Soil Test Based N and P Fertilizer Rate Recommendations of Maize for West Amhara

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Abstract

With the prime objective of developing soil test based N and P fertilizer rate recommendations of maize for West Amhara, field experiments were conducted in two years time on 24 sites. At each site, both N and P experiments were conducted. The treatments included five rates of N fertilizer (0, 30, 60, 90 and 200 kg N $ha^{-}1$) and five rates of P fertilizer (0, 30, 60, 90 and 150 kg P_2O_5 $ha^{-}1$) 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. For soil P analysis Bray-1, Bray-2, Olsen, Mehlich-1, anion exchange resin and extraction with 0.01*N* $CaCl_2$. Parameters of the Quantity/Intensity relationships were also determined. Reliable methods were identified in the first year 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. In the second year, the selected methods were retested and to confirm their reliability. Consequently, nitrogen and phosphorus availability indices that were found most reliable and grain yield data were fitted into the Mitscherlich-Bray model.

Results of the experiments revealed that organic matter, total N, and NO_3-N were the most reliable N availability indices. Similarly, Bray-2 and Olsen methods gave the most reliable P available indices. In the second year cropping season, the first two indices for nitrogen and the above two indices for phosphorus were retested with field experiment data collected from 4 locations. Results of the two years (24 locations) experiments indicated that the tested methods give reliable availability indices. Hence, from the two years' data the equations developed for estimating N fertilizer requirements of maize were: (a) log (100 - y) = 2 - 0.1343b - 0.006419x and (b) log (100 - y) = 2 - 2.2088b - 0.006479x for organic matter and total N, respectively, where y was relative yield goal, b was N availability index expressed as % and x was the N fertilizer requirement. Similarly, the equations developed for estimating P fertilizer requirements of maize from soil analysis were: (a) log (100 - y) = 2 - 0.1468b - 0.007546x and (b) log (100 - y) = 2 - 0.1167b - 0.007546x for Olsen and Bray-2 methods, respectively, where y was desired relative grain yield (%); b was soil P availability index (mg kg^{-1}); and x was P fertilizer requirement (kg ha^{-1}).

Introduction

In West Amhara, 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 with marginal fertilizer application could not produce enough even to feed their own family for one 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 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).

Phosphorus is also of primary concern in the appraisal of the soil resources of Ethiopia (Miressa and Robarge, 1996) since most of the soils on the highland plateau are reported to be deficient in phosphorus (Asnakew *et al*., 1991; Desta, 1982; Tekalign *et al*., 1988). Phosphorus is one of the most limiting elements in the majority of the Alfisols of Ethiopia. In P-deficient soils, crops usually recover less than 10 percent of the applied amount of phosphorus in the first season, even if they respond well and the total recovery after four years is often only 20-30 percent (Russel, 1972). In addition to the inherently low available P content, the high P fixation capacity of these soils made the problem complex. Tekalign and Haque (1987), and Taye (1998) have reported a sorption range of 150-1500 μg g^{-1} in several Alfisols of Ethiopian highlands. Therefore, following nitrogen, phosphorus is the most limiting nutrient in the tropics (Sanchez, 1976). Deficiency of nitrogen and phosphorus in these soils eventually led to severe yield decline in Northwestern Ethiopia.

The role of chemical fertilizers in increasing yield is evident. Fertilizers accounted for more than 50% of the increase in yield (FAO, 1984). Experience has shown that in seasons with good rain, farmers of Northwestern Ethiopia managed to produce surplus yield through fertilization. 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 into the extension system. This approach, however, had shortcomings in extrapolating the results to farmers' 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). The objective of this study was, therefore, to develop soil test based N and P fertilizer recommendations for maize growing in West Amhara.

Materials and Methods

Site selection

The experiment was conducted for two years in 2002/2003 and 2004/2005 cropping seasons in West Amhara. To select the experimental sites, in the first year 52 composite soil samples were collected from farmlands having different cropping history, slope and management practices. The collected soil samples were analyzed for organic matter, total N, available phosphorus content (Bray-2 method), texture and pH. Out of the sampled sites, 20 experimental sites covering the widest possible ranges of the indicated parameters were selected. In the second cropping season, 4 sites that had high variability in the above mentioned parameters were selected from soil analysis results of the first season.

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 (%)	Bray-II P (mg kg^{-1})	pH in H_2O (1:2.5)	Particle size (%)			Soil texture
								Sand	Silt	Clay	
					Year I						
1	2240.0	11°17.2'N	37°28.9'E	3.8	2.84	3.42	4.91	7	25	68	Clay
2	2243.1	11°17.3'N	37°28.8'E	2.6	3.35	2.55	5.21	5	25	70	Clay
3	2348.8	11°14.3'N	37°30.7'E	0.3	3.25	3.82	5.00	7	21	72	Clay
4	2347.9	11°14.2'N	37°30.9'E	2.3	1.78	2.81	5.35	13	17	70	Clay
5	1897.3	11°44.0'N	37°30.8'E	5.4	3.09	10.80	5.40	15	29	56	Clay
6	1918.0	11°44.7'N	37°31.9'E	5.1	2.66	3.13	4.73	5	17	78	Clay

7	1955.8	11°45.7’N	37°32.4’E	3.1	3.19	8.02	4.99	7	27	66	Clay
8	1969.8	11°46.8’N	37°33.2’E	2.3	3.11	10.73	4.83	9	27	64	Clay
9	1916.8	11°44.4’N	37°31.7’E	8.1	2.31	11.41	5.26	55	21	24	SanCL
10	2048.7	11°24.8’N	37°24.8’E	1.1	3.93	9.43	5.25	9	25	66	Clay
11	2067.6	11°25.0’N	37°07.9’E	3.5	4.22	7.59	5.25	15	49	36	SilCL
12	2039.8	11°24.8’N	37°07.4’E	0.2	4.08	6.66	5.05	9	25	66	Clay
13	2038.9	11°24.6’N	37°07.1’E	0.3	4.24	6.48	5.13	11	23	66	Clay
14	2002.7	11°21.6’N	36°58.1’E	1.6	5.56	10.96	5.01	13	23	64	Clay
15	1900.0	10°80.0’N	36°85.0’E	5.0	6.06	7.96	5.75	11	21	68	Clay
16	2150.7	10°42.7’N	37°05.6’E	1.8	3.99	16.04	5.78	15	25	60	Clay
17	2106.3	10°42.2’N	37°06.3’E	5.2	4.51	9.48	5.43	9	21	70	Clay
18	1897.9	10°40.8’N	37°16.4’E	2.3	4.33	9.48	5.63	11	23	66	Clay
19	1888.4	10°40.5’N	37°16.4’E	2.9	4.12	4.14	5.42	11	23	66	Clay
20	1882.0	10°40.9’N	37°19.0’E	0.6	3.71	2.54	5.28	11	23	66	Clay
					Year II						
1	2243.1	11°17.3’N	37°28.8’E	2.6	2.13	9.56	5.21	5	24	71	Clay
2	2150.7	10°42.7’N	37°05.6’E	1.8	2.25	20.99	5.78	13	25	62	Clay
3	2106.3	10°42.2’N	37°06.3’E	5.2	2.14	6.84	5.43	8	20	72	Clay
4	1882.0	10°40.9’N	37°19.0’E	0.6	2.01	4.92	5.28	10	22	68	Clay

Field layout and experimental design

The distance between rows was 75 cm and the distance between plants within a row was 30 cm. The distance between blocks was 1.5m. No space was left between plots in each replication.

The treatments for Experiment 1 were 0, 30, 60, 90 and 200 kg N ha^{-1}. For this experiment, half of the nitrogen fertilizer as urea (46-0-0) for each treatment were applied at planting by banding along one side of the seed 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, 120 kg P_2O_5 ha^{-1} as triple superphosphate (0-46-0) was added as basal fertilizer to minimize the effect of the law of the minimum

The treatments for Experiment 2 were 0, 30, 60, 90 and 150 kg P_2O_5 ha^{-1}. For this experiment, all of the phosphorus fertilizer for each treatment was applied at planting by banding along one side of the seed row at a distance of about 10 cm below and 5 cm aside the seeds. Triple superphosphate was used as source of phosphorus. A fixed rate of N fertilizer (150 kg N ha-1) was added to all plots. The N fertilizer in the form of urea was added in split, half at planting and the remaining at 35 days after emergence.

Both Experiments were arranged in randomized complete block design with five treatments and four replications.

Soil Sample Collection and Analysis for Indexing Availability of N and P

In the first cropping season, from each replication of the selected locations, one composite soil sample was collected from the top 0 - 20cm soil layer at planting and before fertilizer application. The collected samples were air-dried under the shade and crushed to pass through 2 mm sieve. The following soil analyses were conducted: determination of organic matter content according to the Walkley-Black procedure (Nelson and Sommers, 1982); total N determination by the Kjeldahl method (Bremner and Mulvaney, 1982); NO_3-N, NH_4-N, and NO_3+NH_4-N determination by steam distillation as outlined by Keeney and Nelson (1982); aerobic incubation and estimation of inorganic-N production as outlined by Ryan *et al.* (1971), and determination of ammonium released on autoclaving with dilute calcium chloride as outlined by Keeney (1982).

Indexing availability of phosphorus was conducted following six soil P analysis methods: Bray-1 (Olsen and Sommers, 1982), Bray-2 (Sahlemedihin and Taye, 2000), Olsen (Olsen and Sommers, 1982), Mehlich-1 (Tan, 1996), anion exchange resin (AER) extraction (Tan, 1996), 0.01*N* $CaCl_2$ extraction (Olsen and Sommers, 1982), equilibrium P concentration (EPC), phosphorus buffering capacity (PBC) and labile P determined from Quantity/Intensity (Q/I) curves (Kpomblekou and Tabatabai, 1997).
In the second cropping season, from the N availability indices tasted, organic matter content and total N, which were found to be reliable (based on the correlation between soil test values and yield responses) from the first year experiment, were tasted again. Similarly, Olsen and Bray-II methods that were identified to be reliable for indexing availability of P in the first year experiment were tested again.

Yield data collection

The crop was harvested after physiological maturity from the three central rows excluding the two boarder plants in each end of the row. Grain yield at 12.5% moisture content was determined

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

Calculation of relative yields

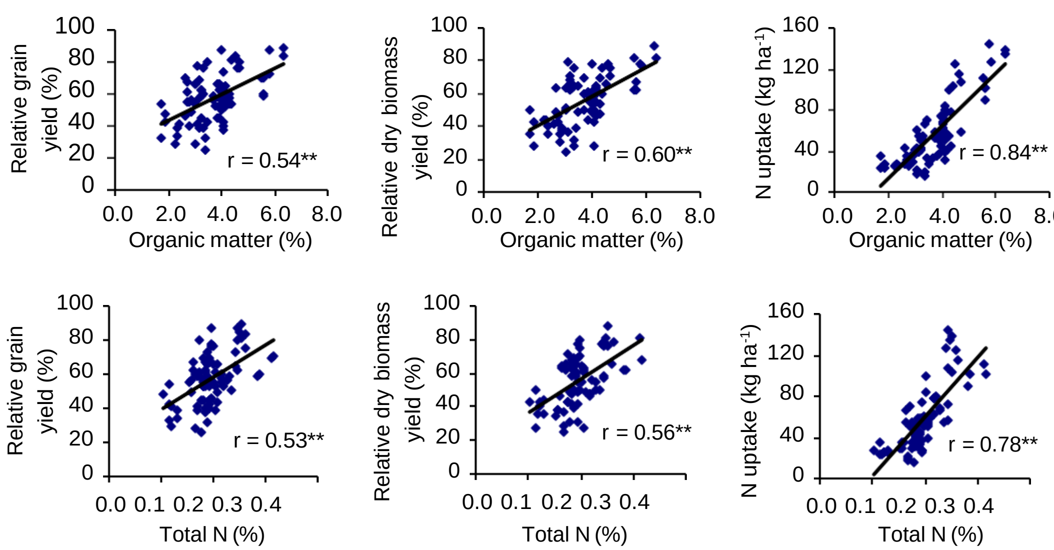
Relative grain and dry above ground biomass yields were determined by calculating maximum values of each parameter using a second degree polynomial regression model: $Y = a + b_1x + b_2x^2$, where Y = the dependent variable (yield); x = the independent variable (N or P fertilizer rate); a = the intercept on the y-axis; and b_1 and b_2 = regression coefficients. The maximum values for grain yield 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).

Equations for calculating N abd P fertilizer rates for desired maize grain yield

Relationships among relative grain yields, obtained N/P availability indices and amount of fertilizer applied were expressed by the Mitscherlich-Bray model. The model for each selected chemical method will be 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/P fertilizer rates used and y = relative grain yield of fertilized plots. Mean of all the c values of all the fertilized plots were used for the model.

Results and DiscussiW* nBT/F5 11.04 Tf1 0 0 1 191.33 450.67 Tm0 g0 ld41

Results of the first year 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 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. Therefore, organic matter content, total N and NO_3-N were selected as reliable indices of availability of N.



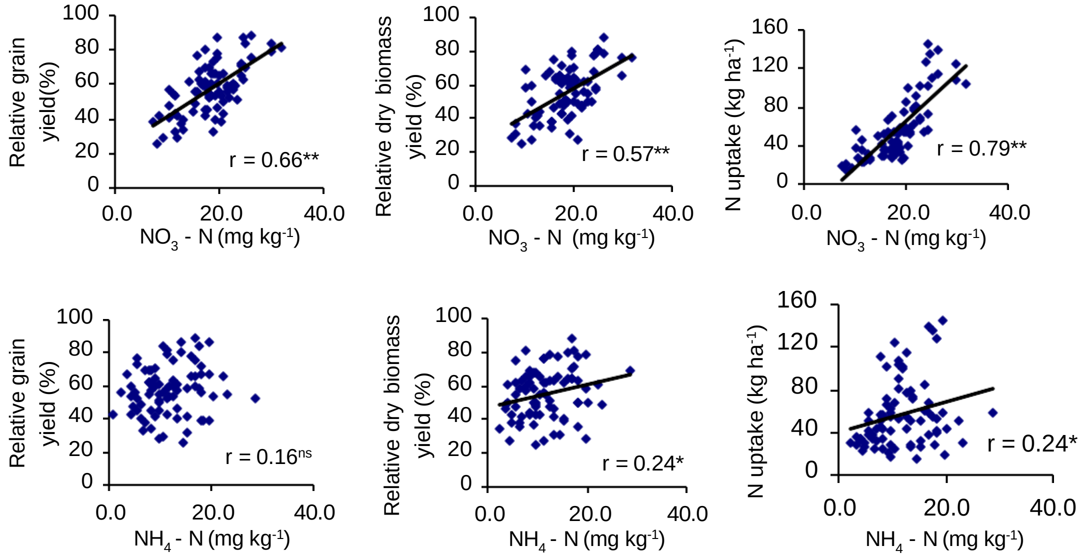
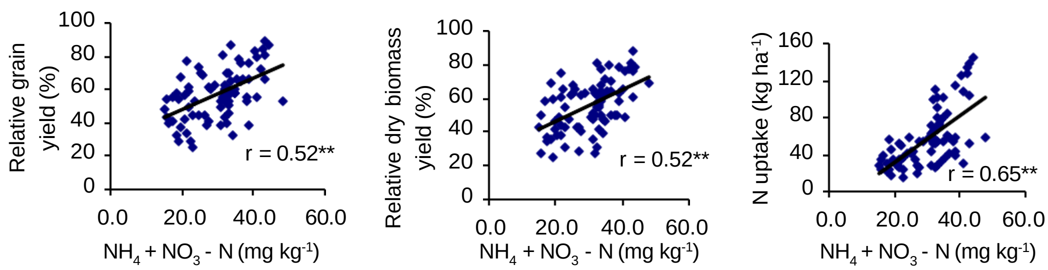


Figure 1: Relationships between availability indices and relative grain, relative dry biomass and N yields (*, ** significant at 5% and 1% probability levels, respectively; ns non- significant at 5% probability level; n = 80)



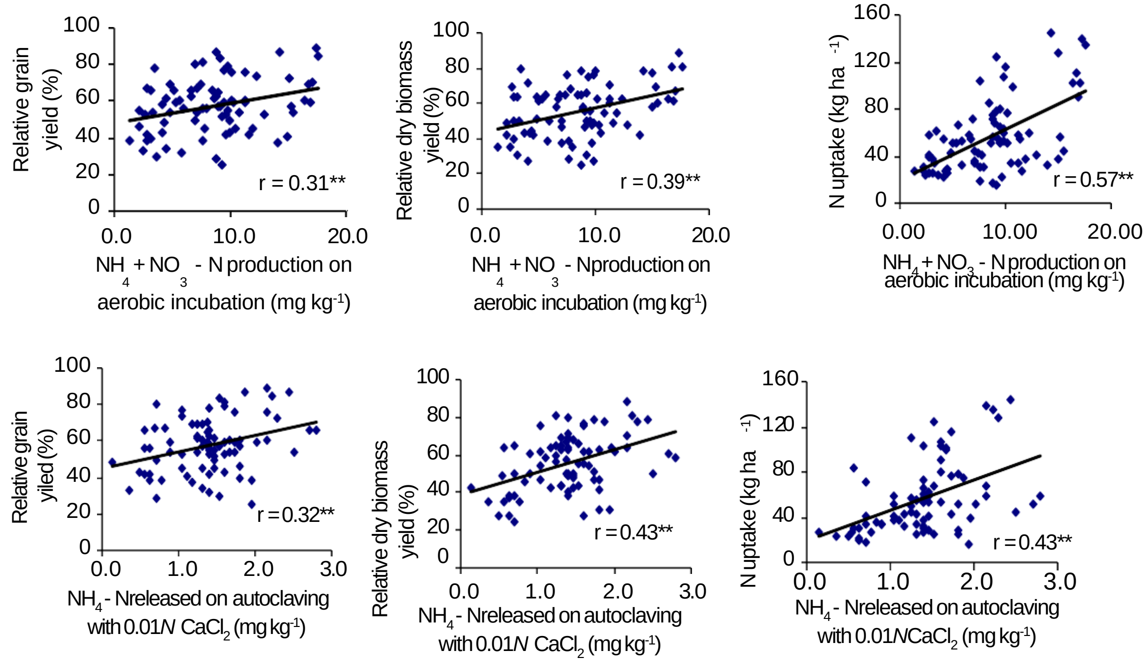


Figure 1 (contd.): Relationships between availability indices and relative grain, relative dry biomass and N yields (*, ** significant at 5% and 1% probability levels, respectively; ns non- significant at 5% probability level; n = 80)

In the next cropping season organic matter and total N were retested for their reliability as index of availability of N. Results showed that even though the field experiment was conducted on 4 locations with four replication on each location, the result showed that the two indices were reliable.

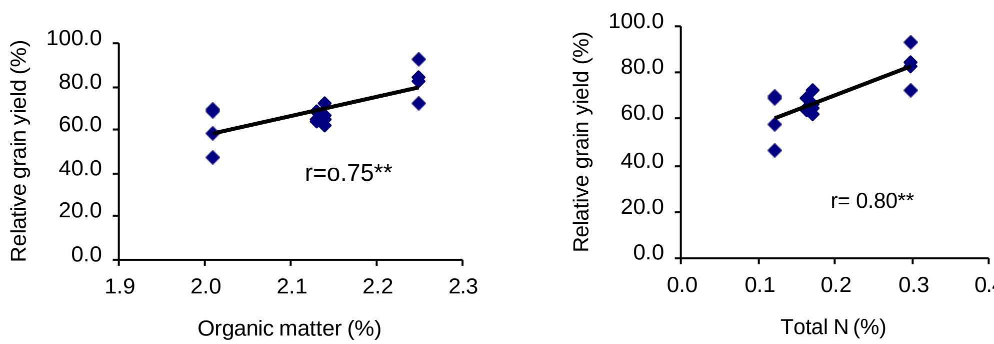
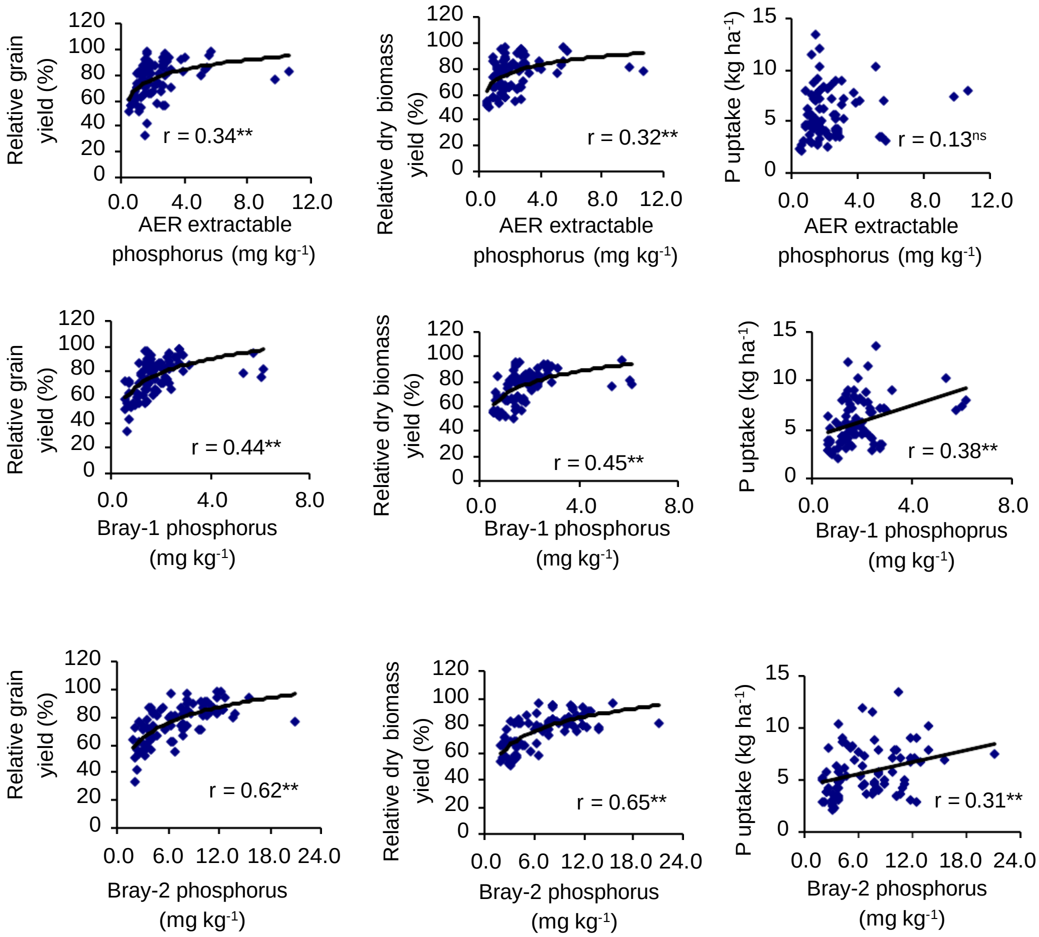
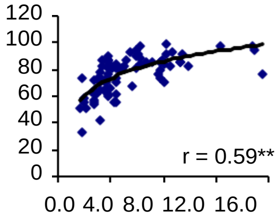


Figure 2: Relationships between availability indices and relative grain yield ** significant at 1% probability levels; n = 16)

Results of the P experiment of the first cropping season indicated that, all indices except the parameters of the quantity/intensity relationships, highly significantly ($P < 0.01$) correlated with relative grain and dry biomass yields (Figure 3). The relative yield curves have shown more typical Mitscherlich type yield trend for Olsen, Bray-2, Mehlich-1, Bray-1 and AER methods. With other availability indices, the relative yield curves had either linear trend or had no significant relationship. This was especially true for those methods that extracted low amount of P from the soil. It was observed, however, that P uptake relatively poorly correlated with availability indices when compared with other yield parameters, and Mitscherlich type yield trend was not obtained. Among the parameters of the quantity/intensity curves, EPC (the x-intercept in the Q/I graph) had no significant relationship with relative grain yield but had significant relationship with relative dry biomass yield ($p < 0.05$) and P uptake ($p < 0.01$). Labile P (y-intercept in the Q/I graph) provided significant correlation coefficients at rather lower level of significance ($p < 0.05$) with relative grain yield and relative dry biomass yield. PBC ($\Delta Q/\Delta I$ in the Q/I graph) exhibited negatively significant ($p < 0.05$) relationship with relative grain yield ($r = -0.26^{*}$); and non-significantly negative relationship with relative dry biomass yield ($r = -0.18^{ns}$) and P uptake ($r = -0.17^{ns}$). Generally, only indices from Olsen and Bray-2 methods exhibited relatively higher correlation coefficient values exceeding 0.5 with relative grain and dry biomass yields. From the above, it is possible to recommend that Olsen and Bray-2 P can be used as reliable indices of availability of P.

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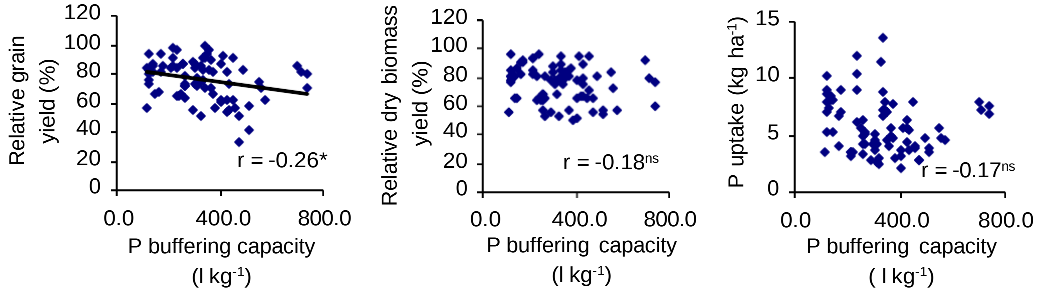

Figure 3(contd.): Relationships between P availability indices and relative grain, relative dry biomass and P yields (*, ** significant at 5% and 1% probability levels, respectively; ^{ns} non-significant at 5% probability level; n = 80)

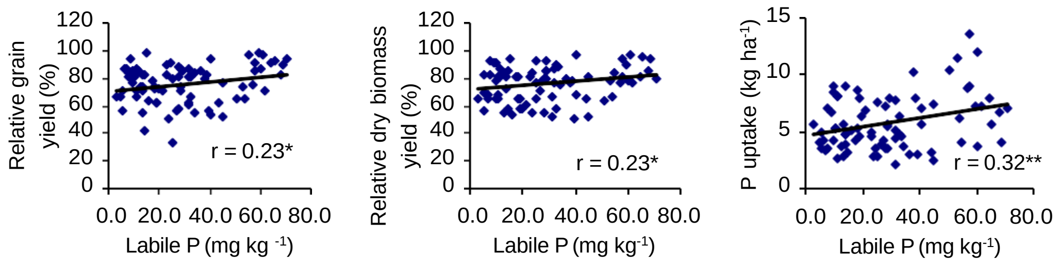

Figure 3 (contd.): Relationships between P availability indices and relative grain, relative dry biomass and P yields (*, ** significant at 5% and 1% probability levels, respectively; ^{ns} non-significant at 5% probability level; n = 80)

In the next cropping season Bray-II and Olsen P were retested as indices of availability of P. Results of the experiment indicated that both indices gave Mitscherlich type curve which is the most accepted type of response of crops to fertilizer application (Figure 4).

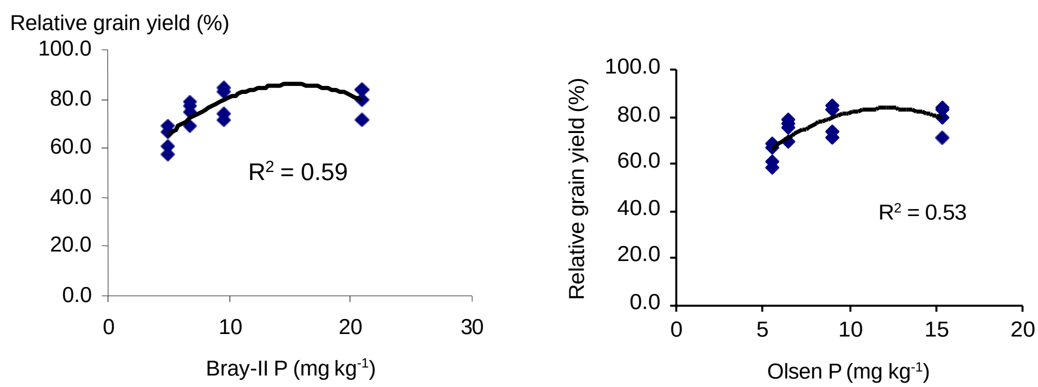

Figure 4: Relationships between P availability indices and relative grain yields

Equations for estimating N and P fertilizer rates from superior availability indices

The Mitscherlich-Bray equations for estimating nitrogen fertilizer requirements of maize from soil analysis for organic matter and total N are shown in Table 2.

Table 2: Equations for estimating nitrogen fertilizer requirements of maize from soil analysis results of reliable methods

Method No.	Availability index	Unit of index	Equation[1/]
1	Organic matter[2]	%	$\log(100 - y) = 2 - 0.1343b - 0.006419x$
2	Total N	%	$\log(100 - y) = 2 - 2.2088b - 0.006479x$

[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

From the models it was possible to make predictions that for a unit increase in soil organic matter content (%), the amount of N fertilizer to be applied shall be reduced by 20.9 kg ha^{-1}, taking 94% as optimum relative yield goal. 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 indices of organic matter and total N were zero were 190.37 and 188.61, respectively (Appendix Table 1 and 2). This indicates that the developed Mitscherlich-Bray equations give equivalent fertilizer recommendations.

Equations for estimating P fertilizer requirements of maize from soil analysis results of the reliable methods are presented in Table 3. Coefficients for indigenous soil P (c_1) and fertilizer rates (c) were calculated as mean of 80 and 280 data points, respectively. The second year data were not used in calculating the coefficients because they reduced the reliability of the model. However, the data was used to verify the reliability of the indices. The Olsen method extracted less P than Bray-2 from most of the soil samples analyzed and eventually the c_1 value was higher for the former than the later. From the models it was possible to make predictions that for a unit increase in soil P concentration (mg kg^{-1}) measured by Olsen and Bray-2 methods, the amount of P fertilizer to be applied shall be reduced by 19.4 and 15.4 kg P_2O_5 ha^{-1}, respectively, taking 98% as optimum relative yield goal. Higher yield goal was used to calculate the mineral fertilizer equivalency values for the indices because high P deficiency and fixation is expected on Alfisols of West Amhara which requires higher amount of nutrient application.

Table 3: Equations for estimating phosphorus fertilizer requirements of maize from soil analysis results of reliable methods

Method	P availability index	Unit of index	Equation [1/]
Olsen	Olsen P	mg kg^{-1}	$\log(100-y) = 2 - 0.1468b - 0.007546x$
Bray-2	Bray-2 P	mg kg^{-1}	$\log(100-y) = 2 - 0.1167b - 0.007546x$

[1/] y = relative yield goal (as % of maximum yield); b = P availability index obtained from soil analysis (mg kg^{-1}); x = P fertilizer requirement (kg P_2O_5 ha^{-1}).

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. Simple linear regression technique was employed to see the relationships between actual grain yields obtained from the experimental plots and predicted grain yields by the developed equations. All the equations gave grain yield predictions that were highly significantly ($P < 0.01$) correlated with actual yields (Figure 5).

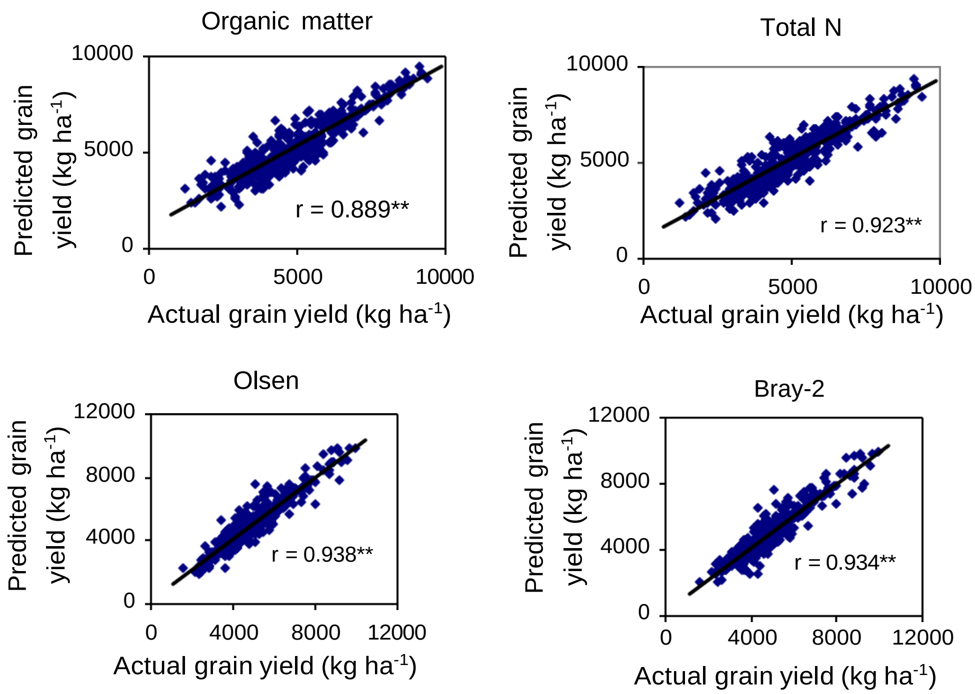

Figure 5: Relationships between actual maize grain yields and the yields predicted by the equations for the specified methods (** significant at 1% probability level)

Determination of the critical soil N and P concentration

The Cate-Nelson graphical technique (Cate and Nelson, 1965) was compared with the developed equations in determining the P critical level. The former method involves superimposing vertical and horizontal lines on a scatter diagram so as to maximize the number of points in the positive quadrants. The vertical line divides the data into two classes (high probability of response and low probability of response).The point where the vertical line intersects the x axis has been termed as the critical level.

Based on this, 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 9.01% and 0.595% for organic matter and total N, taking 94% as optimum relative yield goal.

The critical P concentration beyond which applied fertilizer becomes non-responsive was identified to be 11.6 and 14.6 mg kg^{-1} for Olsen and Bray-2 methods, respectively taking 98% as optimum relative yield goal. The Cate-Nelson technique also gave comparable result. It is apparent that in acidic soils like Alfisols of the study area, the inherently low P content coupled with high P fixation capacity makes application of larger amount of P fertilizer of paramount importance.

Conclusions

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

- From the soil analysis methods incorporated in the experiment, determination of organic matter and total N were found to give reliable N availability indices. Similarly, Bray-2 and Olsen methods were found to be superior in providing reliable indices of indigenous P availability in the soil.
- The Mitscherlich-Bray equations developed for indices of organic matter and total N and the two reliable soil P extraction methods (Bray-II and Olsen) were statistically proven to provide reliable estimates of P fertilizer requirements of maize on Alfisols of Northwestern Ethiopia.
- The extrapolated critical levels beyond which application of N fertilizers becomes non- responsive were identified to be 9.01% and 0.594% for organic matter and total N, respectively measured at planting. Similarly, the critical P concentration beyond which applied fertilizer becomes non-responsive was identified to be 11.6 and 14.6 mg kg^{-1} for Olsen and Bray-2 methods, respectively.

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Table 2: Calculated N fertilizer requirement for soil nitrogen levels measured in organic matter

Organic matter (%)	N requirement		Organic matter (%)	N requirement	
	N (kg ha^{-1})	Urea (kg ha^{-1})		N (kg ha^{-1})	Urea (kg ha^{-1})
0	190.4	413.9	5	85.8	186.4
0.1	188.3	409.3	5.1	83.7	181.9
0.2	186.2	404.8	5.2	81.6	177.3
0.3	184.1	400.2	5.3	79.5	172.8
0.4	182.0	395.7	5.4	77.4	168.2
0.5	179.9	391.1	5.5	75.3	163.7
0.6	177.8	386.6	5.6	73.2	159.1
0.7	175.7	382.0	5.7	71.1	154.6
0.8	173.6	377.5	5.8	69.0	150.1
0.9	171.5	372.9	5.9	66.9	145.5
1	169.5	368.4	6	64.8	141.0
1.1	167.4	363.8	6.1	62.7	136.4
1.2	165.3	359.3	6.2	60.7	131.9
1.3	163.2	354.7	6.3	58.6	127.3
1.4	161.1	350.2	6.4	56.5	122.8
1.5	161.1	350.2	6.4	56.5	122.8
1.6	156.9	341.1	6.6	52.3	113.7
1.7	154.8	336.5	6.7	50.2	109.1
1.8	152.7	332.0	6.8	48.1	104.6
1.9	150.6	327.4	6.9	46.0	100.0
2	148.5	322.9	7	43.9	95.5
2.1	146.4	318.3	7.1	41.8	90.9
2.2	144.3	313.8	7.2	39.7	86.4
2.3	142.3	309.2	7.3	37.6	81.8
2.4	140.2	304.7	7.4	35.5	77.3
2.5	138.1	300.1	7.5	33.5	72.7
2.6	136.0	295.6	7.6	31.4	68.2
2.7	133.9	291.0	7.7	29.3	63.6
2.8	131.8	286.5	7.8	27.2	59.1
2.9	129.7	282.0	7.9	25.1	54.5
3	127.6	277.4	8	23.0	50.0
3.1	125.5	272.9	8.1	20.9	45.4
3.2	123.4	268.3	8.2	18.8	40.9
3.3	121.3	263.8	8.3	16.7	36.3
3.4	119.2	259.2	8.4	14.6	31.8
3.5	117.1	254.7	8.5	12.5	27.2
3.6	115.1	250.1	8.6	10.4	22.7
3.7	113.0	245.6	8.7	8.3	18.1
3.8	110.9	241.0	8.8	6.3	13.6
3.9	108.8	236.5	8.9	4.2	9.1

4	106.7	231.9	9	2.1	4.5
4.1	104.6	227.4	9.1	0.0	0.0
4.2	102.5	222.8			
4.3	100.4	218.3			
4.4	98.3	213.7			
4.6	94.1	209.2			
4.7	92.0	204.6			
4.8	89.9	200.1			
4.9	87.9	195.5			

Table 3: Calculated P fertilizer requirement for soil P levels measured by Bray-II method

Bray-II P (mg kg^{-1})	P requirement		Bray-II P (mg kg^{-1})	P requirement	
	P_2O_5 (kg ha^{-1})	DAP (kg ha^{-1})		P_2O_5 (kg ha^{-1})	DAP(kg ha^{-1})
0	225.2	489.5	5	147.8	321.4
0.1	223.6	486.1	5.1	146.3	318.0
0.2	222.1	482.7	5.2	144.7	314.6
0.3	220.5	479.4	5.3	143.2	311.3
0.4	219.0	476.0	5.4	141.6	307.9
0.5	217.4	472.6	5.5	140.1	304.5
0.6	215.9	469.3	5.6	138.5	301.2
0.7	214.3	465.9	5.7	137.0	297.8
0.8	212.8	462.6	5.8	135.5	294.5
0.9	211.2	459.2	5.9	133.9	291.1
1	209.7	455.8	6	132.4	287.7
1.1	208.1	452.5	6.1	130.8	284.4
1.2	206.6	449.1	6.2	129.3	281.0
1.3	205.0	445.7	6.3	127.7	277.6
1.4	203.5	442.4	6.4	126.2	274.3
1.5	202.0	439.0	6.4	126.2	274.3
1.6	200.4	435.7	6.6	123.1	267.6
1.7	198.9	432.3	6.7	121.5	264.2
1.8	197.3	428.9	6.8	120.0	260.8
1.9	195.8	425.6	6.9	118.4	257.5
2	194.2	422.2	7	116.9	254.1
2.1	192.7	418.9	7.1	115.3	250.8
2.2	191.1	415.5	7.2	113.8	247.4
2.3	189.6	412.1	7.3	112.3	244.0
2.4	188.0	408.8	7.4	110.7	240.7
2.5	186.5	405.4	7.5	109.2	237.3
2.6	184.9	402.0	7.6	107.6	233.9
2.7	183.4	398.7	7.7	106.1	230.6
2.8	181.8	395.3	7.8	104.5	227.2
2.9	180.3	392.0	7.9	103.0	223.9
3	178.8	388.6	8	101.4	220.5
3.1	177.2	385.2	8.1	99.9	217.1
3.2	175.7	381.9	8.2	98.3	213.8
3.3	174.1	378.5	8.3	96.8	210.4
3.4	172.6	375.1	8.4	95.2	207.0
3.5	171.0	371.8	8.5	93.7	203.7
3.6	169.5	368.4	8.6	92.1	200.3
3.7	167.9	365.1	8.7	90.6	197.0
3.8	166.4	361.7	8.8	89.1	193.6
3.9	164.8	358.3	8.9	87.5	190.2
4	163.3	355.0	9	86.0	186.9

4.1	161.7	351.6	9.1	84.4	183.5
4.2	160.2	348.2	9.2	82.9	180.2
4.3	158.6	344.9	9.3	81.3	176.8
4.4	157.1	341.5	9.4	79.8	173.4
4.5	155.6	338.2	9.5	78.2	170.1
4.6	154.0	334.8	9.6	76.7	166.7
4.7	152.5	331.4	9.7	75.1	163.3
4.8	150.9	328.1	9.8	73.6	160.0
4.9	149.4	324.7	9.9	72.0	156.6

Table 3 (contd.) Calculated P fertilizer requirement for soil P levels measured by Bray-II method

Bray-II P (mg kg^{-1})	P requirement		Bray-II P (mg kg^{-1})	P requirement	
	P_2O_5 (kg ha^{-1})	DAP (kg ha^{-1})		P_2O_5 (kg ha^{-1})	DAP(kg ha^{-1})
10	70.5	153.3	13	24.1	52.4
10.1	69.0	149.9	13.1	22.6	49.0
10.2	67.4	146.5	13.2	21.0	45.7
10.3	65.9	143.2	13.3	19.5	42.3
10.4	64.3	139.8	13.4	17.9	38.9
10.5	62.8	136.4	13.5	16.4	35.6
10.6	61.2	133.1	13.6	14.8	32.2
10.7	59.7	129.7	13.7	13.3	28.9
10.8	58.1	126.4	13.8	11.7	25.5
10.9	56.6	123.0	13.9	10.2	22.1
11	55.0	119.6	14.0	8.8	19.1
11.1	53.5	116.3	14.1	7.1	15.4
11.2	51.9	112.9	14.2	5.5	12.1
11.3	50.4	109.5	14.3	4.0	8.7
11.4	48.8	106.2	14.4	2.5	5.3
11.5	47.3	102.8	14.5	0.9	2.0
11.6	45.8	99.5	14.6	0.0	0.0
11.7	44.2	96.1			
11.8	42.7	92.7			
11.9	41.1	89.4			
12	39.6	86.0			
12.1	38.0	82.7			
12.2	36.5	79.3			
12.3	34.9	75.9			
12.4	33.4	72.6			
12.5	31.8	69.2			
12.6	30.3	65.8			
12.7	28.7	62.5			
12.8	27.2	59.1			
12.9	25.6	55.8			

Table 4: Calculated P fertilizer requirement for soil P levels measured by Olsen method

Olsen P (mg kg^{-1})	P requirement		Olsen P (mg kg^{-1})	P requirement	
	P_2O_5 (kg ha^{-1})	DAP (kg ha^{-1})		P_2O_5 (kg ha^{-1})	DAP(kg ha^{-1})
0	225.2	489.5	5	127.9	278.0
0.1	223.2	485.2	5.1	125.9	273.8
0.2	221.3	481.0	5.2	124.0	269.5
0.3	219.3	476.8	5.3	122.0	265.3
0.4	217.4	472.5	5.4	120.1	261.1
0.5	215.4	468.3	5.5	118.2	256.9
0.6	213.5	464.1	5.6	116.2	252.6
0.7	211.5	459.8	5.7	114.3	248.4
0.8	209.6	455.6	5.8	112.3	244.2
0.9	207.6	451.4	5.9	110.4	239.9
1	205.7	447.2	6	108.4	235.7
1.1	203.7	442.9	6.1	106.5	231.5
1.2	201.8	438.7	6.2	104.5	227.2
1.3	199.9	434.5	6.3	102.6	223.0
1.4	197.9	430.2	6.4	100.6	218.8
1.5	196.0	426.0	6.4	100.6	218.8
1.6	194.0	421.8	6.6	96.8	210.3
1.7	192.1	417.6	6.7	94.8	206.1
1.8	190.1	413.3	6.8	92.9	201.9
1.9	188.2	409.1	6.9	90.9	197.6
2	186.2	404.9	7	89.0	193.4
2.1	184.3	400.6	7.1	87.0	189.2
2.2	182.3	396.4	7.2	85.1	185.0
2.3	180.4	392.2	7.3	83.1	180.7
2.4	178.5	388.0	7.4	81.2	176.5
2.5	176.5	383.7	7.5	79.2	172.3
2.6	174.6	379.5	7.6	77.3	168.0
2.7	172.6	375.3	7.7	75.4	163.8
2.8	170.7	371.0	7.8	73.4	159.6
2.9	168.7	366.8	7.9	71.5	155.4
3	166.8	362.6	8	69.5	151.1
3.1	164.8	358.3	8.1	67.6	146.9
3.2	162.9	354.1	8.2	65.6	142.7
3.3	161.0	349.9	8.3	63.7	[redacted]

4.1	145.4	316.1	9.1	48.1	104.6
4.2	143.4	311.8	9.2	46.2	100.4
4.3	141.5	307.6	9.3	44.2	96.1
4.4	139.6	303.4	9.4	42.3	91.9
4.5	137.6	299.1	9.5	40.3	87.7
4.6	135.7	294.9	9.6	38.4	83.5
4.7	133.7	290.7	9.7	36.4	79.2
4.8	131.8	286.5	9.8	34.5	75.0
4.9	129.8	282.2	9.9	32.6	70.8

Table 4(contd.): Calculated P fertilizer requirement for soil P levels measured by Olsen method

Olsen P (mg kg^{-1})	N requirement		Olsen P (mg kg^{-1})	N requirement	
	P_2O_5 (kg ha^{-1})	DAP (kg ha^{-1})		P_2O_5 (kg ha^{-1})	DAP(kg ha^{-1})
10	30.6	66.5	11	11.2	24.2
10.1	28.7	62.3	11.1	9.2	20.0
10.2	26.7	58.1	11.2	7.3	15.8
10.3	24.8	53.9	11.3	5.3	11.6
10.4	22.8	49.6	11.4	3.4	7.3
10.5	20.9	45.4	11.5	1.4	3.1
10.6	18.9	41.2	11.6	0.0	0.0
10.7	17.0	36.9			
10.8	15.0	32.7			
10.9	13.1	28.5			