Selassie *Environ Syst Res (2015) 4:21*
DOI 10.1186/s40068-015-0048-8

Environmental Systems Research
a SpringerOpen Journal

RESEARCH

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The effect of N fertilizer rates on agronomic parameters, yield components and yields of maize grown on Alfisols of North-western Ethiopia

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Abstract

Background: Nitrogen is the most limiting nutrient for crop growth and development; and as in most soils of Ethiopia, the soils of the study area are deficient in nitrogen. Therefore, the objective of this research was to study the effects of mineral N fertilizer rates on agronomic parameters, yield components and yields of maize grown on Alfisols of Northwestern Ethiopia.

Results: Analysis of variance indicated no significant variation among treatments ($p > 0.05$) in plant height, shelling percentage and 1000-grain weight. However, nitrogen fertilizer rates significantly ($p < 0.05$) affected kernel number per ear and number of ears per plant. All the yield parameters have also shown a significant increase up to the rate of 90 kg N ha^{-1}. Increasing the N rate from 90 to 200 kg N ha^{-1}, however, did not give a significant grain, dry stubble and dry aboveground biomass yields increase. The MRR analysis showed that the treatment with N fertilizer rate of 60 kg N ha^{-1} gave the highest MRR of 256.7 % followed by the treatment with N fertilizer rate of 90 kg N ha^{-1}.

Conclusions: From the results of the study it is possible to conclude that application of nitrogen fertilizer improves yield and yield components of maize. Moreover, judicious nutrient management in maize could ensure high grain yield production and profit. Application of 60 kg N ha^{-1} gave maximum profit from unit investment which can be recommended for the study area.

Keywords: Alfisols, N fertilizer rate, Optimum grain yield, Marginal rate of return

Background

In Northwestern Ethiopia, population growth is rapid and there is a rapidly growing demand for food. Therefore, cultivation of subsistence crops must be stimulated and production augmented in a sustainable way. The trend in all research endeavors including research on soil nutrients, therefore, is going through a development process away from agricultural production per se towards sustainable production (Smaling and Oenema 1998). Among others, mineral nutrition is becoming one of the most important factors for increasing maize production in Northwestern Ethiopia. Unfortunately, many soils of Ethiopian highlands are inherently poor in available plant nutrients and organic matter (Tekalign et al. 1988). Murphy (1963) conducted a survey or rapid appraisal work 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 marginal fertilizer application could not produce enough even to feed their own family for a year.

As in other soils of Ethiopia, nitrogen is probably more often deficient than any other essential element in Alfisols, mainly because organic matter of these soils is not preserved (Mesfin 1998). In addition to this, the cereal dominated cropping systems, aimed at meeting the

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farmers' subsistence requirements, coupled with low usage of chemical fertilizers have led to the widespread depletion of soil nitrogen in the maize growing areas of Ethiopia. Moreover, the heavy rains during the early part of the main cropping season (June–August) cause substantial soil nutrient losses due to intensive leaching and erosion (Amsal and Tanner 2001).

It is apparent that in many farming systems of Ethiopia, input of manures and fertilizers is still low and not sufficient to sustain the productivity of the soils. Bringing more land into cultivation is not possible in the densely populated areas. Preference, therefore, should be given to raising the production of subsistence crops by increasing the productivity of the soils on which crops are being grown. Improving soil fertility is one of the major factors to improve soil productivity. Organic and inorganic fertilizers, therefore, should be applied to restore and improve the soil fertility and to compensate for the withdrawal and losses of nutrients during cultivation. Nevertheless, organic fertilizers are scarce resources in most farming households of Ethiopia where farmyard manure and crop residues are used as energy source to cook food. Therefore, efficient use of artificial fertilizers should be given due attention. The objective of this research was, therefore, to study the effects of mineral N fertilizer rates on agronomic parameters, yield components and yields of maize grown on Alfisols of Northwestern Ethiopia.

Methods

Site selection

To select the experimental sites, composite soil samples were collected from 52 farmlands that had different cropping history, slope and management practices. The collected soil samples were analyzed for organic matter content (Nelson and Sommers 1982), texture (Sahelemedhin and Taye 2000) and pH (Thomas 1996). Out of the sampled sites, 20 experimental sites covering the widest possible ranges of the indicated parameters were selected (Table 1).

Experimental design, field layout and cultural practices

At each site, the field experiment was arranged in randomized complete block design with five N fertilizer rates as treatments (0, 30, 60, 90 and 200 kg N ha^{-1}) as urea (46-0-0) and four replications. Plant spacing was 70 cm between rows and 30 cm between plants. The gross plot had three harvestable and two boarder rows (with 4.8 m length). Two plants in each end of the harvestable rows were used as boarder plants. Seed beds for maize planting in each location were prepared following farmers' practice.

Planting was conducted from May 28 to June 7, 2002 depending on the onset of rainfall in different areas. Planting was made by keeping two seeds in one hill at a distance of 30 cm within a row. Two weeks after emergence, plants were thinned to one plant per hill. Half of the nitrogen fertilizer for each treatment was applied at planting by banding along the row at a distance of about 10 cm below and 5 cm aside the seeds. The remaining nitrogen was side-dressed at 35 days after emergence. To all plots, phosphorus (120 kg P_2O_5 ha^{-1}) as triple superphosphate (0-46-0) and potassium (60 kg K_2O ha^{-1}) as potassium chloride (0-0-60) were added as basal fertilizers. Two times ridging and, as necessary, weeding operations were performed in all sites.

Data collection

Data collection was carried out during the vegetation period, at harvest and after harvest. Data on agronomic parameters (plant height and lodging percentage), yield components (number of ears per plant, shelling percentage, 1000-grain weight and kernel number per ear), and yields (grain, dry stubble and dry biomass) were collected as outlined in Yihenew (2004).

Plant height from the ground level up to the collar of the upper leaf with developed leaf sheath was measured at 35 and 60 days after emergence, and at harvest. Lodging percentage was measured at harvest by dividing the number of lodged plants by the number of harvested stands. Those plants that inclined to the ground at an angle of $\leq 45^{\circ}$ were considered lodged.

The number of ears per plant was determined by dividing the number of harvested ears by the number of harvested stands. Shelling percentage was determined as the ratio of the weights of shelled grain and unshelled ear expressed in percentage. Thousand-grain weight was determined by weighing with analytical balance the weight of 1000 sampled grains from the bulk harvest and adjusting to 12.5 % moisture level. To determine the kernel number per ear, first shelled grain of the harvested maize in each plot was weighed and divided by the number of ears. This gave grain weight per ear. After this, the weight of 1000 grains was determined. At last, kernel number per ear was determined mathematically as follows: kernel per ear = grain weight per ear (g) × 1000 grains/weight of 1000 grains (g).

Grain and stubble yield data were collected from the three harvestable rows by excluding over-favored plants (plants that stand at a spacing exceeding the required distance due to missing plants in a row). The harvested biomass was weighed for fresh biomass weight after which the ears and the stubble were separated and weighed. The ears were shelled and grain yield was determined by adjusting to 12.5 % moisture content. Stubble of two stands from each plot was collected from each plot at harvest. The stubble samples were oven dried until

Table 1 Locations and some chemical and physical characteristics of soils of the experimental sites

Site No.	Altitude (meters above sea level)	Geographic position	Slope (%)	Organic matter (%)	pH in H_2O (1:2.5)	Particle size (%)			Soil texture
						Sand	Silt	Clay	
1	2240.0	11°17.2′N 37°28.9′E	3.8	2.84	4.91	7	25	68	Clay
2	2243.1	11°17.3′N 37°28.8′E	2.6	3.35	5.21	5	25	70	Clay
3	2348.8	11°14.3′N 37°30.7′E	0.3	3.25	5.00	7	21	72	Clay
4	2347.9	11°14.2′N 37°30.9′E	2.3	1.78	5.35	13	17	70	Clay
5	1897.3	11°44.0′N 37°30.8′E	5.4	3.09	5.40	15	29	56	Clay
6	1918.0	11°44.7′N 37°31.9′E	5.1	2.66	4.73	5	17	78	Clay
7	1955.8	11°45.7′N 37°32.4′E	3.1	3.19	4.99	7	27	66	Clay
8	1969.8	11°46.8′N 37°33.2′E	2.3	3.11	4.83	9	27	64	Clay
9	1916.8	11°44.4′N 37°31.7′E	8.1	2.31	5.26	55	21	24	Sandy clay loam
10	2048.7	11°24.8′N 37°24.8′E	1.1	3.93	5.25	9	25	66	Clay
11	2067.6	11°25.0′N 37°07.9′E	3.5	4.22	5.25	15	49	36	Silty clay loam
12	2039.8	11°24.8′N 37°07.4′E	0.2	4.08	5.05	9	25	66	Clay
13	2038.9	11°24.6′N 37°07.1′E	0.3	4.24	5.13	11	23	66	Clay
14	2002.7	11°21.6′N 36°58.1′E	1.6	5.56	5.01	13	23	64	Clay
15	1900.0	10°80.0′N 36°85.0′E	5.0	6.06	5.75	11	21	68	Clay
16	2150.7	10°42.7′N 37°05.6′E	1.8	3.99	5.78	15	25	60	Clay
17	2106.3	10°42.2′N 37°06.3′E	5.2	4.51	5.43	9	21	70	Clay
18	1897.9	10°40.8′N 37°16.4′E	2.3	4.33	5.63	11	23	66	Clay
19	1888.4	10°40.5′N 37°16.4′E	2.9	4.12	5.42	11	23	66	Clay
20	1882.0	10°40.9′N 37°19.0′E	0.6	3.71	5.28	11	23	66	Clay

constant weight was attained so that it was possible to calculate the dry stubble yield per plot. The dried biomass yield was determined as the sum of dry grain and dry stubble yields.

Partial budget and marginal rate of return analysis of non-dominated grain yield responses for different N fertilizer rates were done following the method used by Nasreen and Farid (2003). MRR = (marginal increase in gross margin/marginal increase in variable cost) × 100.

Results and discussion

The effect of nitrogen fertilizer rates agronomic properties

Plant height

Analysis of variance of the data collected from 20 locations (80 replications) indicated that there was significant variation ($p < 0.05$) among treatments at all stages of plant height measurements (Table 2). However, the high concentration of nitrogen from the treatment with the highest rate of N application (200 kg N ha^{-1}) had a depressing effect on plant height of young seedlings measured at 35 days after emergence. This treatment gave significantly inferior ($p < 0.05$) plant height than the treatment with 90 kg N ha^{-1}. As time went on, however, plants in plots with the highest fertilizer rate overcame the depressing effect and, even though statistically not significant, exhibited the highest plant height measured at the 60 days after emergence and at harvest compared to other treatments. Abera (2013) reported that increase in N rates extended vegetative growth period of maize that increases photosynthetic assimilate production and its partitioning to stems that might have favorable impacts on heights of maize.

When treatments were compared using Duncan's multiple range test (DMRT), application of 90 kg N ha^{-1} was the rate that gave the highest significant plant height measured at all stages. However, regression analysis of the same data indicated that the highest plant height were obtained at fertilizer rates of 124.4, 140.9 and 151.8 kg N ha^{-1} for the 35 days, 60 days and harvest time, respectively. From these it was possible to note that the fertilizer requirement to achieve maximum plant height showed an increasing trend from earliest time to the latest, which is showing that as plants grow up, their requirement for fertilizer increases. The R^2 values of the three response curves (0.982, 0.988 and 0.995, respectively) also confirmed that the variance in plant height accounted for by the applied fertilizer was higher in the later stages of plant growth than in the earlier stages.

Table 2 The effect of nitrogen fertilizer rates on plant height (cm) measured at different growth stages of maize

Fertilizer rate (kg ha^{-1})	Time of measurement of plant height		
	35 days after emergence	60 days after emergence	At harvest
0	15.3 d	87.1 d	180.4 d
30	21.2 c	121.4 c	197.2 c
60	24.1 b	140.2 b	214.4 b
90	25.6 a	150.3 a	221.2 a
200	24.6 b	150.4 a	225.1 a
CV (%)	10.83	8.86	6.14

Means followed by a common letter in a column are not significantly different at 5 % probability level by DMRT

Lodging percentage

Only the treatment with N fertilizer rate of 200 kg N ha^{-1} exhibited a significant difference ($p < 0.05$) in lodging percentage from the unfertilized treatment (Table 3). The rest of the treatments did not differ significantly from the unfertilized treatment. Nevertheless, even though statistically non-significant, increasing N fertilizer rate linearly increased resistance of plants for lodging. Moreover, the number of data points with higher lodging percentage was more for treatments that received lower fertilizer rates than treatments with relatively higher fertilizer rates.

Brady and Weil (2000) reported that plants deficient in nitrogen develop thin and spindly stems. Such stems could be susceptible for lodging by wind. Moreover, N deficient plants have poor development of root system, which reduces their anchorage capacity. Wilson (1930) showed a positive relationship between resistance to lodging and number of brace roots of maize. Conversely, when too much nitrogen is applied, excessive vegetative growth occurs and top-heavy plants are prone to lodging with heavy rain or wind (Brady and Weil 2000). The significant grain yield response obtained in this experiment from the highest rate of N application with reduced lodging percentage, however, indicates that the point of excess nitrogen rate was not reached to cause excessive biomass production and lodging. Moreover, potassium fertilizer, which was added as basal application to all plots, could have also reduced lodging of maize plants in treatments with higher N fertilizer rates; because, potassium fertilizer strengthens the stems (Brady and Weil 2000). The high coefficient of variation obtained for lodging percentage was due to the wide variations of the data obtained in the experiment that ranged from 0 to 100 %.

Table 3 The effect of nitrogen fertilizer rates on lodging percentage

Fertilizer rate (kg ha^{-1})	Lodging percentage (%)	Shelling percentage (%)
0	15.30 a	79.48
30	13.93 ab	79.40
60	12.29 ab	79.72
90	11.94 ab	79.90
200	8.73 b	79.20
F test	**	ns
CV (%)	136.8	2.8

Means followed by a common letter in a column are not significantly different at the 5 % probability level by DMRT

Shelling percentage

N fertilizer rates did not have a significant effect ($p > 0.05$) on shelling percentage (Table 3). The non-significant difference obtained among treatments might be justified that as N fertilizer rate was increased, both the grain and cob weight increased in equivalent proportions, which kept the shelling percentage constant in all the treatments.

The effect of nitrogen fertilizer rates on yield components

The effect of N fertilizer rate on yield components (1000-grain weight, number of kernels per ear and number of ears per plant) is presented in Table 4. Nitrogen fertilizer rate did not show a significant effect ($p > 0.05$) on 1000-grain weight but affected significantly ($p < 0.05$) kernel number per ear and number of ears per plant. This indicates that the grain yield difference among treatments was attributed more to the increase in number of kernels per ear and number of ears carried by each stand than the kernel weight.

It was, however, clear that treatments with higher fertilizer rates carried significantly higher number of kernels per ear and ears per stand as compared to the treatments with lower fertilizer rates. This caused distribution of biomass accumulation into the significantly higher number of kernels and ears produced due to higher rates of N that might have diminished the effect of fertilizer rate on kernel weight. This suggests that the effects of

Table 4 The effect of nitrogen fertilizer rates on yield components

Fertilizer rate (kg ha^{-1})	1000-grain weight (kg)	Number of kernels per ear	Number of ears per plant
0	0.406	295.43 e	0.993 d
30	0.408	337.16 d	1.020 c
60	0.410	387.19 c	1.018 c
90	0.413	422.53 b	1.047 b
200	0.397	451.80 a	1.077 a
F test	ns	**	**
CV (%)	15.6	20.8	7.4

Means followed by a common letter in a column are not significantly different at the 5 % probability level by DMRT; **, ns = significant and non-significant at 5 % probability levels, respectively

treatments were more pronounced before or during ear formation and kernel initiation stage rather than during kernel filling. Other possible reason may be prevalence of stressed condition during grain filling. Fageria et al. (1997) reported that yield of maize is the product of kernel number per unit area and kernel weight. Of these, grain weight is more stable and large differences in yield are usually the result of fluctuations in grain number. Neilson (2003) also reported that the number of harvestable kernels per ear to be an important contributor to the grain yield potential of maize plant. Similarly, Abera (2013) indicated that higher rate of N level increased kernel weight in maize. The mean value of the number of ears per plant data for the unfertilized plots was below unit, because some stands in the control plots did not carry productive ears even though these stands were not exposed to any stressed condition differently from other plants of the fertilized plots.

The effect of nitrogen fertilizer rates on yield parameters

N fertilizer rate had a significant effect on grain, dry stubble and dry aboveground biomass yields of maize (Table 5). All the yield parameters have shown a significant increase up to the rate of 90 kg N ha^{-1}. Increasing the N rate from 90 to 200 kg N ha^{-1}, however, did not give a significant ($p > 0.05$) grain, dry stubble and dry above ground biomass yields increase. The regression analysis of treatment means, however, indicated that maximum yield response in grain, stubble and biomass yield was attained at fertilizer rates of 160.72, 144.88 and 149.25 kg N ha^{-1}, respectively.

Based on the results of the analysis of variance, the coefficients of variation (CV) for the grain, dry stubble and dry biomass yields data were high (29.76, 27.50, and 25.59 %, respectively). It was mainly because locations with wide variations in nitrogen and organic matter status were incorporated in the experiment. The difference in the level of the fertility status of the soils consequently gave colossal difference in response level to fertilizer applications. Incorporating these data in the analysis of variance, therefore, increased the error mean square and eventually raised the CV. Nitrogen increases shoot dry matter, which is positively associated with grain yield in cereals and legumes (Fageria 2007). In agreement with the results of this study, Hammad et al. (2011), Khaliq et al. (2009) and Abera (2013) reported significantly higher biomass yield at higher N rates. Workayehu (2000) also reported that grain yield of maize increase progressively with added nitrogen fertilizer up to a certain rate.

The correlation analysis calculated among yield components and grain yield indicated that all the yield components correlated highly significantly with grain yield (Table 6). Comparison of the correlation coefficients, however, indicated that number of kernels per ear gave correlation coefficient that was superior ($r = 0.74^{**}$) to other yield components followed by number of ears per plant ($r = 0.53^{**}$). Shelling percentage and 1000-grain weight exhibited relationships with grain yield with

Table 5 The effect of nitrogen fertilizer rates on yield parameters

Fertilizer rate (kg ha^{-1})	Grain yield (kg ha^{-1})	Dry stubble yield (kg ha^{-1})	Dry biomass yield (kg ha^{-1})
0	3655.61 d	5376.36 d	8575.01 d
30	4396.29 c	6990.51 c	10837.26 c
60	5093.91 b	8216.28 b	12683.79 b
90	5625.61 a	9094.42 a	14029.44 a
200	5911.19 a	9086.06 a	14258.35 a

Means followed by a common letter in a column are not significantly different at the 5 % probability level by DMRT

Table 6 Correlation coefficient matrix of the relationship among yield components and grain yield

	Number of kernels per ear	Shelling percentage	1000-grain weight	Number of ears per plant
Shelling percentage	0.041^{ns}			
1000-grain weight	0.02^{ns}	0.08^{ns}		
Number of ears per plant	0.27**	0.05^{ns}	0.12*	
Grain yield	0.74**	0.30**	0.31**	0.53**

*, ** significant at 5 % and 1 % probability levels, respectively; ^{ns} non-significant at 5 % probability level; n = 400

correlation coefficients of relatively lower magnitudes as compared to the former yield components. This suggests that the former two yield components more determined grain yield. The correlation coefficients among yield components indicated the existence of marginal, and in some cases, non-significant relationships.

Economic evaluation

Gross return was calculated from price (seasonal average) of maize grain in the study area (0.6 Birr kg^{-1}). Variable cost was calculated from the costs involved for purchase and application of fertilizer. Urea, which was used as the source of nitrogen, was bought for 1.8 Birr kg^{-1}. For application of fertilizer, at planting 80 Birr ha^{-1} would be needed considering that 16 laborers can apply fertilizer on a hectare of land in 1 day (daily wage of one laborer is 5 Birr). The same amount of money will be required for side dressing.

The partial budget analysis of fertilizer rates revealed that the maximum gross margin was attained from application of 90 kg N ha^{-1} and the least gross margin was obtained from the unfertilized treatment (Table 7). The dominance analysis showed that the treatment with the highest fertilizer rate (200 kg N ha^{-1}) was cost dominated; i.e., it provided gross margin that was less than that of the preceding treatment. Therefore, it was omitted from the analysis of marginal rate of return (MRR).

The MRR analysis showed that the treatment with N fertilizer at the rate of 60 kg N ha^{-1} gave the highest MRR of 256.7 % followed by the treatment with N fertilizer rate of 90 kg N ha^{-1} (Table 8). The treatment with N fertilizer rate of 30 kg ha^{-1} gave MRR below 100 %, which indicates that this rate is not economically optimum. Considering a situation at which gross margin would drop by 10 % and variable cost would rise by the same rate, the treatment with 60 kg ha^{-1} still will give the highest MRR.

Table 7 Partial budget and dominance analysis of maize grain yield response for different N fertilizer rates

N fertilizer rate (kg ha^{-1})	Urea (kg ha^{-1})	Grain yield (kg ha^{-1})	Gross return (Birr ha^{-1})	Variable cost (Birr ha^{-1})			Gross margin (Birr ha^{-1})	Cost dominance[a]
				Fertilizer	Fertilizer application	Total		
0	0	3655.61	2193.37	0	0	0	2193.37	Non-dominated
30	65.2	4396.29	2637.77	117.36	160	277.36	2360.41	Non-dominated
60	130.4	5093.91	3056.35	234.72	160	394.72	2661.63	Non-dominated
90	195.7	5625.61	3375.37	352.26	160	512.26	2863.11	Non-dominated
200	434.8	5911.19	3546.71	782.64	160	942.64	2604.07	Dominated

[a] Non-dominated are treatments that gave higher gross margin than treatments with lower N fertilizer rates; dominated is the treatment that gave lower gross margin than treatments with lower N fertilizer rates

Table 8 Marginal rate of return analysis of non-dominated maize grain yield response for different N fertilizer rates

N fertilizer rate (kg ha^{-1})	Gross margin (Birr ha^{-1})	Variable cost (Birr ha^{-1})	Marginal increase in gross margin (Birr ha^{-1})	Marginal increase in variable cost (Birr ha^{-1})	MRR (%)
90	2863.11	512.26	201.48	117.54	171.4
60	2661.63	394.72	301.22	117.36	256.7
30	2360.41	277.36	167.04	277.36	60.22
0	2193.37	0	–	–	–

Conclusions

From the results of the experiment, it is possible to conclude that nitrogen fertilizer rate had a significant effect on plant height, lodging percentage, number of kernel per ear, number of ears per plant, grain yield, dry stubble yield and dry biomass yield of maize. However, it did not have a significant effect on shelling percentage and 1000-grains weight of maize grown on Alfisols of Northwestern Ethiopia. Application of 60 kg N ha^{-1} gave maximum profit from unit investment which can be recommended for the study area.

Acknowledgements

The author acknowledges Agricultural Research and Training Project (ARTP) of Ethiopian Institute of Agricultural Research (EIAR) for funding the research work.

Competing interests

The author declares no competing interests.

Received: 4 August 2015 Accepted: 19 October 2015
Published online: 04 November 2015

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