Methods and Limitations of Zone Sampling Using Topography as a Logical Basis[1]

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ABSTRACT

Two forty-acre fields in North Dakota were sampled in a 110 foot grid. Each field was measured for elevation in the same 110 foot grid. Topographic sampling zones were identified in each field and a correlation of the sampling based on these zones was compared to the correlation values from a 220 foot grid. Nitrate-N and the 220 foot grid were both correlated to the 110 foot sampling values for nitrate-N and P. A map of field nitrate-N levels from topography sampling compared to the 220 foot grid map showed that boundaries of similar nitrate-N levels were defined by topography. Alternate methods of defining sampling zones may also include a combination of aerial photography, satellite imagery, yield monitor results and soil electrical conductivity, with landscape as one possible basis for pattern development.

INTRODUCTION

The basis of grid sampling is the premise that soil fertility patterns are developed in a random manner and that a systematic method of sampling is required to reduce sampling bias. Early references to grid sampling were developed to elucidate patterns for a variable-rate fertilizer application (Linsley and Bauer, 1929), while later systematic sampling was intended to allow the determination of a fields' central tendency (Peck and Melsted, 1973) without the bias of sampler interpretation. There still exists the tendency for researchers to believe that sampling bias is undesirable, choosing instead to recommend dense soil sample grids to elucidate patterns (Wollenhaupt, et al., 1994; Franzen and Peck, 1995). However, there is sufficient literature to suggest that there are some logical reasons why certain areas of a field may test at one fertility level and other areas test at a different level. The effect of topography on soil fertility levels is one logical reason to question the need to grid sample all fields for certain nutrients.

Topography, or landscape is based on elevation measurements, but the result of elevation mapping is depiction of a surface, classified into landscape features defined as upland, pediment backslope, pediment footslope and alluvial toeslope by Ruhe (1960). Ruhe described that there are developmental differences in soil profile A horizon depth and clay content at each landscape zone. Troeh (1964) found that the curvature of slope (convex vs. concave) influenced soil drainage, which influences the flow of water at the surface and within the soil, and the subsequent growth of crops. Zaslavsky and Rogowski (1969) showed that soil water infiltration streamlines which govern water movement

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[1]Presented at the 1997 North Central Extension-Industry Soil Fertility Conference, November 19-20, 1997, St. Louis, MO.

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diverge on convex hillslopes and converge in concave areas. The higher water content in the concave areas lead to more pronounced profile development.

Sinai, et al. (1981) recorded a linear correlation between soil surface curvature and soil water content, which influenced wheat yield. Stone, et al. (1985) showed that corn grain yields were more consistently related to landscape position than to erosion class. Jones, et al. (1989) related yield to landscape position, redefining Ruhe's landscape postions as upper interfluve, lower interfluve, shoulder, upper linear, lower linear and the footslope. Yield was related to position in corn, soybeans and sorghum in the following manner-

Lower interfluve>Foot>Upper interfluve>Shoulder>Upper linear>Lower linear

Additional studies have shown the relationship of crop yields and slope position (Aspinall and Hayes, 1995; Fiez, et al., 1994; Halvorson and Doll, 1991; Miller, et al., 1988; Miller, et al., 1992; Schroeder, 1995; Simmons, et al., 1989) . Many of these studies have noted the influence of soil water content as a probable reason for crop yield relationship to topography. Pennock, et al. (1987) illustrated probable water movement and concentration associated with topography.

Several studies have recorded the relationship of soil physical and fertility factors with topography (Brubaker, et al., 1993; Fiez, et al., 1994; Jones, et al., 1989; Miller, et al., 1988; Simmons, et al., 1989). Additional studies have described the relationship of soil nitrogen specifically with topography (Bruulsema, et al., 1996; Cassel, et al., 1996).

Residual soil nitrogen may be especially influenced by landscape due to the number of kinds of possible transformations and its movement in the soil. Landscape and associated soil water influences mineralization (Stevenson, et al., 1995), nitrification, and denitrification (Stevenson, 1982). Soil water movement also directs the movement of soil nitrate to certain areas of the landscape. In North Dakota, saline areas, which develop due to a locally high water table as a consequence of subsurface water movement, often have a high level of nitrate (Seelig and Richardson, 1991). Differences in crop removal of nutrients due to landscape induced crop yield variability may also influence residual nitrogen and other nutrient levels.

The concept of directed sampling by landscape position is not without precedent. Carr, et al. (1991) reported improvements in economic return to wheat by fertilizing based on soil type sampling compared to uniform application. Penney, et al. (1996) describes the value of using a combination of crop yield maps with topography. Pocknee (1996) discusses methods of directed soil sampling. In North Dakota, a method of composite soil sampling for uniform fertilizer application used a method of reverse-bias soil sampling by not sampling unusual areas such as eroded areas, saline areas and other areas not representative of the greatest part of the field (Swenson, et al. 1984). Since these unusual areas are important for site-specific management, could the same reasons why parts of a field were not sampled in the past now be reasons to define certain management zones?

Landscape may be a logical reason to define initial management zones. However, measuring elevations and determining where to draw zone boundaries from landscape may be difficult to conduct. Even if elevation is recorded and landscape maps produced, the question for some may be where to draw the lines for boundaries defining management zones. North Dakota studies are currently investigating several methods for directing zone sampling, including satellite imagery and aerial photography (Moraghan, 1996). This paper will address initial experiences with satellite imagery, yield monitor information and electrical conductivity as methods that may provide patterns similar to landscape patterns. Some or all of these techniques may be useful in defining management zones, with the knowledge that the patterns expressed have a logical basis, in part due to landscape.

METHODS AND MATERIALS

Two forty acre fields were sampled in a 110 foot grid. One of the fields is located near Valley City, North Dakota in the glacial till plain region. The Valley City site was sampled each fall from 1994 to 1997. The field was in spring wheat in 1994, sunflower in 1995, spring wheat in 1996 and barley in 1997. A uniform rate of N and P was applied each year based on a composite soil test, except in 1997 when a variable-rate of N as anhydrous ammonia was applied prior to the barley crop. The second field is located southwest of Colfax, North Dakota in the Red River Valley. The Colfax site was sampled each fall during 1995 and 1996. The Colfax site was in corn in 1995 and spring wheat in 1996. At each site, five to eight soil cores were taken at each sample location at two depths, 0-6 inches and 6-24 inches. Nitrate-N and P were analyzed on the 0-6 inch depth. Nitrate-N was also analyzed on the 6-24 inch depth. Nitrate-N was reported as the total of two depths.

Elevation was measured using a laser-surveying device, taking recordings in a 110 foot grid. The SPOT image of the Colfax site was taken late in the 1994 corn growing season prior to the first soil sampling. Pixel size is approximately 30 feet square. The electrical conductivity mapping at Valley City was conducted using a Veris Corporation soil conductivity instrument. The Veris apparatus consists of conductivity sensors attached to straight-set tillage discs that run in the soil at a depth of about 1 inch while being pulled through the field with a pickup truck. The sensor is coupled to a DGPS receiver and the data recorded in readings taken about 1 second apart. Mapping of elevation, nutrient levels and conductivity was conducted using Surfer for Windows (Golden Software, Inc., Golden CO). Interpolation was performed using inverse distance squared with eight nearest neighbors and a simple search. Correlation was conducted using SYSTAT for Windows, Evanston, IL.

RESULTS AND DISCUSSION

Relationship of nutrient levels with topography at Valley City

The nitrate-N maps from 1994, 1995 and 1996 at Valley City form complex but similar patterns between years (Figure 1). From the stable patterns that appear in these years came the incentive for the researchers to explore topography as the source of pattern stability. Elevation measurement produced the map shown in Figure 2. The field varied from one side of the field to the other by about 40 feet. The simple contour map in Figure 3 was not adequate to define landscape, compared to the 3-dimensional map in Figure 2. Elevation itself is not related to nutrient levels in this field. The structure of the landscape-hilltop, sideslope, concave areas- appear to be the defining elements in the nutrient/landscape relationships. The correlation of topography-based sampling compared to a 220 foot grid is shown in Table 1. The topography based map for 1995 compared to the 110 foot and 220 foot grids is shown in Figure 4. In 1994 and 1995, comparisons between topography were made with a topography map based on five sampling zones. These zones were chosen based on the zones of similar topography patterns from the 3-dimensional mapping.

P levels at Valley City were not as correlated with topography-based sampling as nitrate-N (Table 1). The farm cooperator stated that forty years ago, their was a small feedlot in the northwest corner of the area currently being examined. The old feedlot area may be masking landscape affects on P levels in this portion of the field. The map of Valley City P levels is given in Figure 5. Outside of the old feedlot area, the patterns of high and low P follow closely the patterns of nitrate-N.

Alternative methods of management zone definition at Valley City

In 1996, the first yield map at Valley City was produced using a John Deere yield monitor. The yield map (Figure 6) showed a very low yielding area in the northwest corner of the field. By separating out this area as a separate management zone, the 1996 correlation of topography N with the 110 foot grid was better correlated than in 1995 (Table 1). Because of the many factors producing yield differences, using a yield map as the primary basis for directed sampling may not be prudent. However, by using the landscape zones as the main basis for establishing sampling zones, and then dividing a zone into two zones based on an area of low yield in the northwest corner, correlation with zone sampling with the 110 foot nitrate-N map is increased.

In the fall of 1997, an on-the-go soil conductivity sensor was used to map the Valley City field for salinity. The resulting map of the 0-1 foot soil conductivity is shown in Figure 7. The stated purpose of the conductivity sensor by the manufacturer is not to determine nitrate levels, other nutrient levels, depth to clay, depth to sand, clay content or moisture. The purpose is to detect zones of similar conductivity. The user is then encouraged to sample within those areas of similar conductivity and determine what is the source of the differences between zones.

The patterns of soil conductivity are very similar to the patterns of nitrate-N. However, correlation of soil conductivity with soil nitrate-N levels may not be appropriate. The high conductivity in the northwest is similar to the high nitrate-N levels in the same area. However, in the "horsehead-shaped" pattern of nitrate-N in the center of the field, nitrate-N levels are relatively higher than its surroundings. The soil conductivity in the same area has the "horsehead-shaped" pattern, but the values are relatively low compared to the surroundings. A simple correlation of conductivity with nitrate-N levels would result in an overestimation of nitrate-N levels in that area. By using the patterns of conductivity differences as a way to define management zones, then sampling within those zones, conductivity zone sampling would be expected to give similar boundaries and similar correlation as topography sampling.

Relationship of topography and nutrient levels at Colfax

The nitrate-N levels Colfax in 1995 and 1996 are shown in Figure 8. The maps are similar between years, suggesting again that the nitrate-N levels are related to landscape. The elevation mapping, shown in the contour map in Figure 9, shows that the patterns of nitrate-N follow landscape patterns. In this field, where the elevation differences are only about 2 feet, a contour map is sufficient to define fertility boundaries. Correlation of nitrate-N levels with the 110 foot and 220 foot grids are shown in Table 2.

The SPOT image of the Colfax site in 1994 is shown in Figure 10. Using the map to define management zones based on patterns in the image result in patterns similar to those defined by topography. In 1994, the poor corn growth areas were the result of excessive rainfall during the season, which stunted the corn and probably lowered the level of nitrate in those areas through denitrification. The areas of better corn growth were at higher elevations where there was no standing water. By identifying areas of poor corn growth due to water stress, the image also identified areas of low and high N.

SUMMARY

Soil nitrate-N levels were related to topography at two sites in North Dakota. Soil P levels were not as related to topography perhaps because of the past existence of a feedlot in a portion of the field. Using a yield map to identify low yielding areas within a zone may be a reason to divide one zone into two zones and strengthen a management zone strategy in a field. Soil conductivity measurements also defined similar zones as given by landscape. Use of satellite imagery was related to topography patterns at the site where an image was available.

Landscape may serve as a logical basis for expecting the presence of nutrient patterns, especially nitrate-N, to appear in fields. However, other methods, such as satellite imagery, aerial photography and satellite imagery may help to determine where to draw sampling zone boundaries. Use of a zone sampling strategy should not rely exclusively on elevation mapping as its only method of zone definition. Zone sampling should be considered an iterative process, where additional sources of information about the field are used to further define areas of importance to crop growth, including more intensive grid sampling when appropriate. Zone sampling may be most useful in regions where plant or soil testing for nitrogen requirement is well established and the cost of annual intensive grid sampling is prohibitive.

REFERENCES

Aspinall, D. and A. Hayes, 1995. The relationship of corn and soybean yields, soil properties to slope positions and landform. pp. 1-5 *In*:Poster Paper Abstracts, Information Agriculture Conference. June 27-30, 1995. Champaign, IL. Potash & Phosphate Institute, Norcross, GA.

Brubaker, S.C., A.J. Johnes, D.T. Lewis, and K. Frank. 1993. Soil properties associated with landscape positions. SSSAJ 57:235-239.

Bruulsema, T.W., G.L. Malzer, P.C. Robert, J.G. Davis and P.J. Copeland. 1996. Spatial relationships of soil nitrogen with corn yield response to applied nitrogen. pp. 505-512. *In*:Precision Agriculture. Proceedings of the 3rd International Conference, June 23-26, 1996, Minneapolis, MN. ASA-CSSA-SSSA, Madison, WI.

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

Cassel, D.K., E.J. Kamprath, and F.W. Simmons. 1996. Nitrogen-sulfur relationships in corn as affected by landscape attributes and tillage. Agron. J. 88:133-140.

Fiez, T.E., B.C. Miller, and W.L. Pan. 1994. Winter wheat yield and grain protein across varied landscape positions. Agron. J. 86:1026-1032.

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

Halvorson, G.A. and E.C. Doll. 1991. Topographic effects on spring wheat yields and water use. SSSAJ 55:1680-1685.

Jones, A.J., L.N. Mielke, C.A. Bartles, and C.A. Miller. 1989. Relationship of landscape position and properties to crop production. J. Soil Water Conserv. 44:328-332.

Linsley, C.M. and F.C. Bauer. 1929. Test your soil for acidity. Univ. of Il. Col. of Ag. and Ag. Exp. Sta. Circ. 346.

Miller, M.P., M.J. Singer, and D.R. Nielsen. 1988. Spatial variability of wheat yield and soil properties on complex hills. SSSAJ 52:1133-1141.

Miller, B.C., T. Fiez, and W.L. Pan. 1992. Impact of landscape variability on grain yield and quality. pp. 3-6. *In*:Precision farming variable cropland:An introduction to variable management within whole fields, divided slopes and field strips. Proceedings 10th Northwest Conserv. Farming Conf., Pullman, WA. R.J. Veseth and B.C. Miller, ed. Wash. St. Univ., Pullman, WA.

Moraghan, J., K. Horsager, L.Smith, and A. Sims. 1997. Canopy reflectance and GPS technology in relation to sugar production. pp. 121-133. *In*:Sugarbeet Research and Extension Reports. Vol. 27. N. Dak. St. Univ. Ext. Serv., Fargo, ND.

Peck, T.R. and S.W. Melsted. 1973. Field sampling for soil testing. pp. 67-75. *In*:Soil Testing and Plant Analysis. Second edition. SSSA, Madison, WI.

Penney, D.C., R.C. McKenzie, S.C. Nolan, and T.W. Goddard. 1996. Use of crop yield and soil landscape attribute maps for variable rate fertilization. pp. 126-140. *In*:1996 Great Plains Soil Fertility Conference Proceedings, Denver, CO, March 5-6, 1996. J. Havlin, ed. K.St. Univ., Manhattan, KS.

Pennock, D.J., B.J. Zebarth, and E. DeJong. 1987. Landform classification and soil distribution in hummocky terrain, Saskatchawan, Canada. Geoderma 40:297-315.

Pocknee, S., B.C. Boydell. H.M. Green, D.J. Waters, and C.K. Kvien. 1996. Directed soil sampling. pp. 159-168. *In*:Precision Agriculture. Proceedings of the 3rd International Conference. June 23-26, 1996. Minneapolis, MN. ASA-CSSA-SSSA, Madison, WI.

Ruhe, R.V. 1960. Elements of the soil landscape. pp. 165-170. *In*:Transactions of the 7th International Congress of Soil Science. Vol. 4. Int. Soc. of Soil Science. Madison, WI.

Schroeder, S.A. 1995. Topographic influences on soil water and spring wheat yields on reclaimed mineland. Journ. Env. Qual. 467-471.

Seelig, B.D. and J.L. Richardson. 1991. Salinity and sodicity in North Dakota soils. N.Dak. Ext. Serv. Bull. EB-57. 16 pp.

Simmons, F.W., D.K. Cassel, and R.B. Daniels. 1989. Landscape and soil property effects in corn grain yield response to tillage. SSSAJ 53:534-539.

Sinai, G., D.Zaslavsky, and P. Golany. 1981. The effect of soil surface curvature on moisture and yield-Beer Sheba observations. Soil Sci. 132:367-375.

Stevenson, F.J. 1982. Origin and distribution of nitrogen in soil. pp. 1-42. *In*:Nitrogen in Agricultural Soils. Agonomy Monograph No. 22. F.J. Stevenson, ed. ASA-CSSA-SSSA, Madison, WI.

Stevenson, F.C., J.D. McKnight, and C. van Kessel. 1995. Dinitrogen fixation in pea:controls at the landscape- and micro-scale. SSSAJ 59:1603-1611.

Swenson, L.J., W.C. Dahnke, and D.D. Patterson. 1984. Sampling for soil testing. N. Dak. Dept of Soil Sci. Res. Report No. 8. April 1984.

Stone, J.R., J.W. Gilliam, D.K. Cassel, R.B. Daniels, L.A. Nelson, and H.J. Kleiss. 1985. Effect of erosion and landscape position on the productivity of Piedmont soils. SSSAJ 49:987-991.

Troeh, F.R. 1964. Landform parameters correlated to soil drainage. SSSAP 28:808-812.

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.

Zaslavsky, D. and A.S. Rogowski. 1969. Hydrologic and morphologic implications of anisotropy and infiltration in soil profile development. SSSAP 33:594-599.

ACKNOWLEDGEMENTS

Funding for this project was provided through the US-EPA 319 Water Quality grant program, the Minnesota-North Dakota Sugarbeet Research and Education Board, Agrium, Inc., the Soil Conservation Districts of Stutsman Co., Cass Co., and Wild Rice, and the Phosphate & Potash Institute.

Table 1. Comparison of topography-based and 220 foot grid-based N and P with a 110 foot grid at Valley City, ND.

	Correlation (r)			
	Topography		220 foot grid	
Year	N	P	N	P
1994	0.29	0.27	0.18	0.29
1995	0.38	0.34	0.50	0.75
1996	0.49	0.53	0.34	0.51

Table 2. Comparison of topography-based and 220 foot grid-based N and P with a 119 foot grid at Colfax, ND.

	Correlation (r)			
	Topography		220 foot grid	
Year	N	P	N	P
1995	0.27	0.21	0.62	0.62
1996	0.39	0.53	0.41	0.25

Figure 1. Valley City nitrate-N levels, 1994-1996.

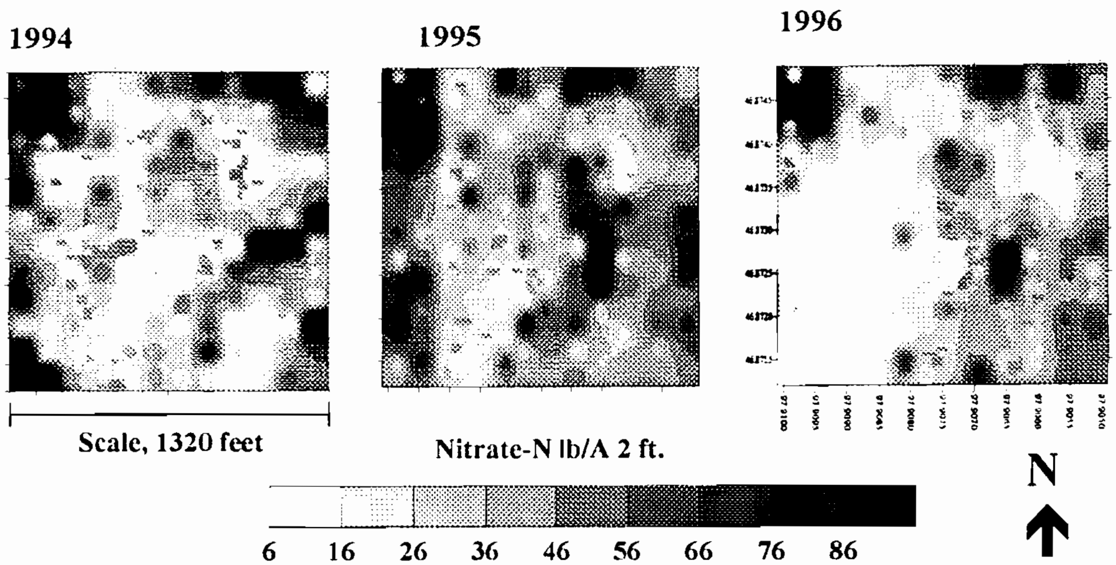


Figure 2. Valley City topography.

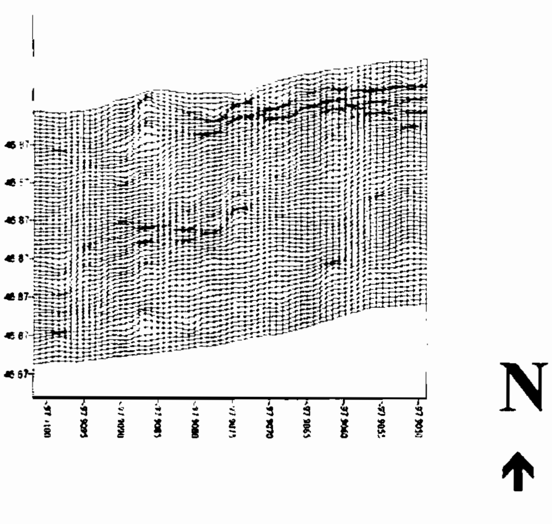


Figure 3. Relative elevations at Valley City using a contour map.

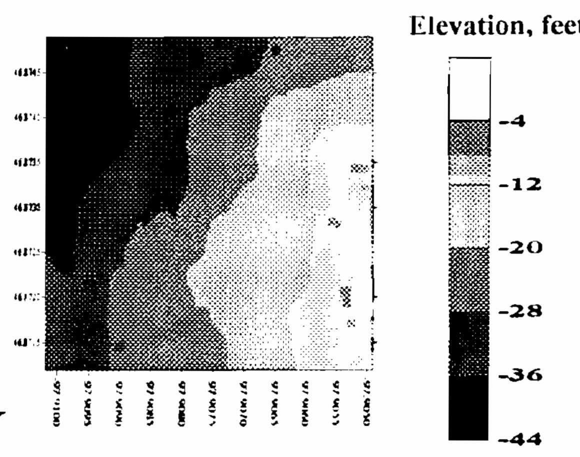


Figure 4. Comparison at Valley City, 1995, of nitrate-N between topography and a 220 foot grid.

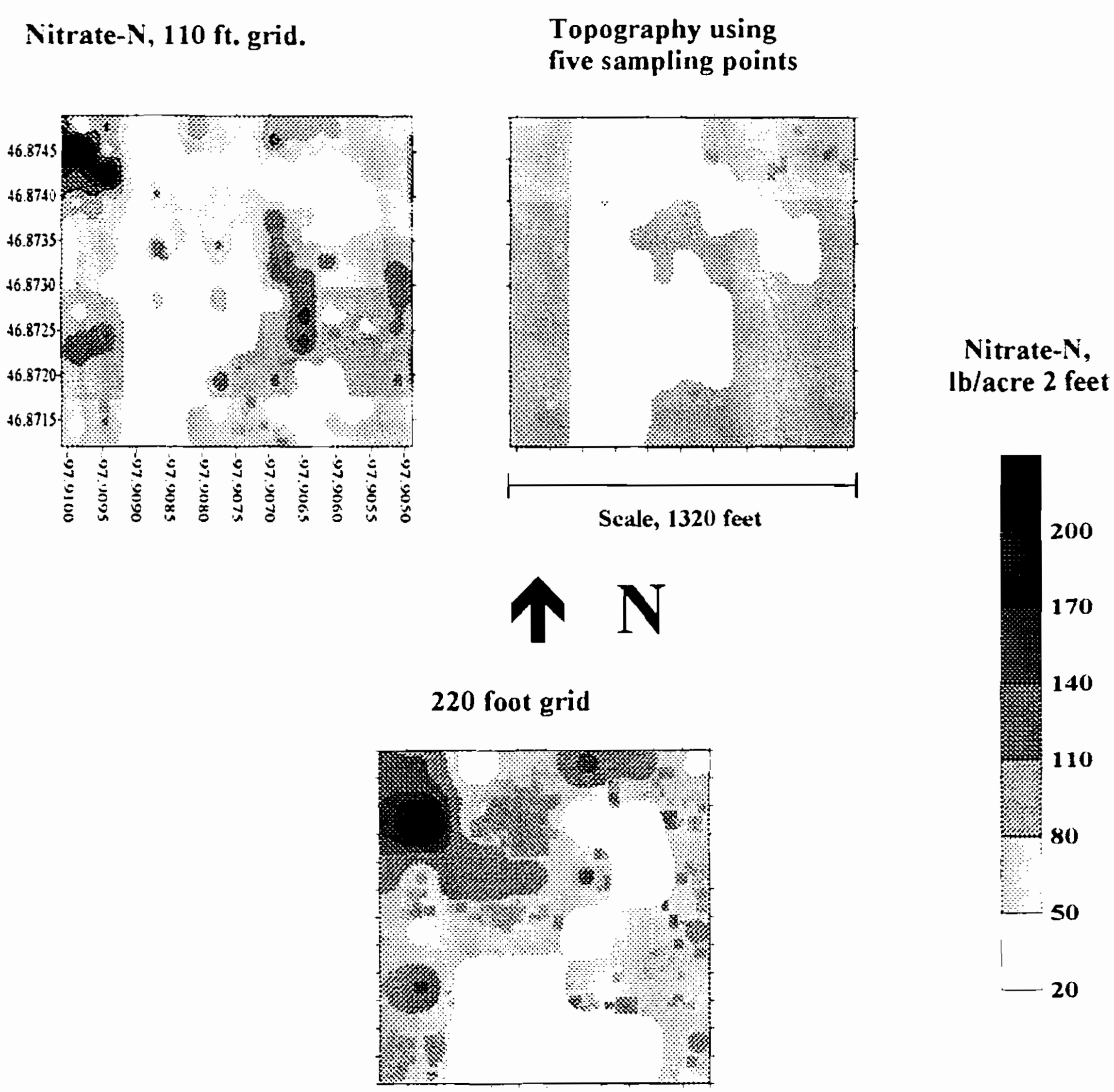


Figure 5. Valley City P levels, 1995.

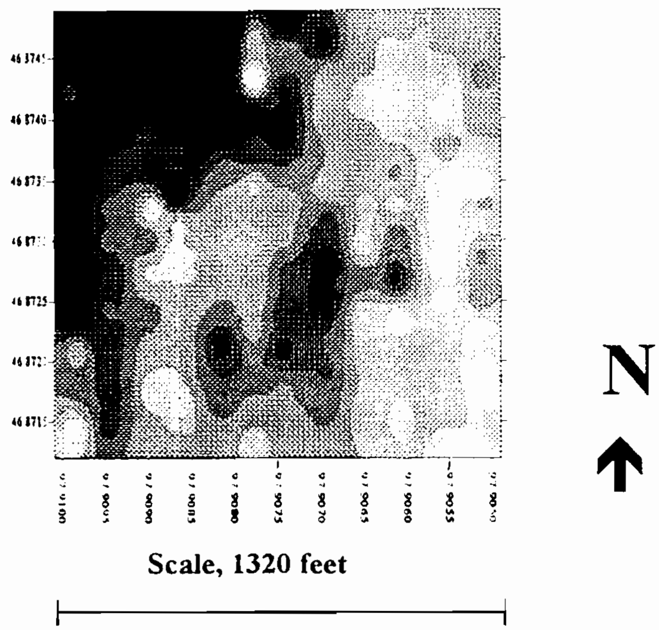


Figure 6. Valley City hard red spring wheat yields, 1996.

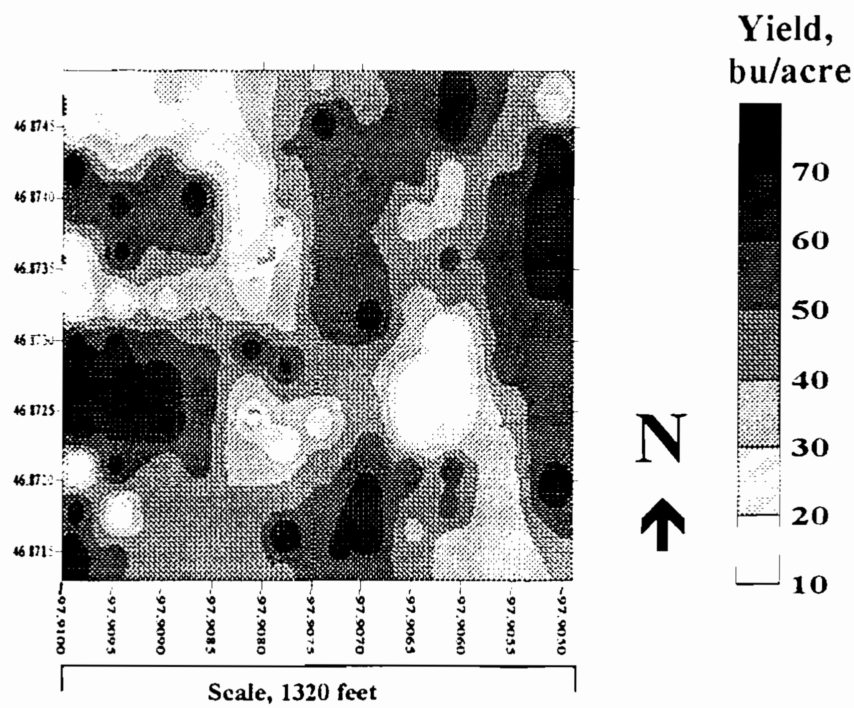


Figure 7. Electrical conductivity at Valley City, 0-1 foot.

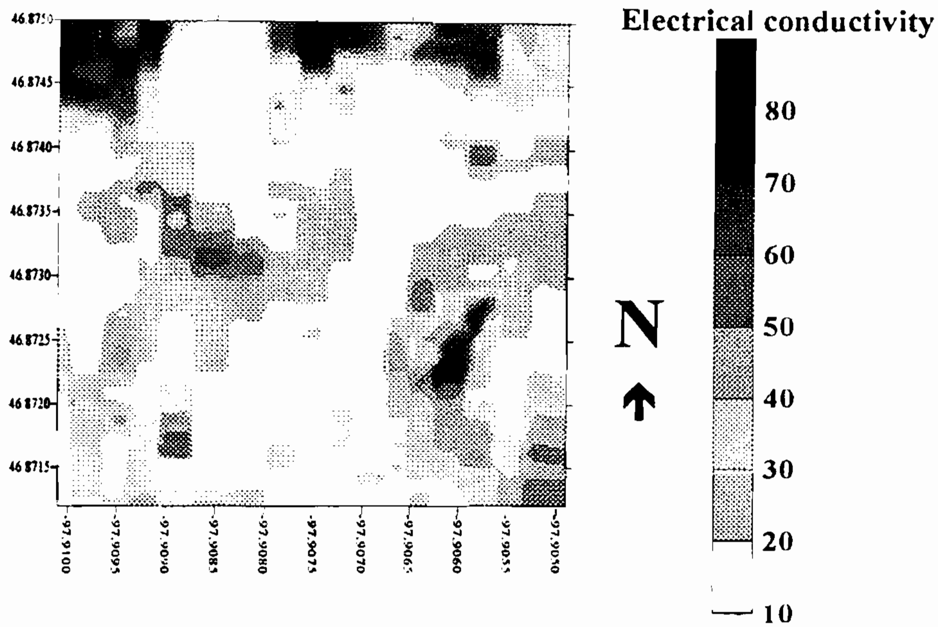


Figure 8. Colfax nitrate-N levels, 1995-1996.

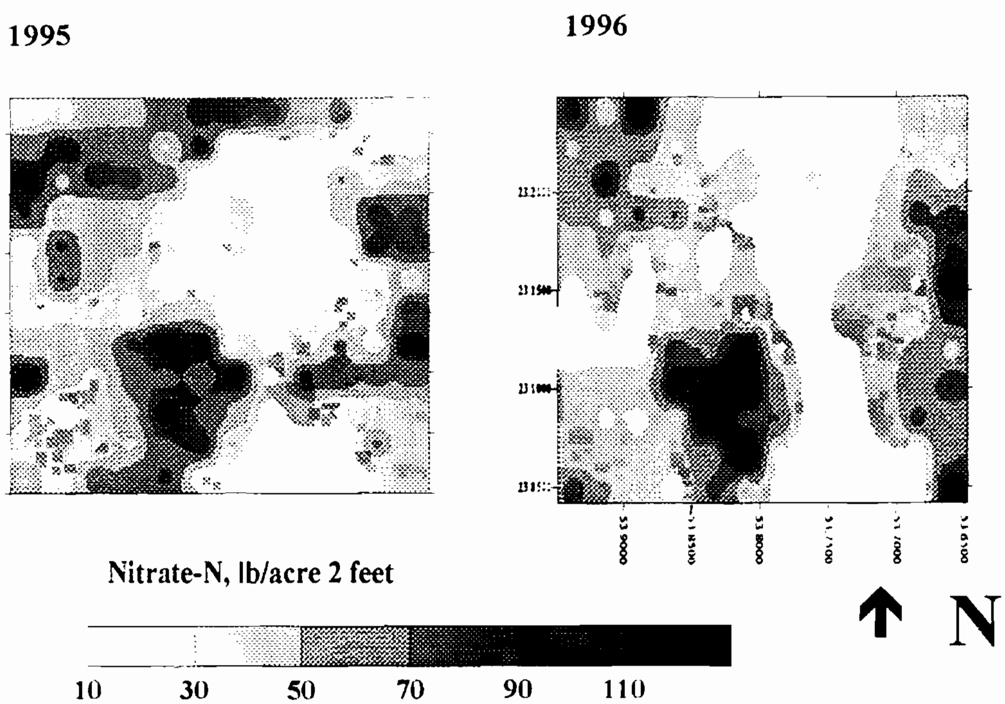


Figure 9. Colfax topography.

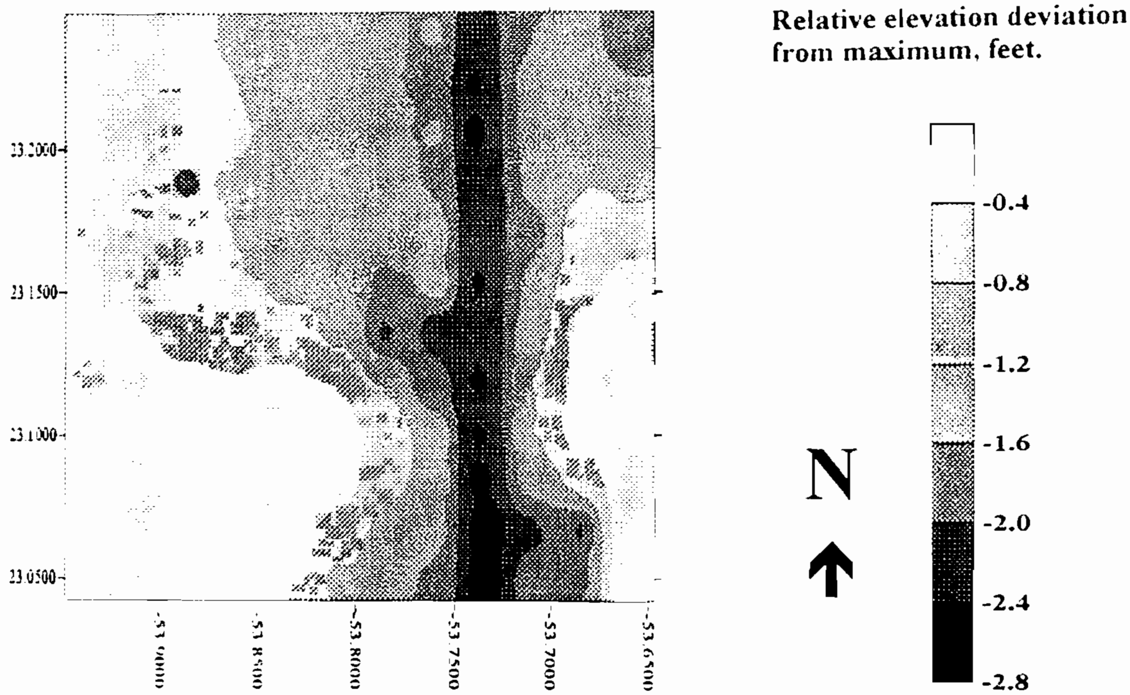
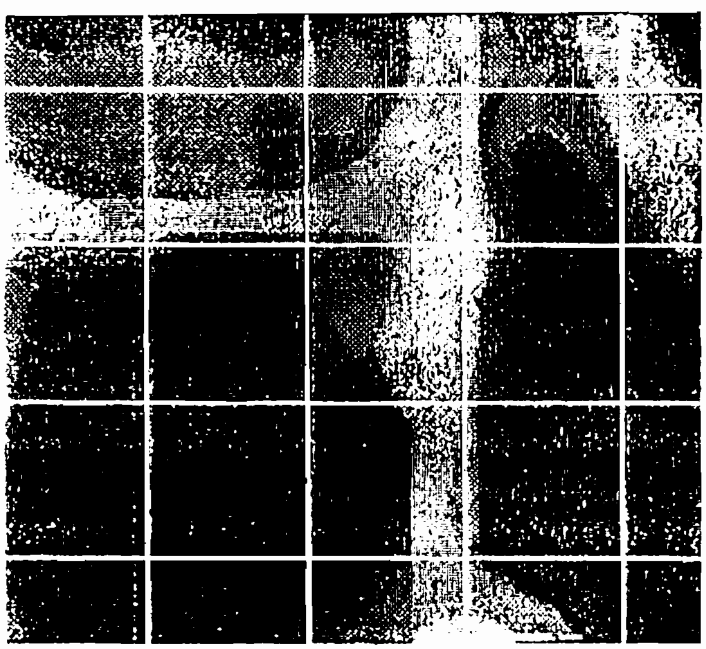


Figure 10. Satellite imagery from Colfax, July, 1994.



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NORTH CENTRAL EXTENSION-INDUSTRY

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Published for
The North Central Extension-Industry Soil Fertility Conference
by
Potash & Phosphate Institute
772 - 22nd Avenue, South
Brookings, SD 57006
605-692-6280

November 19-20, 1997

St. Louis Westport Holiday Inn
St. Louis, Missouri

Volume 13

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