World Journal of Agricultural Sciences 16 (1): 27-33, 2020
ISSN 1817-3047

DOI: 10.5829/idosi.wjas.2020.27.33

Phosphorus Response and Fertilizer Recommendations under Balanced Fertilizers for Wheat Grown on Nitisols in the Central Highlands of Ethiopia

Girma Chala and Zeleke Obsa

Holetta Agricultural Research Center, Ethiopian Institute of Agricultural Research,
EIAR P.O. Box: 2003, Addis Ababa, Ethiopia

Abstract: Phosphorous response and fertilizer recommendation under balanced fertilizer study was conducted for wheat grown on nitisols in Welmera district, West Shewa, in central highlands of Ethiopia. The experiment was arranged in a complete block design with five levels of phosphorous fertilizer (0, 10, 20, 30 and 40 kg ha^{-1}) with three replications. Based on a yield difference between the phosphorus treatments and negative control treatments, Relative yield at 80% of sites responded to phosphorus fertilizer. Phosphorous fertilizer application at different rates wheat grain yield increased up to 20.6% when compared to the negative control treatment (zero p treatment). Extractable soil P concentrations (Bray II method, 0- 20 cm depth) three weeks after planting significantly responded to P fertilizer rate. Relative yield correlated with soil phosphorous values revealed that the soil phosphorous levels greater than 14.8 mg kg^{-1} (critical phosphorous concentration) was found to be optimum for production of wheat on nitisols area. Phosphorous requirement factor (Pf) average was calculated from soil phosphorous values of all treatments for the study area was 11.13. In the absence of a soil test, a recommendation of 30 kg P ha^{-1} to prevent a potential loss of wheat. Further study is needed to determine interaction effect of phosphorus with other nutrient requirement of wheat involving more soil types and agro-ecological zones supported by appropriate soil and plant analysis.

Key words: Nitisols · P concentration · Phosphorus · P requirement factor · Relative yield · Wheat

INTRODUCTION

Soil fertility depletion and soil quality decline are the main constraints affecting the yield and sustainability of crop production in Ethiopia. Balanced fertilizers in blend form have recommended ameliorating site specific nutrient deficiencies and thereby increasing productivity. The need for site-specific fertilizer prescriptions is increasingly apparent, however, fertilizer trials involving multi-nutrient blends that include micronutrients are rare in Ethiopian context. Although there is general opinion that the new fertilizer blends better than the traditional fertilizer recommendation (Urea and DAP), their comparative advantages not explicitly examined and understood under various production environment [1].

Wheat is grown over a large area (1.63 million ha), but productivity is as low as 2.6 t ha^{-1} in the Ethiopia and also in the west Shewa zone, 2.7 t ha^{-1} [2]. This is due to declining soil fertility, low fertilizer usage, lack of resistant varieties to rust diseases [3, 4]. Limited use of legumes in the cropping system, continuous cropping and applications of suboptimal rates of mineral fertilizers have aggravated the decline in soil fertility and crop yield [5- 7]. The rate of chemical fertilizer application is low in the country due to unaffordable price for resource-poor smallholder farmers [8].

Phosphorous is the most yield limiting of soil-supplied elements and soil P tends to decline when soils are used for agriculture [9]. Studies have demonstrated that nitisol and vertisols areas in the central highlands of Ethiopia are marginally to severely deficient in P [10, 11]. In Ethiopia, the blanket recommendations that are presently in use all over the country were issued several years ago, which may not be suitable for the current production systems [5, 12]. Since the spatial and temporal fertility variations in soils were not considered, farmers have been applying the same P fertilizer rate to their fields regardless of soil fertility differences.

Corresponding Author: Girma Chala, Holetta Agricultural Research Center,
Ethiopian Institute of Agricultural Research, Ethiopia.

Calibration is a means of establishing a relationship between a given soil test value and the yield response from adding nutrient to the soil as fertilizer. It provides information how much nutrient should be applied at a particular soil test value to optimize crop growth without excessive waste and confirm the validity of current P recommendations [13, 14]. They enable to revise fertilizer recommendations for an area based on soil and crop type, pH and soil moisture content at time of planting. An accurate soil test interpretation requires knowledge of the relationship between the amount of a nutrient extracted by a given soil test and the amount of plant nutrients that should be added to achieve optimum yield for a particular crop [15, 16]. Soil tests are designed to help farmers predict the available nutrient status of their soils. Once the existing nutrient levels are established, producers can use the data to best manage what nutrients are applied, decide the application rate and make decisions concerning the profitability of their operations [17]. However, local assessments for the soil P critical levels and soil P requirement factors even for the major crops of the country are negligible. Currently, soil fertility research improvement is agreed with respect to site specific fertilizer recommendation in the country [18].

This helps to feed crops that Urea and DAP have not managed to promote and in the long run, instead of DAP and Urea, blended fertilizer shall be distributed to smallholder farmers which own farm lands with deficiency in some important nutrients. Here, the right rate of recommended blended fertilizer for the specific soil, ecology and crop type is important. Therefore, the objectives of this study were to correlate the Bary-2 method soil test P with the relative grain yield response of wheat on nitisols areas of west shewa, to established preliminary agronomic interpretations and to determine the critical P concentration and P requirement factor.

MATERIALS AND METHODS

Experimental Site: The experiment was conducted on permanent fields in 2018 during the main cropping seasons in West Shewa zone, at Welmera district on nitisols. Geographically, the experimental site is located at 09° 02'N and 380 12'E and an altitude of 2400m above sea level at a road distance of about 29 km West of Addis Ababa. The area is characterized by a mono-modal rainfall pattern and receives an average annual rainfall of 1100 mm, about 85% of which is received from June to September.

A total of 240 soil samples at a till layer of 0-20 cm were collected from all experimental plots three weeks after planting. Soil samples were analyzed for pH using a ratio of 2.5 ml water to 1 g soil available P using Bray-2 method, organic C content using according to Walkley and Black [19], total N content using Kjeldahl method, exchangeable cations and cation exchange capacity (CEC) using ammonium acetate method at the soil and plant analysis laboratory of Holeta Agricultural Research Center. The available soil P (using Bray-2 method) ranges prior to planting considered for classification were <10mg P kg^{-1} for low, 10-25 mg P kg^{-1} for medium and >25 mg P kg^{-1} for high. Based on this categorization, an experimental field was created in four gradient groups with low P, medium P and high phosphorus fields.

Experimental Procedures: The experiment was arranged in randomized complete block design with five levels of phosphorus (0, 10, 20, 30 and 40 kg ha^{-1}) and replicated three times. The gross plot size was 3m x 2m ($6m^2$) and accommodating 15 rows per plot. The net plot size was determined with area and plant density leaving the one outermost row and sides of each row the spacing between blocks, plots and rows were 1m, 0.5m and 0.2m, respectively. The harvested plot area measured $6m^2$. The sources of N and P were urea and triple super-phosphate (TSP), respectively. Types of balanced fertilizer were determined based on EthioSIS [18] soil fertility map. The fertilizer type recommended to area was NPSB. Source of S and B were $CaSO_4$ and borax, respectively. All agronomic practices were applied based on local research recommendations.

The experimental plot was cultivated by local an oxen-drawn implement to the depth of 20-30 centimetres. The land was levelled and ridges were made manually. Wheat (Limu variety) was planted by using 150 kg ha^{-1}. Application of phosphorus fertilizer was done by banding the granules of TSP (Triple super-phosphate) at the depth of 5 cm below at planting. Nitrogen at the rate of 60 kg N ha^{-1} was applied in the form of urea in two splits (1/2 at planting and 1/2 at mid-stage of). Harvesting was done at physiological maturity.

Data Collection: Agronomic parameters collected were plant height and spike length (cm), was measured by taking five randomly selected plants per plot as the distance in cm from the soil surface to the top most growth point of aboveground at full maturity. Grain and biomass yield were measured based on plant samples taken from ten central rows (2m x 2m= 4m^2) at full maturity stage. Grain yield and biomass yields recorded on plot basis were converted to kg ha^{-1} for statistical analysis.

Determination of Critical P Concentration (Pc): To correlate relative yield vs soil test P values and determine critical P concentration, the available P was extracted from the soil samples taken three weeks after planting from each plot of all experimental fields using Bray-2 method.

The Cate-Nelson graphical method [20] was determine the critical P value using relative yields and soil test P values obtained from 16 P fertilizer trials conducted at different p levels. To assess the relationship between tuber yield response to nutrient rates and soil test P values, relative grain yields in percent were calculated as follows:

$$Relative\ yield\ (\%) = \frac{Yield}{Maximum\ yield}\ \text{X}\ 100 \quad (1)$$

The scatter diagram of relative yield (y-axis) versus soil test values (x-axis) was plotted. The range in values on the Y-axis was 0 to 100%. A pair of intersecting perpendicular lines was drawn to divide the data into four quadrants. The vertical line defines the responsive and non-responsive ranges. The observations in the upper left quadrants overestimate the P fertilizer P requirement while the observations in the lower right quadrant underestimate the fertilizer requirement. The intersecting lines were moved about horizontally and vertically on the graph, always with the two lines parallel to the two axes on the graph, until the number of points in the two positive quadrants was at a maximum (or conversely, the number of points in the two negative quadrants was at a minimum). The point where the vertical line crosses the X-axis was defined as optimum critical soil test level [20].

Determination of P Requirement Factor (P_f): Phosphorus requirement factor (p_f) is the amount of P in kg needed to raise the soil phosphorus by 1mg kg^{-1}. It enables to determine the quantity of P required per hectare to raise the soil test by 1mg kg^{-1} and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level [21]. It was calculated using available P values in samples collected from unfertilized and fertilized plots. Phosphorous requirement factor was expressed as:

$$Pf = \frac{kg\ P\ applied}{\Delta\ \text{soil P}} \quad (2)$$

Therefore the rate of P fertilizer to be applied (*Pa*) was expressed in terms of critical P concentration (P_c), initial soil P value (P_i) and P requirement factor (P_f).

$$Pa = (Pc\text{-}Pi)\ x\ Pf \quad (3)$$

Statistical Analysis: The data were subjected to analysis of variance using the procedure of the SAS statistical package version 9.0 [22]. The total variability for each trait was quantified using the following model.

$$T_{ijk} = \mu + Y_i + R_{j(i)} + P_k + PY_{(ik)} + e_{ijk} \quad (4)$$

where T_{ijk} is the total observation, μ = grand mean, Y_i = effect of the ith year, $R_{j(i)}$ is the effect of the jth replication (with in the ith year), P_k is the effect of the kth treatment, $PY_{(ik)}$ is the interaction of kth treatment with ith year and e_{ijk} is the random error. Means for the main effects were compared using the means statement with the least significant difference (LSD) test at the 5% level.

RESULTS AND DISCUSSION

The statically analysis of wheat yield and yield components revealed that significantly (p<0.05) on plant height, spike length, grain and biomass yield of wheat. The highest mean of plant height was recorded at application of 40 kg P + 60kgN +7kgS + 4.9kg Borax but highest panicle length was recorded from application of 40 kg P + 60kgN +7kgS + 4.9kg Borax. Similarly, the highest grain and biomass yield (6802.9kg ha^{-1} and 17930.9kg ha^{-1}) were recorded from the application of 40 kg P + 60kgN +7kgS + 4.9kg Borax respectively. As the application of Phosphorus fertilizer at rates increased from 10 to 40 kg ha^{-1} grain yield also increased from 12.8 to 20.6%, compared to the negative control (without P fertilizer) (Table 2).

Critical P concentration (Pc) and P requirement factor (Pf): Soil Phosphorus values determined three weeks after planting differed significantly (P = 0.01) among Phosphorus levels. The main effect of Phosphorus fertilizer treatments resulted in mean soil test Phosphorus values 9.2 to 18.6mg kg^{-1} (Table 3). Bray-2 method soil test Phosphorus values below 10mg kg^{-1} are considered low. Increase in soil Phosphorus content in response to

Table 1: Soil chemical characteristics of the trial site before application of treatments at HARC

Trial field	pH (H_2O)	Nitrogen (%)	Phosphorus (mg/kg)	OC (%)	Exchangeable cations ($cmol^+$/kg of soil) K	CEC
1	4.81	0.14	7.84	1.56	1.97	16.28
2	4.84	0.16	10.91	1.52	1.55	17.16
3	4.86	0.18	11.34	1.68	1.69	18.32
4	5.02	0.14	13.10	1.62	2.11	17.88
Mean	4.88	0.16	10.79	1.59	1.83	17.41

Phosphorus test Bray-2 method

Table 2: Response of phosphorus fertilizers application on wheat yield and yield components

Treatments	Plant height (cm)	Spike length (cm)	Grain yield (kg/ha)	Biomass yield (kg/ha)
Zero P + 60kgN +7kgS + 4.9kg Borax	88.9[b]	7.9[b]	5404.5[b]	15546.9[c]
10kg P + 60kgN +7kgS + 4.9kg Borax	94.3[a]	8.2[a]	6195.2[ab]	16409.7[b]
20 kg P + 60kgN +7kgS + 4.9kg Borax	92.9[a]	8.1[ab]	6549.9[a]	17690.6[ab]
30 kg P + 60kgN +7kgS + 4.9kg Borax	94.8[a]	8.3[a]	6816.2[a]	17882.3[ab]
40 kg P + 60kgN +7kgS + 4.9kg Borax	92.9[a]	8.1[ab]	6602.9[a]	17930.9[a]
LSD (5%)	2.15	0.27	376.6	951.6
CV (%)	5.8	8.3	14.6	13.9

Table 3: Determination of P requirement factor for wheat on nitisols

Phosphorous rate (kg/ha)	Soil test P (Bray-2) Range	Average	P increase over Control	P requirement factor (Pf)
0	9.2 -13.4	11.8		
10	11.6-13.8	12.6	0.8	12.5
20	11.9-14.3	13.7	1.9	10.5
30	12.2-16.4	14.8	3.1	9.7
40	12.7-18.6	15.2	3.4	11.8
Average				11.13

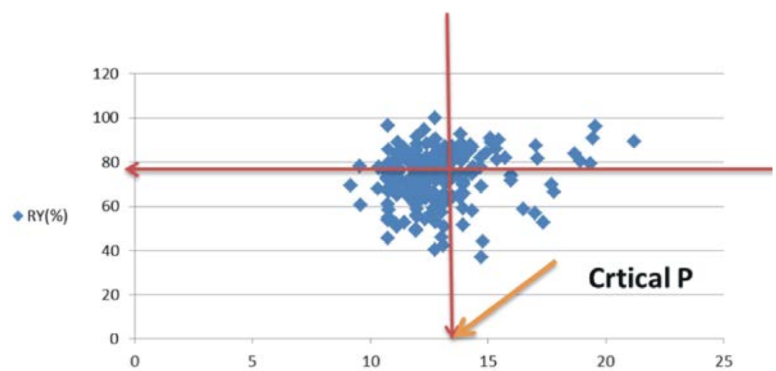

Fig. 1: Relationships between relative yield response of wheat and soil-test P measured using Bray-2 method. The arrow indicates the critical P concentration (*Pc*) for wheat on nitisols.

Phosphorus fertilizer application up to 30kg Phosphorus ha^{-1} but showed slight decrease beyond 40kg Phosphorus ha^{-1}. The highest mean soil Phosphorus concentration (14.8mg kg^{-1}) was recorded from 40 kg Phosphorus ha^{-1} (Figure 1).

Phosphorous Critical Concentration: The relationship between relative grain yield response and soil P measured with the Bray-2 method is shown in the Figure 1. The critical P concentration (*Pc*) was determined from the scatter diagram drawn using relative grain yields of wheat and the corresponding soil test P values for all P levels (0-40 kg ha^{-1}). The *Pc* defined by the Cate- Nelson method in this study was about 14.8mg P Kg^{-1}, with mean relative grain yield response of about 80% (Figure 1).

When the soil test value is below the critical level additional information is needed on the quantity of P required to elevate the soil P to the required level. This is the P requirement factor (*Pf*), the amount of P required to raise the soil test P by 1mg kg^{-1}, computed from the from the difference between available soil test P values from plots that received 0-40 kg P ha^{-1} using the second formula motioned above. Accordingly the calculated *Pf* were 9.7-12.5 and the overall average *Pf* of all treatments for the study area were 11.13 (Table 3). Thus the rate of P fertilizer required per ha can be calculated using the soil critical P concentration and the P requirement factor as indicated above in the third formula.

DISCUSSION

Our results showed that significant variations in yield and other agronomic parameters were observed. Availability of nutrients to crops is a function of the soil, crop, environment and management; their interactions affects fertilizer use efficiency and the crop growth condition [17]. These factors need to be considered when using methods to calibrate soil- test nutrient values with relative grain yields. According to. Jones, Olson-Rutz and Dinkins [23] low nutrient uptake early in a plant's growth lowers nutrient quantity for the seed affecting yield. Analysis of variance show that phosphorous had a highly significant effect on grain, biomass yield and yield component of wheat.

According to the Cate- Nelson method, the critical levels of Bray 2 method P in the top 20cm of soil about 14.8mg kg^{-1}; at values of greater than or equal to 14.8mg kg^{-1}, the crop achieved about 80% of its maximal yield in the absence of P fertilizer application (Figure 1). This implies that P fertilizer application could be recommended for a build-up of the soil P to this critical value, or maintaining the soil P at this level. Increasing P beyond this level, the cost of additional P fertilizer to produce extra yield would likely be greater than the value of additional yield. Thus, in soils with available P status below 14.8mg kg^{-1}, yield of wheat could show a significant response to applications of P fertilizers. Whereas in areas with available P status greater than 14.8mg kg^{-1}, the P concentration in the soil exceeds crop needs so that further addition of P fertilizer may not result in a profitable yield increase. Mallarino [24] reported that a critical concentration of 13 mg P kg^{-1} for corn response within this category (13-20 mg P kg^{-1}) may be considered small and maintenance fertilization can be recommended based on expected nutrient removal with harvest.

Hence, to protect a potential loss of wheat yield, at least a maintenance application of 14.8kg P ha^{-1} may be required depending on the wheat yield goal and profitability. Dodd and Mallarino [25] also showed that soils testing 43 to 96 mg P kg^{-1} needed 10 to 20 years of cropping without P fertilization before yield response to P was observed. Overall, to develop a valid soil test phosphorous recommendations for wider applicability using low, medium and high categories, several years of research is required to generate sufficient information for the most important crop- soil system [17].

At optimum level of phosphorus fertilizer is necessary to improve grain yield of wheat on nitisols areas. Soil fertility is sub- optimal for the production of wheat in Ethiopian highlands, particularly on nitisols where soil pH and the associated P availability is in medium rage. Following the pre- planting soil analysis results all of the trial sites had lower soil P values than the critical P concentration.

The results seem promising and could be used as a basis for soil-test P fertilizer recommendation for the production of wheat on nitisols areas of central Ethiopian highlands. They can also be used for future intensification in other areas for developing a system for soil test based fertilizer recommendation [17]. Nevertheless, to develop an effective guideline for wider applicability of soil test based fertilizer recommendations, more research assisted by appropriate soil P extraction methods is required to generate sufficient information for the most important crop-soil systems.

CONCLUSION

Phosphorus fertilizer at different rates had a significance difference on grain yield of wheat. The amount of phosphorus fertilizer applied based on the critical P concentration level and P requirement factor. Critical phosphorus concentration was found 14.8 mg kg^{-1} and requirement factor of phosphorus is 9.7 mg kg^{-1}. Therefore, Critical P concentrations (Pc) and P requirement factors (Pf) have been determined for wheat and which could be extrapolated to similar agro-ecological zones of the country. Interventions to increase P use efficiency and reduce P losses to the environment must be accomplished at the farm level through a soil teste based crop response P fertilizer technologies and carefully crafted local policies that promote the adoption of improved P management practices while sustaining yield increases. Further studies should be done on phosphorous use efficiency and other related plant nutrition parameters.

ACKNOWLEDGEMENTS

The authors acknowledge the Ethiopian Institute of Agricultural Research (EIAR) and I would like to express my thanks and appreciation to Mr. Haile Beza, Mr. Beyene Ofa, Mr. Mrs. Kessach Birhanu, Mrs.Tigist Feyisa, Tesfaye Negash and Mr. Hailamariam Makonin for their technical assistance during the execution of the experiments under field condition. Appreciation is also due for the services of the analytical soil laboratory of Holeta Agricultural Research Center of EIAR.

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