academicresearchJournals

Vol. 8(1), pp. 44-52, January 2020
DOI: 10.14662/ARJASR2019.225

ISSN: 2360-7874
http://www.academicresearchjournals.org/ARJASR/Index.htm

Academic Research Journal of Agricultural Science and Research

Full Length Research

Soil-Test Based Phosphorus Fertilizer Recommendation Model for Wheat (*Triticum aestivum*) in Jamma District of Amhara Region

Abebe Getu and Abreham Teshager

Sirinka Agricultural Research Center, P. O. Box 74, Woldia, Ethiopia
Corresponding author: Abebe Getu Asfaw: abegetu3@gmail.com

Accepted 2 December 2019

Soil phosphorus (P) calibration for optimum wheat (*Triticum aestivum*) yield was conducted by uniformly applying a pre-determined optimum nitrogen fertilizer level of 138 kg ha^{-1} with 0, 46, 92, 138 and 184 kg P_2O_5 ha^{-1} in a randomized complete block design with three replications. Phosphorus fertilizer was applied three weeks before planting and was incubated under the soil. Soil samples from 0-20 cm depth were taken before and after incubation for Olsen's extractable P analysis. The soil analyses results showed that 13.4 kg P_2O_5 ha^{-1} is required to raise the soil test P level by 1 mg kg^{-1}. While, the agronomic data analyses revealed highly significant ($P \leq 0.01$) differences in the yields of wheat due to application of P fertilizer. The regression analyses of the soil test P after incubation with yield indicated a significant ($P \leq 0.05$) and strong quadratic (r=0.54) relation between grain yield and soil test P. Accordingly, the critical soil test P (Pc) level based on the Cate-Nelson graphical model was found to be 11.0 mg kg^{-1}. Thus, the equation developed for the P fertilizer recommendation (Pr) for wheat was found to be Pr (kg P_2O_5 ha^{-1}) = (11.0-Po) x 13.4, where Po is the soil test P level.

Keywords: Cate-Nelson, Jamma, phosphorus fertilizer, Olsen method, Soil test.

Cite this article as: Abebe G., Abreham T (2019). Soil-Test Based Phosphorus Fertilizer Recommendation Model for Wheat (*Triticum aestivum*) in Jamma District of Amhara Region. Acad. Res. J. Agri. Sci. Res. 8(1): 44-52

INTRODUCTION

Ethiopia is the second largest wheat producer after South Africa, in Sub-Saharan Africa (CSA, 2010). In terms of caloric intake, wheat is the second most important food crop in the country next to maize (FAO, 2014). However, low soil fertility is recognized as an important constraint to increased food production and farm incomes in Ethiopia (Henao and Baanante, 1999; Heluf, 2005).

Next to nitrogen, phosphorus (P) is often one of the most growth limiting nutrients for crop production in tropical soils. Most of the Vertisols in the Ethiopian highlands, 70% of the cases, are reported low in available phosphorus content, below 5 ppm (Berhanu, 1985). Phosphorus fractionation results show low levels of the available forms in the Ethiopian highland Vertisols. Phosphorus sorption studies indicated high sorption capacity of Vertisols and other soils in Ethiopia which is mainly controlled by content of Fe and Al oxides (Tekalign and Haque, 1991). The problem is further exacerbated by nutrient mining due to the low-input agriculture practiced in the country.

Therefore, P fertilizers should be applied to the soil to offset the P mined by crop production and removal with runoff along with the top soil. The role of chemical fertilizers in increasing yield is evident. The N and P fertilizer recommendations developed by FAO before thirty years (FAO, 1984) and extrapolated to different agro-ecologies in the country did not consider the differences in the nutrient demand of different crop types, variation in nutrient availability in different soil types and effect of climate on nutrient availability.

This approach, so far, has led over or under-application of fertilizers which in turn has resulted in either an economic loss or below optimum crop yields in the country. Hence, fertilizer recommendations should take into account the existing nutrient availability in the soil and should be developed specifically for different crops in different agro-ecologies (Bermudez and Mallarino, 2007). The objective of this study was, therefore, to develop soil-test based P fertilizer recommendation equation for wheat crop.

MATERIALS AND METHODS

Experimental Site Description

The study was conducted for four years from 2011-2014 under rainfed in Jamma District of South Wollo Zone of Amhara Region in Ethiopia. Jamma District lies between the geographical coordinates of 10^o 23’ to 10^o 27’ N and 39^o 07’ to 39^o 24’ E at an altitude of 2630 meters above sea level. The mean annual rainfall of the District is 868.2 mm. While, its annual mean minimum and maximum temperatures are, 9 and 21.6 ^oC, respectively. The District is characterized by its dominant Vertisols with heavy clay soil texture (Getachew, 1991). Some of the physico-chemical properties of the surface soils (0-20 cm) in the study area are shown in the table below (Table 1).

Table 1. Ranges of physical and chemical properties of the surface soils of the study district

Soil Property	Values range
pH	6.51-6.78
Organic matter (%)	1.02-1.63
Total Nitrogen	0.08-0.11
C/N ratio	6.7-11.8
Available Phosphorus (mg kg^{-1})	4.20-8.46
Ca ($cmol_C$ kg^{-1})	33.3-43.7
Mg ($cmol_C$ kg^{-1})	13.1-15.0
K ($cmol_C$ kg^{-1})	0.6-0.9
Na ($cmol_C$ kg^{-1})	0.3-0.4
CEC ($cmol_C$ kg^{-1})	50.1-58.0
PBS (%)	93.2-99.7
Sand, Silt and Clay	10.0-20.0, 20.0-25.0, 60.0-65.0, respectively

Note: CEC: Cation Exchange Capacity, PBS**:** Percentage Base Saturation

Experimental Procedures

The study was conducted on an improved wheat (*Triticum aestivum*) variety in two phases; the first phase was determination of optimum rate of nitrogen (N) interacting best with phosphorus (P) fertilizer for the second phase of the study; the second phase was calibration of Soil test P with wheat yields.

The first phase was conducted in the first year of the study on four farmer’s fields with different cropping history, slope and management practices. Considering N as the most plant growth limiting nutrient in the study area, determination of optimum rate of nitrogen (N) interacting best with P was conducted in the first phase of the study. Four levels of N (0, 46, 92 and 138 kg N ha^{-1}) and two levels of P (46 and 92 kg P_2O_5 ha^{-1}) were evaluated in a factorial arrangement laid in a randomized complete block design with three replications.

The second phase, which was the P-Calibration phase, of the study was conducted in the second and third experimental years of the study on five farmers’ fields in each year. In this phase of the study, five rates of P visa vis 0, 46, 92, 138 and 184 kg P_2O_5 ha^{-1} were evaluated in randomized complete block design with three replications. An optimum and uniform rate of the N fertilizer that was determined in the first phase of the study was applied to all experimental plots in a split; half at planting and the rest half 45 days after planting.

Fertilizer Application and Soil Sampling

In the P calibration phase, the P fertilizer rates were applied to the respective experimental plots by broadcasting three weeks before planting and incubated for three weeks period under the soil. Composite soil samples were collected at a depth of 0-20 before and after incubation from each experimental plot. The soil samples collected before and after incubation of the P-fertilizer were analyzed using Olsen’s method (Olsen et al., 1954). Half of the optimum N fertilizer was applied at planting and the remaining half was top dressed 45 days after planting.

Yield Data Collection and Data Analysis

Grain yield data was collected from the harvestable rows and finally was adjusted to 12.5% grain moisture level. Fresh and dry biomass yield and plant height were also measured from the harvestable rows. The collected data were subjected to analysis of variance (GLM procedure) using SAS software version 9.00 (SAS 2004). Significant difference between treatment means were delineated by Fisher's Protected Least Significant Difference method at $P \leq 0.05$. Simple non-linear regression analysis was run using SAS to determine the goodness of fit and correlation of yield response to application of P fertilizer.

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 (yield x (100/ maximum yield)) and Soil test P (STP) values of soil samples collected from each experimental plot after P incubation. All the relative yield values against the STP values of each treatment were laid out on a scatter diagram. Vertical and horizontal lines were superimposed on the scatter diagram so as to maximize the number of points in the first and third quadrants. The horizontal line on the X-Y coordinate is purposely drawn at the point on the Y-axis where 90% of the relative maximum yield was obtained. The vertical line divides the data into two classes (high probability of response and low probability of response). The point where the vertical line intersects the X-axis has been termed as the critical soil test level.

Determination of P Requirement Factor

The measure of the quantity of P nutrient per hectare required to raise the STP level of the surface soil (0-20 cm) by 1 mg kg^{-1} is known as P requirement factor (Pf). It was calculated as described in the Table below (Table 2).

Table 2. Methods for calculating P requirement factor (Pf).

P fertilizer rates (kg P_2O_5 ha^{-1})	Soil Test P level after incubation (mg kg^{-1})	Soil test P level increase over the control (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

Development of Equation

According to Cate and Nelson (1965) graphical model, to develop the equation for the determination of P fertilizer requirement, three parameters are required: 1. P critical level (P_c), 2. Soil test P value (P_0) and 3. P requirement factor (P_f). P_c is determined from the Cate-Nelson graph; P_0 is the existing level of Olsen's extractable available P in the surface soil and P_f is calculated as shown in the above Table (Table 2). Therefore, P fertilizer requirement (P_r) is the amount of P (kg P_2O_5 ha^{-1}) required to raise the STP level from the existing level to the critical level. It is calculated with the following formula:

$P_r = (P_c - P_0) \times P_f$

Where P_r = P fertilizer requirement (kg P_2O_5 ha^{-1})

P_c = Critical P level by Olsen's method (mg kg^{-1})

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

P_f = P requirement factor determined by the experiment

Verification of the Equation

A verification study was conducted on three farmers' fields for one extra year to verify the performance of the equation. In the verification study, four treatments including the full soil-test based P rate, 66% of the soil test based P rate, 133% of the soil test based P rate and the current agronomic P recommendation (46 kg P_2O_5 ha^{-1}) were evaluated on the grain yield of wheat in a randomized complete block design with three replications (farmers' fields were considered as replication).

RESULTS AND DISCUSSION

Phase I - Determination of Optimum Rate of N Fertilizer

The first year experimental result showed that the grain and biomass yields obtained were significantly ($P \leq 0.05$) affected by the interaction effects of N and P fertilizers (Table 3). Tthe highest mean grain and biomass yields of 3.27 and 8.69 t ha^{-1}, respectively, were obtained from the combined application of 138 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1}. Study reports of Eylachew (1996) and Schulthess et al., (1997) also indicated that increasing levels of N and P application and their interaction significantly and positively affected grain yield of wheat. Accordingly, N fertilizer rate of 138 kg ha^{-1} was selected as an optimum and the best interacting N rate with P fertilizer for the P calibration phase of the study. Giovani et. al. (2011) also reported maximum wheat yields, 3.1-3.9 t ha^{-1}, at the higher application rates of N, up to180 kg ha^{-1}. Similarly, Tayebih et al. (2011), revealed application of N fertilizer from 120-360 kg ha^{-1} had a significant effect on grain yield increment (46% at N_{120}, 72% at N_{240}, and 78% at N_{360}) compared to control.

Table 3. Interaction effects of N and P fertilizer rates on the grain and biomass yields of wheat

Treatment*	Grain yield (kg ha^{-1})	Biomass yield (kg ha^{-1})
46/0 (P_2O_5/N kg ha^{-1}**)**	1078.1de	3604.4e
46/46 (P_2O_5/N kg ha^{-1}**)**	1298.4cd	3975.6e
46/92 (P_2O_5/N kg ha^{-1}**)**	1998.3b	6355.6c
46/138 (P_2O_5/N kg ha^{-1}**)**	3032.9a	7455.6b
92/0 (P_2O_5/N kg ha^{-1}**)**	701.1e	2583.2f
92/46 (P_2O_5/N kg ha^{-1}	1616.3bc	4924.4d
92/92 (P_2O_5/N kg ha^{-1}**)**	1653.0bc	4933.3d
92/138 (P_2O_5/N kg ha^{-1}**)**	3273.4a	8688.9a
GM	1790.9	5132.6
CV (%)	19.3	10.7
SEM	345.2	549.2

*Treatment means within a column followed by the same letter are not significantly different at P = 0.05.

Phase II – Calibration of Soil Test P with Yields of Wheat

Yield responses to P fertilizer

The statistical analysis result revealed that there was a highly significant ($p \leq 0.01$) difference in the grain and biomass yield data in both experimental years due to the effect of different levels of P fertilizer applied. Similarly, the combined analysis result over the two experimental years also revealed a highly significant ($P \leq 0.01$) difference in the grain and biomass yield among the plots which received different P fertilizer levels (Table 4).

Data analysis obtained from each experimental year and the combined analyses result over the two years revealed that though the highest yield was recorded from application of 184 kg P_2O_5 ha^{-1}, application of 92 and 138 kg P_2O_5 ha^{-1} gave statistically similar yield. While, the combined analyses result showed that application of 184 kg P_2O_5 ha^{-1} gave highest grain and biomass yields of 3.1 and 9.7 t ha^{-1}, respectively, followed with insignificant ($P > 0.05$) difference by the grain and biomass yields measured from application of 138 kg P_2O_5 ha^{-1} (Table 4).

Minale et al. (2002) reported similar results on Vertisols in Bichena District of North-Western Ethiopia in which maximum wheat yield of 33.2 t ha^{-1} was recorded by application of 138/92 kg N/P_2O_5 ha^{-1}. Kaleem et al. (2009) also reported a maximum wheat yield of 35.6 t ha^{-1} by applying 128/128 kg P/N ha^{-1} indicating importance of P at its higher rates to achieve maximum wheat productivity.

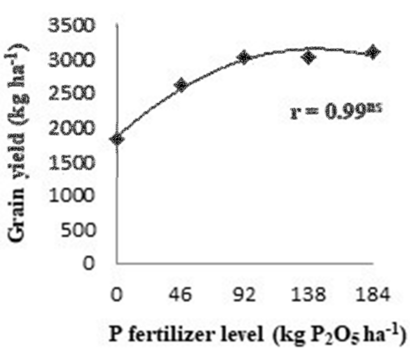
Table 4. Effect of application of different P fertilizer rates on the grain and biomass yields (kg ha^{-1}) of wheat in 2012 and 2013 cropping seasons

Treatment*	2012 Grain Yield	2012 Biomass weight	2013 Grain Yield	2013 Biomass weight	Combined over years Grain yield	Combined over years Biomass weight
0 P_2O_5 + 138 N kg ha^{-1}	1822.5c	6388.9c	1530.3d	5832.8c	1732.6d	6217.8b
46 P_2O_5 + 138 N kg ha^{-1}	2611.6b	8916.7b	2404.9bc	9496.8b	2528.9c	9148.7a
92 P_2O_5 + 138 N kg ha^{-1}	3033.8a	9954.5a	2185.7c	9365.7b	2676.7bc	9706.6a
138 P_2O_5 + 138 N kg ha^{-1}	3011.4a	9963.0a	2805.9b	8544.3b	2948.2ab	9526.5a
184 P_2O_5 + 138 N kg ha^{-1-}	3088.1a	9218.1b	3497.1a	14960.8a	3122.2a	9696.7a
GM	2734.3	8943.6	2302.7	8934.8	2594.2	8940.7
CV (%)	10.9	9.1	11.4	9.9	17.0	14.4
LSD	269.7	735.6	483.3	1633.7	325.4	947.5

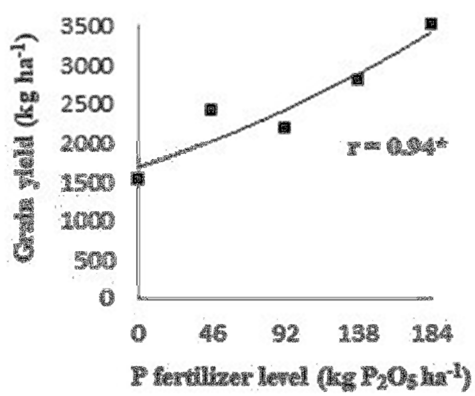
*Treatment means within a column followed by the same letter are not significantly different at P = 0.05.

As it is depicted in Figure 1 (a), (b) and (C), though it was not statistically significant in the first year, the second year and the pooled analyses results over the two years showed that there was a significant ($p \leq 0.05$) quadratic yield response to the application of P fertilizer. Asegelil et al., (1994) had also conducted a P response study on red and black soils in Northwestern Ethiopia and reported a tendency for yield of wheat to increase up to a certain level of P beyond which the yield tends to increase with diminishing returns. Similarly, as it is shown in figure 2 below, like the grain yield, the biomass yield result also showed similar quadratic trend of response to the application of P fertilizer both in the first and second experimental years.

a)



b)



c)

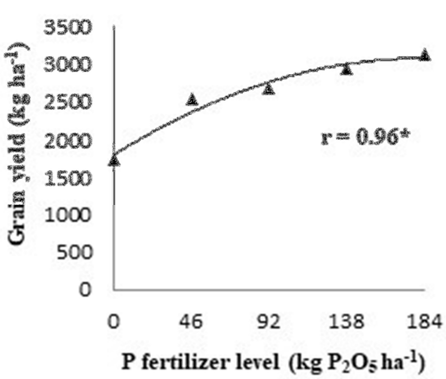
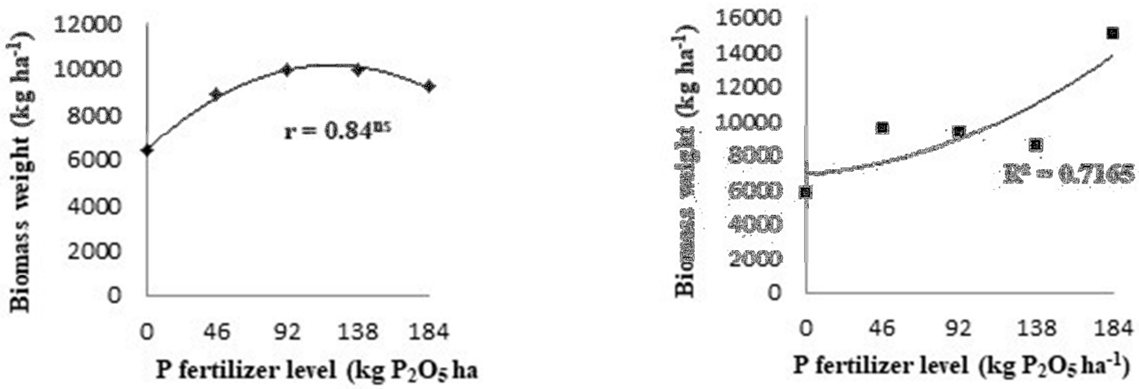


Figure 1. Yield response of wheat to P fertilizers in a) 2012 b) 2013 and c) pooled over years

a) b)



c)

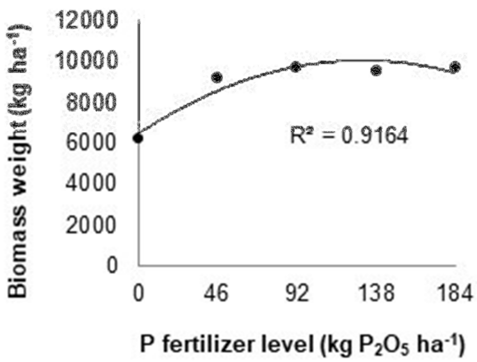
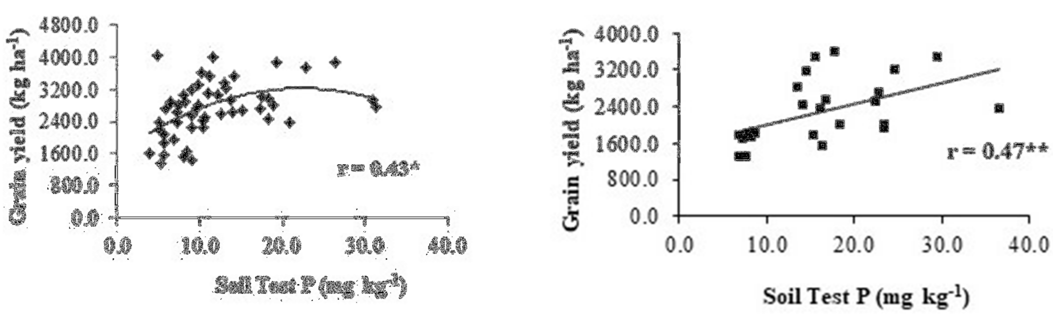


Figure 2. Effect of application of different P fertilizer levels on biomass yield of wheat in a) 2012 b) 2013 and c) pooled over years.

Relationship between yield and soil test P

The regression analyses results of the grain yield and the Olsen's extractable STP data collected in the first and second experimental years of the P calibration phase indicated that there were significant ($p \leq 0.05$) quadratic ($r = 0.43$) and linear ($r = 0.47$) relations between the grain yield and STP in the first and second year, respectively (Figure. 3. a and b). Similarly, the combined analyses over the two experimental years, as shown in Figure. 3 (c) revealed that there was a significant ($P \leq 0.05$) quadratic (r=0.54) relation between grain yield and STP.

a) b)



c)

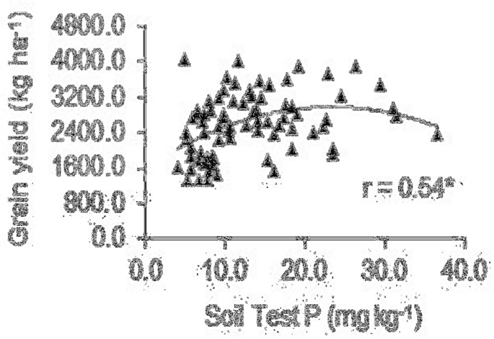


Figure 3. Relationships between soil test P and grain yield in a) 2012, b) 2013 and c) combined over years. (* and ** significant at 5% and 1% probability levels, respectively).

Critical soil P (Pc) determination

Based on the Cate and Nelson graphical model, the critical STP level beyond which significant yield response to application of P fertilizer is unlikely was found to be 11 mg kg^{-1} (Fig 4). Similar studies conducted in North-central Montana showed that the critical STP level based on Olsen's method for spring wheat is 16 mg kg^{-1} (Grant et al., 1998). While, other study conducted in Australia by Moody and Bolland (1999) indicated that the critical STP level by Colwell soil testing method for wheat crop ranges from <15 mg kg^{-1} for low P soils with low P sorption to >90 mg kg^{-1} with high P status and moderate to high P sorption.

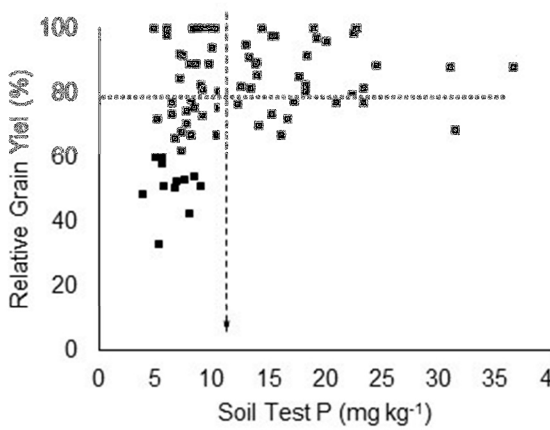


Figure 4. A scatter diagram showing STP (mg kg^{-1}) Vs relative grain yield (%) and the STP critical level

Phosphorus requirement factor (Pf) determination

The amount of fertilizer that is required to increase the STP level of the surface soil by 1 mg kg^{-1} is known as the P requirement factor (Pf). The Pf, as shown Table 5, was obtained to be 13.4 kg P_2O_5 ha^{-1}, which implies 13.4 kg P_2O_5 ha^{-1} is required to raise the STP level by 1 mg kg^{-1}.

Table 5. Calculation of the P requirement factor (Pf)

P fertilizer level (kg P_2O_5 ha^{-1})	Soil-test P (mg kg-1) after P incubation	Soil-test P (mg kg^{-1}) difference from the control treatment	P requirement factor (Pf)
0	6.7	-	-
46	10.6	3.9	11.8
92	13.2	6.6	14.1
138	15.7	9.0	15.3
184	21.6	14.9	12.4
Mean		8.6	13.4

Thus, finally, the P fertilizer rate recommendation for Jamma can be made using the following equation: Pr = 13.4 x (11.0 - Po), where Pr = P fertilizer required (kg P_2O_5 ha^{-1}) and Po = Soil test P (mg kg^{-1}) value.

Phosphorus Fertilizer Recommendation

Based on the P calibration and the P-critical level determined in the study, Olsen's extractable P of the surface soil (0-20 cm) of 90% of the farmers' fields included in the study were found to be below the critical level, which indicated P fertilizer application up to the critical level is required for maximum yield. However, for the rest of the farmers' fields of which Olsen's extractable P of the surface soil (0-20 cm) exceeded the P critical level, only maintenance of the soil P reserve to stay optimum is required.

Verification of the P-calibration equation

The verification result showed that the highest grain yield was obtained from application of the soil test based P-fertilizer rate which was significantly ($P \leq 0.05$) higher than the grain yields obtained from application of 66 and 133% of the soil test based P-fertilizer rate and the agronomic P recommendation (Table 6). This indicated that the P calibration equation developed in the study is more efficient than the other P rates tested in predicting the optimum P fertilizer required for optimum wheat yield.

Table 6. Effect of application of the full soil-test based P rate as compared to 66 and 133% of the soil test based P-fertilizer rate and the current P rate on grain yield

Treatment*	Grain yield (kg ha^{-1})
1. 66% of soil test P + Recommended N	3304.7b
2. 100% of soil test P + Recommended N	3748.0a
3. 133 % of soil test P + Recommended N	3078.7b
4. Current P recommendation (46 kg P_2O_5 ha^{-1}) + Recommended N	3278.3b
GM	3352.4
CV (%)	7.7
LSD	360.0

*The recommended N is 69 kg ha^{-1}. *Treatment means within a column followed by the same letter are not significantly different at P = 0.05.

CONCLUSION AND RECOMMENDATION

Crop response to fertilizers varies depending upon soil, climate and crop type factors. Thus, nutrient calibration for different agro-ecologies is essential to make fertilizer recommendations. Taking these in to account, this study was conducted to calibrate Olsen's extractable soil P for optimum wheat yield. The result obtained in this study showed that 90% of the farmers' fields included in the study showed a significant yield response to application of P fertilizer. Thus, based on the Cate and Nelson graphical model, the soil test based P fertilizer rate determination equation developed for the district is Pr = (11.0-Po) x 13.4. Therefore, using this equation, it is possible to make P fertilizer recommendations for optimum wheat yield for Jamma District and similar agro-ecologies.

ACKNOWLEDGEMENTS

We would like to thank Sirinka Agricultural Research Center for providing the fund and facility support from the commencement up to the end of the experiment. We would also like to appreciate Debrebirhan Agricultural Research Center laboratory technicians for allowing us to use their soil laboratory facility to run the soil analysis.

REFERENCES

Asgelil Dibabe, Andualem Taye, Sahemedhin Sertsu (1994). A Phosphorus Calibration Study on Bread Wheat in Northwestern Ethiopia.

Berhanu Debele (1985). The Vertisols of Ethiopia: their properties, classification and management. In: Fifth Meeting of the Eastern African Sub-Committee for Soil Correlation and Land Evaluation.

Bermudez M, Mallarino AP (2007). Impacts of variable rate phosphorus fertilization based on dense grid soil sampling on soil-test phosphorus and grain yield of corn and soybean. Agron. J. 99:822-832.

Cate RB, Nelson LA (1965). A rapid method for correlation of soil test analysis with plant response data. Int. Soil Testing Series Tech. Bull. No. 1.

CSA (Central Statistical Authority). 2010. Agricultural Sample Survey. Report on Forecast of Area and Production of Major Crops. Statistical Bulletin 271.Addis Ababa, Ethiopia.

Eylachew Zewdie (1996). Effect of nitrogen and phosphorus fertilizers on bread wheat grain yield on three soil types in Ethiopia. In: Douglas G. Tanner, Thomas payne, and O.S. Abdalla(eds.). Proceeding of the 9th Regional Wheat Workshop for Eastern, Central and Southern Africa, CIMMYT: AA, Ethiopia.163p.

FAO (Food and Agricultural Organization of the United Nations) 1984. World Food Report 1984, FAO, Rome.

FAO (Food and Agricultural Organization), 2014. Crop Production Data. Rome: FAO. Accessed at http://faostat.fao.org.

Getachew Asamenew (1991). A study of the farming systems of some Ethiopian highland Vertisols areas (draft report). ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. 150p.

Giovani B, Elesandro B, Eduardo B, Eduardo S, Cristiano L, Cilas P (2011). Agronomic performance of wheat cultivars in response to nitrogen fertilization levels. actasciagron, vol 34i3.14468.

Grant J, Gregg C, Greg K, Dave W (1998). Fertilizing Spring Wheat with Phosphorus. Western Triangle Ag Research Center, Northern Ag Research Center, Western Triangle Ag Research Center, and Central Ag Research Center Montana State University. Fertilizer Facts, Number 19.

Heluf Gebrekidan (2005). Soil and Water Conservation Practices (Tied Ridges and Planting Methods) on Cultivated Lands of Eastern Ethiopian Highlands: Experience of Soil and Water Research Program, Alemaya University. Soil Science Technical Bulletin No. 2. Department of Plant Sciences, AU, Alemaya.

Henao J, Baanante C (1999). Estimating rates of nutrient depletion in soils of agricultural lands of Africa. International Fertilizer Development Center (IFDC). Musck Shoals, Alabama USA.

kaleem Shuaib, Muhammad Ansar, Muhammad Anjum Ali, Ahmad Sher, Ghulam Ahmad and Muhammad Rashid (2009). Effect of phosphorus on the yield and yield components of Wheat variety “inqlab-91” under rainfed conditions. Sarhad J. Agric. Vol.25, No.1.

Minale Liben, Alemayehu Assefa, Tanner, DG, Tilahun Tadesse, (2002). The response of bread wheat to N and P application under improved drainage on bichena Vertisols in North-Western Ethiopia. Dublin Core Metadata Initiative.

Moody PW, Bolland MDA (1999). Phosphorus. In “Soil Analysis: an interpretation manual”. (Eds KI Peverill, LA Sparrow, DJ Reuter). Pp 187-220.

Olsen SR, Cole CV, Watanabe FS, Dean LA (1954). Estimation of available phosphorus in soils by the extraction with sodium bicarbonate; Circ. 939; U.S. Dep. of Agric.

(SAS) Statistical Analysis System. 2004. Institute. SAS/STAT user’s guide. Proprietary software version 9.00. SAS Institute, Inc., Cary, NC.

Schulthess UR, Feil B, Jutzi SC (1997). Yield independent variation in grain nitrogen and phosphorus concentration among Ethiopian wheat: Agronomy Journal. 89(3): 497-506.

Tayebeh Abedi, Abbas Alemzadeh, Seyed Abdolreza Kazemeini (2011). Wheat Yield and Grain Protein Response to Nitrogen Amount and Timing. Australian Journal of Crop Science. AJCS 5(3):330-336.

Tekalign Mamo, Haque I (1991). Phosphorus status of some Ethiopian soils. III. Evaluation of soil test methods for available phosphorus; Tropical Agriculture (Trinidad); 68:51–56.