Validation of Soil Test Based Phosphorus Fertilizer Recommendations for Bread Wheat (*Triticum aestivum* L.) on Vertisols of North Shewa Zone

Beza Shewangizaw[1*], Kenzemed Kassie[1], Shawel Asefa[1] and Tesfaye Feyisa[2]

[1]Debre Birhan Agricultural Research Center, P.O.Box: 112, Debre Birhan, Ethiopia

[2]Amhara Region Agricultural Research Institute, Bahir Dar, Ethiopia

*Corresponding author: Beza Shewnagizaw: email: bezashewangezaw@gmail.com

Abstract

This study was conducted to verify the recommended soil test based calibration equation for phosphorus (P) fertilizer around Moretina Jiru and Syadebirnawayu Woredas for two treatments were compared but in the second year, one additional treatment was considered. Before planting, the initial soil P level was analyzed using Olsen method, and the soil P level ranged from 5.8 to 11.4 ppm. Based on the P calibration model of Debre Berhan Agricultural Research Center (DBARC), the fertilizer requirement of the site ranged from 17 to 102 P_2O_5 kg ha^{-1}. Nevertheless, in the second year, the initial P level of the site was between 5.04-14.29 ppm and the need for P_2O_5 ranged from zero to 110.4 kg P_2O_5 ha^{-1} with DBARC model. In contrast, with agronomic phosphorus fertilizer recommendation, the need for P_2O_5 was 138 kg ha^{-1} for both locations for the two years. The first year result revealed that using soil test based fertilizer application, about 51% of the P_2O_5 to be applied could be saved compared to the agronomic fertilizer recommendation (138 P_2O_5 kg ha^{-1}). However, in the second year DBARC and GARC model, the amount of P_2O_5 fertilizer to be applied could be reduced by 65.94% and 44.2%, respectively compared to the agronomic P fertilizer recommendation (138 P_2O_5). The first year result indicated that DBARC phosphorus fertilizer calibration model had a mean grain and straw yield penalty of 24.6 kg ha^{-1} (0.8%) and 25.94 kg ha^{-1} (0.7%) compared to the agronomic phosphorus fertilizer recommendation. Similarly, in the second year DBARC model had a mean grain and straw yield penalty of 336.3 kg ha^{-1} (10.3%) and 18.4 kg ha^{-1} (7.8%) respectively as compared to the agronomic P fertilizer recommendation. The two years result indicated that DBARC P calibration model had a higher net benefit than the agronomic P fertilizer recommendation and resulted in a mean net benefit of 19088 *ETB ha^{-1}. The same was true for the benefit cost ratio.*

Keywords*:* Nitrogen, phosphorus critical value, phosphorus factor, phosphorus, wheat

Introduction

In Northestern Ethiopia, there is a rapidly growing demand for food due to a rapid population growth. Therefore, cultivations of subsistence crops must be stimulated and production augmented sustainably. The trend in all research endeavors including research on soil nutrients is going through a development process away from agricultural production per se towards sustainable production (Smaling, 1993). Among others, mineral nutrition is becoming one of the most important factors for increasing crop production in Northwestern Ethiopia. Unfortunately, many soils of Ethiopian highlands are inherently poor in available plant nutrients and organic matter content (Tekalign *et al*., 1988, Zeleke *et al*., 2010). Murphy (1963) conducted a survey or rapid appraisal to assess the fertility status of Ethiopian soils and concluded that the major part of Ethiopian soils is deficient in nitrogen and phosphorus. Hence, farmers who attempted to grow crops without or with marginal fertilizer application could not produce enough even to feed their own families for one year.

Phosphorus is of primary concern in the appraisal of the soil resources of Ethiopia (Miressa and Robarge, 1996) since most of the soils in the highland areas of the country, particularly Nitisols are reported to be deficient in phosphorus (Asnakew *et al*., 1991; Desta, 1982; Bekele and Hofner, 1993; Agegnehu *et al*., 2015). Phosphorus is one of the most limiting elements in the tropics and majority of the soils of Ethiopia (Brady and Weil, 2008; Bekele and Hofner, 1993). In P-deficient soils, crops usually recover less than 10% of the applied amount of phosphorus in the first season, even if they respond well and the total recovery after four years is often only 20-30% (Russel, 1972). In addition to the inherently low available P content, the high P fixation capacity of some soils made the problem complex.

The role of chemical fertilizers in increasing yield is evident. Fertilizers accounted for more than 50% of the increase in yield (FAO, 1984). Experience has shown that in seasons with good rain, farmers of Northwestern Ethiopia managed to produce surplus yield through fertilization. The rates applied, however, should meet the demand of the crop, but should not exceed the demand to any major extent. For this purpose, in Ethiopia, some blanket fertilizer recommendations have been developed and introduced into the extension system. This approach, however, had shortcomings in extrapolating the results to farmer fields, because the available nutrient status on the experimental fields was lower than, equal to or higher than that of the farmers' fields. Hence, fertilizer recommendations should take into account the available nutrient already present in the soil (Mengel, 1982).

To take in to account of the available nutreints in the soil and undertake more scientific and precise option of fertilizer recommendation, soil laboratories are being built in many Regional States of the country including the study area. Nevertheless, since no universally accepted method exists for indexing the availability of nutrients, reliable methods must be selected through research to meet the specific conditions under which the crops are intended to grow. Bray-II and Olsen methods have been proven to be the best indices for Ethiopian soils (Tekalign and Haque, 1991; Sahlemedihin and Taye, 2000). Using these indices, mathematical models that integrate the soil test indices with fertilizer rate requirements can be developed for each crop species on specific soil types and agro-ecologies. Research works on soil test-based fertilizer recommendations are at preliminary stages in Ethiopia, although some recent research recommendations have been made for some crops (e.g., Agegnehu and Lakew, 2013; Agegnehu *et al*., 2015). Other researchers also reported research findings on soil test crop response studies in different parts, crops and soils of Ethiopia (Getachew and Berhane, 2013; Gebremedhin *et al*., 2015; Girma *et al*., 2018; Dagne, 2019; Gidena, 2016) However, the effort must be further strengthened. Therefore, the objectives of this study were to: 1) develop mathematical models that will give phosphorus fertilizer recommendations using Olsen phosphorus levels according to P availability indices; 2) verify the recommended soil test based calibration equation for P; and demonstrate the advantage of soil test based recommendation over agronomic fertilizer recommendation for the study site.

Materials and methods

Description of the Study Area

The experiment was conducted in *Moretina Jiru* and *Saya deber ena Wayu* districts, North Shewa Zone of the Amhara Regional State, about 195 and 176 km northeast of Addis Ababa, respectively. The capital of *Moretina Jiru* and *Saya deber ena Wayu* are *Enewari* and *Deneba* respectively. The geologic materials at and around the districts consist of the Aiba basalt of the middle-late Oligocene era of the Paleocene period. The areas are characterized by a unimodal rainfall pattern and receive an average annual rainfall of 929 and 1276.3 mm, respectively. The annual average maximum and minimum air temperatures are 21.4 and 9.0 °C at *Enewari* and 22.3 and 6.9 at *Deneba*, respectively. Vertisols, are the dominant soil type in both districts. The crops widely grown in the study area include wheat, teff, faba bean and lentil; whereas chickpea, grass pea and others have low area coverage and they are mainly grown on residual soil moisture at the end of the rainy season. Figure 1 shows the geographical location of the experimental sites.

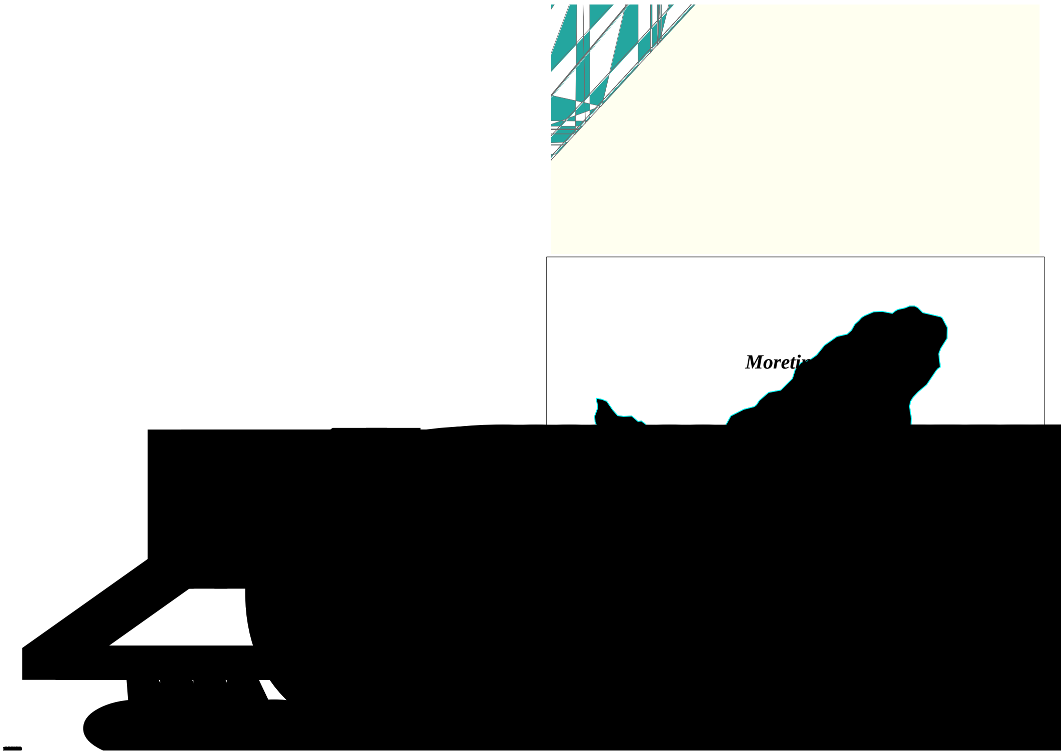

Figure 1. Location map of the study sites

Determination of P-critical and P-factor

The phosphorus calibration study was conducted in two phases. In the first phase, the optimum rate of N (192 N) that gave the highest yield was determined at Debra Birhan agricultural research center. In the next phase, the calibration study was conducted and the P critical and requirement factor were determined for the development of the final equation:

$Pr = (Pc - Po) * Pf$ ………………..equation 1 (***DBARC Model***)

Where

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

Pc= Critical P concentration =12.56 (mg kg^{-1})

Po = Initial P values for the site

Pf = P requirement factor =6.41

DBARC-Debrebirhan agricultural Research center

$Pr = (Pc - Po) * Pf$ ………………..equation 2 (*GARC model*)

Where

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

Pc= Critical P concentration =15.8 (mg kg^{-1})

Po = Initial P values for the site

Pf = P requirement factor =5.4

GARC-Gonder agricultural research center

Based on this equation, the verification of the developed model was implemented at *Enewari* and *Deneba* areas on 16 sites by using each farmer as a replication. The research was conducted for two years in the main rainy-season. The soils at both locations were generally referred to as Vertisol. The composite soil samples collected before planting were analyzed using the Olsen method (Sahlemdihin and Taye, 2000). Based on the available phosphorus and the above equation the phosphorus requirement of each farmer's field was calculated. The test crop for the experiment was wheat (*Menzaie variety*) at a seed rate of 175 kg ha^{-1}. Nitrogen was applied for all plots at the rate of 192 kg ha^{-1} half at planting and half at the tillering stage of the crop.

Treatments

1. ***Agronomic phosphorus fertilizer recommendation***. This is the P fertilizer previously recommended for the study areas. The agronomic P recommendation for the areas is 138 P_2O_5 and this fertilizer is recommended for all farmers plots without considering the inherent soil P level.
2. ***Soil test based phosphorus fertilizer recommendation (DBARC Model).*** This fertilizer recommendation is based on the soil P level and considers the inherent soil P levels of the farmer's field. For this recommendation, soil samples were collected from each farmer's field. The samples were analyzed for available P and hence this P level was modeled with DBARC phosphorus calibration equation (equation 1).
3. ***Soil test based phosphorus fertilizer recommendation (GARC model).*** This fertilizer recommendation is also based on the soil P level and consider the inherent soil P levels of farmers field. For this recommendation, soil samples were collected from each farmer's field. The samples were analyzed for available P and hence this P level was modeled with GARC phosphorus calibration equation (equation 2).

In the first year, the trial included two treatments *(*agronomic phosphorus fertilizer recommendation and Debra Birhan Agricultural Research Center (DBARC). In the second year Gonder Agricultural Research Center (GARC) model was also incorporated as the third treatment.

Results and Discussion

Initial soil P and phosphorus fertilizer requirement for the first year

The initial phosphorus level of the soil ranged from 5.8 to 11.4 ppm and hence based on the developed model the need for P_2O_5 fertilizer ranged from 17 to 102 kg ha^{-1} (Figure 2B). However, with agronomic fertilizer recommendation, the need for P_2O_5 was found to be 138 kg ha^{-1}, indicating that the P calibration model of DBARC could save about 51% of the P fertilizer to be applied.

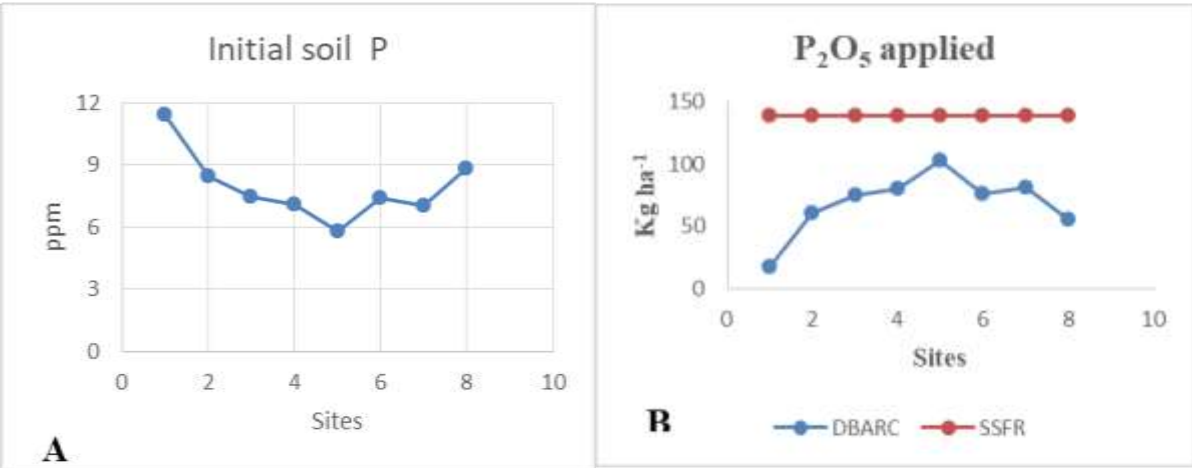

Figure 2. A-Initial soil phosphorus level (ppm), **B-**P_2O_5 kg ha^{-1}applied at each farm for the first year

*DBARC: Debra Birhan Agricultural Research Center phosphorus calibration model; SSFR: agronomic phosphorus fertilizer recommendation.

Initial soil P and P fertilizer requirement factor for the second year

The initial soil P-value ranged from 5.04 ppm to 14.29 ppm, indicating that the soil phosphorus level ranged from low to medium phosphorus, respectively (Figure 3A). Thus, based on the phosphorus requirement equation developed by DBARC, the needs for P_2O_5 were between 110.4 kg and 0 kg ha^{-1}. However, based on the P requirement equation developed by GARC, the need for P_2O_5 ranged from 133.6 kg ha^{-1} to 18.56 kg ha^{-1}. The mean phosphorus fertilizer applied to the soil also showed great difference and the mean P_2O_5 requirements of the soil were 138, 77 and 47 Kg ha^{-1} for agronomic phosphorus fertilizer recommendation, GARC and

DBARC model respectively. The results of the study also demonstrated that about 65.94% and 44.2% of P_2O_5 ha^{-1} could be saved by using DBARC and GARC P calibration model, respectively compared to the agronomic phosphorus fertilizer recommendation (138 kg P_2O_5). Likewise, GARC P calibration model resulted in a 30 kg P_2O_5 penalty compared with DBARC model. Similarly, Gebremedhin *et al*., (2015) reported that based on soil test based phosphorus fertilizer recommendation saves 23.8 kg P_2O_5 compared with blanket recommendation of 46 P_2O_5 in wheat-growing area of *Hintalo-wajirate* district

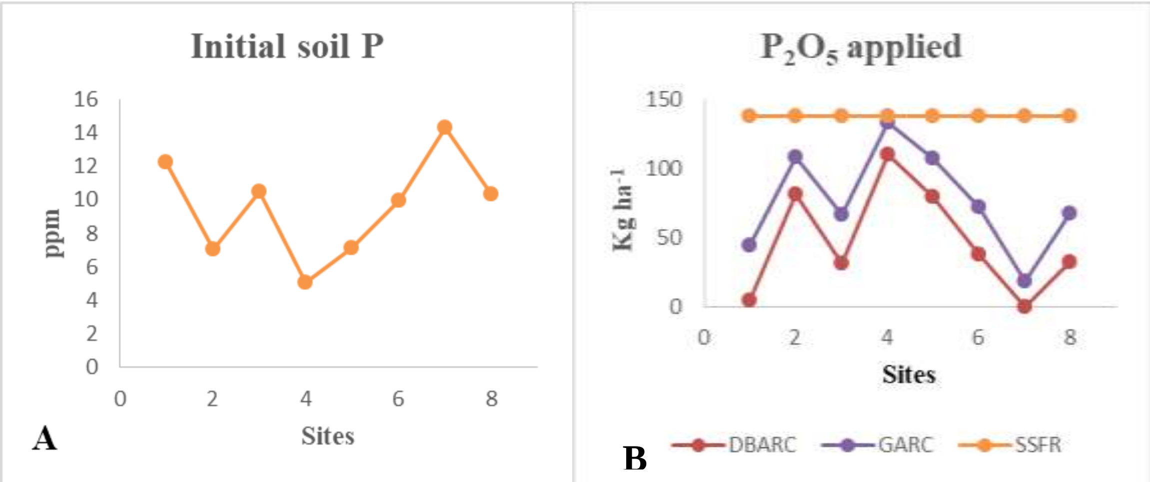

Figure 3. A- Initial soil phosphorus level, **B-**P_2O_5 applied at each farm for the second year

*DBARC: Debra Birhan Agricultural Research Center phosphorus calibration model; SSFR: agronomic phosphorus fertilizer recommendation; GARC: Gondar Agricultural Research Center phosphorus calibration model.

Grain yield

In the first year of the experiment, the statistical analysis showed that there was a non-significant difference between the model and agronomic fertilizer recommendation (Table 1) and the model worked best for most of the sites but failed to show the expected result for few locations (Figure 4A). Implying that there is high possibility of using the model in most sites instead of agronomic phosphorus fertilizer recommendation for the areas. For instances, for site 2, 3 and 8 the model resulted in yield advantages of 15.4% (535 kg ha^{-1}), 2.3% (59 kg ha^{-1}), and 6.8% (213 kg ha^{-1}) compared to the agronomic phosphorus fertilizer recommendation (138 kg ha^{-1} P_2O_5) respectively. However, in site 1, 4, 5, 7 and 8 agronomic phosphorus fertilizer recommendations (138 kg ha^{-1} P_2O_5) produced grain yield advantages of 4.4% (118 kg $ha^{-1)}$), 6.6% (230 kg ha^{-1}), 8.8% (279 kg ha^{-1}), 10.2% (304 kg ha^{-1}) and 3.2% (73 kg ha^{-1})

over the DBARC model, respectively. Generally, agronomic fertilizer recommendation had a mean grain yield advantage of 0.8% (24.6 kg ha^{-1}) over the DBARC model.

In the second year, the DBARC model worked best in some sites and produced a comparable and even higher grain yield than the agronomic phosphorus fertilizer recommendation (Figure 4B). In sites 1 and 2, DBARC model had a comparable wheat grain yield over agronomic phosphorus fertilizer recommendation, but in site 8, the model had a grain yield advantage of 339.3 kg ha^{-1} (7.9%). In contrast, in sites 2, 3, 4, 5 and 7, agronomic phosphorus fertilizer recommendation resulted in grain yield advantages of 411.5 kg ha^{-1} (8.9%), 798.2 kg ha^{-1} (24.4%), 543.3 kg ha^{-1} (9.7%), 149.5 Kg ha^{-1} (4.2%) and 876.6 kg ha^{-1} (20.9%), respectively over DBARC P calibration model. Generally, agronomic phosphorus fertilizer recommendation produced a yield advantage of 336 kg ha^{-1} (7.8%) over DBARC model. As compared to DBARC model, GARC model showed comparable and even higher yield on most of the testing sites. In sites 2, 4, 5 and 8, GARC model had gain yield advantages of 7.2 kg ha^{-1} (0.2 %), 193.9 kg ha^{-1} (5.4%) and 685.8 kg ha^{-1} (16%), respectively compared with agronomic phosphorus fertilizer recommendation.

Nevertheless, on sites 1, 3, 6 and 7, GARC model resulted in grain yield penalty of 702.9 kg ha^{-1} (14.9%), 318.7 kg ha^{-1} (9.8%), 329 kg ha^{-1} (10.8%), respectively compared to agronomic phosphorus fertilizer recommendation. Generally, the result indicated that GARC model had mean a yield penalties of 79.9 kg ha^{-1} (1.8%) and 256.4 kg ha^{-1} (6%) compared to agronomic phosphorus recommendation and DBARC P calibration model, respectively. In line with the present study, Gebremedhin *et al.*, (2015) reported that soil test based phosphorus fertilizer recommendation increase wheat yield by 14% compared with blanket recommendation (50 urea: 100 DAP). Similar results were also reported by Girma *et al*., (2018) for faba bean on nitisols, *Gidena* (2016) for teff on vertisols, Getachew and Berhane (2013) for malting barley on nitisols.

Table 1. Yield response of wheat as influenced by the treatment

Treatment	Grain Yield (kg ha^{-1})	Straw Yield kg ha^{-1})
First Year		
DBARC	2953	3872.18
Agronomic P Fertilizer recommendation	2977.6	3898.2
LSD	530.3	251.9
CV (%)	6.82	13.04
α = 0.05	Ns	Ns
Second Year		
DBARC	3989.6	5559.83
GARC	4246.1	5615.11
Agronomic P Fertilizer recommendation	4326.9	5579.41
LSD (0.05)	338.7	780.8
CV (%)	7.54	5.48
α = 0.05	Ns	Ns

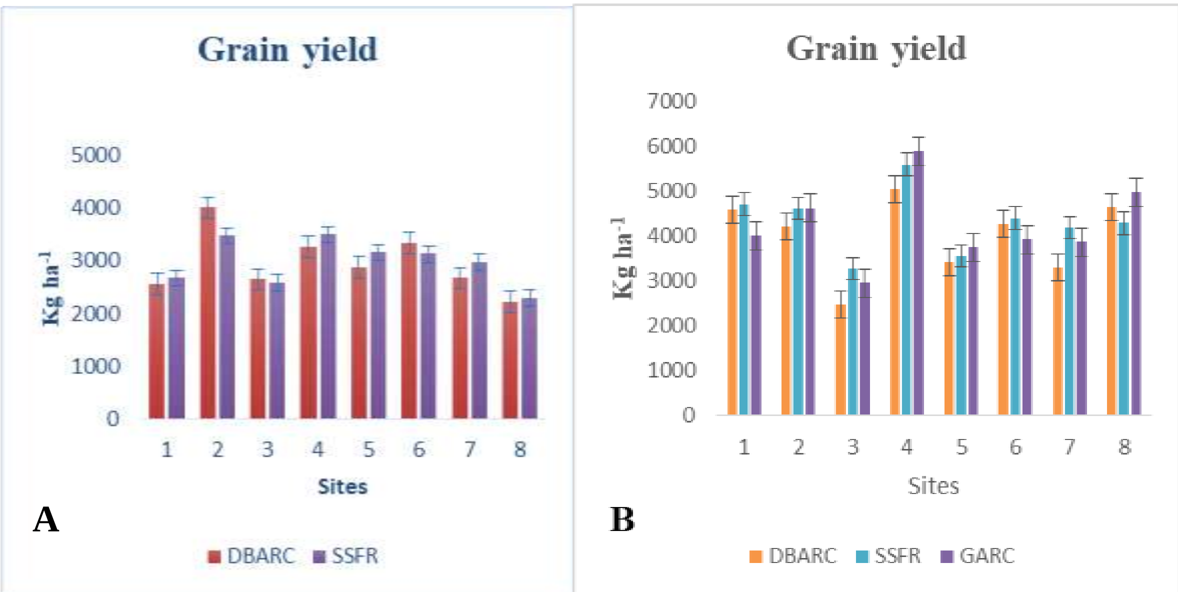

Figure 4: A-Grain yield of first year, **B-**Grain yield of second year

**DBARC means Debra Birhan agricultural research center phosphorus calibration model; SSFR, agronomic phosphorus fertilizer recommendation; GARC, Gondar agricultural research center phosphorus calibration model.*

Straw yield

In the first year, the model worked best for most of the tested sites. In sites 2, 3 and 6 DBARC model had straw yield advantages of 563.6 kg ha^{-1} (12.7 %), 62.15 kg ha^{-1} (1.7%) and 224.4 kg ha^{-1} (5.5 %), respectively. However, on sites 1,4,5,7 and 8, agronomic phosphorus fertilizer recommendation (138 kg ha^{-1}) resulted in straw yield advantages of 124.3 kg ha^{-1} (3.5%), 242.3 kg ha^{-1} (5.5%), 293.9 kg ha^{-1} (7.2%), 320.2 kg ha^{-1} (8.2%) and 76.9 kg ha^{-1} (2.4%), respectively. Generally, agronomic fertilizer recommendation produced a mean straw advantage of 25.9 kg ha^{-1} (0.7 %) as compared to the model.

In the second year, Figure 9 indicates that in most of the sites the DBARC phosphorus calibration model showed the expected result. In sites, 1, 2, 4, 5 and 8 the model outwitted that of agronomic phosphorus fertilizer recommendation (Figure 5B). In those sites, the model had straw yield advantages of 355.7 kg ha^{-1} (5.3 %), 81.5 kg ha^{-1} (1.7%), 2214 kg ha^{-1} (26.8%), 696 kg ha^{-1} (11.2%) and 300 kg ha^{-1} (5.7%), respectively. But on sites 3, 6 and 7 agronomic phosphorus fertilizer recommendation (138 kg ha^{-1}) resulted in straw yield advantages of 1656.2 kg ha^{-1} (73.3%), 787.9 Kg ha^{-1} (13.9%), and 1350.9 kg ha^{-1} (25.6%), respectively compared to the DBARC phosphorus calibration model. GARC model also showed the

Cost-Benefit Analysis

The two years results indicated that DBARC phosphorus calibration model resulted in the highest net benefit compared to the agronomic phosphorus fertilizer recommendation and had a mean net benefit of 19088 ETB ha^{-1}. The same was true for the benefit-cost ratio . The result also revealed that GARC phosphorus calibration model also resulted in the highest net benefit (26457 ETB ha^{-1}) and benefit-cost ratio as compared to agronomic phosphorus fertilizer recommendation.

Table 2. Cost-benefit analysis of the soil test phosphorus calibration treatments

Treatment	GY (Kg ha)	SY (kg ha)	WP (ETB Kg)	TWP (ETB ha)	SP (ETB Kg)	TSP (ETB ha)	GB (ETB ha)	TC(ETB ha)	NB (ETB ha)	BCR
Mean of 1st year										
SSFR	2978	3898	8	22332	1.5	5847	28179	16638	11541	1.7
DBARC	2953	3872	8	22148	1.5	5808	27956	14911	13045	1.9
Mean of 2nd year										
SSFR	4326	5578	7.5	34608	1.5	8367	42975	17587	25388	2.4
GARC	4246	5615	7.5	33969	1.5	8423	42391	15934	26457	2.7
DBARC	3990	5560	7.5	31918	1.5	8340	40257	15125	25132	2.7
Grand mean of 2 years										
SSFR	3652	4738	7.8	28470	1.5	7107	35577	17113	18465	2.1
DBARC	3471	4716	8	27033	2	7074	34107	15018	19088	2.3

**GY: Means grain yield; SY: Straw yield; WP: Wheat price; TWP: Total wheat price; SP: Straw price; TSP: Total straw price; GB: Gross benefit; TC: Total cost; NB: Net benefit; BCR: Benefit-cost* ratio; *ETB: Ethiopian birr; SSFR: agronomic phosphorus fertilizer recommendation; DBARC: Debra Birhan Agricultural Research Center phosphorus calibration model; GARC: Gondar Agricultural Research Center model.*

Conclusion and Recommendation

Routine soil analysis for fertilizer recommendations is considered as an important component contributing to increased crop yields and maintaining soil productivity. The present study was conducted in wheat-producing areas of North Shewa zone on vertisols to verify the recommended soil test based calibration equation for P fertilizer. Accordingly, a non-significant difference between the model and agronomic fertilizer was found. Hence, it is possible to use the site-specific phosphorous fertilizer recommended model for wheat production in the study sites and similar agroecology and soil types. The P fertilizer model developed by DBARC had a mean phosphorus fertilizer saving advantage of 58.5% compared with agronomic fertilizer recommendation.

The two years result indicated that DBARC P calibration model had a higher net benefit than the agronomic P fertilizer recommendation and resulted in a mean net benefit of 19088 ETB ha^{-1}. Therefore, from this study, it is recommended that soil test based fertilizer recommendation shall be used for farmers having access to soil laboratories, and hence the P critical for the test crop was found to be 12.56. Besides (1) the facility and capacity of regional and different agricultural research center soil laboratories should be strengthened, (2) farmers access for soil laboratories should be secured (3) similar calibration study should be conducted to different soil type, agro-ecologies and test crop.

Acknowledgment

The authors acknowledge Amhara Agricultural Research Institute for granting this research fund. The authors would also acknowledge all staff of Debra Birhan Agricultural Research center for their support at all levels of the experiment.

References

Agegnehu, G. and Lakow, B. (2013). Soil test phosphorus calibration for malting barley (*Hordeum vulgare* L.) production on Nitisols of. Ethiopian highlands. *Trop. Agric* **137**.

Agegnehu, G. Nelson, P. N. Bird, M. I. and van-Beek, C. (2015). Phosphorus Response and fertilizer recommendations for wheat grown on Nitisols in the central Ethiopian highlands. *Communications in Soil Science and Plant Analysis* 46, 2411–2424.

Asnakew Woldeab; Tekalign Mamo; Mengesha B; Tefera A. (1991). Soil fertility management studies on wheat in Ethiopia. In: Hailu GM; Tanner DG; Mengistu H. (eds.), Wheat research in Ethiopia: A historical perspective. Addis Ababa, Ethiopia: IAR/CIMMYT. pp 137-172.

Bekele T. and Höfner, W. (1993). Effects of different phosphate fertilizers on yield of barley and rape seed on reddish brown soils of the Ethiopian highlands. Fertilizer Research, 34:243-250.

Brady, N.C, Weil, R.R. (2008). The Nature and Properties of Soils. USA. 965p

Dagene Chimdessa (2019). Phosphorus calibration study under soil test based maize response in bedele district of oromia, west Ethiopia. *Forestry Research and Engineering: International Journal* 3(4):154-158

Desta Beyene. (1982). Diagnosis of phosphorus deficiency in Ethiopia soils. Soil sience Bulletin No:3. Institute of Agricultural Research, Addis Ababa, Ethopia.18 pp.

FAO (Food and Agricultural Organization of the United Nations). (1984). Fertilizer and nutrition guide. Rome. Italy.

Gebremedhin Gebremeskel, Hagos Brhane and Daniel Berhe. (2015). Verification of Soil Test Based Phosphorus Fertilizer Recommendation for Yield and Yield Components of Wheat in Hintalo-wajirat District, *Ethiopia. Journal of Natural Sciences Research*, 5:17. 84-88.

Getachew Agegnehu and Berhane Lakew (2013) . Soil test phosphorous calibration for malt barley production on Nitisols of Ethiopian highlands. *Trop.Agric*. 90: 177 -187.

Gidena Tasew. (2016). Verification and Demonstration of Soil Test Based Phosphorus Fertilizer Recommendation Rate on Yield of Teff (Eragrostis Tef (Zucc) Trotter) in Vertisols of Northern *Ethiopia. Journal of Natural Sciences Research* 6(1):51-55

Girma Chala, Gemechu Keneni, Zeleke Obsa (2018). Soil Test Based Phosphorous Calibration for Fababean (Vicia faba L.) Production on Nitisols in Central Highlands of Ethiopian. Greener *Journal of Agricultural Sciences*, 8(1): 022-029,http://doi.org/10.15580/GJAS.2018.1.011818007.

Mengel, K.(1982). Factor of plant nutrient available relevant to soil testing. *Plant soil* 64:129-138.

Miressa, D. and Robarge, W.P. (1996). Characterization of organic and in organic phosphorus in the highlands of Ethiopia. Commun. Plateau soil sci. Plant annual.27:2799-2814.

Russel, J.S. (1972). Theoretical approach to plant nutrient response under condition of variable maximum yield. *Soil Sci.* J. 114:387-394.

Sahlemedhin Sertsu and Taye Bekele. (2000). *Procedure for Soil and Plant Analysis* .Technical paper No 74. National soil Research center. EARO. Addis Ababa.

Smaling, E.M.A.(1993). An Agro-ecological Frame Work of Integrated Nutrient management With Special Reference To Kenya.Wageningen Agricultural University, Wageningen.

Tekalign Mamo, Haque I, Kamara, G.S. (1988). Phosphorus status of some Ethiopia Highland Vertisols. In: Jutz, S.C., I. Haque Mdntirc (eds.) Soils in Sub-Saharan Africa, ILCA, Addis Ababa, Ethiopia. pp. 232-249

Tekalign, M. and Haque, I. (1991). Phosphorus status of some Ethiopian soils. III. Evaluation of soil test method for available phosphorus. *Trop. Agr*. 68:61-66.

Zeleke, G., Agegnehu, G., Abera, D., and Rashid, S. 2010. Fertilizer and soil fertility potential in Ethiopia: Constraints and opportunities for enhancing the system. International Food Policy Research Institute (IFPRI). pp. 63, Washington, DC, USA.