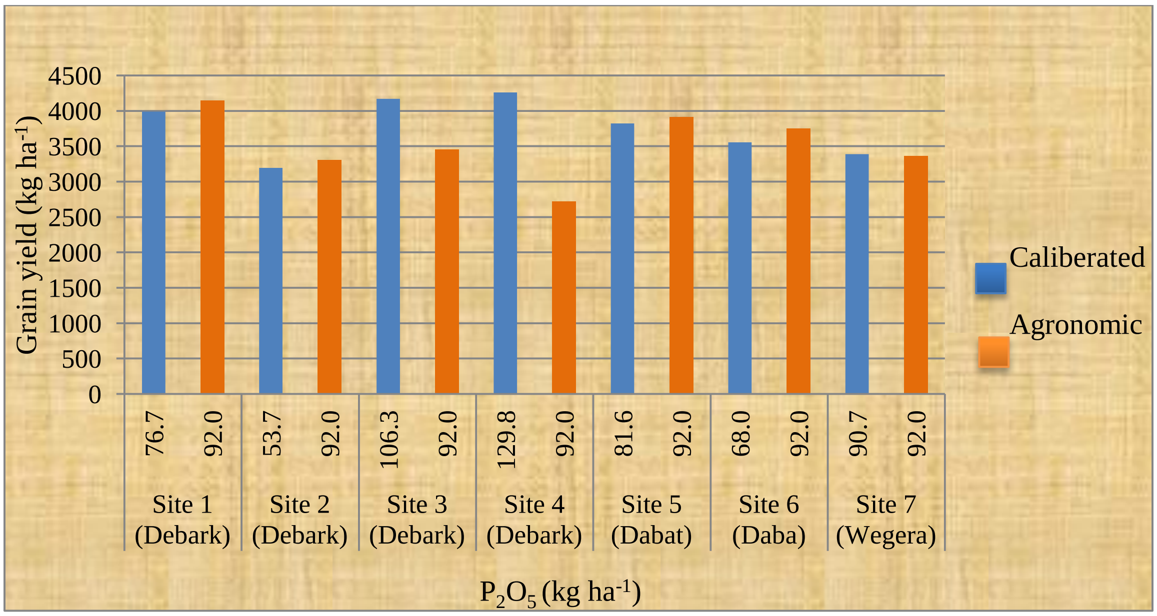


Figure 1. Verification of soil test base phosphorous fertilizer (P_2O_5) recommendation equation for bread wheat grain yield in 2012

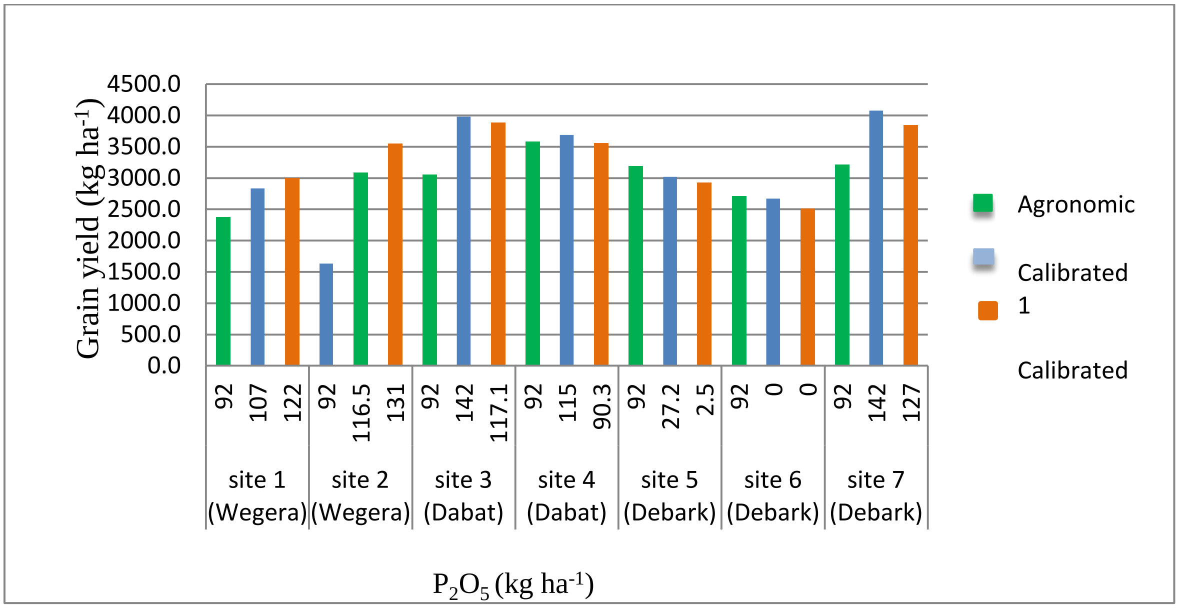


Figure 2. Verification of soil test base phosphorous fertilizer (P_2O_5) recommendation equation for bread wheat grain yield in 2013

Conclusions and Recommendations

The critical soil P concentration beyond which applied fertilizer becomes non-responsive estimated by Cate-Nelson graphic method was 15.8 mg kg^{-1}. Results also showed that the P requirement factor (P_f) was 5.4 and the critical soil P concentration was 15.8 mg kg^{-1} (ppm). Therefore, the equation becomes:

Pr = (15.8-Po)*5.4

This equation can be used for the high lands of North Gondar to determine the optimum P fertilizer recommendation. This recommendation can be further refined, and should result in better allocation of phosphorous fertilizer and major savings to the farmers and agricultural sectors in the region.

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