Variability of Soil Test Phosphorus and Management of Phosphorus Fertilizer

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ABSTRACT

Soil available phosphorus (P) can have appreciable spatial variation which could result in inefficient fertilizer use. The high cost of mapping this variability may make site specific management of P uneconomic. Seed-placing a small amount of P fertilizer has been shown to increase grain yield of corn. Therefore, it may have potential for improving P use efficiency. An experiment was conducted to evaluate the spatial pattern of soil test P and the spatial response of applied P fertilizer. The scale of P variability was such that a 120 ft grid would be required to map soil test P adequately. There was no significant yield response of corn to soil test P over the range of soil test P observed, nor were the areas within the field which responded to applied P related to soil test P, indicating no benefit to mapping soil test P to predict variable P application rates. Combined seed-placed plus banded P fertilizer although economical in parts of the field, was not an economical practice over the entire area of the field.

INTRODUCTION

The availability of soil phosphorus (P), as measured by the standard Ontario soil test soil (Bicarbonate P), can vary considerably within a very short distance in the field making it very difficult to adequately map the level of P fertility in the soil. The use of seed-placed P fertilizer on corn has become an established practice in southern Ontario, and research results have generally shown yield increases even for soil test levels above those at which a yield response is obtained to a 2x2 (2 inches below and to the side of the seed) side-band fertilizer application. While the response of corn to seed-placed P fertilizer has been compared to a side-banded P application in a few experiments, these studies did not have the scope to determine at what soil test level does seed-placed P replace the need for side-banded P or if the response of seed-placed P is additive to the response obtained with side-banded P. The answers to these questions could have a significant impact on how we approach the management of P fertilization for our variable soils.

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Site Specific Management of P

Several methods that are being considered to map field variability such as: satellite imagery, aerial photography, soil based sensors and soil sampling based on either landscape position or a pre-set grid pattern.

Satellite and aerial imagery are also possible tools for detecting spatial variations in crop growth or stress as related to potential nutrient deficiencies. Lozano-Garcia (1991) described how satellite spectral analysis can be used to obtain a normalized difference vegetative index (NDVI). As new sensors are developed and tested there remains an enormous potential for using such imagery in site-specific farming, but the bottom line is the suitability of remotely sensed data for site-specific farming, and for variable rate fertilization of field crops in particular is still not proven.

Carr et al. (1991) used soil classification as a method of mapping fields for soil sampling and fertilizer recommendation in Montana. Returns were slightly increased with this method in three of five fields tested when the current fertilizer recommendation system was used although larger returns were obtained in two fields when "optimum" fertilizer rates were applied. They concluded that soil type has promise as a method of mapping fields for soil sampling. Moore et. al. (1993) measured several soil attributes including; soil moisture, depth of A horizon, soil P, soil organic matter, and soil pH, as related to slope position. On the two sites considered soil organic matter, depth of A horizon and P were greatest at the foot slope position and lowest on the side slope where the slopes were the steepest. Field topography can be quickly mapped with a DGPS system so slope positioning may be a viable method of mapping fields for soil sampling and fertilizing. A research project involving 26 different farms across Ontario has shown that while relationships between slope positions or elevation and soil test phosphorus are statistically significant often less than 20% of the variability in soil test P levels is associated attributed to these landscape parameters (O'Halloran unpublished data).

The most widely used commercial method to-date for attempting to characterize soil variability has been based on grid sampling, with grid sizes often based on the acceptability of the cost rather than the usefulness of the information being generated. The field-specific characteristics of the soil test P (i.e. the range of soil test levels and the nature of the spatial variability) and the anticipated benefit from varying the fertilizer rate which ultimately determines the sampling intensity required. There are numerous reports in the literature describing the impact of grid sampling size and field variability of soil test P. Franzen and Peck (1995) soil sampled two 40 acre fields over 3 years at an 82.5 ft grid and compared soil test P and K maps at this scale to ones at a 165 and 330 ft grid size. Correlation of the 165 ft and 330 ft. grid size with the 82.5 ft. resulted in r^2 values ranging from 0.22 to 0.48 and 0.03 to 0.12 respectively. In 1992 they added a 220 ft. grid and found improved correlations to the 82.5 ft grid over the 330 ft grid. In this experiment they recommended a 220 or smaller grid size for newly sampled fields and then adjusting the size of the grid based on field variability for subsequent sampling. Others, such as Wollenhaupt et al.(1994) recommended smaller grid sizes of not more than 106 ft. Within Ontario the standard grid sampling sized used for most field crops is approximately 330 ft. Our experience with Ontario soils suggests that the nature of soil test P variability is such that there is little hope in economically mapping the level of soil variability for the purpose of developing effective site-specific fertilizer P recommendation maps.

Seed-Placed Fertilizer use on Corn

Experiments conducted at the University of Guelph with corn, indicate that attaining a critical shoot P concentration during very early growth is required for high yields. Barry and Miller (1989) grew corn outdoors with a hydroponic system that allowed P nutrition to be varied during plant growth. They found that attaining high shoot P concentrations by the 6-leaf stage (leaf stage = total number of leaves visible minus one) was critical for high grain yields regardless of the P nutrition at later stages. Lauzon (1995) related shoot P concentration; at the 4-to 5-leaf stage and 6-to 7-leaf stage and leaf concentration at silking, with grain yield. The greatest correlation between plant P concentration and grain yield was found at the 6-to 7-leaf stage. Applying phosphorus fertilizer seed-placed may be a way of increasing early season shoot P concentrations.

The use of P fertilizer in the seed trench of corn is an established practice in southern Ontario. A greenhouse study by Miller et al. (1971) showed that corn plants receiving P with the seed grew and absorbed P more rapidly than plants receiving four times as much P placed in a band to the side and below the seed during the first four weeks of growth. A field experiment with corn by Bates (1971) found delayed emergence but more rapid early growth and a yield increase of 2.9 % when 49 lb ac^{-1} of 6-24-6 was added with the seed. This response was independent of the soil available P and the amount of P applied in a side band. It was concluded that "quite high rates of fertilizer would be required when applied broadcast or away from the seed to eliminate the response from low rates applied with the seed". Bates and Bowles (1986) found that applications of 62 lb ac^{-1} of 6-24-6 with the seed increased early growth, advanced silking, decreased grain moisture content of 1.4 percent and increased grain yield of 3.6 bu ac^{-1} on sites where there was no response to broadcast or band-applied P. Mengel et al. (1988) also reported similar grain moisture reductions (from 33.2 to 32.4 percent) and grain yields increases (from 153 to 158 bu ac^{-1}) when 60 lb ac^{-1} of 10-34-0 was applied in the seed trench, even though there was a very high soil test P levels (106 lb ac^{-1} Bray P_1 extractable P). Hart (1989) reported an average increase in corn grain yield of 2.7 percent over 2 years with seed-placed P. The increased grain yield occurred in spite of a high soil test P level of 40 ppm $NaHCO_3$ extractable P in the first year and a soil test of 21 ppm with 57 lb lb P_2O_5 ac^{-1} P_2O_5 ac^{-1} broadcast in the second year.

More recently Lauzon and Miller (1997) found increased shoot P concentrations and mass during early growth and grain yield increases with seed-placed P across the range of sodium bicarbonate extractable P tested (3 - 35 ppm). This experiment also included a side-band P application at the recommended rates at a low soil test P level (4 ppm) where the recommended rate of application was 80 lb P_2O_5 ac^{-1} and at a medium soil test level (17 ppm) where the recommended rate was 18 lb P_2O_5 ac^{-1}. The early season shoot P concentration increases observed with seed-placement were not seen with side-band P applications, even though a much greater amount of P was applied in the side-band (80 lb P_2O_5 ac^{-1} side-banded vs 13 lb P_2O_5 ac^{-1} seed-placed). A yield increase was observed with side-banded P at the low soil test level however 80 lb P_2O_5 ac^{-1} side-banded did not significantly increase yields more than 13 lb P_2O_5 ac^{-1} seed-placed. At the medium soil test level 18 lb P_2O_5 ac^{-1} side-banded did not increase corn yields, although 13 lb P_2O_5 ac^{-1} seed-placed did increased yields. The effect of combining both a seed-placed and band application was not examined.

The current practice of applying a constant fertilizer rate based on a field average soil test undoubtedly results in the over and under-fertilization of certain areas of the field. Attempting to reliably identify these areas of the field by soil sampling is unlikely to be a economically profitable practice for the farmer. Research results indicate that while seed-placed fertilizer may not supply enough P for a corn crop at low soil test levels, yield gains could be recognized at higher soil tests. We are currently examining the possibility of utilizing a seed-placed and side-band combination of fertilizer P to capture most of the variable corn yield response to applied P within a field, rather than attempting to map the field variability of soil test P and then vary fertilizer applications based on this map. This study will examine the within field variability of soil test P, its relationship to elevation and corn yield, and the response of corn to P fertilization applied as a side-band, seed-placed or side-band plus seed-placed treatment.

EXPERIMENTAL SITE INFORMATION

The experiment was conducted in 1996 and 1997 at the Elora research station on a Guelph silt loam soil. The site was approximately 5 ac in size (1300 ft long and 160 ft wide) with a simple slope which slopes gently from both ends of the site to a low area in the middle (approximately 8 ft elevation difference) figure 1. The site composite soil test P of the area was 15 ppm $NaHCO_3$ extractable P.

Treatments

Four treatments, replicated four times were applied in strips across the full length of the study area. The treatments were:

1. check: no fertilizer P applied
2. side-banded P fertilizer at the provincial recommended rate for the site (44 lb P_2O_5 ac^{-1}) as liquid 10-34-0.
3. seed-placed P at a rate of 11 lb P_2O_5 ac^{-1} as liquid 10-34-0.
4. side-banded P fertilizer at the recommended rate plus seed-placed P fertilizer at 11 lb P_2O_5 ac^{-1}

All of the soil and plant measurements were taken from an area 16.25 ft in length by two corn rows wide (5 ft) at 48.75 ft intervals in each of the treatment strips (each treatment strip was 10 ft wide, and samples were taken on a 10 ft x 48.75 ft grid). There were 27 sample areas per treatment strip for a total 432 plot areas in the site (27 plots $strip^{-1}$ x 4 treatments x 4 reps).

Site Preparation

The soil was conventionally cultivated (fall moldboard plowing followed by spring secondary tillage). Cultivation was conducted parallel to the long dimension of the site. Corn, Funks variety G-4043, was planted using a John Deere 7000 planter set up to apply liquid fertilizer in a side-band and in the seed trench. Liquid 10-34-0 fertilizer was used as the P source in all the treatments. Potassium was supplied to the entire site at 90 lb K_2O ac^{-1} as broadcast 0-0-60. Nitrogen fertilizer was broadcast to the site at 120 lb ac^{-1}. Additional N was applied to the treatment strips at rates to balance the N applied in the side-band and seed-placed treatments for a total of 136 lb N ac^{-1} .

Soil and Plant Measurements

Soil samples were taken to a depth of 6" from each plot in the spring of 1996 and analyzed for $NaHCO_3$-extractable P, NH_4Ac-extractable K, and soil pH (water paste). Elevation was determine using an ATV mounted high-resolution DGPS system which was driven down the length of the field in 10 ft. transects with readings of elevation recorded in approximately 15 ft. intervals.

Plant shoot samples were taken at the 4-5 leaf stage and the 6-7 leaf stage in 1996 and at the 5 leaf stage in 1997. Leaf stage is defined as the Nth-1 leaf which is visible. The shoot samples were dried at 140° F, and dry weights recorded.

The corn grain yields were determined by hand harvesting each of the two-row wide 16.25 ft. sampling areas. Total grain plus cobs mass was determined from each yield area, from which a subsample of 10 cobs were weighed and dried (140° F), and the grain plus cob moisture calculated. Cobs were then shelled and grain yield (15.5% moisture) determined.

Statistical Analysis

The treatments were applied in strips across the entire length of the experiment with 27 sampling locations per strip in an attempt to pick up field variability in soils and crop response. Crop responses were statistically evaluated using regression analysis in SAS proc GLM and/or NLIN. In the analysis, the applied treatments were added into the model as a class variable and soil test P was added as a regression variable. The average treatment responses were compared using SAS proc mix.

Geostatistical procedures were completed and maps generated for elevation, soil test P, check plot grain yield, and yield changes with each of the P treatments relative to the check yields (delta yield). The elevation map was overlayed on each of the other soil and yield parameters.

Each of the data sets were tested for normality. If any data point deviated more than 4 standard deviations from the mean it was flagged and removed from the data set before determining the variogram model. A variogram model was calculated for each data set using a software program called GS^+. The software allows examination of the semivariance of each pair of data at each lag position. If one data point consistently caused the semivariance of a data pair to be more than three times greater or less than the main cluster of data pairs it was removed from the data set and a new variogram model was calculated. Several types of models were available in the program (linear, linear to a sill, exponential, spherical, and Gaussian). The model which resulted in the best fit (highest r^2) to the data pairs was selected. If more than one of the models had a similar r^2 the visual fit of the model to the data was used to select the variogram model. Variogram models were calculated for elevation, soil test P, and each of the treatment grain yields. The variogram models were used in determining the largest sample spacing which could be employed on this site to adequately pick up the field variability present. This distance was set at ½ the maximum lag distance (distance at which data pairs are no longer spatially related). Going beyond ½ the maximum lag distance will result in data pairs which are not sufficiently well related to calculate accurate variogram models.

Kriging of the data was completed using the variogram models from GS+ and the mapping software package Surfer. All of the data removed from the data sets before calculating the variogram models were reintroduced before kriging. Delta yields were determined in Surfer by subtracting the krigged data file for the check yields from that of the kriged data sets of each of the P treatment yields. During the mapping of the data the scale used in each of the contour plots was based on the standard deviation of the data set involved. In each case the first map unit is ± 0.2 sd from the mean of the data set. The next units are 0.6, 1.0, and 3.0 SD from the mean in either the positive and negative direction. The contour plots of soil test P, check grain yield, and delta yield maps for the three P treatments were overlayed on a 3 D map of the sites surface elevation.

RESULTS AND DISCUSSION

Relationship between check yields and soil test P

Using classical statistics there was no relationship between check grain yield and soil test P level ($r^2 = -0.08$). Figure 2 shows the yield pattern of the check plots over the variability in soil test P. The lack of yield response to soil test P is likely due to the soil test P levels being 12 ppm and greater. Recent studies in southern Ontario (Lauzon and Miller 1997) suggest that corn yield response to soil test P levels often reaches a maximum at about 12 to 15 ppm $NaHCO_3$ extractable P.

The average treatment responses for shoot mass, grain moisture and yield are given in tables 1 and 2 for the 1996 and 1997 field seasons respectively. In both years all fertilizer P treatments resulted in early growth shoot mass increases. Grain moisture content was reduced by all of the P treatments in 1997 but in 1996 only the combination of side-banding plus seed-placement resulted in significant moisture content reductions. There were grain yield increases in 1996 with side-banding plus seed-placement and in 1997 to only side-banding but average over the entire field, these responses would not be economical given the current value of corn and P fertilizer costs.

Table 1. 1996 average plant responses

Treatment	4-5 leaf	6-7 leaf	Grain moisture	Yield
	lb 1000 plants^{-1}		%	bu ac^{-1}
Check	0.75 A*	13.2 A	34.7 A	110 A
Seed-placed	0.95 B	13.7 A	34.7 A	108 A
Side-band	0.93 B	16.5 B	34.0 A	110 A
Both	1.06 C	19.2 C	32.5 B	116 B

*means within the same column followed by the same letter are not significantly (P<0.05) from one another.

Table 2. 1997 average plant responses

Treatment	5-leaf stage	Grain moisture	Grain yield
	lb 1000 plants^{-1}	%	bu ac^{-1}
Check	2.91 A*	33.3 A	95 A
Seed-placed	5.29 B	32.8 B	97 AB
Side-band	5.95 C	32.5 B	98 B
Both	6.61 D	32.0 C	96 AB

*means within the same column followed by the same letter are not significantly ($P<0.05$) from one another.

Spatial soil test P and crop yield patterns

A map of the elevation for the experimental site is given in figure 1, which indicates approximately 8 ft change in elevation. There was a distinct depressional area (at about 1000 ft Northing by 1200 ft Easting).

The spatial pattern of $NaHCO_3$ extractable P relative to elevation is given in figure 3. The variogram model for soil test P was spherical with a nugget (y intercept) of 7.25, a sill of 19.2 and a range of 240 ft. Therefore the maximum distance that grid samples should be taken from at this site is about 120 ft. The current grid size used for commercial grid sampling soil test P is approximately 330 ft. At 120 ft a sampling intensity almost 9 times greater than the current commercial practice would be required. The 330 ft grid size would miss a great deal of the variability and a accurate variogram model could not be calculated.

The spatial pattern of grain yield when no P fertilizer was applied is given in figure 4. Notable is the low yielding area which occurred along the upper slope position of the knoll at about 400 ft Northing, which also tended to be an area of higher soil test P. As indicated by the simple regression between soil test level and check grain yield (Figure 2), however, overall the yield variability present did not appear to be due to variations in soil test P. The yield pattern would indicate a stronger influence of topography than soil test P, which may reflect the growing season soil moisture availability in this rain-fed system.

Delta yields (fertilizer P treatment yields - check yields) are given in figures 5 to 7. Yield response to seed-placed P appeared to occur only in a small proportion of the site in some of the low and high topographic positions (figure 5). Side-banding of the P fertilizer resulted in a slightly larger area of the field responding (figure 6), while the combination of the two fertilizer treatments resulted in the largest area of response in the field (figure 7). The minimum yield increase required for each of the treatments to offset the cost of the fertilizer are approximately, 2 bu ac^{-1} for seed-placement, 8 bu ac^{-1} for side-banding, and 10 bu ac^{-1} for the combination of the treatments. Given this information the areas of economic response are generally quite small, with the exception of the treatment where both seed-placed and banded P fertilizers were applied. Again, soil test P and landscape position had little to do with defining these responsive areas within the field.

Conclusions

The fact that much of the site appeared to be relatively non-responsive to P fertilizer application does limit the extent to which one can draw conclusions regarding the appropriateness of various application techniques for P management. The spatial patterns of yield and yield response to fertilizer application indicated that mapping of soil test P, regardless of whether based on grid or landscape patterns, would do little to predict the requirement of the crop for fertilizer P as measured by the delta yield approach. The fact that many fields in Ontario have soil test levels equal to or higher than those found in this study would also bring serious doubts into the profitability of varying fertilizer P applications.

Compared to either seed placed or side-banded fertilizer applications, the seed-placed plus banded fertilizer treatment increase yields in one of the two study years, although this yield increase would not off-set the additional cost of the fertilizer when applied to the entire field. Economical response were obtained in ceratin areas of the field, but there was no clear method of delineating where one could expect to obtain a profitable response to the applied fertilizer. Research is continuing on sites with lower soil test levels of P and with differing rates of banded P with the seed-placed treatments.

REFERENCES

Barry, D.A. and M.H. Miller. 1989. Phosphorus nutritional requirement of maize seedlings for maximum yield. Agron. J. 81: 95-99.

Bates, T.E. 1971. Response of corn to small amounts of fertilizer placed with the seed: II. Summary of 22 field trials. Agron. J. 63: 369-371.

Bates, T.E., and G. Bowles. 1986. Rates of broadcast fertilizer with and without fertilizer with the seed of corn. Unpublished.

Carr, P.M., G.R. Carlson, J.S. Jacobsen, G.A. Nielson, and E.O. Skogley. 1991. Farming soils, not fields: a strategy for increasing fertilizer profitability. J. Prod. Agric. 4: 57-61.

Franzen, D.W. and T.R. Peck. 1995. Field soil sampling density for variable rate fertilization. J. Prod. Agric. 8: 568-574.

Hart, R.C. 1989. Response of corn to rate and time of nitrogen application, seed placed starter fertilizer and plant population. M.Sc. Thesis, University of Guelph. Ont. Can.

Lauzon, J.D. 1995. Response of corn and soybean to phosphorus. M Sc Thesis. University of Guelph, Ont. Can.

Lauzon, J.D. and M.H. Miller. 1997. Comparative response of corn and soybean to seed-placed phosphorus over a range in soil test phosphorus. Commun. Soil Sci. Plant Anal. 28: 205-215.

Lozano-Garcia, D.F., R.N. Fernandez, and C.J. Johannsen. 1991. Assessment of regional biomass-soil relationships using vegetative indexes. IEEE Transactions on Geoscience and Remote Sensing. 29:331-339.

Mengel, S.E., S.E. Hawkins, and P. Walker. 1988. Phosphorus and potassium placement for no-till and spring plowed corn. J. Fert. Issues. 5: 31-36.

Miller, M.H., T.E. Bates, D. Singh, and A.J. Baweja. 1971. Response of corn to small amounts of fertilizer placed with the seed: I. Greenhouse studies. Agron. J. 63: 365-368.

Moore, I.D., P.E. Gessler, G.A. Nielsen, and G.A. Peterson. 1993. Terrain analysis for soil specific crop management. In: Proceedings of soil specific crop management. ASA. Madison USA 27-55

SAS. 1985. SAS user's guide: Statistics. version 5 edition. SAS Institute Inc.,Cary NC., USA.

Wollenhaupt, N.C., R.P. Wolkowski, and M.K. Clayton, 1994. Mapping soil test phosphorus and potassium for variable-rate fertilizer application. J. Prod. Agric. 7: 441-448.

Figure 1. Field topographic map with sample locations

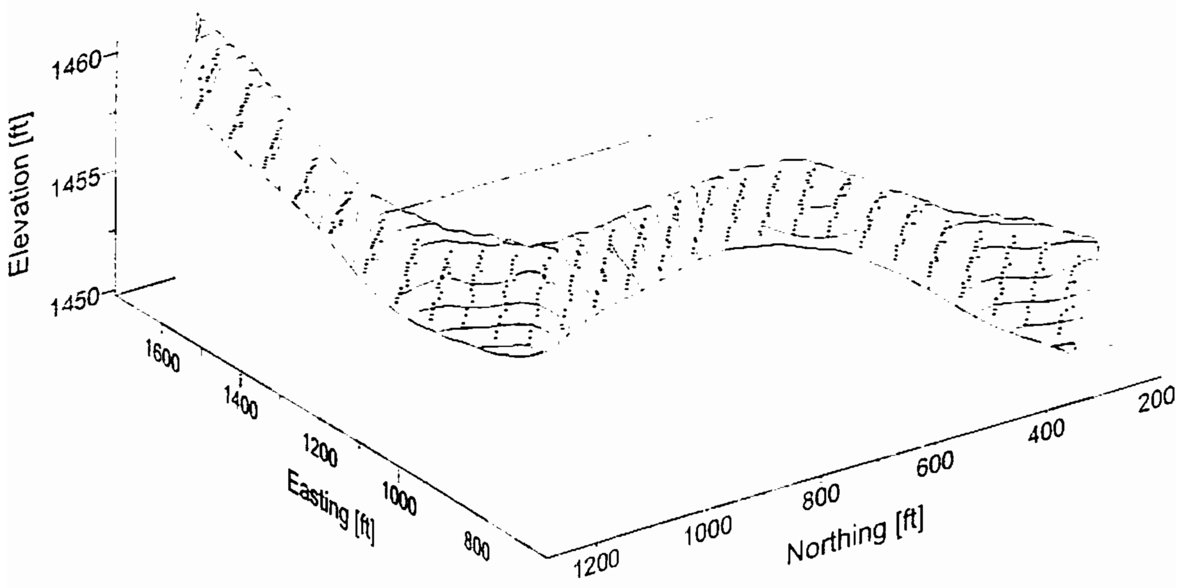


Figure 2. 1996 check yield as a function of soil test P level

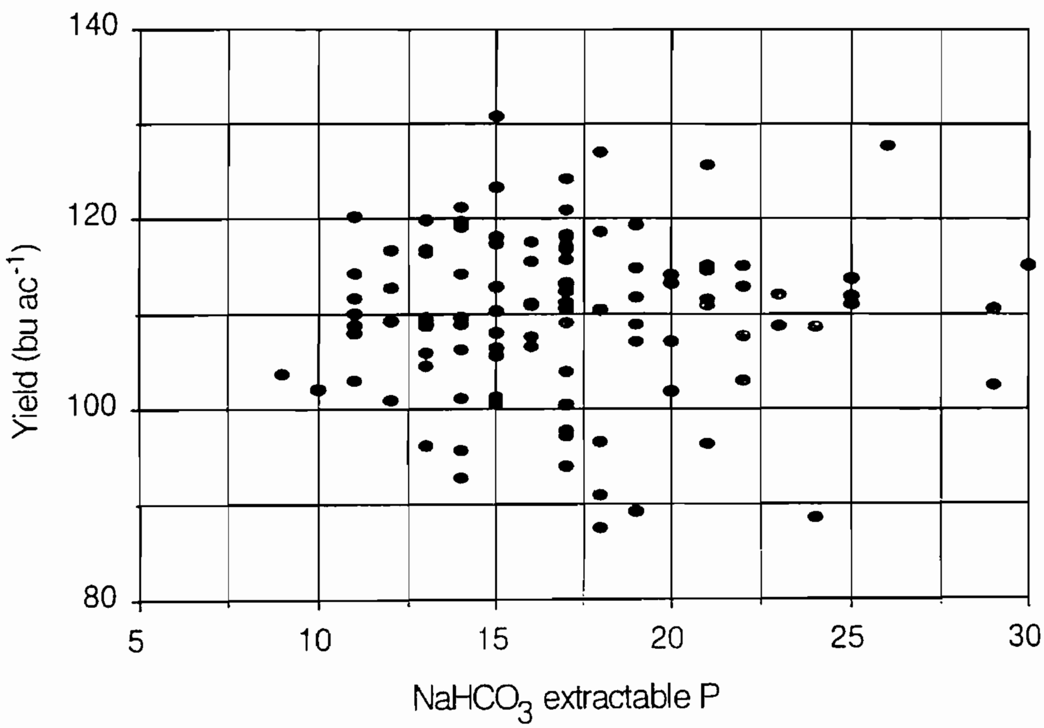


Figure 3. Soil test phosphorus levels

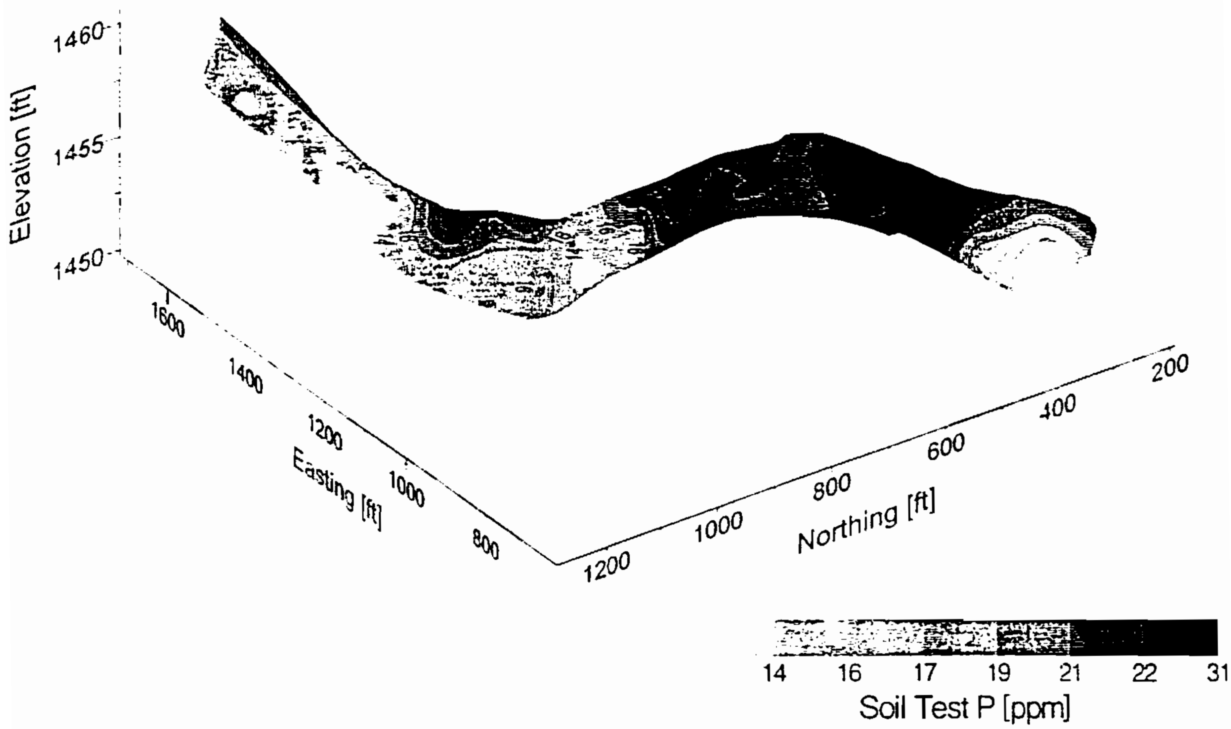


Figure 4. 1996 corn yield with no P fertilizer applied

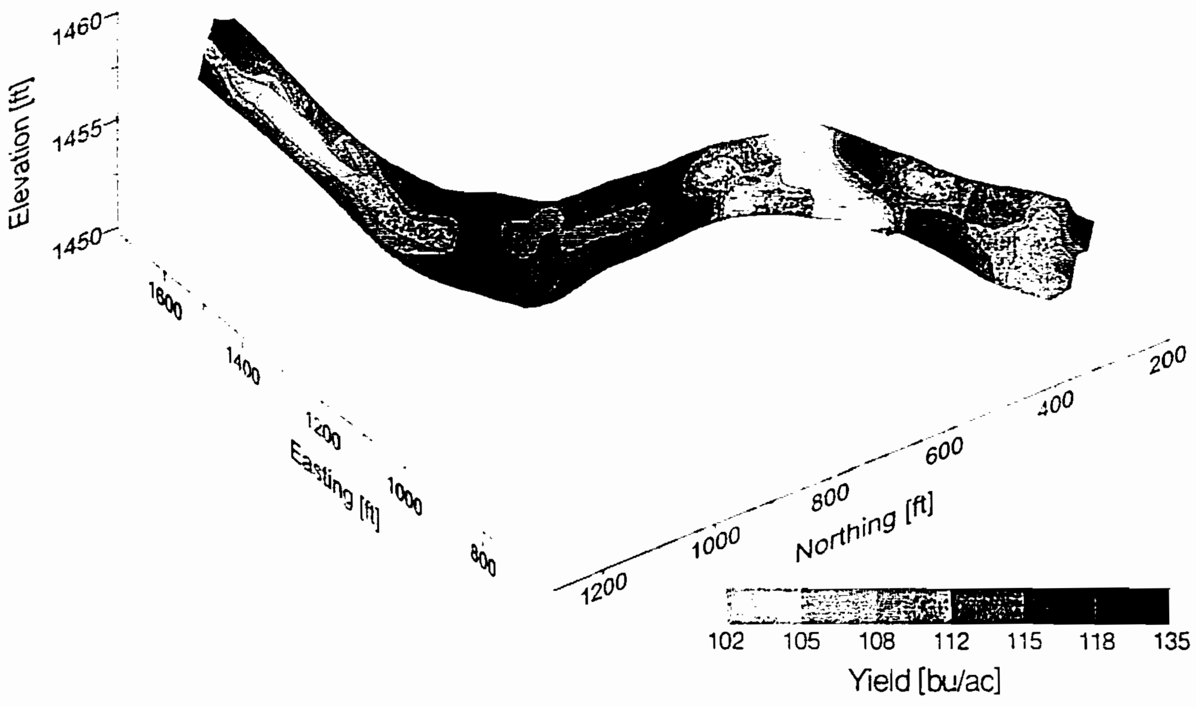


Figure 5. 1996 delta yield with seed-placed P fertilizer

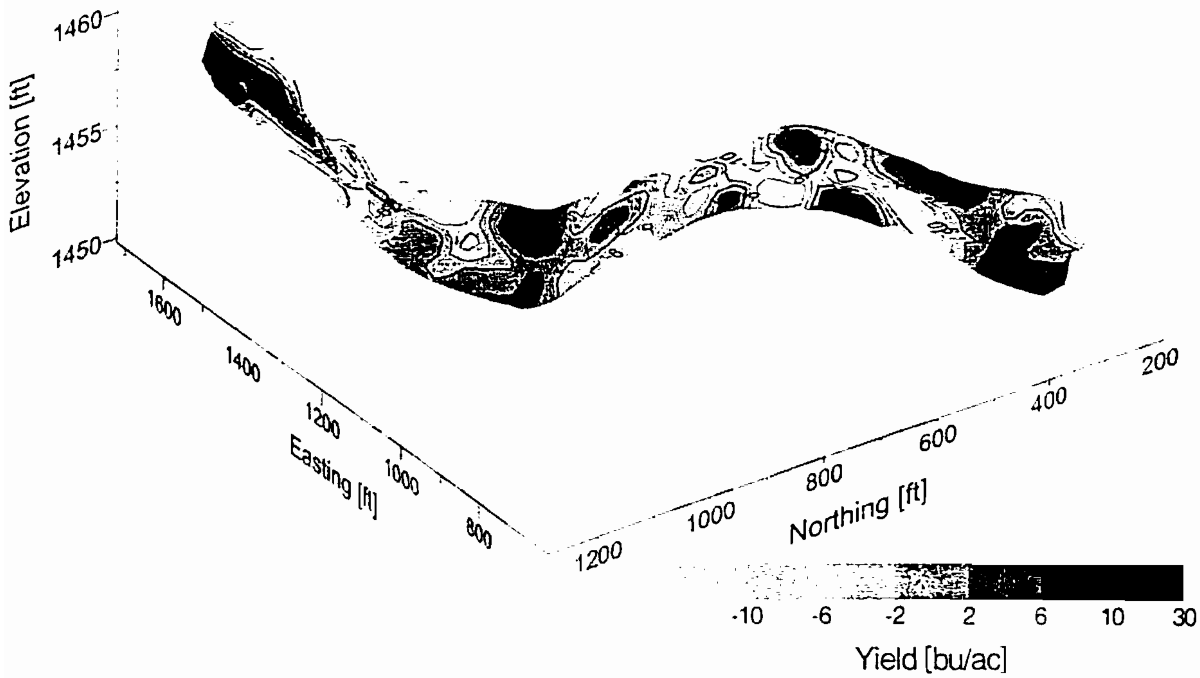


Figure 6. 1996 delta yield with side-banded P fertilizer

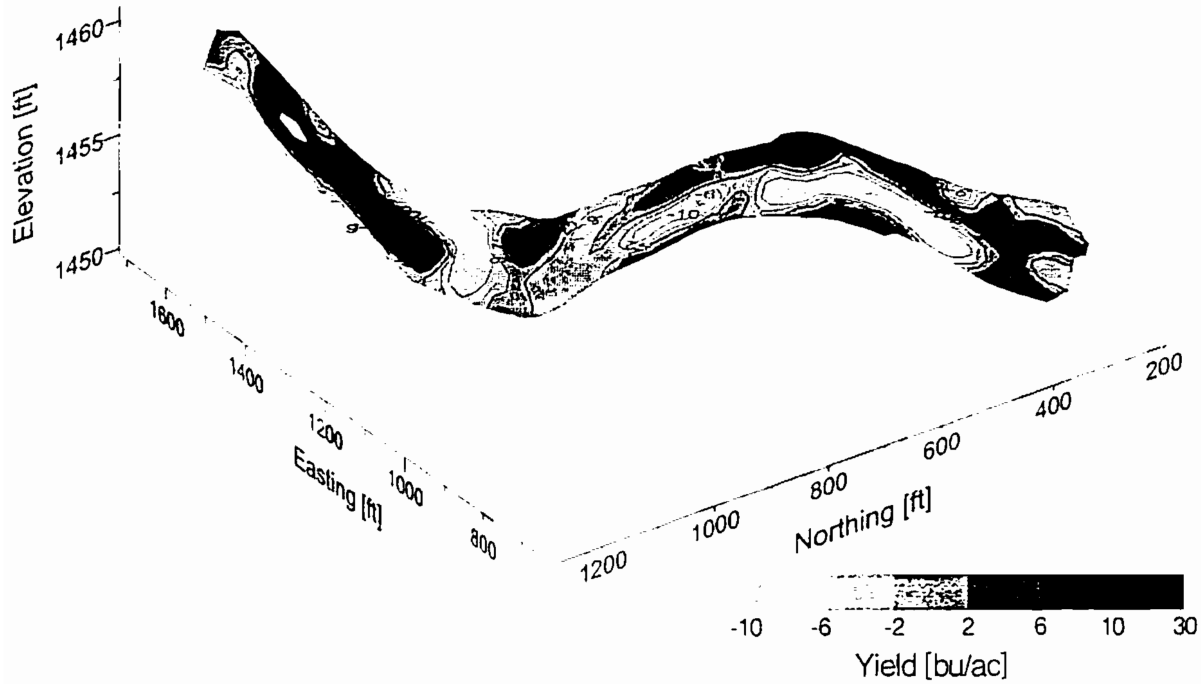
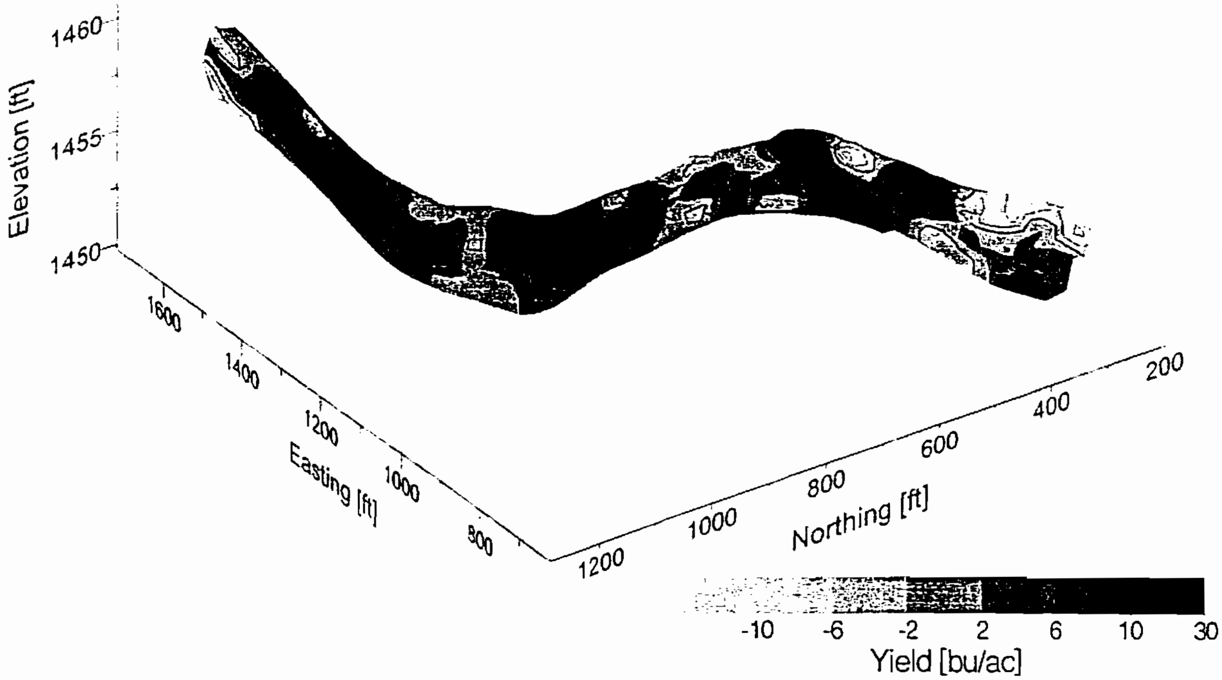


Figure 7. 1996 delta yield with side-band plus seed-placed P fertilizer



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