

Field Soil Sampling Density for Variable Rate Fertilization

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Variable rate fertilizer application being commercially performed today is most often based on a soil test map. The sampling density used to develop a map is often selected without background information regarding field soil test variability. The objective of this study was to determine how many samples should be taken from a field in order to locate and describe major areas of fertility affecting variable rate fertilizer applications. Two 40 acre fields were sampled in an 82.5 ft grid each fall from 1989 to 1992. Soil pH, Bray P1, and available K levels were determined on each sample and maps were made using inverse distance squared estimates. Data were taken from the samplings to represent a 165 ft and 330 ft grid pattern. Maps were developed from these less dense grids and compared with the 82.5 ft grid values. In 1992, a separate 220 ft grid sampling was taken. The 220 ft grid estimates were more highly correlated with the 82.5 ft grid values than were the 330 ft grid estimates, however, membership of 220 ft and 330 ft grid estimates within soil test categories were similar. Fertilizer P and K applications were made in one field following the 1992 sampling. Spring 1993 sampling showed the success of the 220 ft grid in directing a variable rate application of P and K. Comparisons to theoretical P and K applications directed by a 330 ft grid map showed the superiority of the 220 ft grid compared with the 330 ft grid.

APPLYING FERTILIZER only where required for crop yield increase and reasonable maintenance of soil fertility would help conserve resources, decrease water contamination due to leachates, and hold the potential

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for decreased grower costs and increased yields (Sawyer, 1994). Variable rate fertilization relies on soil test information to correctly apply fertilizer to areas of a field. Grower benefits from variable rate fertilizer application include yield increases on low testing soils and fertilizer savings by decreasing application rates on high testing soils (Sawyer, 1994).

The geographic area that describes a fertilizable unit within a field is called a sample unit (Peck & Melsted, 1973). If the sample unit is the field, the field mean is the sample unit. Suspected variability may be a basis for smaller fertilizable areas, requiring more sample units per field.

The number of soil samples needed to represent the variability of the field has been a matter of discussion since at least the 1920s (Linsley and Bauer, 1929). The need for sampling to describe field variability has probably always had an economic basis (Peck, 1990). As sampling density increases, the variation between samples decreases (McIntyre, 1967). The economic success of site-specific fertilizer application will depend on the ability of sampling to represent areas that will respond to fertilizer and avoid fertilization where it is not necessary (Sawyer, 1994), while keeping sampling costs low.

Systemic sampling is suggested by several researchers as the method best used to sample a field (Peck and Melsted, 1973; Petersen and Calvin, 1986; Sabbe and Marx, 1987). Systematic sampling in a grid pattern has been recommended in Illinois for many years. Linsley and Bauer (1929) recommended a grid in a 40 acre field that consisted of 23 surface (1 to 2 in. depth), five subsurface (12 in. depth), and five subsoil (20 in. depth) samples.

In 1943, the recommended grid was reduced to 11 samples per 40 acre field, with an example sampling detailed in the 1979-1980 University of Illinois Agronomy Handbook (University of Illinois, 1978). This grid

Table 1. Soil test categories selected for pH, P1, and K levels.

	Category		
	1	2	3
pH	<6.5	6.5-7.0	>7.0
P1, lb/acre	<50	50-80	>80
K, lb/acre	<300	300-599	>599

reduction was made because of the relative low cost and increased ease of broadcast application of fertilizers. Recently, the grid recommendation has been changed to 16 samples per 40 acres (Peck, 1988) in response to increasing awareness of field variability and the growers ability to respond to it.

Soil sampling for variable rate fertilization is currently performed using the 1943 to 1991 Illinois grid of 3.3 acres/sample (Brunoehler, 1992; Reichenberger, 1992). A variable rate fertilization project in Missouri has used a 2.5 acre grid (Buchholz, 1992). Wisconsin research has shown that needed sampling density depends on the field variability, but generally recommends a 200 ft grid, depending on prior fertility management and soil test history (Wollenhaupt et al., 1994). Work in Washington state has suggested 1 acre grids for irrigated potato (*Solanum tuberosum* L.) fertilization (Hammond, 1993). The objective of this study was to determine the density of soil sampling that would locate and describe the major areas of fertility in two Illinois fields.

METHODS AND MATERIALS

Two square 40 acre fields were examined in this study. The fields have a well known history of cropping, mean yields, and fertilizer treatment, as well as detailed grid sampling (Peck and Melsted, 1973; Peck, 1991; and Franzen, 1993). The first field is located southwest of Mansfield, IL. The soil types of Mansfield are Flanagan silt loam (fine-silty, montmorillinitic, mesic Typic Argiudolls), Drummer silty clay loam (fine-silty, mesic Typic Haplaquolls), and Harpster silty clay loam (fine-silty, mesic Typic Calciaquolls) (Peck, 1991). The Mansfield field was cropped to soybeans [*Glycine max* (L.) Merr.] in 1990 and 1992 and corn (*Zea mays* L.) in 1989 and 1991. Crops were grown in the field with residual P and K for the length of the study.

The second field in the study was located northwest of Thomasboro, IL. The soil types at Thomasboro are Drummer silty clay loam and Harpster silty clay loam (Peck, 1991). The Thomasboro field was cropped to corn in each year of the study with residual P and K.

The fields were sampled in an 82.5 ft grid with 0.156 acres/sample area in the fall annually from 1989 to 1992. Each soil sample consisted of five soil cores. Five cores were taken with one core centered in the middle of the plot and the four other cores taken roughly from a 16 ft radius surrounding the central core. All of the soil from the five cores was placed in a common bag, dried at 36°C, pulverized, and analyzed for pH (1:1 soil:water paste) (Eckert, 1988), Bray P1 (P) (Knudsen and Beegle, 1988), and available potassium (K) using ammonium acetate, pH 7.0 as extractant (Brown and Warncke, 1988).

Using the original 82.5 ft apart sample points within

Table 2. Correlation (r^2) between 82.5 ft grid sampled values with 165 ft grid and 330 ft grid estimates. Values of common locations between comparisons have been deleted before calculation.

Location	Comparison	330 ft grid		165 ft grid		
		n	r^2	n	r^2	
Mansfield	pH	1989	240	0.487	192	0.697
		1990	240	0.448	192	0.732
		1991	240	0.465	192	0.670
	P	1989	240	0.050	192	0.214
		1990	240	0.035	192	0.477
		1991	240	0.031	192	0.222
	K	1989	240	0.152	192	0.335
		1990	240	0.219	192	0.657
		1991	240	0.055	192	0.401
Thomasboro	pH	1989	240	0.156	190	0.300
		1990	240	0.221	190	0.599
		1991	240	0.199	190	0.391
	P	1989	240	0.108	190	0.251
		1990	238	0.118	190	0.398
		1991	238	0.059	190	0.242
	K	1989	240	0.186	190	0.457
		1990	238	0.058	190	0.555
		1991	238	0.288	190	0.412
Means			0.185		0.445	

LSD, Means $P < 0.01$

each 40 acre field for the pH, P1, and K levels in each year, it was possible to determine which of these points would represent a 330 ft grid with approximately 1 sample/2.5 acres and a 165 ft grid with 1 sample/0.625 acres.

Maps were made of the 165 ft and 330 ft grid estimates of pH, P, and K levels using the program Surfer (Golden Software Company, Golden, CO). In all mapping during the study, the inverse distance method was used to estimate unsampled points. The search selected was the four nearest neighbors with a search radius of 500 ft. The method was used to estimate the values in approximately a 20 ft grid in each field. Points estimated with common values were connected with lines within the contouring portion of the Surfer program. If presented in rough fashion, the polygons would have sharp corners, however, the smoothing of the lines was done by increasing the vector nodes between the 20 ft grid estimates using the same inverse distance algorithm as the major nodes. Inverse distance squared is one of the nonkriging methods that are appropriate when estimating values at locations within a regularly spaced grid (Isaaks and Srivastava, 1989). Inverse distance squared estimates compare favorably with Delauney triangulation (Wollenhaupt et al., 1994), another appropriate estimation procedure. Polygons less than 0.1 acre in size were incorporated into the neighboring polygons.

The estimated values of each location of the 165 and 330 ft maps that corresponded to points in the 82.5 ft grid were correlated with the 82.5 ft values. Locations that were common to each grid were deleted before the correlation, so that only estimates from the mapping and corresponding locations on the 82.5 ft grid are represented. Correlations were calculated using the SYSTAT 5.01 for Windows statistical program (1992, SYSTAT, Inc., 1800 Sherman Ave., Evanston, IL, 1st printing).

In 1992, Mansfield and Thomasboro were both sampled in a 220 ft grid on the same day as the 82.5 ft sampling. Maps were prepared of each grid as before, including a 330 ft grid map. Correlation of estimates of

Table 3. Correlation between 220 ft grid and 330 ft grid estimates with 82.5 ft sampled values, 1992.

Location	Soil test	Sampling grid	
		330 ft	220 ft
r^2			
Mansfield	pH	0.292	0.484
	P	0.025	0.174
	K	0.029	0.166
Thomasboro	pH	0.208	0.261
	P	0.222	0.283
	K	0.166	0.345

LSD ($P < 0.05$) between grid patterns within location is 0.156.

each sample location with corresponding sampled values from the 82.5 ft grid was calculated as before.

Current Illinois fertilizer recommendations for a corn and soybean rotation suggest a soil pH of 6.5, a P test level of 50 lb/acre, and a K test level of 300 lb/acre. Soil test categories were selected for pH, P1, and K levels that represented levels of each soil test for which similar fertilizer recommendations are made (Table 1). For example, lime application is recommended below pH 6.5, pH from 6.5 to 7.0 is considered ideal while a pH higher than 7.0 can lead to herbicide carryover and phytotoxicity problems (Univ. of Illinois, 1993).

Soil test values from each location of the 82.5 ft grid and estimates from the 220 ft and 330 ft mapping were grouped into the soil test categories. Membership of each estimate from the less dense grids to the same category as the 82.5 ft sampled value was tabulated. The percentage of the fields correctly represented, overestimated, or underestimated within the three groups of recommended soil test levels was determined for each less dense grid.

Fertilizer applications of P and K were made in the late fall of 1992 following the 1992 sampling at the Thomasboro field. The applications used the 220 ft grid mapping to direct the application. Levels of P used were 0, 53, 79, and 106 lb/acre. Levels of K used were 75, 149, and 249 lb/acre. The boundaries of the applications were determined with a tape measure and flagging on standing corn stalks following a light snow, making the bound-

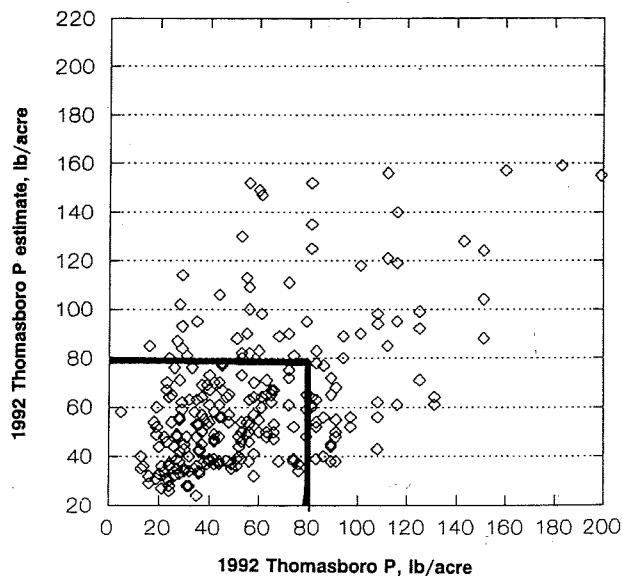


Fig. 1. Scatter diagram of 1992 Thomasboro P compared with estimated values from 220 ft grid mapping.

Table 4. Percentage of estimated values from 220 and 330 ft grid mapping that correctly place, overestimate or underestimate soil test category compared with the 82.5 ft sampled grid values, 1992.

Location	Comparison	Percentage of estimates in each category			
		Correct	Overestimated	Underestimated	
ft					
Mansfield	pH	330	76.7	7.9	15.4
		220	72.7	15.0	12.3
	P	330	55.7	25.3	19.0
		220	62.8	23.3	13.9
	K	330	63.6	19.8	16.6
		220	76.3	18.6	5.1
Thomasboro	pH	330	66.0	15.2	18.8
		220	68.4	10.9	20.7
	P	330	58.6	10.9	30.5
		220	71.9	17.2	10.9
	K	330	66.8	5.1	28.1
		220	65.2	2.7	32.1

aries easy to flag and see. Phosphate was applied as 0-46-0 triple superphosphate. Potassium was applied as 0-0-60, muriate of potash. In each application, an Ag-Chem pneumatic applicator with a 60 ft boom was used.

In March 1993, an 82.5 ft grid sampling was taken to determine the success of the fertilizer application. The increase in soil test P and K due to fertilizer rate was determined for each sampling point. Using the 1992 330 ft mapping as a guide, a theoretical 1993 map of P and K was developed to represent the levels in the field that would have been reached if 330 ft mapping had guided the application of fertilizer.

RESULTS AND DISCUSSION

Correlation of the soil test values estimated from the 1989 to 1991 330 ft and 165 ft maps with the 82.5 ft sampled values are displayed in Table 2. Sixteen of 18 comparisons of the estimates of the 165 ft grids with the values from the 82.5 ft grid were higher than those of the 330 ft grid. The mean correlation of 165 ft grid values with the 82.5 ft grid values was significantly higher than the mean from the 330 ft grid comparison.

Correlation of the 1992 soil test value estimates of the 330 ft and 220 ft sampling map with the 82.5 ft grid are given in Table 3. Correlation of values estimated from the 220 ft grid were higher than estimates from the 330 ft grid. That the correlation of the 220 ft grid estimates with the 82.5 ft sampled values is higher than the 330 ft grid estimate correlation is not surprising. The low level of correlation of the 330 ft grid with the 82.5 ft values is noteworthy, however. With values of 0.013 for 330 ft grid P and 0.021 for 330 ft grid K at Mansfield, the estimates for P and K have almost no relevance to the 82.5 ft grid. The 220 ft grid estimates at Mansfield show a greater relationship with the 82.5 ft grid values.

Although a high correlation between soil test estimates and sampled values is desirable, fertilizer rates applied by a variable-rate applicator may not have to be changed in response to some differences in soil test values. Variation in soil test level between sampled points suggests that grid sampled soil test results represent a range of possible soil test values for each location rather than absolute levels (Franzen and Peck, 1992). In addition, at high soil

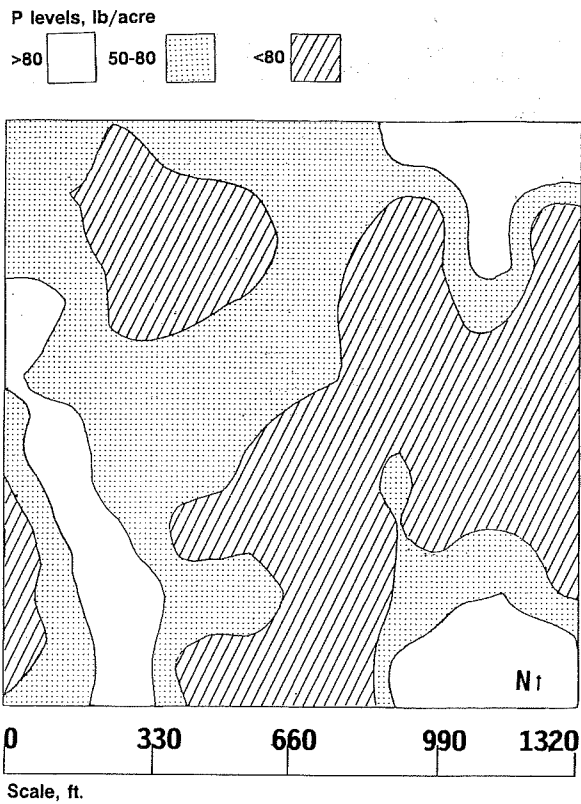


Fig. 2. P levels at Thomasboro, 82.5 ft grid, 1992.

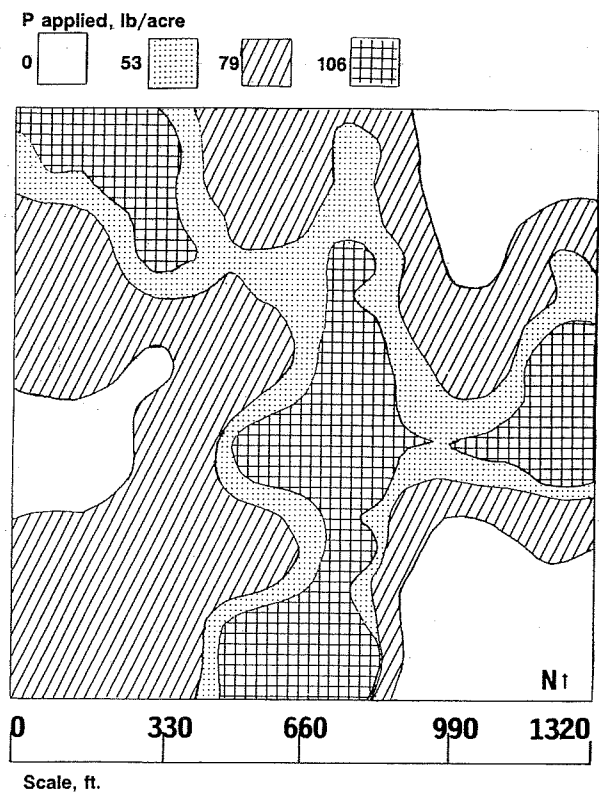


Fig. 4. P fertilizer applied at Thomasboro, fall 1992, based on 220 ft grid mapping.

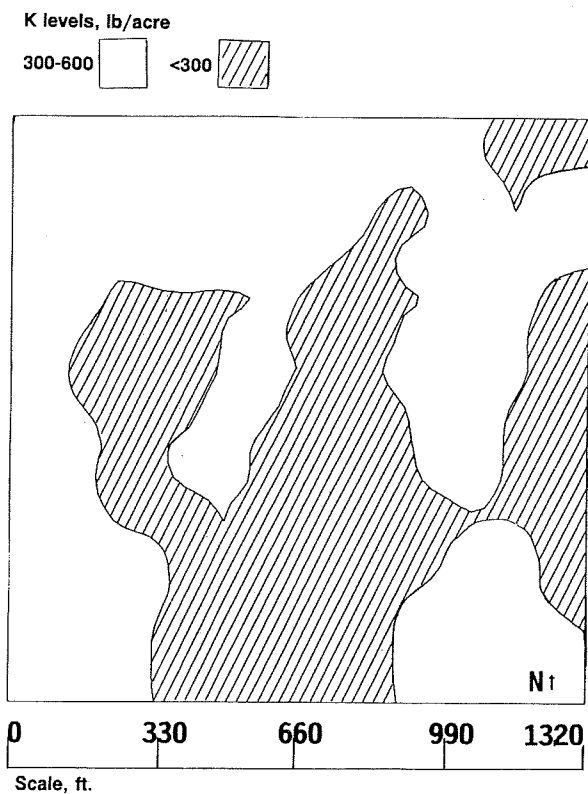


Fig. 3. K levels at Thomasboro, 82.5 ft grid.

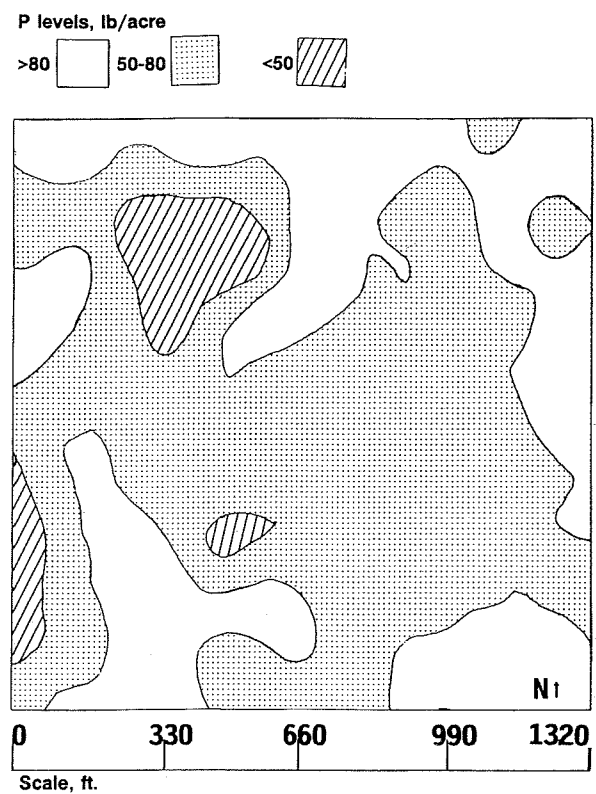


Fig. 5. P levels at Thomasboro, 1993, 82.5 ft grid.

test levels no fertilizer is usually recommended. Correlation between sampled points and estimates mean little if both values are in the high category. Good correlation can be useful at high soil test levels, however, if a balance sheet method was being used to track nutrient removal by site-specific yield monitoring with changes in soil test levels over time. Good correlation is also needed more if the ability to apply over 200 rates of fertilizer to a field with newer application equipment is to be matched with good quality soil test information. Scatter diagrams of sampled values with estimates show more scatter at higher values than at lower values (Fig. 1). More scatter at higher soil test values was important in reducing correlation values.

Soil test estimates from the 1992 330 ft and 220 ft grid maps were placed into soil test categories. The categories for each 82.5 ft grid estimate from the less dense grid maps were compared with soil test categories of the 82.5 ft grid maps. The percentage of estimates falling into the same soil test category, percentage overestimating and percentage underestimating the 82.5 ft grid maps is shown in Table 4. The 220 ft grids were generally better at predicting soil test category than the 330 ft grid, but some of the comparisons between 220 ft and 330 ft soil test categories are similar.

Wollenhaupt et al. (1994) discussed that the ability of sampling grids to correctly classify soil test estimates into soil test categories depended on the field variability and the categories into which the values fall. Classification into the highest P category in this study includes all values higher than 80 lb/acre. If grid estimates from less dense grids and sampled values are both higher than 80 lb/acre, they classify in the same category, while correlation be-

tween the values could be very low. Values estimated by the 330 ft grid often fell into the high soil test category, although correlation with the actual sampled values was low.

The P and K level maps made from the 82.5 ft grid are shown in Fig. 2 and 3 respectively. With the 82.5 ft grid map in Fig. 2 as a guide, a fertilizer P application would be made in most of the field except the northeast and southeast corners and a strip through the southwest portion of the field. The largest fertilizer P application would be made in the south to east-central areas and an area in the northwest. To simulate a more practical sampling grid, however, P fertilizer was applied based on the 220 ft grid pattern in Fig. 4. The P fertilizer application map in Fig. 4 shows that the high P test areas of the northeast, southeast, and part of the southwestern high P strip were avoided. At least 58 lb P/acre was applied to the rest of the field, with heavier rates that correspond well with areas of Fig. 2 that show lower P levels.

The K map made from the 82.5 ft grid shown in Fig. 3 describes higher K levels in the southeast, west, and northern areas of the field. Lower K levels were in the southern and eastern areas. The K fertilizer application map based on the 220 ft grid pattern shows lower K rates applied to areas of the field testing high in K, while heavier rates were applied to the southern and eastern areas of the field. The 220 ft grid fertilizer application does not correspond to all of the boundaries of the 82.5 ft grid, but does locate many features of the more detailed sampling.

The results of the fall 1992 fertilizer P application are shown in the 1993 P level map in Fig. 5. The area of low

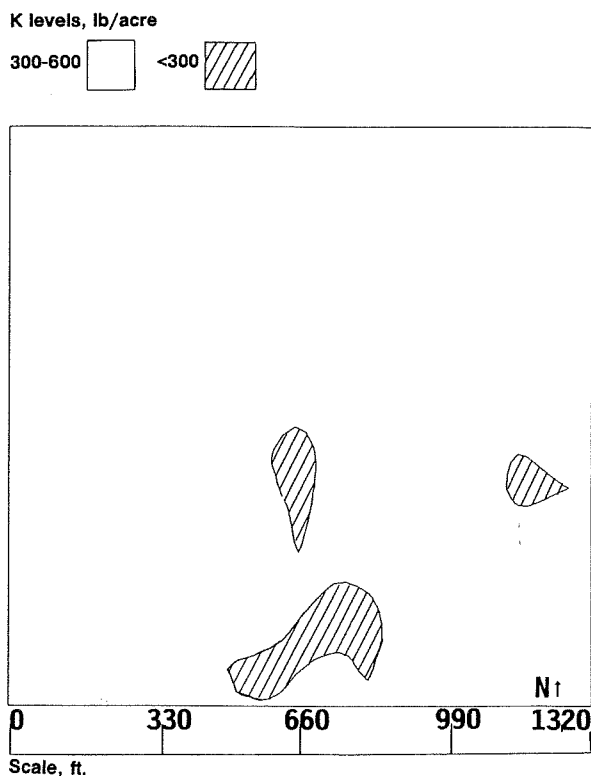


Fig. 6. K levels at Thomasboro, 1993, 82.5 ft grid.

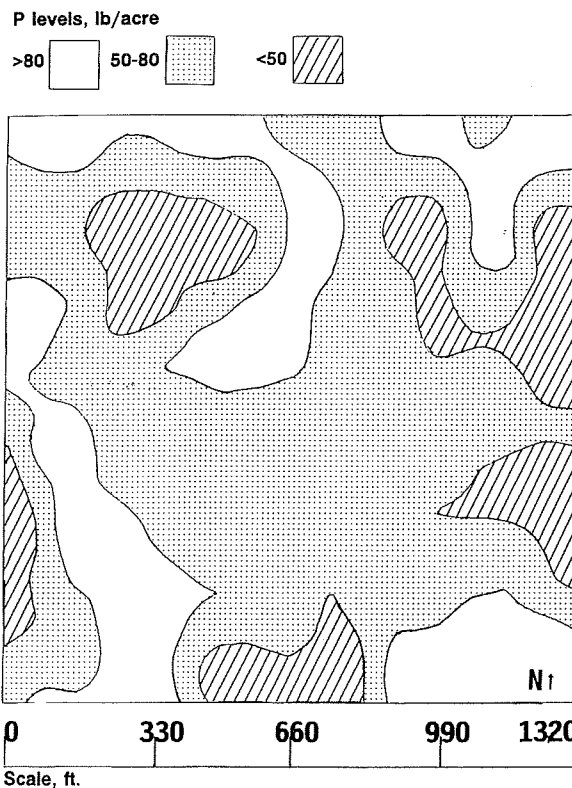




Fig. 7. P levels, 1993, Thomasboro, estimated from a theoretical fertilizer P application based on a 1992 330 ft grid mapping.

P was reduced to three small areas in the west. Some areas in the north were fertilized to levels greater than 80 lb/acre, but most of the areas in the field were fertilized correctly. Although fertilizer application in the northwest part of the field increased soil P levels an average of 20 lb/acre, the increase was not reflected in Fig. 5.

The results from the fertilizer K application in 1992 successfully increased most K levels in the field to at least 300 lb/acre, as shown in Fig. 6. Three small areas in the south and east remained underfertilized, although the K levels in these areas also increased.

The soil test category mapping from a theoretical P and K fertilizer application using 330 ft grid maps to direct rate and location is shown in Fig. 7 and 8. A greater area of both P and K would have been left underfertilized by a 330 ft grid recommendation than in the 220 ft grid directed fertilization. In the theoretical 330 ft grid P result map, two additional areas of low P are present that do not appear in the actual 1993 map in Fig. 9. In Fig. 8, a larger area of low K is still present following the theoretical 330 ft grid directed K application than in the 1993 actual map in Fig. 6.

A 330 ft grid directed P and K fertilization application would not have been as effective as the 220 ft grid for two reasons. First, the boundaries defined by a 330 ft grid did not include important low P and K areas outlined by the 220 ft grid maps. Secondly, the 220 ft grid more accurately represented the measured values of the 82.5 ft grid. The rates used to correct low P and K fertility regions would not have been adequate to raise P and K values to desired levels. The combination of better boundary definition and more accurate P and K level representation was the reason that the fertilized maps in

K levels, lb/acre
300-600  <300 

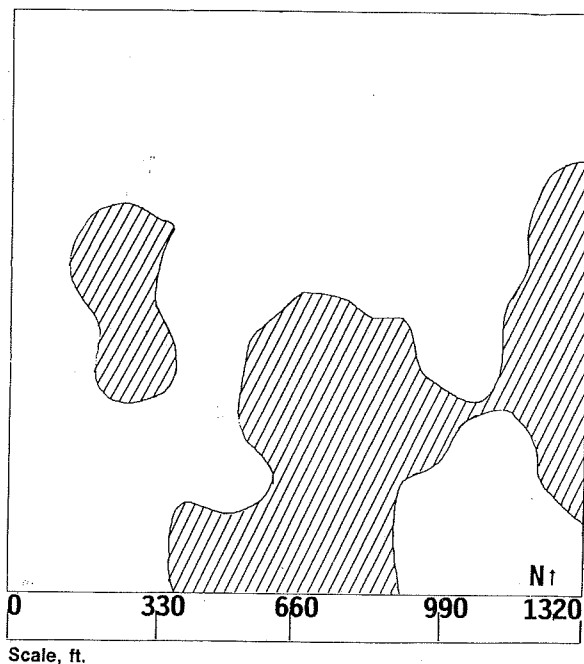


Fig. 8. K levels, 1993, Thomasboro, estimated from a theoretical K fertilizer application based on a 330 ft grid mapping.




Fig. 5 and 6 are more correctly fertilized than the theoretical application in Fig. 7 and 8.

CONCLUSIONS AND COMMENTS

The Mansfield location contained a high level of variability in pH, P, and K, although the soil test categories for P and K were mostly high (Franzen, 1993). The Thomasboro location contained high levels of variability in all three soil test criteria. This study shows that when soil variability is high, sampling a field in at least a 220 ft grid is important if fertilizer application is to be effective in correcting deficiencies while avoiding costs due to excessive overapplication. In fields with little variability, or high variability with all values in a high category, the sample density would not have to be so high.

When beginning a site-specific program, it is difficult to determine how variable sample values would be. Sampling pH, P, and K in a 220 ft grid would seem a good procedure to begin to evaluate field variability. If it were found that values were not highly variable, future sampling could be reduced. Once soil test boundaries were identified with a 220 ft grid sampling, it may be possible to reduce the density of future sampling in high testing areas, while continuing to sample densely in areas where soil test levels are low. To start sampling at a less dense grid than 220 ft in some fields would contribute to application errors that would keep yields low and raise production costs, misleading the grower in his advancement towards understanding his fields' production potential.

Work by Carr et al. (1991) and Ficz et al. (1994) have shown that in areas in which soil type productivity poten-

K applied, lb/acre
75  149  249 

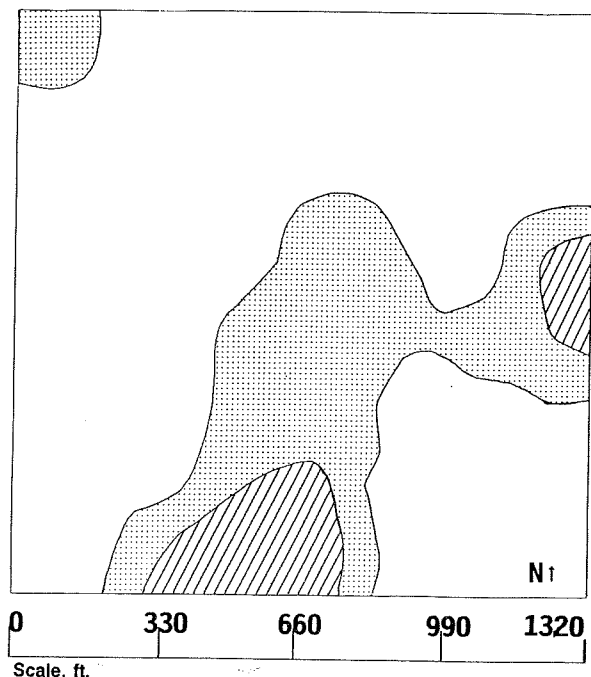


Fig. 9. K fertilizer applied at Thomasboro, fall 1992, based on 220 ft grid mapping.

tial and moisture availability cause large differences in yields of low income per acre crops, soil productivity potential may be evaluated by growers before fertility. In more humid regions, however, growers may first investigate soil test levels, then look toward soil type productivity potential and other site-specific production limitations after soil test levels are corrected or eliminated as a production limitation. The question of what growers in humid regions will look for next in site-specific farming is an important reason why variable-rate fertilizer application based on adequate sampling density is needed at this early stage of technology transfer.

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