Soil Test Based P-fertilizer Recommendation Equation for Eastern Amhara Region

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Abstract

An on-farm experiment was conducted from 2009 to 2011 in Jamma and Wadla Districts of Eastern Amhara. The purpose of the study was to develop soil-test based P fertilizer recommendations for wheat. The experiment was comprised of 5 rates of P (0, 46, 92, 138 and 184 kg P_2O_5 ha^{-1}) applied three weeks before planting to soils of varying available soil P values. A uniform nitrogen rate of 138 kg ha^{-1} was applied in split to all experimental plots at planting and tillering. Treatments were laid in RCBD with three replications. Soil samples were collected from each plot before P fertilizer application and at planting and were analyzed for Olsen extractable P. The result obtained at both locations in both years showed that there was highly significant ($P \leq 0.01$) difference in grain and biomass yields among the P rates. The soil test results of both locations indicated that there was highly significant ($P \leq 0.01$) difference in available soil P among treatments. The regression analysis of available P with grain and biomass yields combined over years also showed significant ($P \leq 0.05$) quadratic ($r=0.54$) relation between the grain yield and available soil P at Jamma. While, there was no significant ($P>0.05$) relation between grain yield and available P in both years at Kon. This might be attributed to high P fixation due to acidic soil reaction at Kon. Based on the Cate and Nelson graphical model, the critical soil test P (Pc) at Jamma and Kon was 11.0 mg kg^{-1} and 11.3 mg kg^{-1}, respectively. While, the P requirement factor (Pf) for Jamma and Kon was 13.4 and 35.0, respectively. Finally, the equation developed for P fertilizer recommendation (Pr (kg P_2O_5 ha^{-1})) is (11.0-Po) x 13.4 for Jamma and (11.3-Po) x 35.0 for Kon.

Key words*:* Cate and Nelson, Critical, Jamma and Kon, Recommendation, Whea

Introduction

Low soil fertility is recognized as an important constraint to increased food production and farm incomes in Ethiopia (Henao and Baanante, 1999; Heluf, 2005). Phosphorus is often one of the most limiting nutrients for crop production in tropical soils. Phosphorus deficiency is particularly widespread and remains to be a major plant nutrient constraint in rain-fed upland farming systems throughout the tropics. Most Ethiopian soils are deficient in P when assayed by chemical methods (Tekalign and Haque, 1991; Tekalign et al., 1993; Sanchez et al., 1997). This deficiency is mainly caused either by the inherent characteristics of the parent material or by the strong sorption of PO_4^{3-} to Al and Fe-(hydr)oxides, which turns large proportions of total soil P into unavailable forms. The problem is further exacerbated by nutrient mining due to the low-input agriculture practiced in the country.

Therefore, inorganic/organic P containing fertilizers should be supplied to the soil to counterbalance 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. Fertilizers accounted for more than 50% of the increase in yield (FAO, 1984). The N and P blanket fertilizer recommendations, which was developed by FAO and extrapolated to different agro-ecologies in the country do not consider the difference 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 has lead to over- or under-application of fertilizers in different agro-ecologies which in turn resulted in either an economic loss or low crop yields. Hence, fertilizer recommendations should take into account the existing nutrient availability in the soil and should be developed for different crops in different agro-ecologies (Mengel, 1982). Different research findings conducted on yield response calibration of wheat crop against available P content of surface soil indicated that the critical levels of soil P extracted by Olsen method fall in the range of 10 - 17 mg kg^{-1} (Cottenie A., 1980). However, critical levels of soil P for yield vary depending on soil reaction, soil sorption capacity of P and P-use efficiency of the crop. The objective of this study was, therefore, to calibrate soil P test against yield response of wheat and in due course develop soil-test based P fertilizer recommendation equations for wheat crop in Jamma and Wadla Districts of Eastern Amhara.

Materials and Methods

Experimental Site Description

The study was conducted in Jamma and Wadla (Kon) Districts of Eastern Amhara from 2009 - 2011 during the main cropping seasons. 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 (masl). The mean annual rainfall, annual mean minimum and maximum temperatures of the District are 868.2 mm, 9 and 21.6 ^oC, respectively. The dominant soil type in the district is Vertisols. While, Wadla District, particularly the study area - Kon is situated at an altitude ranges of 2000 - 2800 masl. The mean annual rainfall ranges from 800-1200 mm, and the mean minimum and maximum temperature of the District are 17 and 22 ^oC, respectively (WWARDO, 2010). The dominant soil types in the District are Regosols and Lithosols.

Site Selection and Experimental Procedure

Phase I (Determination of Optimum N fertilizer)

The experiment was conducted in two phases; In the first phase of the experiment (year 1), based on the low of minimum principle and considering N as the other most plant growth limiting nutrient, investigation of the optimum rate of N that could interact best with phosphorus (P) and gave highest yield was conducted. In this phase, a total of 8 treatments, comprised 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}) combined in a factorial arrangement, were tested.

Two farmers' fields per location with different cropping history, slope and management practices were selected. Composite surface (0-30) soil samples were collected before planting and were analyzed for available P content by Olsen method (Olsen and Sommers, 1982). At each site, the field experiment was arranged in randomized complete block design with three replications. The test crop, wheat, was sown by broadcasting (farmers' practice). The N fertilizer was applied by broadcasting in split, half at planting and the rest half was top dressed at tillering. While, the P fertilizer was applied all as basal by broadcasting.

Phase II (P-Calibration Phase)

The second phase, P-calibration, of the experiment was conducted in the second and third year of the experiment. Five on farm experimental sites in each district were selected based on difference in cropping history, slope and management practices. Five rates of P (0, 46, 92, 138 and 184 kg P_2O_5 ha^{-1}) were tested in randomized completed block design with three replications. A uniform rate of the N fertilizer that was determined and found optimum in the first phase was applied to all experimental plots in split (half at planting and half at tillering). While, P fertilizer were applied and incubated in the soil three weeks before planting. Planting was done by broadcasting method (farmers' practice).

Soil Sampling and Analysis

Composite surface soil samples were collected before P fertilizer application (three weeks before planting). Surface soil samples were also collected at the time of planting (after three weeks of P incubation period in the soil) from each experimental plot. The soil samples collected before and after incubation of the P-fertilizer were analyzed using Olsen's method (Olsen and Sommers, 1982) with the procedure outlined by Sahlemdihin and Taye (2000).

Yield Data Collection

Grain yield data was collected from the harvestable plots, adjusted to 12.5% seed moisture level. Fresh and dry biomass yield and plant height were also measured from the harvestable rows.

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 (available soil P) values of each treatment after incubation. All the relative yield values against the available soil P 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 soil test P level by 1 mg kg^{-1} is known as P requirement factor (Pf). It was calculated by dividing each fertilizer rates to the respective differences between available P values in the soil samples of the control plots and the plots that received the respective P fertilizer rates (Table 1).

Table 1. Table for calculating P requirement factor (Pf)

P fertilizer rates (kg P_2O_5 ha^{-1})	Olsen AVAILABLE SOIL P levels after incubation (mg kg^{-1})	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

Developing the Equation

To develop the equation for the determination of the P fertilizer requirement, three parameters were required: P critical level (P_c), Soil test P level (P_0) and P requirement factor (P_f). P_c is determined from the Cate-Nelson graph, P_0 is the existing level of avail. P in the given soil by the appropriate method of analysis and P_f is calculated as shown above in Table 1. Therefore, P fertilizer requirement (P_r) is the amount of P required to raise the available soil P from the existing level to the critical level. It was calculated with the 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

Results and Discussions

Phase I (Determination of Optimum N fertilizer)

The first year experimental result showed that there were highly significant differences ($P \leq 0.01$) in grain and biomass yields among the treatments for both locations (Kon and Jamma). As it is elucidated in Table 2, the main effects of N and P fertilizer rates had significant ($P \leq 0.05$) effect on grain and biomass yields at Kon trial site. While, at Jamma, the grain and biomass yields were significantly ($P \leq 0.05$) affected by the interaction of N and P (Table 3). The highest grain (4.2 t ha^{-1}) and biomass (11.1 t ha^{-1}) yields (Table 2) were obtained from 138 kg N ha^{-1} followed by 92 kg N ha^{-1} at Kon.

Table 2. Main effects of N and P fertilizers rates on the grain and biomass yields (kg ha^{-1}) of wheat at Kon trial site

N level (kg ha^{-1})*	**Grain yield**	**Biomass weight**
0	2787.7c	7479.2c
46	3445.6b	9260.4b
92	3876.7ab	10145.8ab
138	4211.6a	11072.9a
GM	3580.4	9489.6
CV (%)	16.1	13.0
LSD (0.05)	480.1	1029.4
P level (kg P_2O_5 ha^{-1})*		
46	3402.6b	9052.1b
92	3758.1a	9927.1a
GM	3580.4	9489.6
CV (%)	16.1	13.0
LSD (0.05)	339.5	727.9

**Treatment means followed by the same letter are not significantly (P>0.05) different.*

While, at Jamma (Table 3), the highest grain and biomass yields were obtained from 138/92 N/P_2O_5 kg ha^{-1} followed by 138/46 N/P_2O_5 kg ha^{-1}. Accordingly, N fertilizer rate of 138 kg ha^{-1} was selected as an optimum rate for the second phase of the study at both locations.

Table 3. Interaction effects of N and P fertilizer rates on the grain and biomass yields (kg ha^{-1}) of wheat at Jamma trial site

Treatment* (P_2O_5/N kg ha^{-1})	Grain yield	Biomass weight
46/0/46	1078.1de	3604.4e
46/46	1298.4cd	3975.6e
92/46	1998.3b	6355.6c
138/46	3032.9a	7455.6b
0/92	701.1e	2583.2f
46/92	1616.3bc	4924.4d
92/92	1653.0bc	4933.3d
138/92	3273.4a	8688.9a
GM	1790.9	5132.6
CV (%)	19.3	10.7
LSD (0.05)	345.2	549.2

**Treatment means followed by the same letter are not significantly (P>0.05) different.*

Phase II (P-Calibration Phase)

Jamma study site

Effect of the P fertilizer applied on available soil P

Analysis of variance on available soil P after incubation in both years showed highly significant ($P \leq 0.01$) difference among treatments (Table 4). Combined over years, the highest significant available soil P was recorded from the treatment which received 184 kg P_2O_5 ha^{-1} followed by 138, 92 and 46 kg P_2O_5 ha^{-1} (Table 4).

Table 4. Effect of different levels of P fertilizer applied on available soil P

P levels* (kg P_2O_5 ha^{-1})	Available Soil P (mg kg^{-1})		
	2010	2011	Combined over years
0	6.5d	7.0c	6.7e
46	8.4c	13.9bc	10.6d
92	11.0b	16.3b	13.2c
138	11.4b	25.5a	15.7b
184	20.9a	29.5a	21.6a
GM	11.8	16.0	13.2
CV (%)	12.3	24.2	18.4
LSD (0.05)	1.3	7.2	1.8

**Treatment means followed by the same letter are not significantly (P > 0.05) different.*

Unlike the grain yield, biomass yield didn't show significant relationship (P > 0.05) with available soil P in both years (Fig. 2).

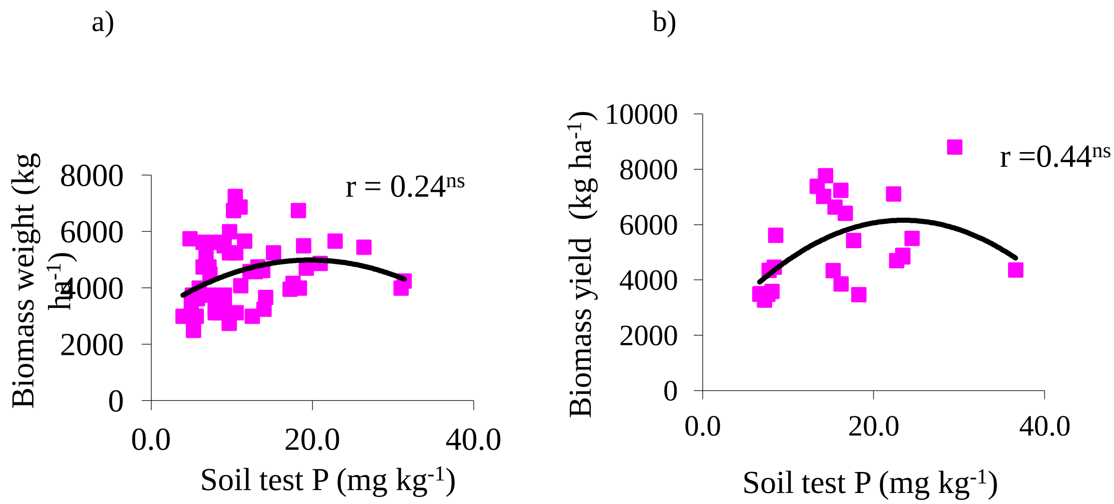

Figure 2. Relationship between available soil P and biomass weight in a) 2010 and b) 2011 growing seasons (ns-non significant at 5% probability level)

Critical P Concentration

The critical soil test P beyond which there is little probability of significant yield response to P fertilizer applied based on the Cate and Nelson graphical model, as shown in Fig. 3, is found to be 11.0 mg kg^{-1}.

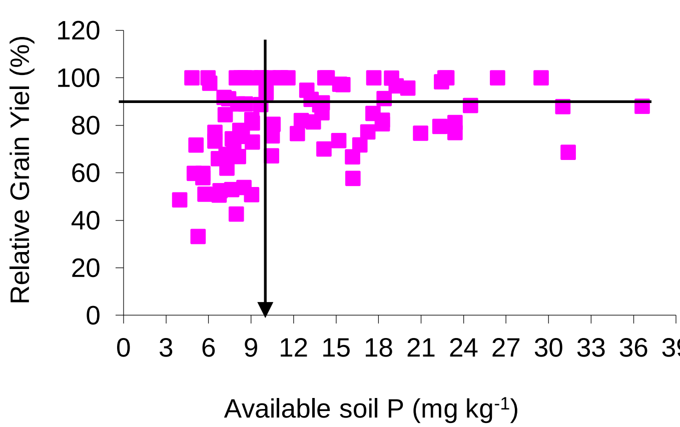

Figure 3. A scatter diagram showing the relationship between soil test P (mg kg^{-1}), relative grain yield (%) and P-critical

Determination of P Requirement Factor (Pf)

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

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

P level (kg P_2O_5 ha^{-1})	Available Soil P (mg kg^{-1})	Available Soil P difference from the control (mg kg^{-1})	P requirement Factor (Pf)
0	6.7036	-	-
46	10.5948	3.8912	11.82155
92	13.2122	6.5086	14.13514
138	15.7474	9.0438	15.25907
184	21.5752	14.8716	12.37258
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 = The P fertilizer required (kg P_2O_5 ha^{-1}) and Po = the soil test P level (mg kg^{-1}).

Phosphorus fertilizer recommendation

Based on the equation developed by this study, the soil analysis results, nine out of the ten farmers' fields at Jamma required P application. However, there was no response for one farmer's field and thus only some P fertilizer is required to apply to maintain the soil P reserve stay optimum. The calculated result of the P fertilizer required for the nine farmers' fields is given below (Table 6).

Table 6. P fertilizer recommendations

Farmer	Available Soil P (mg kg^{-1})	P fertilizer required (kg P_2O_5 ha^{-1})	TSP/DAP required (qt ha^{-1})
1	8.8	29.5	0.64
2	10.2	11.0	0.24
3	5.0	79.9	1.73
4	3.1	106.0	2.30
5	6.2	63.8	1.39
6	10.5	6.8	0.15
7	7.3	49.2	1.07
8	8.1	39.0	0.85
9	13.2	-	-
10	6.6	59.6	1.30

Kon study site

Effect of P fertilizer applied on available soil P

Analysis of variance of the available soil P after incubation revealed significant ($P \leq 0.05$) to different P rates on plant available soil P (Table 7). The highest plant available soil P was obtained from 184 kg P_2O_5 ha^{-1} followed by 138 P_2O_5 ha^{-1}.

Table 7. Effect of different levels of P fertilizer applied on plant available soil P

P fertilizer levels* (kg P_2O_5 ha^{-1})	Available Soil P (mg kg^{-1})		
	2010	2011	Combined over years
0	8.8c	9.6c	9.2c
46	9.6bc	11.3bc	10.8bc
92	10.2bc	12.5bc	11.5b
138	10.7b	13.5b	11.9b
184	16.8a	19.7a	18.3a
GM	11.1	13.1	12.2
CV (%)	15.6	21.4	19.9
LSD (0.05)	1.8	2.9	1.7

**Treatment means followed by the same letter are not significantly ($P > 0.05$) different.*

Relationship between yield and available soil P

The regression analysis, as shown in Fig. 4, revealed that there was no significant ($P > 0.05$) relation between the relative grain yield and available soil P in both experimental years. These might be attributed to acidic soil reaction of the study site which might lead to fixation of available P.

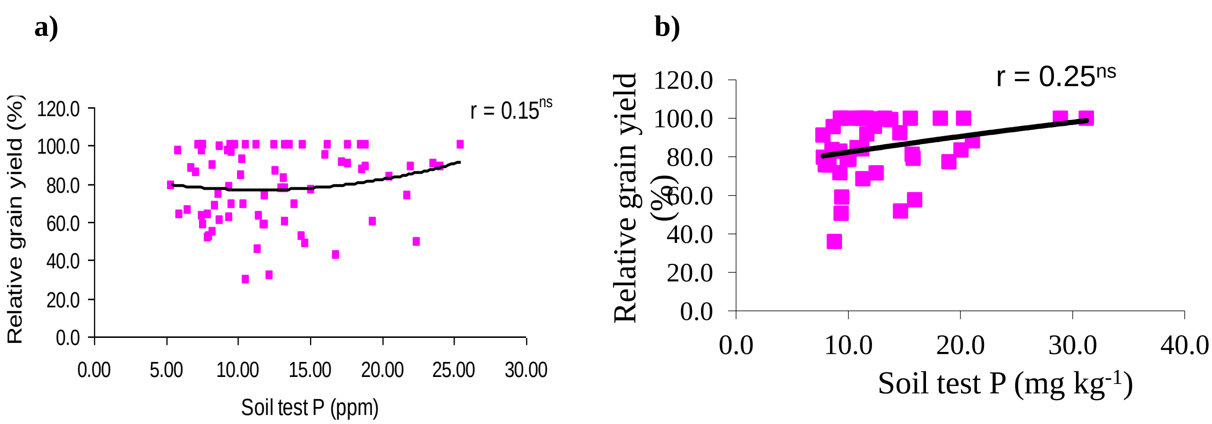

Figure 4. Relationships between Available Soil P and grain yield in the a) 2010 and b) 2011 growing seasons (ns-non significant)

Critical P concentration (Pc)

The critical soil P (Pc) level is determined by using the Cate-Nelson graphical model (Fig. 7). As it is illustrated in the graph below, the Pc beyond which there is little probability of yield response to fertilizer application is found to be 11.3 mg kg-1 (11.3 mg kg^{-1}

following equation; **Pr = (11.3-Po) x 35.01**, where Pr = The P fertilizer required (kg P_2O_5 ha^{-1}) and Po = The available soil P level (mg kg^{-1}).

Phosphorus fertilizer recommendation

Based on the equation and the P-critical (Pc) developed in this study site, seven (7) farmers' fields required P fertilizer application. While, no yield response to P fertilizer on two farmers' fields. Based on the equation, the P fertilizer requirement of those farmer's fields considered in the study is given in Table 11 below.

Table 9. P fertilizer recommendations

Farmers	Available Soil P (mg kg^{-1})	P fertilizer required (kg P_2O_5 ha^{-1})	TSP/DAP required (qt ha^{-1})
1	7.65	127.9	2.8
2	11.83	-	-
3	10.41	31.0	0.68
4	15.50	-	-
5	9.95	47.1	1.02
6	8.84	86.0	1.87
7	10.19	38.9	0.85
8	8.84	86.0	1.87
9	8.84	86.2	1.88

Conclusion and Recommendation

Phosphorus is known as one of the most growth limiting nutrients in crop production next to nitrogen. Thus, P should be supplied to the soil in the form of organic or inorganic fertilizers to counterbalance the P removed by the crops, leached and washed away with runoff. Crop response to fertilizers varies depending upon the climate, soil type and the crop variety. Thus, location- and soil-test based fertilizer recommendations should be made for each crop to develop economically and environmentally sound optimum fertilizer recommendation.

Thus, this study was conducted to develop soil test based P fertilizer recommendation for wheat crop at Jamma and Kon Districts. The result obtained in the study at Jamma showed that except one farmer's field, the rest farmers' fields included in the study (90% of the farmers' fields included in the study) showed significant yield response to P fertilizer. While, 80% of the farmers' fields included in the Kon study site showed significant yield response to P fertilizer. The soil test based P fertilizer rate determination equations developed for Jamma was Pr = (11.0-Po) x 13.4 and for Kon was Pr = (11.3-Po) x 35.3. Therefore, using the equations developed, it is possible to make P fertilizer recommendations for wheat crop for Jamma, Kon and similar agro-ecological areas.

References

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