Soil-test Crop Response Based Phosphorus Calibration Study under Balanced Fertilization of Bread Wheat (*Triticum aestivum* L.) on Nitisols in North West of Ethiopia

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Abstract

In Ethiopia, phosphorus (P) is the second major yield limiting nutrient next to nitrogen. Hence efficient management of P nutrient is critically needed in Northwestern Ethiopia where higher amount of crop is produced. Six years (2014-2019) research on permanent fields were conducted to develop phosphorus requirement equation to recommend P fertilizer based on soil test results for improving wheat (Triticum aestivum L.) productivity. The experiment was started by creating different artificial phosphorus gradient fields in the first 2 years (2014-2015). For the other three consecutive cropping years (2017-2019), plot based field experiment was conducted on different P level gradient fields. The field experiment had seven treatments (0, 10, 20, 30, 40, 50 and 60) P kg ha^{-1}. Randomized complete block design (RCBD) with 3 replications was used. All treatments received equal levels of N, K and S nuutreints in all gradient fields through out the cropping years. Urea, Triple Supper-Phosphate (TSP), Muriate of Potash (KCl) and Calcium sulfate (CaSO4) were used as N, P, K and S sources, respectively. Improved bread whaet variety (TAY) was used as a test crop. In all cropping years, P, K and S fertilizers were applied in band at planting while, N was applied in three equal splits (1/3 at planting, 1/3 at 40-45 days after planting and 1/3 at booting). All other crop management practices were implemented as per the recommendations. Soil samples were taken in P gradient formation period, as well as in all cropping years from each experimental plot from 0-20cm depth and selected chemical soil parameters (pH, SOC, and available P) were analyzed. The yield and yield components such as plant height, grain and biomass yield of bread wheat showed a highly significant dif

phosphorus rate for both each and combined years. Soil phosphorus values also showed increasing trend as the applied phosphorus amount increased within the defined treatments. Finally, 10 mg kg^{-1} of soil P was determined as phosphorus critical point (Pc) and 7.5 phosphorus requirement factor (Pf) values were obtained from over-year combined analysis result using the Cate-Nelson graphical method. Using these two critical values, it is better to conduct a verification study on the farmer fields with similar agro-ecology and soil types to validate whether the developed equation is economically acceptable or not.

Keywords: Bread wheat, Crop Response, Phosphorus, Soil test based

Introduction

Bread wheat (*Triticum aestivum* L.) is one of the most staple food crops in the world as well as in Ethiopia. In Ethiopia it stands fourth in both area coverage and total annual production. But, in yield potential, it is 2nd ranked next to maize (CSA, 2017). Ethiopia is the largest wheat producer in sub-Saharan Africa (SSA) with about 0.75 and 1 million ha of durum and bread wheat respectively. Even though its area coverage is over 1.7 million ha, its productivity is as low as 2.9 t ha^{-1} compared to the average cereal yields of 3 t ha^{-1} in the developing world due to poor soil fertility and crop management practices (Kiflemariam et al., 2022).

However, soil fertility depletion became critical challenge for bread wheat production in Ethiopia. To reverse the situation and advices best fit recommendations for small holder farmers, monitoring and frequent reviewing of soil fertility status are important. In Ethiopia nitrogen (N) and phosphorus (P) are the most yield limiting soil nutrients (Tadele *et al.,* 2018). It has been considered as a major factor for limiting crop productivity and recommended to apply in large amounts on the soil since the green revolution to sustain production of agricultural systems (Tilman *et al.,* 2002). Relative to N, recovery of P fertilizers by plants is very low due to its high fixation capacity in the soil (Balemi and Negisho, 2012).

One of the best methods for nutrient recommendations is to calibrate and validate the nutrient requirements using long term experimental data. Nutrient 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 nutrient recommendations (McKenizie and Kryzanowski, 1997). It enables to revise fertilizer recommendations based on soil and crop types, pH and soil moisture content at time of planting. Soil tests are designed to help farmers to know the available nutrient status of their soil. Once the nutrient status determined, it is possible to decide how much nutrients to be applied to get economically acceptable yields (Getachew and Berhane, 2013 and (Getachew *et al.*, 2015).

However, for P calibration and validations, determination of soil P critical and soil P requirement factor for bread whaet on major agro ecology and soil types for Western Amhara is lacking. Hence, to bridge this gap, Adet Agricultural Research Center (AARC) proposed a long-term soil test-based and site-specific P calibration study under balanced fertilization for bread whaet on nitisols. Therefore, the objective of this research was to develop P calibration equation and recommendations of P fertilizer requirement factor for bread wheat on nitisol for western Amhara region.

Materials and Methods

The experiment was conducted from 2014-2019 on Nitisols permanent plot of AARC research station. At the beginning of the study (2014) the experimental field was divided into 4 sub plots which received equal doses of N, potassium (K) and sulfur (S) using the rates of 92 kg ha^{-1} N, 90 kg ha^{-1} K_2O and 30 kg ha^{-1} S, respectively. By considering 115 kg ha^{-1} P_2O_5 as base line rate, the four fields were received 0, half (57.5 kg ha^{-1}), full (115 kg ha^{-1}) and double (230 kg ha^{-1}) rates of P_2O_5. In 2015, each sub-plot divided in to four sub-sub plot and received 0, half (57.5 kg ha^{-1}), full (115 kg ha^{-1}) and double (230 kg ha^{-1}) rates of P_2O_5 and formed 16 total fields having different P gradient levels. The same amount of NKS fertilizers was applied on the sub-sub plots for the second year.

After creating different P gradient fields (2014-2015), plot based experiment was started on each P gradient fields using seven levels of P nutrient rates (0, 10, 20, 30, 40, 50 and 60 kg ha^{-1}). Randomized complete block design (RCBD) with three replications was used. Similar to the gradient formation years, equal amount of N, K and S were applied on each experimental plot. The plot based experiment was implemented for two cropping years (2018-2019) at all P gradient fields. Artificially created P gradient fields were used as a simulation for three categories of soil with low; medium and high P content.

Improved bread wheat variety (TAY) was used as test crop for this experiment. Urea, triple supper-phosphate (TSP), *muriate*of potash (KCl) and Calcium sulfate ($CaSO_4$) were used as the sources of N, P, K and S, respectively. P, K and S fertilizer sources were normally applied in band at planting while, N was applied in 3 equal splits which was 1/3 at planting, 1/3 at 40-45 days after planting and the remaining 1/3 at booting stage. The other crop management practices were implemented as per the recommendation.

Figure 8. Schematic field layout for the above mentioned experiment

Soil Sampling and Analysis Procedure

One initial, 4 in 2015 (from 1st year gradient fields) and 16 in 2016 (from 2nd

fields) composite soil samples were taken at the depth of 0-15cm. All the collected composite soil samples were subjected for some chemical soil parameters analysis (pH, SOC, and available P) in AARC soil laboratory. According to Landon (1991) available P value for initial soil was under low ratting level (0 09 P mg kg^{1}) (Table 1). Similarly, artificially created fields were catagorized as low (<5 P mg kg^{-1}), medium (5-15 P mg kg^{-1}) and high (>15 P mg kg^{-1}). Therefore, from the total

gradient fields which served as experimental field. Each experimental field was taken as repilication (Table 2).

Similar to gradient formation years, soil samples were collected continuously from each experimental plot at 0-15cm depth before the testing crop planted and were taken as avialble P values for phosphorus critical (PC) value determination. The sampled soils in each year were air dried and sieved (≤2 mm) for analysis. From these, soil pH-H_2O was determined in soil-water suspensions of 1:2.5 ratios according to Taye *et al.* (2002) while, available phosphorus (AP) was analyzed using Olsen method (Olsen, 1954) and soil organic carbon (SOC) was determined following the method stated by Nelson and Sommer (1982).

Table 34. Initial and four P gradient fields (2014) soil data values

			Year 1 (2014)		
Soil parameters	Initial	control plot	Plot received Half (57.5 kg ha^{-1} P_2O_5)	Plot received Full (115 kg ha^{-1} P_2O_5)	Plot received Double (230 kg ha^{-1} P_2O_5)
pH- H_2O (1:2.5)	5.70	5.79	5.54	5.61	5.59
Ava. P (ppm)	3.30	3.04	4.08	5.50	7.51
SOC (%)	1.659	1.505	1.881	1.610	1.756

Table 35. Each P gradient field soil data values in the second year (2015)

	Year 2 (2015)															
Soil parameters	ZZ	ZH	ZF	ZD	HZ	HH	HF	HD	FZ	FH	FF	FD	DZ	DH	DF	DD
pH	5.58	5.58	5.56	5.56	5.57	5.45	5.34	5.39	5.6	5.53	5.55	5.46	5.64	5.57	5.51	5.56
Pppm	4.34	2.65	6.99	7.25	4.21	4.14	4.47	6.54	12.11	5.11	6.99	9.84	10.36	12.63	12.37	15.16
SOC	0.837	0.817	1.111	1.045	0.898	1.431	1.266	0.893	1.061	1.396	1.623	1.130	1.023	0.963	1.372	1.252

Note: *ZZ=zero, zero, ZH=zero, half, ZF=zero, full, ZD=zero, double, HZ=half, zero, HH= half, half, HF=half, full, HD=half, double, FZ=full, zero, FH=full, half, FF=full, full FD=Full, double, DZ= double, zero, DH= double, half, DF= double, full, DD=double, double.*

Determination of critical P concentration (Pc)

Critical P value was determined following the Cate-Nelson graphical method where soil P (available form) values were put on the X-axis and the relative grain yield values on the Y-axis. Relative yield was calculated using equation 1 in excel. The Cate-Nelson graphical method was divided the Y-X scatter diagram into four quadrants and maximizing the number of points in the positive quadrants while minimizing the number of points in the negative quadrants (Nelson LA and RL Anderson, 1997).

Steps for Cate-Nelson graphical methods in Pc determination:

1. Relative grain yield percentage values were obtained from all artificial created fields using the formulas indicated below.

Relative Grain yield percentage (RGY) = $\frac{Yield\ from\ each\ unit}{Maximum\ Yield} * 100 \ldots\ldots Eq\ 1$

2. Soil test values for the nutrient being studied should be obtained from all the locations. The control plot test values should be averaged. Thus, there will be a single percentage yield and one soil test value for each location.
3. The scatter diagram of relative percentage yield (Y-axis) versus soil test value (X-axis) is plotted on arithmetic paper. The range in values on the Y-axis is 0 to 100%.
4. A piece of clear plastic having roughly one and one-half the dimensions of the graph is cut out for use as an overlay. A pair of intersecting perpendicular lines is drawn on the overlay with black ink in such a way that it is divided in to four quadrants.
5. The overlay is 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 showing through the overlay in the two positive quadrants is at a maximum (or conversely, the number of points in the negative quadrants is at a minimum). The positions of the lines on the overlay with respect to the axes of the graph are transferred to the graph by making marks on the edges of the graph. The two intersecting lines are then drawn lightly on the graph with pencil. The point where the vertical line crosses the X-axis is defined as 'critical soil test level.

Determination of P requirement factor (Pf)

Phosphorus requirement factor is the amount of P in kg needed to raise the soil P by 1 mg kg^{-1} soil. Pf is used to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level. It was calculated using available P values in samples collected from unfertilized and fertilized plots. Therefore, Phosphorous requirement factor and the rate of Phosphorus fertilizer to be applied were calculated as follows:

$$Pf = \frac{kg\ P\ applied}{\Delta\ soil\ P} \ldots\ldots\ldots\ldots Eq\ 2$$

$$\text{Rate of P2O5 kg/ha fertilizer to be applied} = (Pc - Pi) * Pf \ldots\ldots\ldots\ldots Eq\ 3$$

Where: Pc=critical P concentration, ΔP= available P value taken after one year P fertilizer applied in each treatment –minus initial P values for the site, Pi= initial P values for the site and Pf=P-requirement factor

Agronomic data collected

Agronomic parameters such as mean plant height (5-10 plants), mean spike length (5-10 spikes), grain and dry biomass yields were collected. To estimate above ground biomass and grain yields of the test crop (bread wheat) 7.8-m^2 was harvested at crop maturity stage in each year. The actual grain yield was adjusted to 12.5% of moisture content.

Data management and analysis

All the collected agronomic and soil data were properly managed using Microsoft excel. The collected data were analyzed using general linear model in SAS software version 9.0 (SAS Institute, 2002). When ever treatment difference existed, Least Significant Difference (LSD) at 5% probability was used for mean sepration.

Results and discussion

Yield and yield components

Plant height and spike length

In each and over year combined results, plant height (PH) of bread wheat showed highly significant difference ($p \leq 0.0001$) among treatment means due to the applied P fertilizer rates which is in agreement with the findings mentioned by (Getachew *et al.,* 2015). Over year combined result as well as the results obtained in each year indicr results obtained in eactha Tf1 0 0 1 149.9 3

Table 36. Response of applied P fertilizer on bread wheat plant height and spike *length*

Treatment P kg ha^{-1}	Plant height (cm)			Year Combined	Spike length (cm)			Year Combined
	2017	2018	2019		2017	2018	2019	
0	100.0	93.7	69.1	87.6	8.96	9.48	6.83	8.43
10	102.9	97.3	74.6	91.6	9.01	9.54	7.33	8.63
20	104.1	98.6	76.4	93.0	9.09	9.37	7.40	8.62
30	104.2	103.5	77.5	95.1	9.10	9.35	7.39	8.61
40	104.5	101.0	77.5	94.3	9.10	9.67	7.48	8.75
50	104.6	100.9	77.9	94.5	9.09	9.41	7.23	8.58
60	105.3	101.8	77.9	95.0	9.06	9.40	7.29	8.58
Mean	**103.7**	**99.5**	**75.8**	**93.0**	**9.06**	**9.46**	**7.28**	**8.60**
LSD (0.05)	1.5	3.8	1.8	1.5	0.17	0.60	0.20	0.22
Pr.	**	**	**	**	NS	NS	**	NS
CV (%)	3.5	9.6	5.8	6.9	4.6	15.9	7.0	11.0

Grain and Biomass yields

As shown the in Table 4, grain yield (GY) of bread wheat showed a highly significant difference ($p \leq 0.0001$) among treatment means due to the applied P levels in each cropping season as well as in the combined analysis over-year. Including the over-year combined result, GY showed a linearly increasing trend without a turning point as the rate of P applied increased in all cropping years which is in lined with the results reported by (Getachew et al., 2015). Therefore, minimum and maximum values of GY values were recorded on the control treatment (zero P) and treatment which received maximum P levels (60 P kg ha^{-1}), respectively.

Similar to the GY values, biomass yield (BMY) of bread wheat also subjected for a highly significant difference ($p \leq 0.0001$) among the treatment means due to the use of different levels of P fertilizers which is again agreed with the findings stated by Getachew et al. (2015). Although some irregularity (in 2017 and 2018) observed on BMY trends, the overall biomass mean values showed an increasing trend as P levels added increased. The minimum and maximum BMY values were recorded on the control treatment (zero P) and treatment which received maximum P level (60 P kg ha^{-1}), respectively in all cropping years (Table 4).

Table 37. Response of applied P fertilizer on bread wheat grain and biomass yields

Treatment P kg ha^{-1}	Grain yield (kg ha^{-1})			Year Combined	Biomass yield (kg ha^{-1})			Year Combined
	2017	2018	2019		2017	2018	2019	
0	3761.0	2997.1	2262.2	3006.8	8763.4	8397.4	5203.0	7454.6
10	4042.5	3557.3	2959.4	3519.8	9214.7	9254.8	6725.4	8398.3
20	4208.9	3890.8	3310.1	3803.3	9738.2	9647.4	7505.3	8963.7
30	4297.9	4048.0	3498.6	3948.2	10098.0	10029.4	7943.4	9356.9
40	4357.6	4101.5	3583.4	4014.2	10109.5	9783.7	8295.9	9396.4
50	4386.8	4292.2	3698.8	4125.9	10162.9	9978.6	8450.9	9530.8
60	4489.9	4411.1	3716.4	4205.8	10154.9	10272.4	8476.0	9634.4
Mean	4220.7	3899.7	3289.8	3803.4	9748.8	9623.4	7514.3	8962.2
LSD (0.05)	158.6	171.3	166.3	98.5	356.1	711.2	337.1	298.1
Pr.	**	**	**	**	**	**	**	**

The critical P concentration (Pc) values were determined from the scatter diagram drawn using relative grain yields of wheat and the corresponding soil test P values obtained one year after the application of P levels (0–60 kg ha^{-1}). Based on Cate-Nelson Pc determination method, the Pc values in 2017, 2018, 2019 and over-year combined were 9, 12, 9 and 10 P mg kg^{-1} soil, respectively (Figure 3).

All Pc values could help to achieve a minimum of 70% of the wheat grain yeild production without any stress if other factors were found normal. However, if an initial soil P value found below the critical levels, additional P nutreint is needed. Hence, to quantify the required P to achieve the required grain yield, calculating of P nutrient based on equation 3 is required. The P requirement factor (*Pf*) one the other hand the amount of P required to raise the soil P by (1 Ppm) and could be computed from the difference between available soil test P values from plots which received (0–60) kg P ha^{-1} and initial P using the formula indicated in (Eq 2). Therefore, in this study, the calculated Pf values in 2017, 2018, 2019 and their over-year combination were 12.0, 5.2, 6.9 and 7.0, respectively (Table 5).

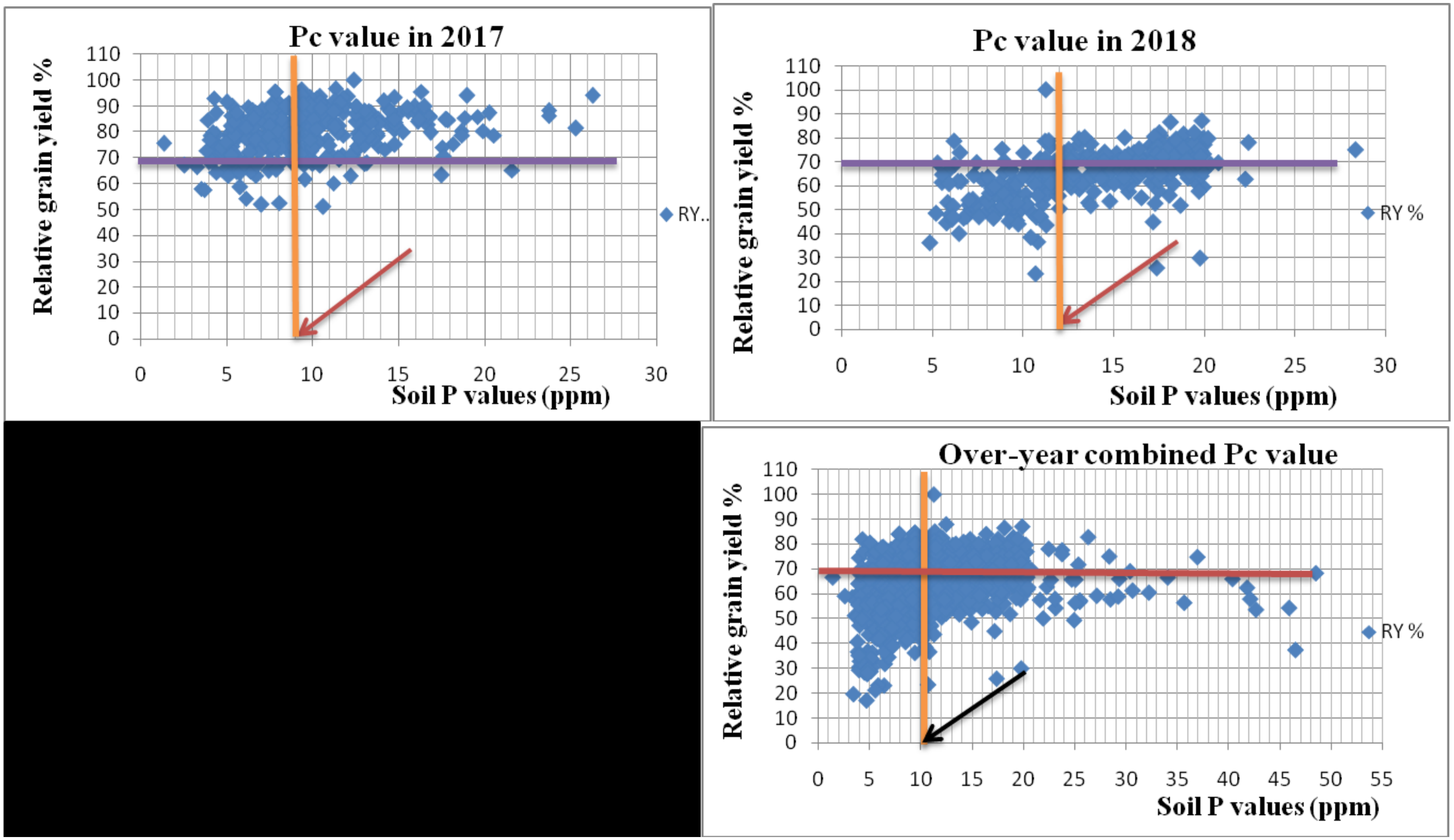

Figure 10. Cate-Nelson graphics for Pc values determination. The point on arrows indicates Pc for wheat on Nitisols

Table 38. The three years and their over-year combined phosphorus requirement factors (Pf) values.

P (kg ha^{-1})	2017				2018			
	range	Mean	P increase over control	Pf	range	Mean	P increase over control	Pf
0	1.4-17.6	7.4	-		4.8-17.4	8.7	-	
10	4.2-17.7	8.4	1.1	9.5	5.5-19.0	11.1	2.3	4.3
20	4.0-18.2	9	1.6	12.5	5.5-22.3	13.6	4.8	4.1
30	4.0-26.3	9.8	2.5	12.1	6.5-19.8	15.4	6.7	4.5
40	4.3-17.8	10	2.7	14.9	6.2-19.9	16.1	7.4	5.4
50	4.4-23.8	12.3	4.9	10.1	10.0-22.4	17	8.3	6.1
60	4.4-25.3	12.1	4.7	12.7	10.9-28.4	17.7	8.9	6.7
				12.0				5.2

	2019				Combined over year			
P (kg ha^{-1})	range	Mean	P increase over control	Pf	range	Mean	P increase over control	Pf
0	4.8-17.4	5.9	-		1.4-17.6	7.3	-	
10	5.5-19.0	7	1.1	8.8	4.2-17.7	8.8	1.5	6.7
20	5.5-22.3	8.7	2.8	7.1	4.0-18.2	10.4	3.1	6.5
30	6.5-19.8	10.8	4.9	6.1	4.0-26.3	12	4.7	6.4
40	6.2-19.9	11.3	5.4	7.4	4.3-17.8	12.5	5.2	7.8
50	10.0-22.4	14.3	8.4	6	4.4-23.6	14.5	7.2	7
60	10.9-28.4	16.3	10.5	5.7	4.4-25.3	15.4	8	7.5
				6.9				7.0

Conclusion and recommendations

Plant height, grain and biomass yield of the testing crop showed a highly significant difference ($p \leq 0.0001$) among treatment means due to phosphorus fertilization in both separate and over-year combined analysis results. Except some inconsistancey, all the above mentioned parameters showed linearly increasing trends as the amount of applied phosphorus increased in both separat and over year results. The obtained Pc and Pf values could be helpful to calculate site specific soil test based P_2O_5 fertilizer to acuire the required bread wheat yield on Nitisols in North West Ethiopia.Avialable soil phosphorus values showed an overall increasing trend due to the applied phosphorus amounts over years. Finally, 10 mg kg^{-1} Pc and 7.0 mg kg^{-1} soil Pf values were obtained from over-year combined analysis result. Using these two important values, it is better to do a validation study on the farmer fields having similar agro ecology and soil types to determine either the developed equation is economically acceptable or not.

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