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Equations for Estimating Nitrogen Fertilizer Requirements from Soil Analysis for Maize (*Zea Mays* L.) Grown on Alfisols of Northwestern Ethiopia

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ABSTRACT

With the prime objective of developing equations for estimating nitrogen fertilizer requirements of maize on Alfisols of Northwestern Ethiopia, field experiments were conducted at 20 sites. At each site, the treatments (five rates of N fertilizer) were arranged in a randomized complete block design with four replications. After maturity, yields and yield components data were collected. Soil parameters determined for indexing availability of nitrogen were organic matter content, total N, NH_4-N, NO_3-N, inorganic N (NH_4+NO_3-N), inorganic N production on aerobic incubation, and ammonium-N released on autoclaving with dilute calcium chloride. Reliable methods were identified by fitting relative grain, relative dry biomass and N yields in a double log curvilinear regression model and those availability indices giving superior correlation were selected. Consequently, nitrogen availability indices that were found most reliable and grain yield data were fitted into the Mitscherlich-Bray model.

Results of the experiment revealed that organic matter, total N, and NO_3-N were the most reliable N availability indices. The equations developed for estimating N fertilizer requirements of maize were: (a) log (100 - y) = 2 - 0.1103b - 0.006411x; (b) log (100 - y) = 2 - 2.0566b - 0.006481x; and (c) log (100 - y) = 2 - 0.0220b - 0.006414x for organic matter, total N and NO_3-N, respectively, where y was relative yield goal, b was N availability index expressed as % for the former two indices and mg kg^{-1} for the later, and x was the N fertilizer requirement. The three equations were statistically proven to give equally reliable estimates of N fertilizer requirement of maize on Alfisols of Northwestern Ethiopia. Nevertheless, in seasons where rainfall is heavy, high probability of nitrate leaching may make the later method less effective.

Key words: N availability indices, Mitscherlich-Bray model, nitrate, organic matter, total nitrogen

INTRODUCTION

Research on soil nutrients 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 achieving sustainable maize production in Northwestern Ethiopia. It is because many soils of Ethiopian highlands are inherently poor in available plant nutrients and organic matter (Tekalign *et al*., 1988).

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To meet the nutrient demand of crops on the nutrient deficient soils of Ethiopia, application of chemical and/ or organic fertilizer is necessary. Organic fertilizer is becoming a meager resource in the farming communities where farmyard manure and plant residues remain to be the major source of fuel energy. Therefore, chemical fertilizers are becoming to be the major sources of plant nutrients. 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 flat fertilizer recommendations have been developed and introduced to the extension system. This approach, however, had shortcomings in extrapolating the results to other fields, because, the available nutrient status on the experimental fields were either 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).

Various soil analysis methods have been proposed as indices of nitrogen availability. A reliable soil testing method, however, should provide precise information on the fertilizer quantity required for optimum growth of a particular crop (Mengel, 1982). To be a useful guide for recommending N fertilization, results from soil tests must be significantly correlated with crop yields without applied fertilizer and with responses to fertilizer application (Welch and Bartholomew, 1963). Since no universally accepted method exists, methods have been designed to meet the specific conditions under which the crops are intended to grow.

Following identification of soil test methods giving reliable availability indices, mathematical models that integrate the soil test indices with fertilizer rate requirements should be developed for each crop species on soil type and agro ecology where that particular crop is growing. The Mitscherlich-Bray model has been successfully used for such purposes (Suwanarit *et al.*, 1995; Santhi *et al.*, 1998; Suwanarit *et al.*, 1999). The objective of this study was, therefore, to develop equations for estimating nitrogen fertilizer requirements of maize (*Zea mays* L.) from soil analysis on Alfisols of Northwestern Ethiopia using the Mitscherlich-Bray equation.

MATERIALS AND 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, texture and pH. 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 practice

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 hills of each plant. 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 each treatment, phosphorus (120 kg P_2O_5 ha^{-1}) as

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

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.

Soil sample collection and analysis for indexing availability of N

At planting, from each replication of the selected 20 locations, one composite soil sample was collected from the top 0 - 20cm soil layer. The collected samples were air-dried under the shade and crushed to pass through 0.5 mm sieve. The following soil analyses were conducted: determination of organic matter content (here after called method 1) according to the Walkley-Black procedure (Nelson and Sommers, 1982); total N determination (here after called method 2) by the Kjeldahl method (Bremner and Mulvaney, 1982); NO_3-N (here after called method 3), NH_4-N (here after called method 4), and NO_3+NH_4-N (here after called method 5) determination by steam distillation as outlined by Keeney and Nelson (1982); aerobic incubation and estimation of inorganic-N production (here after called method 6) as outlined by Ryan *et al.* (1971), and determination of ammonium released on autoclaving with dilute calcium chloride (here after called method 7) as outlined by Keeney (1982). These methods were selected because indices from them were widely reported to be reliable in estimating availability of N.

Yield data collection, plant sampling and analysis

The crop was harvested after physiological maturity and grain yield at 12.5% moisture and dry aboveground biomass yield data were collected from the three central rows excluding the two boarder plants in each end of the row. Maize grain and stubble samples were collected to estimate plant N uptake. For plant tissue analysis, procedures outlined by Sahlemdihin and Taye (2000) were used.

Derivation of equations for calculating N fertilizer rates for desired maize yields

Calculation of relative yields

Relative grain and dry aboveground biomass yields were determined by calculating maximum values of each parameter using a second degree polynomial regression model: $Y = a + b_1x + b_2x^2$, where Y = the dependent variable (yield); x = the independent variable (N fertilizer rate); a = the intercept on the y-axis; and b_1 and b_2 = regression coefficients. The maximum values for grain and dry biomass yields were determined from the model after fitting obtained data. These values were regarded as 100% relative yield values. Other yield values were converted into relative yields as percent of their corresponding maxima (Suwanarit *et al*., 1999).

Calculation of relationships between the availability indices and the relative grain, relative biomass and N yields

N availability indices measured by different soil test methods and relative grain yields, relative dry biomass yields and N uptake of the control plots were fitted into double log curvilinear regression model: $\log y = a + b \log x$, where x = the obtained index value; y = the relative grain yields, relative dry biomass yields or N uptake of the control plots; a = the intercept at the y axis; and b = slope of the line. Among availability indices giving highly significant correlation with the above yield parameters, most reliable ones were selected to develop equations for calculating fertilizer rates for desired maize yields.

Equations for calculating N fertilizer rates for desired maize grain yield

Relationships among relative grain yields, obtained N availability indices from selected soil test methods and amount of fertilizer applied were expressed by the Mtscherlich-Bray model. The model for each selected chemical method was derived by calculating c_1 (coefficient of availability indices) and c (coefficient of fertilizer rates). First c_1 was calculated by substituting b (availability indices) from each replication of the experimental sites in the following equation: $\log (A - y) = \log A - c_1b$, where A = relative maximum grain yield; and y = the relative grain yield from unfertilized plots. Mean of all the c_1 values of all the locations was used for the model. Then the c value was calculated for each fertilized treatment by substituting calculated c_1 value of each replication in the following equation: $\log (A - y) = \log A - c_1b - cx$, where x = the N fertilizer rates used and y = relative grain yield of fertilized plots. Mean of all the c values of all the fertilized plots was used for the model.

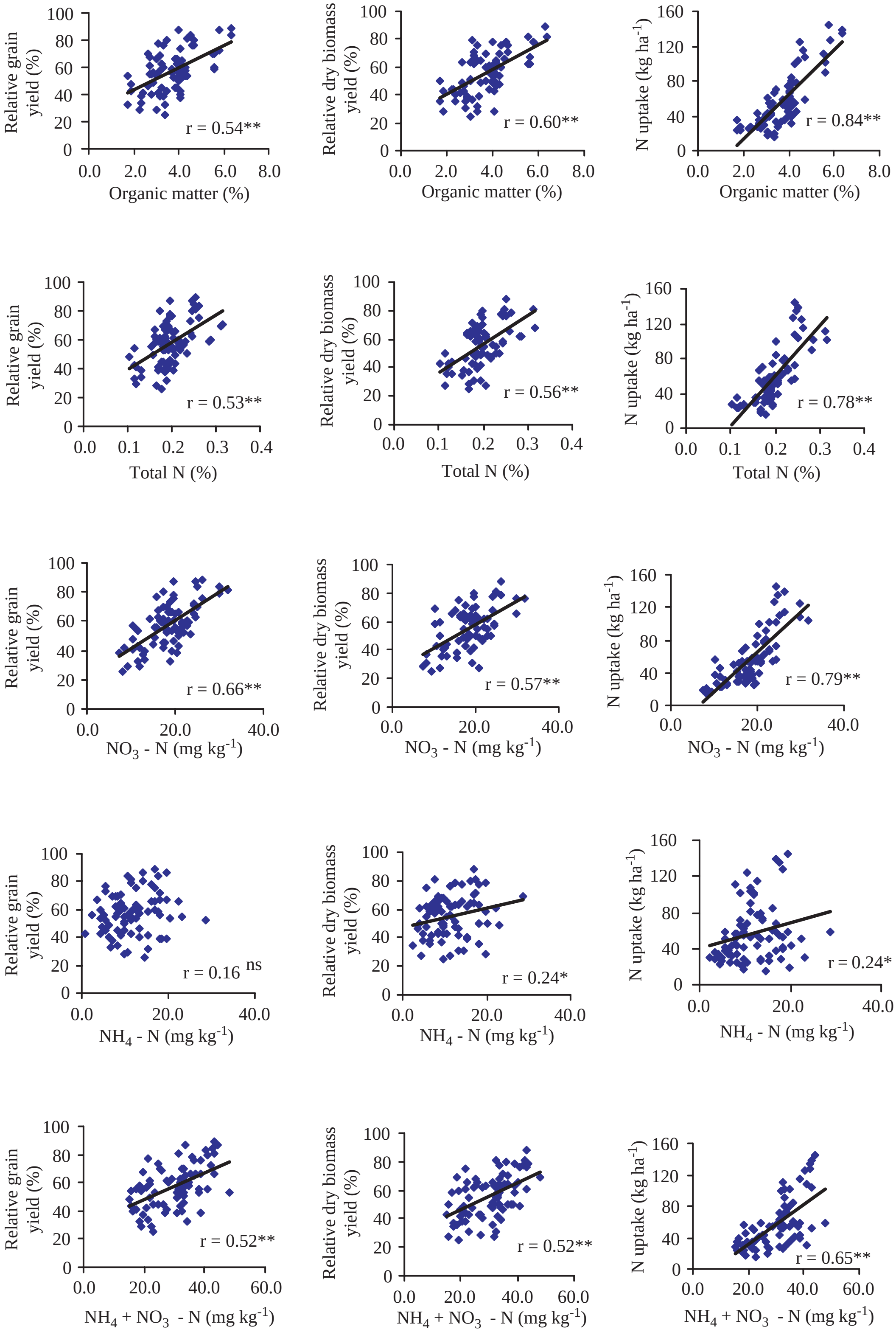
Verifying reliability of obtained equations

Reliability of the derived equations was verified by comparing the actual maize grain yields with grain yields predicted by the obtained equation. A linear regression technique was employed to see the relationship between them. Significant correlation coefficient revealed reliability of the equation.

RESULTS AND DISCUSSION

Relationships among soil N availability indices and relative grain, relative biomass and N yields

Results of the experiment revealed that all the nitrogen availability indices included in the experiment, except available NH_4-N, showed highly significant correlation ($p < 0.01$) with relative grain yield (Figure 1). Relative dry biomass yield and N uptake also correlated highly significantly with all the indices except NH_4-N, which were significant at 5% probability level. The highly significant correlation between NH_4+NO_3-N content and relative yield values was, however, attributed to the NO_3-N content


Relative grain yield (%)
Organic matter (%)
r = 0.54**
Relative dry biomass yield (%)
Organic matter (%)
r = 0.60**
N uptake (kg ha-1)
Organic matter (%)
r = 0.84**
Relative grain yield (%)
Total N (%)
r = 0.53**
Relative dry biomass yield (%)
Total N (%)
r = 0.56**
N uptake (kg ha-1)
Total N (%)
r = 0.78**
Relative grain yield (%)
NO3 - N (mg kg-1)
r = 0.66**
Relative dry biomass yield (%)
NO3 - N (mg kg-1)
r = 0.57**
N uptake (kg ha-1)
NO3 - N (mg kg-1)
r = 0.79**
Relative grain yield (%)
NH4 - N (mg kg-1)
r = 0.16 ns
Relative dry biomass yield (%)
NH4 - N (mg kg-1)
r = 0.24*
N uptake (kg ha-1)
NH4 - N (mg kg-1)
r = 0.24*
Relative grain yield (%)
NH4 + NO3 - N (mg kg-1)
r = 0.52**
Relative dry biomass yield (%)
NH4 + NO3 - N (mg kg-1)
r = 0.52**
N uptake (kg ha-1)
NH4 + NO3 - N (mg kg-1)
r = 0.65**

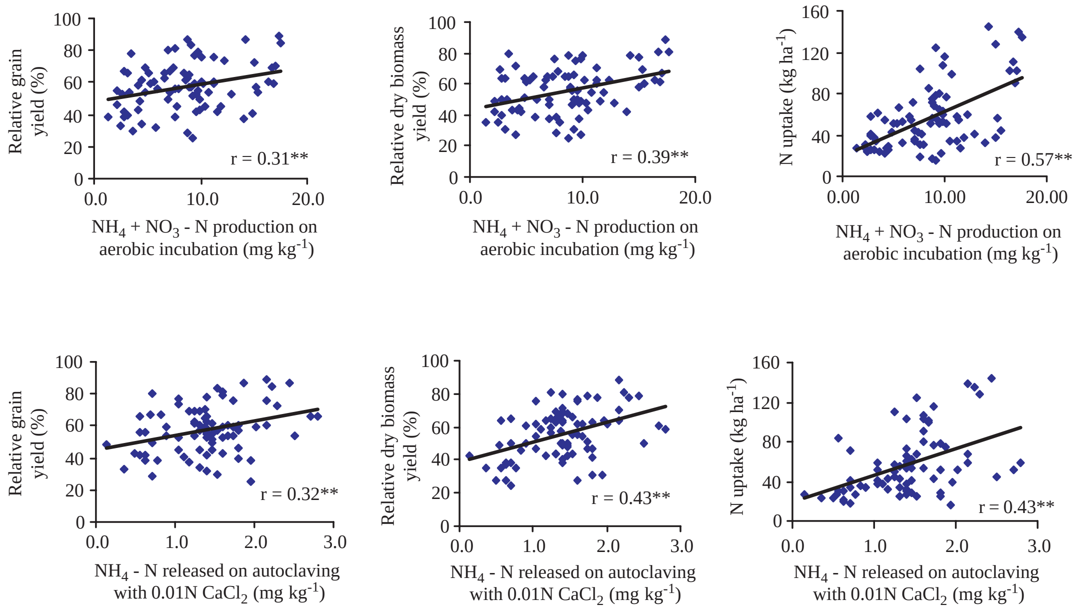


Figure 1 Relationships between availability indices and relative grain, relative dry biomass and N yields (*, ** significant at 5% and 1% probability levels, respectively; ns non-significant at 5% probability level; n = 80).

than to the NH_4-N content, because the later alone did not have significant correlation with relative grain yield and correlated at lower level of significance ($p = 0.05$) with relative dry biomass and N yields. This suggested that inclusion of NH_4-N in inorganic N content analysis as an index rather reduces reliability. Generally, analytical indices that involve measurement of NH_4-N exhibited rather diminished correlation coefficients and, in some cases, lower level of significance. Comparing the obtained correlation coefficients of the relationships between availability indices and relative grain yield, NO_3-N was found to be superior to the other indices followed by organic matter, and total N. However, the correlation coefficients between availability indices and relative dry biomass yield as well as N uptake were superior for organic matter followed by NO_3-N and total N. The overall trend indicated that organic matter was superior to NO_3-N, and the later was superior to total N.

The correlation coefficient matrix calculated among N availability indices (Table 2) also revealed that organic matter, total N and NO_3-N highly significantly ($p < 0.01$) correlated among each other and with other indices except with NH_4-N. However, available NH_4-N had highly significant correlation ($p < 0.01$) with two of the three methods that involve measurement of NH_4-N. Organic matter exhibited exceptionally high correlation (r = 0.85**) with NH_4+NO_3-N production on aerobic incubation. This might be justified that the organic matter pool supplied the nitrogen to be mineralized during the 14 days incubation period. Analogically, total N had relatively higher correlation coefficient (r = 0.64**) with NH_4+NO_3-N production than NO_3-N (r = 0.28*). Generally, indices that involve measurement of NH_4-N content gave relatively lower correlation coefficients with indices that provided superior correlation coefficients with relative yields and N uptake. Based on the above background, organic matter, total N and NO_3-N were identified as most reliable indices for

Table 2 Correlation coefficient matrix among soil N availability indices of different methods.

	Method 1	Method 2	Method 3	Method 4	Method 5	Method 6
Method 2	0.86**					
Method 3	0.65**	0.80**				
Method 4	0.20^{ns}	0.14^{ns}	0.21^{ns}			
Method 5	0.54**	0.59**	0.77**	0.79**		
Method 6	0.85**	0.64**	0.29*	-0.25*	0.01^{ns}	
Method 7	0.50**	0.43**	0.48**	0.59**	0.68**	0.16^{ns}

*, ** significant at 5% and 1% probability levels, respectively; ^{ns} non-significant at 5% probability level; n = 80.

estimating N fertilizer requirements of maize on Alfisols of Northwestern Ethiopia.

Reliability of the total soil N as an index has been supported by results of some workers. Bremner (1965a) reported that cultivated soils generally contained between 0.8 and 4.0 g total N kg^{-1} soil (0.08-0.4%) and 1 to 3% of the total N is mineralized during a growing season (Bremner, 1965b) which provided 15 to 200kg N ha^{-1}. Keeney (1982) supported the above idea that biological and chemical tests of N availability were frequently closely related to total soil N except the procedure was too costly for routine soil testing. Suwanarit *et al*. (1995) found highly significant correlation ($p = 0.01$) between total nitrogen content and relative grain yields, relative dry matter yields and relative N yields of maize and recommended this method as an index for estimating availability of nitrogen for fertilizer recommendation purposes.

Determination of organic matter content of the soil can serve as reliable N availability index because the amount of organic matter content in soil indicates the potential of the soil to supply N provided that suitable conditions exist for mineralization. Miller and Donahue (1990) reported that organic matter holds more than 95% of soil nitrogen and mineralization of 1.5% of organic matter in a soil having an organic matter content of 4% would release about 70kg ha^{-1} nitrogen as ammonium. Suwanarit *et al*. (1995) found significant correlation between organic matter content and relative grain yields ($r = 0.49*$), relative dry matter yields ($r = 0.88**$) and relative N yields ($r = 0.46*$) of maize and recommended this method as an index for estimating availability of nitrogen to maize. Keeney (1982) also indicated that organic matter determination could form the basis for nitrogen recommendation.

The highly significant correlation of NO_3-N with relative yield parameters and N uptake would be due to the aerobic situation in the well granulated soils and the favorable climatic conditions of the testing sites that favored nitrification. It has been reported that in regions where crop's evapotranspiration demand exceeds annual precipitation, measuring the pre-planting NO_3-N content is valuable in predicting N requirements (Havlin *et al*., 1999). Some authors argued, however, that the initial NO_3-N content indicated the amount of NO_3-N available at sampling but did not indicate the ability of the soil to mineralize N (Campbell, 1978). Moreover, NO_3-N is susceptible for leaching which could undermine its reliability as an index in seasons with heavy rainfall.

It is apparent that under aerobic soil conditions nitrification of NH_4-N to NO_3-N takes place quite rapidly that makes NH_4-N less reliable N availability index. This statement was supported by the work of Thicke *et al*. (1993) who obtained a negative correlation ($p < 0.01$) between NH_4-N and grain yield of maize. Blackmer *et al*. (1989)

also reported that the R^2 did not improve when NH_4-N plus NO_3-N were determined in the soil sample compared with NO_3-N alone. This index may be valuable, however, in anaerobic conditions where nitrification is rather slow. Suwanarit *et al.* (1999) reported that measurement of NH_4-N produced from incubation of soils under water logged conditions to be reliable index to measure availability of N for paddy rice. Sahrawat (1978) also reported that measurement of NH_4-N to be reliable index for lowland rice.

Equations for estimating N fertilizer rates from superior availability indices

The Mitscherlich-Bray equations for estimating nitrogen fertilizer requirements of maize from soil analysis for methods 1, 2 and 3 are shown in Table 3. From the models it was possible to make predictions that for a unit increase in soil organic matter content (%) or NO_3-N content (mg kg^{-1}), the amount of N fertilizer to be applied shall be reduced by 17.2 kg ha^{-1} and 3.4 kg ha^{-1}, respectively, taking 94% as optimum relative yield goal (calculation of the optimum relative yield goal is not presented in this paper). Similarly, a 0.1% increase in total N content shall reduce the fertilizer rate by 31.7 kg ha^{-1}. The maximum fertilizer rates that would be applied had methods 1, 2 and 3 given zero values of their respective N availability indices were 190.6, 188.5 and 190.5 kg N ha^{-1}, respectively. This indicates that the developed Mitscherlich-Bray equations give equivalent fertilizer recommendations.

Reliability of the equations

Reliability of the equations was verified by comparing the actual grain yields obtained from the experimental plots with predicted yields by the developed equations (Figure 2). All the equations gave grain yield predictions that were highly significantly ($P < 0.01$) correlated with actual yields. From the 400 data points, there were 218, 223 and 221 cases of overestimation and 182, 177, and 179 cases of underestimation for the equations

Table 3 Equations for estimating nitrogen fertilizer requirements of maize from soil analysis results of reliable methods.

Method No.	Availability index	Unit of index	Equation1/
1	Organic matter²	%	$\log(100 - y) = 2 - 0.1103b - 0.006411x$
2	Total N	%	$\log(100 - y) = 2 - 2.0566b - 0.006481x$
3	NO_3-N	mg kg^{-1}	$\log(100 - y) = 2 - 0.0220b - 0.006414x$

1/ y = relative yield goal (as % of maximum yield); b = N availability index obtained from soil analysis; x = N fertilizer requirement (kg ha^{-1}); ² Organic matter (%) = Organic carbon (%) x 1.726

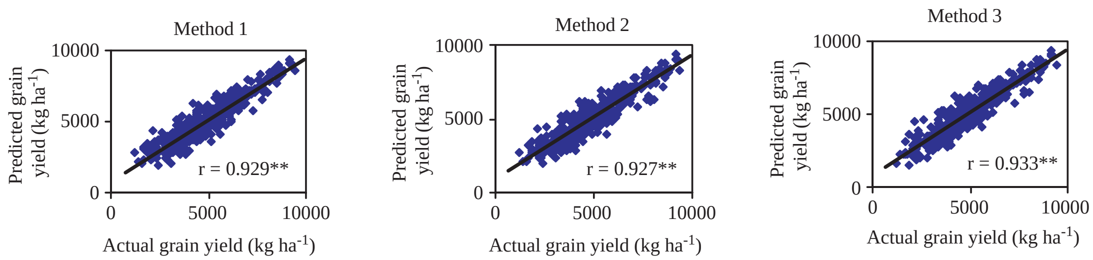


Figure 2 Relationships between actual maize grain yields and the yields predicted by the equations for methods 1, 2 and 3 (** significant at 1% probability level; n = 400).

of organic matter, total N, and NO_3-N, respectively. When the absolute range of error around actual grain yield was designated, i.e., ± 1000kg ha^{-1}, there were only 37, 36 and 31 cases of overestimation and 13, 12 and 12 cases of underestimation for equations of method 1, 2, and 3, respectively. This shows that 87.5, 88.0, and 89.5%, respectively, of all the observations fell with in the 'acceptable' region under this definition. Generally, the three methods can be interchangeably used as reliable N availability indices depending on laboratory reagents available.

Determination of critical levels of N availability indices

The N availability indices of the experimental sites obtained by the three reliable methods were generally low enough to identify the critical N levels using the graphical technique of Cate and Nelson (1965). Nevertheless, the developed equations have provided extrapolated critical N levels (N levels at which application of fertilizer is not required) at planting to be 11.08%, 0.594%, and 55.54 mg kg^{-1} for organic matter, total N, and NO_3-N, respectively taking 94% as optimum relative yield goal. These critical levels are quite high, and have never been reported to be available in Ethiopian highland soils. The reason why high critical values were obtained from the equations was that since the study area had low indigenous N and organic matter content, the fertilized plots of the testing sites highly responded for application of N. Therefore, the relative yields calculated for the control plots were low enough. This eventually reduced the coefficient of availability indices (c_1), and the low c_1 value provided high critical level. This suggests, however, that application of fertilizer is a must to produce maximum maize yield in the study area. Jalil *et al*. (1996) reported organic carbon values ranging from 0.98 to 5.56% (1.69-9.59% organic matter) and total N contents ranging from 0.113 to 0.514% in cultivated soils of Saskatchewan, Canada, and yet fertilizers have been applied for maximum yield.

CONCLUSIONS

From the results of the experiment it is possible to draw the following conclusions:

1. From the soil analysis methods incorporated in the experiment, determination of organic matter, total N and NO_3-N were found to give most reliable N availability indices.
2. The Mitscherlich-Bray equations developed for indices of organic matter, total N and NO_3-N were statistically proven to provide comparable reliable estimates of N fertilizer requirements of maize on Alfisols of Northwestern Ethiopia.
3. The extrapolated critical levels beyond which application of N fertilizers becomes non-responsive were identified to be 11.08%, 0.594%, and 55.54 mg kg^{-1} for organic matter, total N and NO_3-N, respectively measured at planting.

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