Journal of Tropical Crop Science Vol. 10 No. 2, June 2023
www.j-tropical-crops.com

Teff and Wheat Yield Variation With Phosphorus Application In Jamma District, Ethiopia.

Habtemariam Teshome* 0000-0001-5801-9116, Kassa Sisay 0000-0002-6151-6751, Adise Degu, Tesfaye Wubu, Tadesse Hailu

Sirinka Agricultural Research Center, P.O. Box 74, Woldia

*Corresponding author; email: teshomehabte@gmail.com

Abstract

Different plant species has different nutrient requirements and utilize nutrients in different ways. Biological activity contributes to P solubilization through mineralization, wheathering, and other physicochemical reactions so that the soil plow layer is the major source of soil availabile P for crops. Ethiopia Ministry of Agriculture and Natural Resource and ATA recommended six types of blended fertilizers (NPSZnB, NPKSB, NPKSZnB, NPSZn, NPSB and NPS) for the Amhara region. Our study was conducted in Jamma districts of eastern Amhara, Ethiopia, during 2018 cropping season to attest the yield of teff (Dega teff) and wheat (Danda'a) due to phosphorus fertilizer application. Fertilizer treatments tested were the recommended dose of N only, recommended dose of NP, 50 $kg.ha^{-1}$ NPS, 100 $kg.ha^{-1}$ NPS, and 150kg. ha^{-1} NPS, set up in a. randomized complete block design with three replication, and conducted on four sites. Our study demonstrated that applications of N and P fertilizers significantly improved grain yield of wheat and teff, and that there was significant yield differences ($P < 0.05$) between different rates of P fertilizer. Therefore, even though the soil P levels were shown to be sufficient, application of both N and P fertilizer in the Jamma district is essential to increase yield of teff and wheat.

Key words: fertilizer, nutrient, phosphorous, teff, wheat

Introduction

Declining soil fertility status of the soil, inadequate land size, and low crop and livestock productivity are the major challenges of Ethiopian agricultural sector (Agegnehu and Amede, 2017). Maintaining soil fertility and increasing crop yield on smallholder farms in Ethiopia is a major concern, as fertilizer recommendations were typically either based on extremely generic parameters for each type of crop or, more frequently, on a single general recommendation for all crops (100 kg $urea.ha^{-1}$ and 100 kg $DAP.ha^{-1}$). The same dosages of fertilizers for different crops had resulted in nutritional deficiencies, or excesses with regard to plant needs.

Different plant species has different nutrient requirements and utilize nutrients in different ways. How, where, and when plants utilize nutrients can greatly affect the overall yield and plant production. Understanding a crop's nutritional needs can be crucial for a farmer looking to increase crop yields and cut input expenses.

Phosphorus is an essential nutrient in the process of plants converting the sun's energy into food, fiber and oil. Phosphorus plays a key role in photosynthesis, the metabolism of sugars, energy storage and transfer, cell division, cell enlargement and cell enlargement (Hagose and Aberha, 2016). Phosphorus is the most vital nutrient next to N and P is particularly the most yield limiting nutrient in areas where soil acidity or soil alkalinity is a problem due to P fixation in the soil. Phosphorus is crucial for a healthy root growth, early shoot growth, speeds ground coverage for erosion protection, enhances the quality of fruit, vegetable and grain crops, and is vital to seed formation (Hodges, 2010). Phosphorus is often an important limiting factor for crop yields (Girma et al., 2017). Compared to the other major nutrients, phosphorus requirement is less but is critical particularly in the early developmental stages of growth, and for energy transfer in the crop during the entire growing season (Hodges, 2010). The soil reactivity, the level of soil phosphorus deficit, the rate and method of application, the requirements of the particular crops, and other soil variations, may all have an impact on the phosphorus availabilities.

Adequate phosphorus nutrition enhances many aspects of plant physiology, including the fundamental processes of photosynthesis, root growth particularly development of lateral roots and fibrous rootlets (Gebreslassie and Hailemariam, 2016). In highly

P-fertilized soils, the P concentration in soil solution is high, and the depletion zone readily replenished, however, the replenishment is inhibited when the content of P in the solution is low especially for soils with a low buffer capacity, and the quantity of P ions in soil solution at any given time generally represents less than 1% of P annually taken up by crops (Kpongor, 2007). Most (99%) of the phosphorus taken up by plants is bound to soil constituents before uptake (Schneider and Morel, 2000). When the soil is low in phosphorus, plants become stunted with a limited root system, stunted, have thin stems, and older leaves may turn purple because of the accumulation of anthocyanins or purple pigments.

Biological activity contributes to P solubilization through mineralization, weathering and other physicochemical reactions so that the plow layer is the major source of soil availabile P for crops. In regions of developed countries with intensive livestock production, disposal of animal manures on a relatively small land has led to massive acculation of soil available P, soil organic matter, and buildup of organic P (Shi et al., 2013).

The balance between P addition as fertilizer and P removal by crops is an important consideration when examining depletion, maintenance or build-up of soil P levels and fertility. When the same P rates year after year were applied, residual soil P levels may end up being too high for crops with low P requirements, and conversely it may be insufficient for crops with high P requirements. Fertilizer application should be specific for crop species grown in different regions.

Ethiopia Ministry of Agriculture and Natural Resource and ATA (2016) recommended six types of blended fertilizers (NPSZnB, NPKSB, NPKSZnB, NPSZn, NPSB and NPS) for the Amhara region including the study district. According to this recommendation, phosphorous fertilizer was 100% recommended for the districts. So, it is very important to re-examine the soil P status and crop response to applied P fertilizer in affecting crop yield in Jamma district of Eastern Amhara.

Materials and Methods

Description of Experimental Sites

The trials were carried out in Jamma district (Figure 1) during the primary farming season of 2018. Jamma district lies between the geographical coordinates of 10° 23' to 10° 27' N latitudes and 39° 07' to 39° 24' E longitudes with altitude of 2630 meters above sea level (masl) and the rainfall patterns of the district during growing season of the crop is indicated in Figure 2. The principal feature of rainfall in the area is bimodal, with two distinct rainy seasons. The main rainy season is called "Kiremt" which represents the long rainy season (*Meher*) extends from mid-July to early September, while the short rainy season is called "Spring" from February to mid-May. The dominant soil type of the study district is vertisols. Wheat, teff, and faba bean are the three main crops that are produced extensively throughout the study sites.

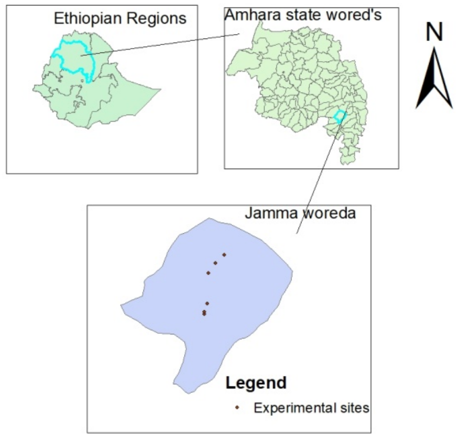

Figure 1. Location map of the study sites

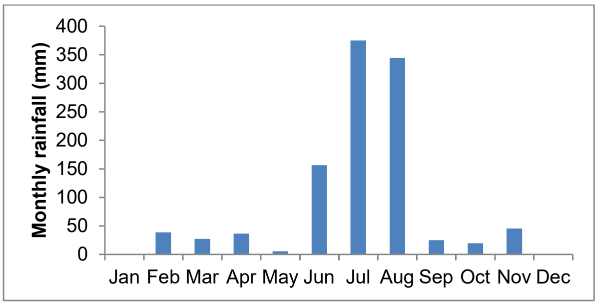

Figure 2. Monthly rainfall of Jamma district, Ethiopia, in 2018.

Experimental Set-up and Procedure

Standard cultivation techniques were used to prepare the test sites before planting: soil on the test fields were plowed using equipment drawn by oxen. After plowing broad bed furrows (BBF) was prepared manually to drain excess water in the experimental sites.

The experiment tested five levels of phosphorous (0, 19, 38, 57 and the recommended P_2O_5 (69 and 46 kg.ha^{-1}). Full recommended nitrogen (115 and 92 kg.ha^{-1} N) were applied for all treatments for wheat and teff crops.

The treatments are crops (wheat and teff) and locations with the specific recommended N, the recommended (crop and location specific) N and P, i.e., 115 kg.ha^{-1} N and 69 kg.ha^{-1} P_2O_5 for wheat and 92 kg.ha^{-1} N and 46 kg.ha^{-1} P_2O_5 for teff (Abebe et al., 2020; Samuel et al., 2016), 50 kg.ha^{-1} NPS (N was be adjusted to recommended dosage), 100 kg.ha^{-1} NPS (N was be adjusted to the recommended dosage), and 150 kg.ha^{-1} N, P, S (N was be adjusted to recommended dosage). Phosphorus was applied as triple supper phosphate (TSP) for the recommended rate of N and P, and P and NPS for the rest rates of phosphorous, whereas nitrogen was from NPS and Urea. Nitrogen rates were equal for all treatments for each crop in each location.

A randomized complete block design was used to apply the treatments on plots with a size of 5m × 5m (25 m^2) for teff, and 5m x 4.5m (22 m^2) for wheat. Each treatment had three replicates for each site (farm); four sites per location for teff and five sites per location for wheat. Broad bed furrow (80 cm x 40 cm) were prepared for wheat production. Spaces between treatments and blocks were 0.5 m and 1 m, respectively, for both crops. Spacing between rows were 20 cm for wheat, whereas teff was planted as broadcast. Sowing was done second week of July for teff and wheat trials. Nitrogen was applied half at planting and the other half at tillering stage for teff and wheat just after weeding with the presence of small rainfall. Other standard agronomic practices were applied as per the recommendations for the crop and as farmers practice (Abebe et al., 2020; Samuel et al., 2016).

Soil Data Collection and Analysis

Surface soil samples (0-20 cm depth) were collected randomly in a zig-zag pattern before sowing from the entire experimental field. The soil analysis was carried out in the soil testing laboratory of Sirinka agricultural research center for selected chemical and physical soil properties (texture, pH, OC, Total N and available P). The texture of the soil was determined by the hydrometer method (Bouyoucos, 1962). Potentiometric analysis was used to determine the pH of the soils in water suspension at a ratio of 1 : 2.5 (soil to liquid) (Van-Reewijk and Clark, 1992), Micro-Kjeldahl digestion method was used to calculate total nitrogen (TN) (Jackson,1958). Olsen method was used for the determination of available P from the soil sample (Olsen et al., 1954). Using the wet digestion method, the soil's organic carbon content was examined (Bayu and Rethman, 1934).

Yield Data Collection

Harvesting was done from the second week of December for wheat and first week of January for teff. To measure total above-ground biomass and grain yields the central BBF was harvested for wheat and the teff aboveground biomass was harvested using quadrants (4m x 4m).

At the maturity stage, the net plot area's entire plant parts (only excluding boarder row), including leaves and stems, and seeds, were picked, and the biomass was calculated (dry matter basis). Grain yield was measured by harvesting the crop from the net (middle) plot area to avoid border effects, after threshing seeds were cleaned and weighed. Finally, grain yield was adjusted to standard moisture contents of wheat (12.5%) as described in the following formula:
Adjusted yield = actual yield x (100 – M) / (100 – D)
where M is the measured actual grain moisture content and D is the designated wheat standard moisture content (12.5%).

Data Analysis

Analysis of variance was carried out for the yield following statistical procedures appropriate for the experimental design using SAS Version 9.4. Whenever treatment effects was significant, the means was separated using the least significant difference (LSD) procedures test at 5% level of significance.

Result and Discussion

Physico-chemical Properties of the Soil

The results of soil analysis showed that the soil in all experimental sites had moderate total nitrogen content according to Tekalign (1991). The soil has organic matter ranges from 0.86%-1.61 % which is categorized low level (Berhanu, 1980) (Table 1). Based on USDA textural classification the soil textural class of the experimental site was clay. The soil test result reveals that the available phosphorus content of the soil, as per the Olsen's method and based on the rating of Cottenie (1980) was moderate to high. According to Wiens (2017) when soil P levels are near sufficient, the application of P fertilizer at rates to account for previous crop removal may be the desirable approach, without expectation of a yield response.

Teff Yield Response to Applied Phosphorous Fertilizer

The combined analysis indicated that the teff grain yield was significantly ($p \leq 0.05$) increased with different P rates (Table 2), but the yield increases were significant only in the two out of four sites. The highest teff grain yield (1.720 t.ha^{-1}) were recorded

Table 1. Soil properties at planting

Site	pH	% OM	%TN	Available P (ppm)	Textural class
Teff	6.2-6.9	0.86-1.04	0.18-0.28	15.7-22.4	clay
Wheat	6.0-6.1	1.07-1.61	0.15-0.24	11.0-22.3	clay

Note: OM=organic matter; TN= total nitrogen; P=Phosphorus

with the application of recommended rate of N and P fertilizer (46 kg.ha^{-1} P_2O_5 NS 92 kg.ha^{-1} N), and the yields were not significantly different from the yields with 38 kg.ha^{-1} and 57 kg ha^{-1} P_2O_5 with 46 kg.ha^{-1} N. Application of 46 kg.ha^{-1} P_2O_5 and 46 kg.ha^{-1} N resulted in 9% teff yield increment in comparison to the control (without P) (Table 2). According to the combined statistical analysis above ground biomass yield of teff with P treatments was not increased over control, even though the highest biomass yield was obtained from the application of 46 g kg.ha^{-1} P_2O_5 (Table 4).

Wheat Yield Response to Applied Phosphorous Fertilizer

Application of different rates of P significantly affected ($P \leq 0.05$) grain and biomass yield of wheat (Table 3). Except at Farm 3 (Table 3) and Farm 2 (Table 5) application of different rate of P fertilizer increased yield of wheat in comparison with control; therefore, application of P with N fertilizer increased yield of wheat in vertisols of Jamma district. The highest grain yield (2.64 t.ha^{-1}) and biomass yield (6.08 t.ha^{-1}) were obtained from the application of 69 kg.ha^{-1} P_2O_5 with 115 kg.ha^{-1} N and 57 kg.ha^{-1} P_2O_5 with 115 kg.ha^{-1} N respectively. Application of 69 kg.ha^{-1} P_2O_5 with 115 kg.ha^{-1} N resulted 22% and 26% grain yield and biomass yield advantage over the control, respectively (Table 3 and 5).

The results of this study demonstrated that the use of chemical P fertilizer in combination with N consistently enhanced grain yield of wheat and teff compared to inorganic N fertilizer applied alone. These results, however, is not supported by pre-planting soil test results which shows a high available phosphorus in the study sites (Table 1). The result obtained falsifies the thought that there is no increase in yield when P fertilizer was applied to soil with sufficient levels of P. This research result were similar to the previous refining trials of wheat in the same district (Samuel et al., 2016).

The finding of this research disagreed with the results of Selassie et al. (2014) who reported that in areas with

Table 2. Effect of P fertilizer on teff grain yield (t.ha^{-1}) in 2018.

Fertilizer treatment (kg.ha^{-1})	Farm 1	Farm 2	Farm 3	Farm 4	Average
$0P_2O_5$	1.952^{bc}	1.142^{a}	1.356^{b}	1.848^{a}	1.575^{b}
$19P_2O_5$	1.822^{c}	1.223^{a}	1.462^{ab}	1.772^{a}	1.570^{b}
$38P_2O_5$	2.009^{b}	1.256^{a}	1.342^{b}	1.785^{a}	1.598^{ab}
$46P_2O_5$	2.280^{a}	1.236^{a}	1.681^{a}	1.680^{a}	1.720^{a}
$57P_2O_5$	2.113^{ab}	1.257^{a}	1.485^{ab}	1.765^{a}	1.655^{ab}
CV (%)	5.0	12.6	8.1	8.9	9.4

Note: CV= Coefficient of variation. Means within the same column followed by the same letters are not significantly different at 5% level of significance.

Table 3. Effect of P combined with N fertilizer with on wheat grain yield (t.ha^{-1}) in 2018

Fertilizer treatment (kg.ha^{-1})	Farm 1	Farm 2	Farm 3	Farm 4	Farm5	Average
92 N only	2.140^{b}	2.095^{b}	3.165^{a}	1.921^{b}	1.477^{b}	2.160^{b}
$19P_2O_5$+115N	2.817^{a}	2.243^{ab}	3.362^{a}	2.276^{ab}	1.616^{b}	2.463^{a}
$38P_2O_5$+115N	2.774^{a}	2.379^{ab}	3.513^{a}	2.154^{ab}	1.794^{ab}	2.523^{a}
$57P_2O_5$+115N	2.305^{ab}	2.742^{a}	3.397^{a}	2.138^{ab}	1.852^{ab}	2.487^{a}
P_2O_5+115N	2.498^{ab}	2.546^{ab}	3.597^{a}	2.370^{a}	2.218^{a}	2.646^{a}
CV (%)	11.0	12.6	8.9	10.8	17.2	11.8

Note: CV= Coefficient of variation. Means within one column followed by the same letters are not significantly different at 5% level of significance.

Table 4. Effect of P fertilizer on teff biomass yield (t. ha^{-1}) in 2018

Fertilizer treatment ($kg.ha^{-1}$)	Farm 1	Farm 2	Farm 3	Farm 4	Average
$0P_2O_5$	7.200^{ab}	5.889^{b}	6.903^{bc}	7.768	6.940^{ab}
$19P_2O_5$	6.507^{b}	6.396^{ab}	7.275^{bc}	7.692	6.967^{ab}
$38P_2O_5$	7.147^{ab}	6.322^{ab}	6.728^{c}	7.225	6.856^{b}
$46P_2O_5$	7.627^{a}	6.089^{b}	8.347^{a}	7.440	7.376^{a}
$57P_2O_5$	7.520^{a}	6.750^{a}	7.618^{ab}	7.365	7.313^{ab}
CV (%)	5.0	5.5	6.3	8.5	7.9

Note: CV= Coefficient of variation. Means within one columns followed by the same letters are not significantly different at 5% level of significance.

Table 5. Effect of P combined with N fertilizer on wheat biomass yield ($t.ha^{-1}$) in 2018

Fertilizer treatment ($kg.ha^{-1}$)	Farm 1	Farm 2	Farm 3	Farm 4	Farm5	Average
92 N only	4.533^{d}	4.533	7.167^{c}	1.921^{b}	3.767^{b}	4.800^{c}
$19P_2O_5$+115N	6.233^{ab}	4.733	7.900^{b}	2.276^{ab}	3.867^{ab}	5.560^{b}
$38P_2O_5$+115N	6.567^{a}	5.333	9.033^{a}	2.154^{ab}	4.233^{ab}	5.953^{ab}
$57P_2O_5$+115N	5.667^{bc}	5.567	8.700^{a}	2.370^{a}	5.167^{a}	6.087^{a}
$69P_2O_5$+115N	5.000^{cd}	6.033	8.467^{ab}	2.138^{ab}	4.300^{ab}	5.693^{ab}
CV (%)	7	19	5	10.9	17	12

Note: CV= Coefficient of Variation, Means within one column followed by the same letters are not significantly different at 5% level of significance.

high initial soil phosphorus application of P fertilizer is wastage for wheat production. On the other hand, as phosphate fertilizers are applied continuously over time, the amount of phosphorous nutrients in the soil tends to rise, especially in the labile forms that can release phosphorus into the soil solution (Brady and Weil, 2002). Even if the soil data revealed high range of available P (Table 1), both crops responded positively to the applied P fertilizers. Our results agreed with Alemayhu (2014) and Fissehaye et al. (2009) findings in that grain yield and yield related parameters were significantly affected by P application and excess P supply could result in low grain yield of teff. Liben et al. (2005) also reported that there is a linear increase in growth parameters for wheat by the application of NP fertilizers but the response is higher for N than P fertilizer at Northwestern Ethiopia. Application of 23 up to 92 kg $P_2O_5.ha^{-1}$ resulted in a grain yield increment of 171- 203% on vertisols in the central Ethiopia (Tamene et al., 2017).

Our findings showed that application of both nitrogen and phosphorus fertilizer increased the yield of both teff and wheat crops. The increase in grain yield with increasing levels of P fertilizer was likely due to better plant growth and health which eventually increased the final grain yield.

Conclusion

Application of different rates of P and N significantly increased wheat and teff grain yield over fertilizing with N only. Wheat biomass were significantly affected by different rates of P and N fertilizer but biomass yield of teff were not affected. Therefore, even though the soil P levels were shown to be sufficient, application of both N and P fertilizer in the Jamma district is essential to increase yield of teff and wheat. Further studies should be directed to determine the optimal phosphorus and nitrogen fertilizer rates for teff and wheat production in the districts.

Acknowledgement

We would like to express our sincere appreciation to Sirinka Agricultural Research Center for funding the research and for supporting most of the research materials and equipment to undertake the research.

References

Agegnehu, G., and Amede, T. (2017). Integrated soil fertility and plant nutrient management in tropical agro-ecosystems: a review. *Pedosphere* **27**, 662–680.

Alemayhu, B. (2014). Effect of phosphorus rates and varieties on grain yield, nutrient uptake and phosphorus efficiency of tef [*Eragrostis tef* (Zucc.) Trotter]. *American Journal of Plant Sciences* **5**, 262.

Bayu, W., and Rethman, N. F. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method, *Soil Science* **37**, 29-38.

Bouyoucos, G.J. (1962). Hydrometer method improved for making particle size analyses of soils 1. *Agronomy Journal* **54**, 464-465.

Brady, N.C., and Weil R. R. (2002). Phosphorus and potassium *In* "The Nature and Properties of Soils". 352 pp. Prentice-Hall of India, Delhi.

Cottenie, A. (1980). "Soil and Plant Testing As Basis of Fertilizer Recommendations". FAO Soil Bulletin No. 38/2.

Debele, B. (1982). "The Physical Criteria and Their Rating Proposed For Land Evaluation In The Highland Regions of Ethiopia". World Soil Resources Reports. FAO.

Fessehaye, Y., Bovenhuis, H., Rezk, M.A., Crooijmans, R., van Arendonk, J.A. and Komen, H., (2009). Effects of relatedness and inbreeding on reproductive success of Nile tilapia (*Oreochromis niloticus*). *Aquaculture* **294**,180-186.

Girma, T., Beyene, S., and Biazin, B. (2017). Effect of organic and inorganic fertilizer application on soil phosphorous balance and phosphorous uptake and use efficiency of potato in Arbegona District, Southern Ethiopia. *Journal of Fertilizers and Pesticides* **8**, 1-6.

Hagose, G., and Aberha, H. (2016). A Review on effect of phosphorus fertilizer on crop production in Ethiopia. *Journal of Biological Agriculture Healthcare* **6,** 117-120.

Haileselassie, B., Habte, D., Haileselassie, M., and Gebremeskel, G. (2014). Effects of mineral nitrogen and phosphorus fertilizers on yield and nutrient utilization of bread wheat (*Triticum aestivum*) on the sandy soils of Hawzen district, Northern Ethiopia. *Agriculture, Forestry and Fisheries* **3,** 189-198

Hodges, S.C., (2010). "Soil Fertility Basics" pp. 6-9. Soil Science Extension, North Carolina State University.

Jackson, M.L. (1958). "Soil Chemical Analysis" pp. 23-45 Prentice-Hall. New Jersey, U.S.A.

Van-Reewijk, L.P. and Clark, F.E, (1992). Procedures for soil analysis. *International Soil Reference Center (ISRIC)* **9,** 3.

Kpongor, D.S. (2007). "Ecology and Development" Series No. 51, pp.51-57.

Liben, M., Assefa, A., Tadesse, T., and Mariye, A., (2005). Response of bread wheat to nitrogen and phosphorous fertilizers at different agro-ecologies of Northwestern Ethiopia *In* "Proceedings of the 12th Regional Wheat Workshop for Eastern, Central and Southern Africa".

Tekalign, T. 1991. Soil, Plant, Water, Fertilizer, Animal Manure and Compost Analysis. Working Document No. 13.

Addis Ababa: International Livestock Research Center for Africa

Tekalign, T. (1991). "Soil, Plant, Water, Fertilizer, Animal Manure and Compost Analysis". Working Document No. 13. International Livestock Reaserch Center for Africa. Addis Ababa.

Ministry of Agriculture and Natural Resources and Agricultural Transformation Agency of Ethiopia. (2016). "Soil Fertility Status and Fertilizer Recommendation Atlas of Amhara National Regional State, Ethiopia".

Olsen, S.R., Cole, F.S., and Dean, L.A. (1954). "Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate" pp. 132-135.USDA Circular, Accra, Ghana.

Adissie, S., Teshome, H., Getu, A., and Hailu, T. (2016). Refining fertilizer recommendations for bread wheat production in South Wollo of Amhara region *In* "Proceedings of the 9th and 10th Annual Regional Conferences on Completed Research Activities on Soil and Water Management Research". pp 9–20.

Schneider, A. and Morel, C., (2000). Relationship between the isotopically exchangeable and resin-extractable phosphate of deficient to heavily fertilized soil. *European Journal of Soil Science* **51**,709-715

Shi, Y., Lalande, R., Hamel, C., Ziadi, N., Gagnon, B. and Hu, Z., (2013). Seasonal variation of microbial biomass, activity, and community structure in soil under different tillage and phosphorus management practices. *Biology and Fertility of Soils* **49**, 803-818.

Tamene, L., Amede, T, Kihara, J., Tibebe, D., and Schulz, S. (2017). "A Review of Soil Fertility Management and Crop Response to Fertilizer Application in Ethiopia: Towards Development of Site- and Context-Specific Fertilizer Recommendation". International Center for Tropical Agriculture (CIAT) Publication no 443. 86 p. Addis Ababa. Ethiopia.

Wiens, J.T. (2017). "Agronomic and Environmental Effects of Phosphorus Fertilizer Application Methods". [Thesis]. University of Saskatchewan. Canada.