Effect of Nitrogen and Phosphorous on Maize (*Zea mays* L.) Green Cob Yield under Irrigation in North Gonder

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Abstract

A field experiment was conducted in 2011 and 2012 irrigation seasons to determine the optimum levels of nitrogen (N) and phosphorus (P) fertilizers for maize production at Megech irrigation area, Dembia District of North Gonder. The experiment was arranged in Randomized Complete Bock Design with three replications. There were 16 treatments (4 rates of N (0, 69, 92 and 115 kg ha^{-1}) and 4 rates of P_2O_5 (0, 23 46 and 69 kg ha^{-1})). Maize variety, HB 545 was used for the experiment. Soil samples were collected from 0-20 cm depth to evaluate the soil fertility. Agronomic data such as plant height, cob length and cob number were collected, and the data were subjected to SAS statistical software. Partial budget analysis was done to evaluate the economic benefit against the fertilizers used. The combined analysis of variance in both years indicated that, N and P had significant effects on plant height, cob length and cob number. Application of 92 kg N and 69 kg P_2O_5 ha^{-1} gave the maximum cob number and cob length while the minimum was obtained from the control. The partial budget analysis for the green maize cob number also revealed that the maximum benefit was obtained from the combination of 92 kg N and 69 kg P_2O_5 ha^{-1}. Therefore, this fertilizer rate is recommended for Megech irrigation site and similar agro-ecologies under irrigation system.

Key words: green maize, nitrogen, phosphorous, fertilizer, green cob

Introduction

Maize (*Zea mays* L.) is an important cereal crop ranking third after wheat and rice in the world (Gibbon and Pain, 1985; FAO., 2011). In Africa, the bulk of maize produced is used as human food and the area coverage of maize in West and Central Africa alone increased from 3.2 in 1961 to 8.9 million ha in 2001. This remarkable expansion increased the quantity of maize production from 2.4 in 1961 to 10.6 million Mt in 2001 (FAO, 2002). Developing countries contribute 67% in the world cultivated land of maize but their share in quantity of production is only about 46%, where approximately 60% of the world maize is produced by USA and China collectively (Ghaffari *et al*., 2011).

In Ethiopia, maize is the major staple food and one of the main sources of calorie (Million and Getahun, 2001; Tolessa *et al*., 2001) being cultivated on about 1.75 million ha and accounts for 20% of the 8.5 million ha (79.98%) of land allocated for cereals. It ranks second after teff (*Eragrostis tef* (Zucc.)) in area coverage and first in total national production and yield per ha (CSA, 2008). Ethiopia has a potential to increase its productivity up to 8 tons per hectare. However, the national average yield, 3.2 t ha^{-1} (CSA, 2014) is still very low compared to the global average of 5.2 t ha^{-1} (FAO, 2011). This low productivity may be attributed to low soil fertility (Worku and Zelleke, 2007) and poor management practices (Tolessa *et al*., 2001) of which nitrogen and phosphorus nutrient deficiency and improper tillage can be mentioned as the most growth and yield limiting factors in the country.

Poor soil fertility is one of the bottlenecks for sustaining maize production and productivity in Ethiopia (Tolessa *et al.*, 2002). In most regions of Ethiopia, soils are deficient in nitrogen (N) and phosphorus (P). This adverse soil conditions prevail, and frequently a combination of these limit crop production. The situation has been further aggravated by the long history of cultivation without any nutrient replenishment including NP, which led to low soil fertility and low crop yields. Maize is heavy nutrient feeder and has high demand for N and P which are often the limiting nutrients for maize production. In Megech irrigation area the farmers usually produce shallot and garlic during the irrigation season and couldn't benefit from it due to high supply and short shelf life of the crops. Hence, after systematic investigation maize was introduced to the system as an enterprise choice. It is known that maize is a cash, food and feed crop which has multiple uses. The lack of alternate crops to the irrigation system and the importance of maize necessitates the introduction of high yielding varieties adaptive to the system with full package was important. Hence, HB-545 and Wonchi varieties were recommended after variety adaptation trial for higher grain and green cob yield for Megech irrigation area. However, the optimum nitrogen and phosphorus fertilizer rate for optimum production was lacking. Therefore, this experiment was conducted to determine the optimum levels of N and P fertilizers for maize (*Zea mays* L.) production under irrigation in Megech irrigation area.

Materials and methods

Geographic Location of the study Area

The study was conducted on farmers' fields for two years (2011 and 2012) in Megech irrigation area which is located in Dembia Woreda, North Gondar Zone, of the Amhara National Regional State, at 37.30º Longitude and 12.25º Latitude with an altitude of 1800 m.a.s.l. The area receives an average precipitation of 900 mm per annum, with maximum rainfall occurring from June to September when more than 85% of the annual rainfall was received. The average daily temperature ranges from 18.7°C to 23°C with the mean value of 20 °C. According the survey report by Ministry of Water, Irrigation and Energy, the soil types (units) identified in the area were: Eutric Vertisols, Eutric Fluvisols and Eutric Gleysols. The study was conducted on Eutric Fluvisols which occur along the Megech River. The soils are derived from alluvial/lacustrine deposits and are very deep. The texture is dominantly heavy clay with firm, sticky and plastic consistency. The study area is generally characterised by slow/poor drainage, with relatively slow infiltration and permeability associated with heavy clay texture, flat topography and shallow groundwater table.

Experimental design and procedures

The experiment was conducted in 2011 and 2012 irrigation seasons on farmer's field. The experiment was laid down in Randomized Complete Bock Design in factorial arrangement with three replications. The treatments were composed of factorial combinations of four rates of nitrogen (0, 69, 92 and 115 kg ha^{-1}) and four rates of P_2O_5 (0, 23, 46 and 69 kg ha^{-1}). All the phosphorus fertilizer from DAP and TSP was applied at planting while the nitrogen fertilizer from urea was applied in three equal splits at three stages including: 1/3 at planting, 1/3 at knee height and 1/3 at tasseling. Maize variety (BH-545) was used as a test crop and was planted in rows at a spacing of 70 cm between rows and 30 cm between plants. In a week interval, each experimental plot received 31mm irrigation water using furrow irrigation method uniformly. Other agronomic practices such as plowing, thinning, weeding earthling up and pest control were applied to all plots uniformly. The gross and net plot sizes were 9 m^2 (3m*3m) and 6.75 m^2 (3m*2.25m) respectively. The spacing between blocks and plots were 1.5 m and 1 m respectively.

Data collection

Soil sampling and analysis

Prior to planting, composite soil sample from 0 - 20 cm depth was collected following the standard soil sampling procedure (FAO, 2006). The soil samples were air dried, thoroughly mixed and grounded to pass 2 mm sieve to determine necessary soil chemicals parameters. Available P was extracted with sodium bicarbonate solution at pH 8.5 following the procedure described by Olsen *et al*. (1954). Total nitrogen was determined by the micro-Kjeldahl digestion, distillation and titration method as described by Jackson (1958). Soil pH was measured potentiometrically in the supernatant suspension of a 1:2.5 soil:water mixture using a pH meter according to method outlined by Sahlemedhin and Taye (2000). Organic carbon was determined following the Walkley and Black wet oxidation method as described by Jackson (1958). The CEC was determined at pH 7 after displacement of the cations by using 1 N ammonium acetate; thereafter, the ammonium was estimated titrimetrically by distillation of ammonium that was displaced by sodium following the procedure in Sahlemedhin and Taye (2000). Total exchangeable bases were determined after leaching the soils with ammonium acetate; Ca^{2+} and Mg^{2+} in the leachate were analyzed by atomic absorption spectrophotometer and K^+ and Na^+ were analyzed by flame photometer following the procedure in Sahlemedhin and Taye (2000).

Yield and yield component data

Data on plant height, cob length and cob number per plot were taken from ten random plants in the middle rows of the maize experiment. The plant height was measured from the base of the plant to the top of plant and expressed in centimeters. The number of cobs per plot was counted in the middle rows and converted to hectare bases.

Statistical and Partial Budget Analyses

The collected data was analyzed using SAS software (SAS V9.0, SAS Institute Inc., Cary, NC, USA). Whenever significant differences between treatments are detected, mean separation was done using least significant difference (LSD). The partial budget analysis was done to compare the impact of technological change on farm costs to evaluate economic advantage of fertilizer used to boost maize production following the CIMMYT partial budget analysis procedure (CIMMYT, 1988). Following CIMMYT's partial budget analysis methodology, total variable costs (TVC), gross benefit and net benefit were calculated. Net benefit was calculated as the difference between gross benefit and the TVC.

Variable costs include:

- Cost of fertilizers (N and P) which vary between fertilizer rates/treatments).
- Cob numbers per hectare resulted from each treatment which was adjusted by 5% decrement for each treatment
- Farm price i.e. prices of harvested cobs which was 1.25 birr per cob at time of harvesting

Costs for land preparation, weeding, seed, watering, harvesting were uniform for each treatment and were considered as fixed costs.

Results and discussions

Soil chemical properties of the of the study area

The analytic results indicated that the soil of the experimental site was low in its organic matter content which is about 3.17 % (Table 1). According to Landon (1991) organic matter: >20 % is very high, 10-20 % is high, 4-10 % is medium, 2-4 % is low and < 2 % very low. The low organic matter content of the soils of the experimental site may been attributed to continuous mono cropping and frequent and complete removal of farm residues commonly carried out by farmers in the area which tends to destroy much of the organic materials that could have been added to the soil. The CEC of the soil of the experimental site was 62.48 $cmol_c\ kg^{-1}$ which could be considered as very high (Landon, 1991) which may be attributed to high clay content. According to Olsen *et al*. (1954) P rating (mg kg^{-1}), P content of < 3 is very low, 4 to 7 is low, 8 to 11 is medium, and > 11 is high. Thus, the experimental site of available P content was 6.47 which were considered as low. The soil has very high exchangeable Ca (>20 $cmol_c\ kg^{-1}$ soil) and exchangeable Mg (>8 $cmol_c\ kg^{-1}$ soil) (Table 1). Ca to Mg ratio is 2.5 which indicate the likely inhibition of Ca uptake by the higher amount of exchangeable Mg. Exchangeable K and Na contents were high and low respectively (Table 1). The ratio of K to Mg is 0.06 which showed favorable proportion between the two cations in the soil. The soil pH of the study area was 6.85 (neutral). Maize grows at a pH range of 5 to 8. However, the ideal pH for optimum yield is between 6.5 and 7. Thus the pH of the study site is suitable for maize production. In general, the soil chemical properties including CEC and pH were good for maize production while the others including nitrogen and phosphorus need improvement (amendment) to a level that they could give optimum maize yield.

Table 1 Soil chemical properties of the initial soil samples

Parameters	Values
pH	6.85
Available P (ppm)	6.47
Total nitrogen (%)	0.09
Organic matter (%)	3.17
CEC cmol(+) kg^{-1}	62.48
Exchangeable Ca, cmol(+) kg^{-1}	48.47
Exchangeable Mg, cmol(+) kg^{-1}	11.77
Exchangeable K, cmol(+) kg^{-1}	0.74
Exchangeable Na, cmol(+) kg^{-1}	0.09

Plant height and cob yield

The analysis of variance of the experiment indicated that there was statistically significant difference ($p < 0.05$) among the treatments for parameters such as: plant height, cob length and number of cobs (Table 2, 3 and 4). Plant height was significantly ($P < 0.05$) influenced by levels of nitrogen and phosphorous fertilizers (Table 2). The taller plant height was obtained from the plots applied with of maximum inputs, (115 kg N $ha^{-1}$and 69 kg P ha^{-1}) while the smallest plant height was obtained from the control plot (plot without input). This result clearly revealed that fertilizer application is very important to increase the height of maize plant.

As described in Table 3, the longest cob length was recorded by the application of 92 kg N ha^{-1} and 69 kg P_2O_5 ha^{-1}. Similarly there was significant ($P < 0.05$) response in number of cobs per hectare to the application of nitrogen and phosphorous (Table 4). The maximum cob number (44556 cob ha^{-1}) was obtained from the plots applied with 92 kg N ha^{-1} and 69 kg P_2O_5 ha^{-1} followed by the plots applied with 115 kg N ha^{-1} and 69 kg P_2O_5 ha^{-1} while the smallest cob length and cob number were recorded from the plots receiving no fertilizer (Table 4). In general, increased application of N and P fertilizer was accompanied by increased maize yield. Similar results were reported by Tenaw (2000) Tolessa *et al*., (2002), Jehan *et al*., (2006) and Kolawole and Joce (2009). Tolessa (1999) also found progressive increases in maize grain yield with an increase in the levels of N and P fertilizers.

Table 2. The interaction effect of Nitrogen and Phosphorous fertilizer on maize plant height (cm)

	N rates (kg/ha)			
P_2O_5 rates (kg/ha)	0	23	46	69
0	117.1^{i}	141.9^{gh}	138.0^{h}	139.1^{h}
69	142.7^{gh}	146.5^{fgh}	157.1^{de}	166.4^{bc}
92	143.2^{fgh}	149.2^{efg}	172.2^{b}	170.2^{b}
115	151.8^{def}	159.5^{cd}	174.4^{b}	188.4^{a}
CV (%)	7.2			
LSD (0.05)	9.05			

Table 3. The interaction effect of Nitrogen and Phosphorous fertilizer on maize cob length (cm)

	N rates (kg/ha)			
P_2O_5 rates (kg/ha)	0	23	46	69
0	8.7^{g}	9.8^{fg}	13.4^{de}	10.9^{efg}
69	12.5^{def}	14.3^{d}	17.6^{bc}	15.0^{cd}
92	13.4^{de}	13.6^{de}	17.7^{bc}	22.0^{a}
115	14.1^{d}	14.9^{cd}	17.4^{bc}	20.1^{a}
CV (%)	10.8			
LSD (0.05)	2.76			

Table 4. The interaction effect of Nitrogen and Phosphorous fertilizer on maize cob number

	N rates (kg/ha)			
P_2O_5 rates (kg/ha)	0	23	46	69
0	15555.6^{g}	19333.3^{fg}	19333.3^{fg}	22222.2^{efg}
69	28888.9^{efg}	29555.6^{de}	31777.8^{cd}	33777.8^{bcd}
92	26666.7^{def}	33333.3^{bcd}	384444.4^{abc}	44555.6^{a}
115	29777.8^{de}	40666.7^{ab}	44000.0^{abc}	43777.8^{abc}
LSD (0.05)	10666.6			
CV (%)	4.8			

Partial budget analysis

Economic analysis was done to identify the most profitable nitrogen and phosphorous fertilizer rate. The partial budget analysis showed that application of 92 kg N ha^{-1} and 69 kg P_2O_5 ha^{-1} is economically profitable for sorghum production for it gave a rate of return above 100% acceptable rate of return (Table 5). Similarly, the highest MRR (555.67 %) was recorded by applying 92 kg N ha^{-1} and 69 kg P_2O_5 ha^{-1}. This result indicated that for each 1.ETB additional investment on fertilizer farmers can earn a return of 4.67 ETB (Ethiopian birr). According to Horton (1982), the greater the increase in net income and the higher rate of return, the more economically attractive the fertilizer rate is. The author further explained that the fertilizer rate is accepted only if the return is higher than 1.0. Hence, from the partial budget analysis the maximum benefit 42579.89 ETB per hectare was obtained by the application of 92 kg N ha^{-1} and 69 kg P_2O_5 ha^{-1} (Table 5). The marginal rate of return (MRR) was 555.67%. This indicates that for every 1 ETB invested for fertilizer there will be a net benefit of 4.67 ETB.

Table 5: Partial budget analysis for green cob number

(N, P_2O_5) kg/ha	Adjusted yield kg/ha	Total Revenue birr/ha	P costs birr/ha	Total costs birr/ha	GFB birr/ha	NB birr/ha	V. cost birr/ha	DA	MC birr/ha	MNB birr/ha	MRR %
(0,0)	14777.82	18472.28	6000	6000	12472.28	12472.28	0				
(0,23)	18366.64	22958.29	6000	6676	16958.29	16282.29	676		676	3810.02	563.61
(0,46)	18366.64	22958.29	6000	7352	16958.29	15606.29	1352	D			
(69,0)	21744.46	27180.57	6000	7726.5	21180.57	19454.07	1726.5		1050.5	3171.78	301.93
(0, 69)	21111.09	26388.86	6000	8028	20388.86	18360.86	2028	D			
(92,0)	25333.37	31666.71	6000	8302	25666.71	23364.71	2302		575.5	3910.64	679.52
69, 23	28077.82	35097.28	6000	8402.5	29097.28	26694.78	2402.5		100.5	3330.07	3313.50
(115,0)	28288.91	35361.14	6000	8877.5	29361.14	26483.64	2877.5	D			
(92, 23)	31666.64	39583.29	6000	8978	33583.29	30605.29	2978		575.5	3910.52	679.50
(69, 46)	30188.91	37736.14	6000	9078.5	31736.14	28657.64	3078.5	D			
(115, 23)	38633.37	48291.71	6000	9553.5	42291.71	38738.21	3553.5		575.5	8132.91	1413.19
(92, 46)	36522.18	45652.73	6000	9654	39652.73	35998.73	3654	D			
(69, 69)	32088.91	40111.14	6000	9754.5	34111.14	30356.64	3754.5	D			
(115, 46)	41800.76	52250.95	6000	10229.5	46250.95	42021.45	4229.5		676	3283.24	485.69
(92, 69)	**42327.92**	**52909.89**	**6000**	**10330**	**46909.89**	**42579.89**	**4330**		**100.5**	**558.44**	**555.67**
(115, 69)	41588.91	51986.14	6000	10905.5	45986.14	41080.64	4905.5	D			

Note: *P cost: production cost, GFB: gross field benefit, NB: Net benefit, V. cost: variable cost, DA: dominance Analysis, MC: Marginal cost, MNB: Marginal net benefit, MRR: Marginal rate of return*

Conclusions and Recommendations

The soil data analysis of the study site showed that the pH of the soil neutral which is suitable for the production of many crops including maize. But the content of some of the soil chemical properties need to be amended for optimum maize production. The analysis of variance revealed that fertilizer rates (N and P_2O_5) significantly affected plant height, cob length and cob number. The maximum cob number and the longest cob length were obtained by applying 92 kg N ha^{-1} and 69 kg P_2O_5 ha^{-1}. Application of 115 kg N ha^{-1} and 69 kg P_2O_5 ha^{-1} gave the tallest plant height. Similarly the partial budget analysis result indicated that the maximum net benefit was obtained by the application of 92 kg N ha^{-1} and 69 kg P_2O_5 ha^{-1}. Therefore, it is recommended to apply 92 kg ha^{-1} N and 69 kg P_2O_5 ha^{-1} for profitable green maize production for Megech irrigation area and similar agro-ecologies.

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