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Validation and Demonstration of Calibrated Phosphorus fertilizer for Maize on Nitisols of Jimma Zone, Southwestern Ethiopia

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Abstract

The use of right amount of fertilizer based on crop requirement has a significant importance for sustainable crop production. Nitrogen and phosphorus fertilizers are the major limiting factors in most Ethiopian soils. The use of exact amount of fertilizer based on crop requirement has significant importance for sustainable crop production. Phosphorus calibration experiments were conducted in Southwestern Ethiopia for phosphorus fertilizer recommendation for maize producing area and critical concentration and requirement factor of phosphorus fertilizer were developed. Using these critical concentrations verified at Omo Nada and Limmu Seka districts on farmers' fields by the year of 2016/17 and 217/18 cropping season. The treatments were control (farmers' practice), calibrated phosphorus (critical concentration) and the recommended N fertilizer for the area and existing NP fertilizer recommendation (blanket recommendation (92 kg N ha^{-1}, 69 kg P_2O_5 ha^{-1}). The result of soil test based phosphorus fertilizer recommendation rate (STBR) on maize resulted in higher yield than blanket fertilizer recommendation. The maximum maize grain yields of 5666.7 kg ha^{-1} and 5252.1 kg ha^{-1} were obtained from the application of soil test based phosphorus fertilizer recommendation rate at Omonada and Limmu Seka districts respectively. The minimum maize grain yields of 3666.7 kg ha^{-1} and 2100 kg ha^{-1} were obtained from the control treatment at Omonada and Limmu Seka, respectively. Generally, soil test based phosphorus fertilizer recommendation rate resulted in grain yield increments of 7.63% and 10.29% and straw yield increments of 2.14% and 1.17% over the blanket fertilizer application rate at Omonada and Limmu Seka district, respectively. Hence, based on the results of this trial farmers perceived positively on the soil test based phosphorus fertilizer recommendation rate (STBR).

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Keywords

Blanket recommendation, maize, soil test, urea fertilizer.

Introduction

Maize (*Zea mays* L.) is one of the major food crops in Ethiopia leading in the volume of production and productivity (3.67 t ha^{-1}) (CSA, 2017). Poor soil fertility is one of the bottlenecks for sustaining maize production and productivity in Ethiopia in general (Aticho *et al.*, 2011). In many acidic soils of developing countries P deficiency is the main limiting factor for crop production and, therefore, requires the application of P fertilizers for optimum plant growth and production of food and fiber. Maize is an exhaustive crop having higher potential than other cereals and absorbs large quantities of nutrients from the soil during different growth stages. Nitrogen is a vital plant nutrient and a major yield determining factor required for maize production. It is very essential for plant growth and makes up one to four percent of the dry matter of the plants (Jeet *et al.,* 2012). Phosphorus is among the essential nutrients, which are the most important nutrients for higher yield in larger quantity and control mainly the reproductive growth of the plant (Khan *et al.,* 2014). Appropriate fertilizer recommendations must be used to sustain increased maize yield. The major plant nutrients are N and P that are applied to the soil in the form of di-ammonium phosphate (DAP) and urea fertilizer (Henry, 1990). Regardless of considering the physical and chemical properties of the soil, blanket fertilizer recommendations do not take into account climatic condition and available nutrients present in the soil (Taye *et al.,* 2000; Girma*et al.,* 2018). This blanket fertilizer recommendation for maize production in Ethiopia particularly in Jimma zone does not ensure efficient and economic use of fertilizers, as it does not take into account the soil fertility variations.

However, a controlled fertilization program through a sound soil test-crop response calibration and recommendation brings the application rates more in line with crop requirement, minimizes over- or under-application of fertilizer and could save hundreds of thousands of tons of fertilizer each year, minimizes the potential for water pollution due to over fertilization, especially N and P (Dahnke *et al.,* 1992; Agegnehu *et al.,* 2015), and minimizes losses in yield and crop quality. Consequently, fertilizer recommendations based on soil test approach considers the fertility status of individual fields and believed to be more advantageous than blanket recommendation (Agegnehu *et al.,* 2015). Hence, soil test results correlated against crop responses from applications of plant nutrients in question is the ultimate measure of a fertilizer recommendation program in order to apply nutrients at the right rate and in the right place as a best management practice for achieving optimum nutrient efficiency and crop production (Roberts, 2008).

Ethiopia is one of the sub-Saharan African countries where severe soil nutrient depletion and low agricultural production as well as economic growth are observed, even though the country has potentially rich in land resource (Getahun, 2003). Soil fertility is considered to be the major constraint in crop production in Ethiopia which is due to continuous cultivation of the soils without adequate replenishment for many years (FAO, 1999; Zeleke *et al.,* 2010). Declining soil fertility is a major constraint for crop production and productivity in Ethiopia. Urea and DAP fertilizers have been popularized for decades through the extension program of the Ministry of Agriculture. However, there is a major challenge facing the smallholder farmers not only to find ways of making fertilizer available at affordable price but also extension of fertilizer application among the all farmers has been a major challenge. Due to this fact, farmers have been using blanket fertilizer recommendation which is not recommended based on soil fertility status and crop nutrient requirements.

Since the last some years, most research projects consisted of trials to determine the appropriate amount and type of fertilizers needed to obtain the best yields for particular soil types and specific agro-ecology. Accordingly, the Ethiopian Institute of Agricultural Research and Regional Agricultural Research Institutes have developed information on soil test based critical P concentrations (Pc) and P requirement factors (Pf) for major crops and soil types of various agro-ecologies of the country. Unfortunately, these soil testing results were not validated. Therefore, these research achievements should be verified and demonstrated on farmers' fields, and this trial was initiated with the following objectives: 1) To verify and demonstrate the soil test based calibrated phosphorus fertilizers findings for major crops and soil types; 2) to create awareness on soil test based fertilizer recommendation on end users; 3) to develop phosphorus fertilizer recommendation guide line; and 4) to enhance crop production and productivity per unit area in the project sites and similar areas.

Materials and Methods

Area description

The field experiments were conducted at Omonada and Limmu Seka districts, south western Ethiopia, Oromia regional state for two consecutive main cropping seasons under rain fed conditions during 2017 and 2018. Omo Nada district lies at 7°17'to 7°49'N 37°00' to 37°28'E. It is located at a distance of about 71 kms from the zonal capital town, Jimma. It is bordered by Dedo in the west, Sokoru in the North, kersa in the South and TiroAfata in the east. The rainfall of the area is bimodal, with unpredictable short rains from March to April and the main season ranging over June to September. The minimum and maximum annual rainfall ranges from 1066 to 1200mm with a mean annual temperature ranging from 18 to 25°C. The area is characterized by gentle, flat and undulating topography with the altitude ranging from 1650-2200 m above sea level. The land cover categories of the district comprises 26.5% potential arable or cultivable land which include 23.4% annual crops and 7.0% pasture and 56.6% forest land and the remaining 9.9% was classified as degraded, built up or otherwise unusable. Limmu Seka is one of the wored as in the Oromia Region, Jimma zone, Southwestern Ethiopia lies between 08^{o}22'22''N - 036^{o}57'28'' E and 08^{o}23'55'' N -036^{o}58'33'' E. The administrative center of the district is Atnago town, which is located at about 454km southwest of Addis Ababa, and 109km from Jimma town. It is named in part after the former kingdom of Limmu-Enariya, whose territories included the area this woreda now covers. Limmu Sekaworeda is part of Jimma zone, bordered on the Southwest by the Didessa River which separates it from the IlluAbbabor, onthe Northwest by the East Wellega on the Northeast by the Gibe River which separates it fromthe West Shewa Zone, and on the Southeast by Limmukosa. The administrative center of theworeda is Atnago; other towns in the Woreda include Seka, Koma, Dame, Mero. According to the LimuSekaWoreda agricultural office data, the Woreda covers an area of approximately 1,694 km2. The total populations of the Woreda are189,463, of whom 95,869are men and 93,594 are women (LWOANR, 2015). The soils of Omonada and Limmu Seka districts were characterized with Nitisols.

Experimental procedures and treatments

The experiments were laid out in randomized complete block design (RCBD) with three replications in two districts of Omonada (3 farmers) and Limmu Seka (3 farmers) for two consecutive years (2016-2017). The trial was executed on farmers' fields in AGP II implementing districts. The experiments were consisting total of three treatments including control (farmers' practice), existing NP fertilizer recommendation and calibrated phosphorus (critical concentration) and recommended N fertilizer for the area (92 kg N ha^{-1}). Innovative farmers were selected through the help of development agents and agricultural experts of the district. The experimental fields were prepared using a local plow (maresha) according to farmers' conventional farming practices. The fields were ploughed two times to a depth of 15-20 cm and furrows were constructed by a hand-held hoe. A full dose of Phosphorus was applied at planting time close to seed drilling line, while N fertilizer was applied in split application, half at planting time and the rest 35 days after planting. The sources of the fertilizers for N and P were Urea and Triple super phosphate, respectively. The plot size was 10 m * 10 m (100 m^2) with 14 rows. For both study districts well adapted Bako hybrid maize (BH-661) which is high yielder as compared to other improved maize varieties in the study area was used as a test crop. A plant spacing of 80cm (inter-row) and 50 cm (intra-row) was used. Three seeds of maize were planted per hill and later thinned to two seedling ten days after emergence. All other management practices were performed as per the research recommendation required for maize crop. All growth, yield and yield component parameters were measured and the data pooled over two years. Composite soil samples collected from each farm were analyzed for selected chemical properties and presented below (Table 1).

Harvesting was done after the crop has reached physiological maturity and the cobs have dried through monitoring the grain moisture content. All the plants in the net-plot were cut at the soil surface and total bio-mass fresh weights determined in the field. The cobs were then harvested in such a way that the husk still remain on the plant. The cobs were counted and the weight of the total number of cobs was determined.

Grain and bio-mass yields were determined by harvesting the entire net plot area and converted into kilogram per hectare. Grain yield was adjusted to 12.5% moisture level; whereas bio-mass yield was weighed after leaving it in open air for seven days. The total dry matter yield, grain yield (at 12.5% moisture content), and harvest index were calculated as a ratio of grain yield to total biological yield.

The collected agronomic data were analyzed using statistical analysis software (SAS) 9.3 (SAS, 2012). Analysis of variance (ANOVA) was carried out to determine whether there was a significant difference among treatments. Mean separation of significant treatments was carried out using the least significant difference (LSD) test at $P \leq 0.05$ levels.

Soil sampling and analysis

Before planting, surface composite soil samples were collected at a depth of 0-20 cm from the fields using auger for site characterization. The collected samples were properly labeled, packed and transported to JARC soil laboratory. The surface soil samples collected from the experimental fields were air dried, grinded and allowed to pass through a 2 mm sieve. The pH of the soil was measured in the supernatant suspension of a 1:2.5 soil to water ratio using a pH meter (Rhoades, 1982).

Available soil P was determined according to Bray-II method as described by Bray and Kurtz (1945).

The treatments included: 1) control (farmers' practice; 2) calibrated phosphorus (critical concentration) and recommended N fertilizer for the area; and 3) existing NP fertilizer recommendation. The treatments were laid out in randomized complete block design using farmers' fields as replications.

$$Rate\ of\ P\ to\ be\ applied\left(\frac{kg}{ha}\right) = (Pc - Po) * Pf$$

Where: P_c = Critical P concentration, P_o = Initial P values for the site and P_f = P requirement factors

Results and Discussion

Soil chemical properties before planting

Soil analytical data is important to identify the level of nutrients in the soil and to determine suitable rates and types of fertilizers for recommendation.

Pre- treatment soil characteristics

The soil of the study area was initially characterized in order to assess its fertility status before the establishment of the cropping systems and application of fertilizers. The baseline data was then used for measuring changes after application of different nutrients.

The analyzed soil characteristics included soil pH; available P and exchangeable acidity which were determined from the composite surface (0-20 cm) soil samples collected from the experimental plots before fertilizer application were presented in Table 1.

The soil of the trial plots contained available P ranging from 0.74 mg $kg^{-1}$to 4.13 $mgkg^{-1}$(with the mean value of 2.77 mg kg^{-1}). Thus, the available P of the trial plots before application of fertilizer falls below the critical level (8 mg kg^{-1}) for most crop plants, as established by Tekalign *et al.*, (1991) for some Ethiopian soils respectively (Table 1). This could be attributed to the uptake or utilization by crops due to continuous cultivation, low input of amendment and generally poor management practices. Also, Marschner (1995) stated in most cases, soils with pH values less than 5.5 are deficient in P. The soil pH ranged from4.78 to 5.23 which were classified as very strongly acidic to moderately acidic (Landon, 1991; FAO, 1990) and ideal for the production of most field crops. The main cause of acidity is the loss of exchangeable bases through leaching from the top soil and is replaced with Al ions (Lechisa *et al.*, 2014). Therefore, under very acidic conditions, the soil solution is occupied mostly by Al and H ions. This has a direct effect on maize growth by suppressing the root development and reducing availability of macronutrients to plants especially phosphorus, which is readily available under medium pH range (Brady and Weil, 2008)(Table 1).

Grain yield and total biomass yield

Grain and bio-mass yield of maize was significantly affected ($P<0.05$) by the fertilizer treatments (Table 2&3). Grain yield is the end result of many complex morphological and physiological processes occurring during the growth and development of crop (Khan *et al.*, 2008). Grain yield of maize significantly differed for all fertilizer treatments. The result of the trial conducted at Omo Nada and Limmu Seka districts showed that maize grain yield was highly affected by different fertilizer application. Among the three treatments, the highest grain yield was obtained from calibrated phosphorus and recommended nitrogen fertilizer at Omo Nada (5666.7 kg $ha^{-1}$and 5543.4 kg ha^{-1}) and at Limmu Seka (4650 and 5252.1 kg ha^{-1}) respectively in the year of 2016 and 2017.Grain yield of maize involves the cumulative effect of a large number of components and metabolic processes that act with varying intensity throughout the plant's life cycle (Gungula *et al.*, 2007). Similarly, the lowest grain yield was obtained from control plots. The result indicated that application of calibrated phosphorus and recommended nitrogen fertilizer rate of the area (92 kg ha^{-1} N) gave the maximum grain yield of 5666.7 kg ha^{-1} and total biomass yield of 11933.8 kg ha^{-1}at Omonada district (Tables 2). Similarly, at Limmu Seka district, the highest maize grain yield of 5252.1kg $ha^{-1}$and total biomass yield of 12800.8kg ha^{-1}were recorded from the same treatment (Tables 3).

Table.1 Selected chemical properties of soil before planting on farmer's field

Parameter tested	Year and location			
	Omo Nada		Limmu Seka	
	2016/17	2017/18	2016/17	2017/18
pH(H_2O)	5.23	5.21	4.88	4.78
Av. Phosphorus(ppm)	4.13	2.6	3.6	0.74
Ex. Acidity(meq/100g)	0.9	1.1	0.20	1.2

Table.2 Effect of phosphorus fertilizer on maize grain and bio-mass yield (kg/ha) at Omonada district

Treatments	20116/17		2017/18		
	GY	BMY	GY	BMY	YI (%)
Control (Farmers practices)	3666.67^{c}	5500^{c}	3946.3^{b}	9706.3^{b}	
Calibrated Phosphorus (Critical concentration & Rec. N)	5666.67^{a}	9500^{b}	5543.4^{a}	11933.8^{a}	47.25
Existing NP fertilizer recommendation	5400^{b}	9966.7^{a}	5453.9^{a}	11674.6^{a}	42.57
Mean	4911.11	8322.22	4981.22	11104.93	
CV (%)	2.15	1.68	2.55	2.27	
LSD(0.05)	238.96	316.11	288.45	571.59	

Note GY= Grain Yield, BMY= Bio-mass yield, YI= Yield Increment over control

Table.3 Effect of calibrated phosphorus fertilizer on maize grain and biomass yield (kg/ha) at Limmu-Seka district

Treatments	20116/17		2017/18		
	GY	BMY	GY	BMY	YI (%)
Control (Farmers practices)	2100^{b}	2950^{b}	2779.5^{c}	6949.6^{b}	
Calibrated Phosphorus (Critical concentration & Rec. N)	4100^{a}	5450^{ab}	5252.1^{a}	12800.8^{a}	91.66
Existing NP fertilizer recommendation	4650^{a}	6500^{a}	4758.9^{b}	12591.9^{a}	92.83
Mean	3616.7	4966.7	4263.5	10780.8	
CV (%)	12.21	13.83	3.94	5.01	
LSD(0.05)	1900	2955	380.96	1224.2	

Note GY= Grain Yield, BMY= Bio-mass yield, YI= Yield Increment over control

Nutrient availability is the most yield-limiting factor to produce higher yields. The ability to better identify crop response to the application of fertilizers, soil indigenous nutrient supply capability, and the maintenance of soil fertility over time are crucial to the development of improved nutrient management practices. The result of soil laboratory analysis revealed that, most of chemical properties of the experimental site indicated low fertility status. The ability to better identify crop response to the application of fertilizers, soil indigenous nutrient supply capability, and the maintenance of soil fertility over time are crucial to the development of improved nutrient management practices. The site specific fertilizer recommendation rate with optimum N fertilizer rate of 92 kg N ha^{-1} influenced grain and biomass yields of maize. The maximum mean grain yield were 5666.7 kg $ha^{-1}$and 5252.1 kg ha^{-1} at Omonada and Limmu Seka, with 7.63% and 10.29% grain yield advantages over the blanket type fertilizer recommendation rate, respectively. Similarly, the highest mean straw yield of 11933.8 kg ha^{-1} was obtained from site specific fertilizer recommendation rate at Omonada, with 1.17% straw yield advantage over the blanket type fertilizer recommendation rate. Based on the results of this study, the farmers perceived positively the soil test based phosphorus fertilizer recommendation rate. Therefore, further effort should be made to disseminate the soil test based phosphorus fertilizer recommendation rate

(STBR). Soil laboratories should be functional and expanded throughout the region so that farmers will get access to test their soil.

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