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Topography-Based Sampling Compared with Grid Sampling in the Northern Great Plains

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A practical variable-rate fertilizer application should be based on information gathered at low cost that represents field fertility levels. The number of soil samples gathered and analyzed may limit the effectiveness of some variable-rate fertilizer applications. Topography-based soil sampling is attractive because it suggests a lower number of samples needed to characterize fertility levels and patterns in a field than some current grid sampling recommendations. A 40-acre North Dakota field consisting of Barnes loam (fine loamy, mixed, Udic Haploborolls), Swenoda loam (mixed, Pachic Udic Haploborolls), and Wyard clay loam (fine loamy, mixed, frigid Typic Haplaquolls) soil types was sampled in a 110 ft grid each fall from 1994 to 1996. Nitrate N, P, sulfate S, and chloride level patterns were similar in all 3 yr. Correlation of both area- (sample cores obtained from a wide area within a topography zone) and point-based (a topography zone represented by a composite taken from a point location) topography sampling with the 110 ft grid values was compared with correlation from a 220 ft, 330 ft, and 5 acre grid. Area-based topography sampling for nitrate N was superior in correlation to the 220 ft grid values in 2 of 3 yr. Area-based topography sampling with P was superior to the 220 ft grid in only 1 of 3 yr, but was superior to the 5 acre grid in all years. The 220 ft grid was superior to topography sampling for sulfate S in all years, but area-based topography sampling was better than the 330 ft grid in 2 of 3 yr and superior to the 5 acre grid in all years. Area-based topography sampling for chloride was superior to the 220 ft grid in 1 of 3 yr, but was more highly correlated with the 110 ft grid than the 330 ft and 5 acre grid in all years. Area-based topography sampling was more highly correlated than point-based topography sampling in seven of 12 comparisons. Topography-based sampling for nitrate N better represented fertility patterns than did grid sampling.

VARIABLE-RATE FERTILIZER application is based on soil fertility information collected spatially over a surface volume of soil. Spatial soil fertility information to direct variable-rate application is normally determined using soil testing. Use of grid soil sampling has been preferred by some researchers because it eliminates personal biases into what portions of the field may be important to sample, which may have influenced the field average or "central tendency" of a field in the past (Peck and Soltanpour, 1990). However, when collecting spatial data it becomes important to identify unique, unusual fertility areas in a field and define boundaries so that they can be treated differently to maximize fertilizer efficiency and minimize environmental risks related to over-application of some nutrients. Wollenhaupt et al. (1994) recommended grids of about 200 ft between sampling points to direct variable-rate fertilizer application of P and K. Franzen and Peck (1995) recommended a 220 ft grid, or 1 sample/acre, to represent field P, K, and soil pH levels. Wollenhaupt (1996) further recommended that a systematic unaligned grid of about 200 ft be used instead of a regularly aligned grid.

Franzen and Peck (1993) determined that a 220 ft grid was superior to soil type sampling for P and K in two Illinois fields. These fields received heavy applications of fertilizer P and K several years prior to their observations. Reexamination of the field pH levels (Franzen and Peck, 1996) showed that field soil pH levels were similar to soil series patterns in both fields, except in old farmstead areas.

Soil N levels may be affected by topography (Stevenson, 1982). Landscape affects soil N through its influence on soil water movement and microclimate. Soil water content may be related to landscape patterns (Halvorson and Doll, 1991). Basing fertilizer N applications on yield goal and sampling based on the soil mapping unit has been shown to be effective in increasing crop productivity (Carr et al., 1991), however, soil mapping units often contain inclusions of other soil series that may contribute to errors (Steinwand et al., 1996). Soil survey maps may not be accurate for an individual field. Even when boundaries are correct, they may not be strongly related to soil nutrient levels (Franzen and Peck, 1993). On the other hand, landscape position has been shown to be related to soil N levels (Fiez et al., 1994; Nolan et al., 1995) and may increase profitable recommendations based on yield goals for each landscape (Fiez et al., 1994). Landscape sampling may reduce the number of samples necessary to represent nutrient levels in some fields compared with intensive grid sampling (Hollands, 1996). Variable rate application will only become common in the Northern Plains if the number of samples needed to represent a field are low (Lenz, 1996). Although wheat yields in a previous study were higher with variable rate application based on a dense grid, Wibawa et al. (1993) concluded that the variable-rate fertilizer application system as studied was not profitable. The objective of this study was to compare various grid sampling methods with topography-based sampling for nitrate N, P, sulfate S, and chloride to determine whether topography-based sampling represents fertility levels similar to grid sampling while requiring fewer soil samples.

METHODS AND MATERIALS

A 40-acre field southeast of Valley City, ND, was sampled in a 110 ft grid each fall from 1994 through 1996. Soil series in the field were Barnes loam, Swenoda loam, and Wyard clay loam. The field parent material is the product of water-worked glacial till with no loess cover, as is typical of the central till plain of North Dakota. From five to eight soil cores were taken at each grid location and the latitude and

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longitude of each location recorded and used to resample the following fall. Soil cores were taken from 0 to 24 in. in depth and divided into a 0 to 6 in. sample and a 6 to 24 in. sample.

Phosphorus was analyzed on the 0 to 6 in. core depth only using the Olsen sodium bicarbonate extraction as described by Knudsen and Beegle (1988). Nitrate N, sulfate S, and chloride were analyzed on each depth and reported as the sum of the 0 to 2 ft core. Nitrate N was analyzed by the transnitration procedure of Vendrell and Zupancic (1990), sulfate S was analyzed by a turbidometric procedure of Schulte and Eik (1988), and chloride was analyzed with a chloride sensitive electrode described by Fixen et al. (1988). Relative elevations were measured in a 110 ft grid, using a laser-surveying device to record elevations within 1 in. accuracy.

Mapping was conducted using Surfer for Windows (Golden Software Co., Golden, CO). Mapping parameters were inverse distance squared estimators, with eight nearest neighbors used for the 110 ft and 220 ft grids, four used for the 330 ft grid, and two for the 5 acre grid. Correlation of grids was conducted after deleting identical locations from both the less dense grid and the 110 ft grid to avoid autocorrelation. Topography-based sampling maps were produced by selecting five to six landscape areas in the field that were similar (hilltops, slopes, low-lying landscapes) and using a point-based sample or area-based sample value to represent all of the 110 ft grid locations within each topography zone. Under the point-based topography, a value from the center of a topography zone was selected alone to represent the zone. Under the area-based topography, an average value from six surrounding 110 ft grid locations from the center of the topography zone was used to represent each 110 ft grid within the zone. Once all 110 ft grid locations were represented by a value in the topography-based methods, maps were produced using inverse distance squared estimators based on eight nearest neighbors.

Less dense grids were compared by deleting locations from the 110 ft grid data base that would not be included in a 220 ft, 330 ft, or a 5 acre grid. Correlations were calculated using SYSTAT for windows (SYSTAT, Inc., 1992, Evanston, IL).

Spring wheat (*Triticum aestivum* L.) was grown in 1994, sunflower (*Helianthus anuus* L.) in 1995 and spring wheat in 1996. Uniform rates of fertilizer N and P were applied in each year (100 lb N/acre and 20 to 30 lb P_2O_5, band applied) by the producer-cooperator.

RESULTS and DISCUSSION

Field Nutrient Variability

Nitrate N levels ranged from 4 to 554 lb/acre in 1994, 9 to 374 lb/acre in 1995, and 9 to 336 lb/acre in 1996 (Table 1). Mean nitrate N levels were up slightly following the 1995 sunflower crop, which averaged 2000 lb/acre and decreased in 1996 following a 44 bu/acre spring wheat crop. Phosphorus levels were consistent over the 3 yr, with a range between 4 to 55 ppm and means between 16 and 18 ppm. Sulfate S levels were extremely variable each year, with ranges between 4 to 554 lb/acre. Mean sulfate S levels increased each year, from 72 lb/acre in 1994 to 123 lb/acre in 1995. The variability of sulfate also increased, as shown by the standard deviation increases from 113 lb/acre in 1994 to 187 lb/acre in 1996. Chloride levels were variable each year, with ranges between 3 and 125 lb/acre. Mean chloride levels ranged from 35 lb/acre in 1994 to 29 lb/acre in 1996. The standard deviation of chloride was between 18 lb/acre in 1994 and 16 lb/acre in 1996. No chloride or sulfur fertilizer was added between 1994 and 1996.

Table 1. Variability of nutrient levels 1994–1996.

Nutrient	Year	Range	Mean	Standard deviation
Nitrate N	1994	4–554 lb/acre	51 lb/acre	54 lb/acre
	1995	9–374 lb/acre	59 lb/acre	42 lb/acre
	1996	9–336 lb/acre	35 lb/acre	42 lb/acre
P†	1994	4–55 ppm	18 ppm	10 ppm
	1995	4–52 ppm	16 ppm	8 ppm
	1996	4–50 ppm	18 ppm	9 ppm
Sulfate S	1994	4–564 lb/acre	72 lb/acre	113 lb/acre
	1995	4–564 lb/acre	89 lb/acre	160 lb/acre
	1996	4–564 lb/acre	123 lb/acre	187 lb/acre
Chloride	1994	4–112 lb/acre	35 lb/acre	18 lb/acre
	1995	6–120 lb/acre	34 lb/acre	16 lb/acre
	1996	3–125 lb/acre	29 lb/acre	17 lb/acre

† Phosphate in the Northern Plains is commonly reported in ppm. The purpose of reporting of P in ppm is to remain consistent with other publications in these states.

Nitrate N

Nitrate N levels formed a "horsehead pattern" of relatively higher nitrate levels in all 3 yr in the central to south-central part of the field (Fig. 1). A high nitrate N area also appears each year in the northwest corner of the field. Higher nitrate N is also evident along the north boundary each year. Low nitrate N levels appear in each year in the central part of the field, except in the horsehead area. The reappearance of similar intricate patterns of nitrate N levels, especially the horsehead pattern, in 1995 following the 1994 sampling was the stimulus for initiating elevation mapping in 1995. The probability of random sampling events producing similar nitrate N patterns between years is remote. The presence of similar nitrate N patterns suggests that an underlying soil landscape structure might be directing nitrate N levels from year to year. The elevation mapping (Fig. 2) shows a long, horsehead shaped slope winding from the south-central border first northeast, then northwest from south to north. It also shows ridges bordering the horsehead pattern and lower elevations in the northwest and northeast. Comparison of topography mapping with nutrient levels, especially nitrate N, were strong arguments to pursue correlation of nutrient levels not only with less dense grid patterns, but with topography sampling.

Area-based topography sampling for nitrate N was more highly correlated to the 110 ft nitrate N grid values than to grid sampling at 220 ft or greater grids and point-based topography sampling in 1994 and 1996 (Table 2). Point-based topography sampling was not as highly correlated in 1994 as grid sampling at any interval. In 1995, 220 ft grids were more highly correlated than either topography-based sampling, but both area-based and point-based topography sampling were better correlated than the 330 ft or 5 acre

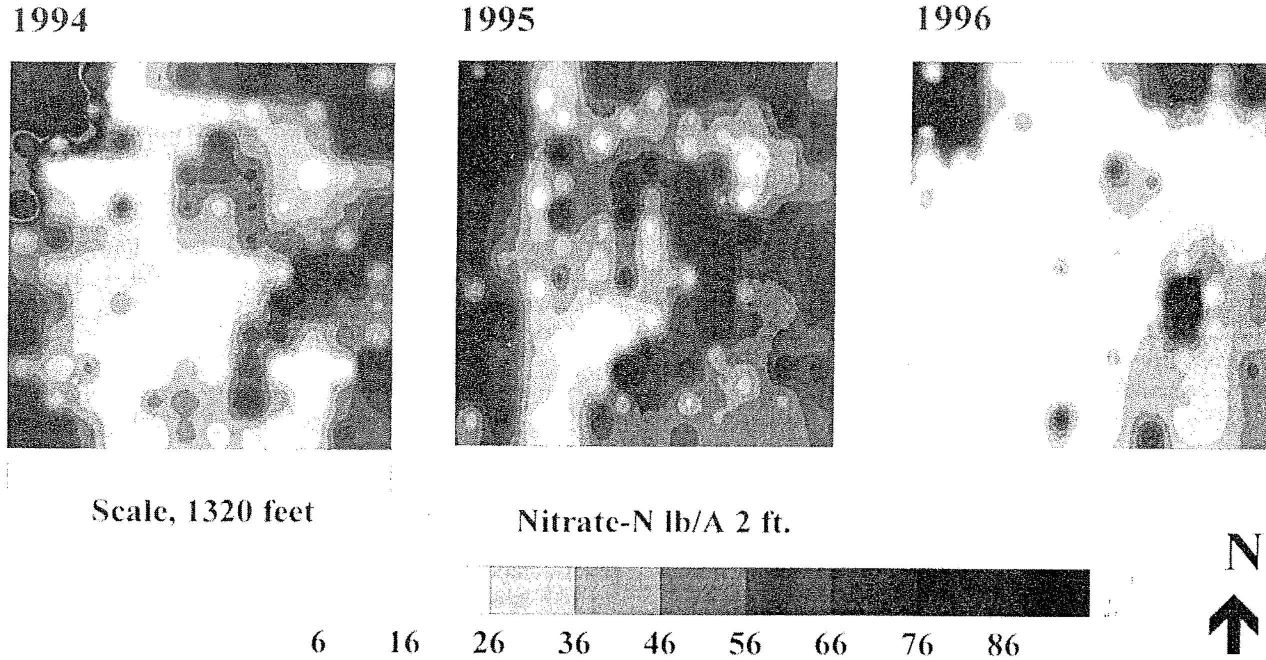

Fig. 1. Nitrate N levels, 1994–1996.

grids. In 1996, point-based topography sampling was superior to the 5 acre grid, but not to the 220 ft and 330 ft grid and area-based topography sampling.

Phosphate

Phosphorus level patterns were consistent between years (Fig. 3). Highest P levels were in the west half of the field, with particularly high levels in the northwest corner of the field. According to reports from the cooperator on the field history, livestock were fed in a lot northwest of the field until about 1960, with pasture extending into the northwest part of the study field. No evidence remains of the pasture boundaries today except the suggestions made by elevated P levels in this area. In the south-central and northeast parts of the field, high P levels follow landscape patterns, with higher P levels in the low-lying and level areas and lower P levels on ridgetops and slopes. In 1996, point-based and area-

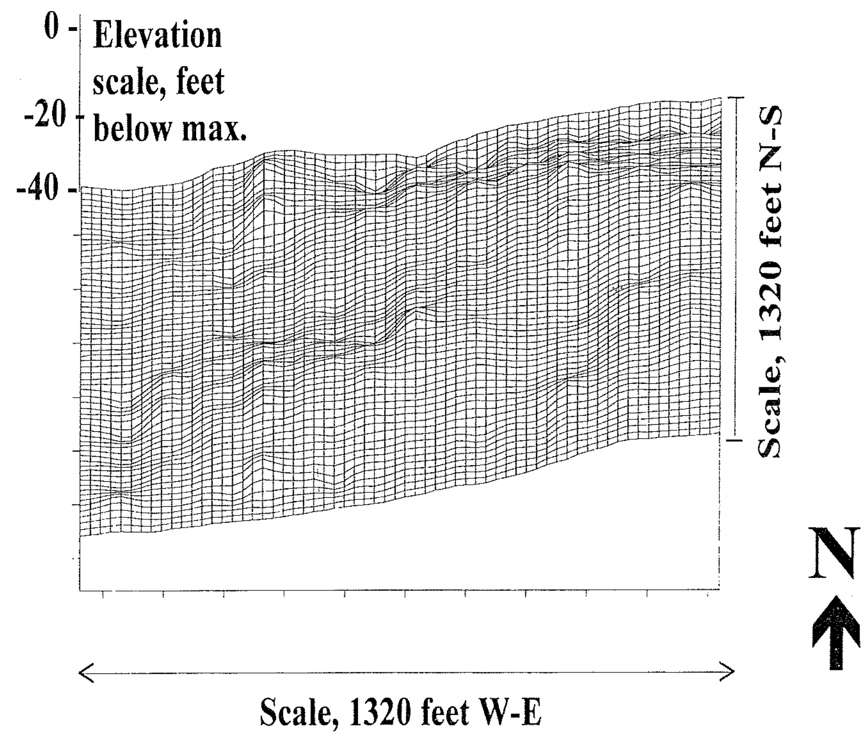

Fig. 2. Relative elevation.

Table 2. Correlation values of the 110 ft sampling grid with estimates from less dense grids and topography-based sampling, 1994–1996.

Nutrient	Year	Topography point-based	Topography area-based	220 ft grid	330 ft grid	5 acre grid
		r				
Nitrate-N	1994	0.03	0.29**	0.18	0.07	0.07
	1995	0.35**	0.38**	0.50**	0.21*	0.21*
	1996	0.22**	0.49**	0.34**	0.41**	0.01
P	1994	0.28**	0.27**	0.29**	0.40**	0.07
	1995	0.47**	0.34**	0.75**	0.68**	0.09
	1996	0.57**	0.53**	0.51**	0.61**	0.19*
Sulfate-S	1994	0.25**	0.35**	0.37**	0.31**	0.04
	1995	0.00	0.02	0.72**	0.09	0.30**
	1996	0.14	0.31**	0.33**	0.29**	0.15
Chloride	1994	0.07	0.38**	0.24*	0.31**	0.07
	1995	0.33**	0.21*	0.56**	0.13	0.05
	1996	0.53**	0.31**	0.33**	0.29**	0.15

*,** Denotes significance at the 0.05,0.01 probability levels, respectively.

based topography samplings were more highly correlated with the 110 ft grid P values than to the 220 ft and 5 acre grids, but not as highly correlated as the 330 ft grid (Table 2). In 1994 and 1995, the 220 ft and 330 ft grids were better correlated than topography sampling. Both area-based and point-based topography sampling were more highly correlated than the 5 acre grid in 1994 and 1995. Point-based topography sampling was generally slightly better correlated than area-based topography sampling for P.

Sulfate S

High sulfate S levels were concentrated in the northwest, northeast, southwest, and southeast in 1994 (Fig. 4). In 1995, the relatively high testing southwest area was not evident, while the high testing areas in the northwest, northeast, and southeast to central area of the field expanded in size. Generally, consistently high areas of sulfate S were located in lower landscapes, such as depressions. In 1996, areas of high sulfate S from 1995 expanded in size so that the resulting pattern resembled the nitrate N level patterns, including the horsehead shape. In 1994 and 1996, area-based topography sampling was slighly less correlated with the 110 ft sulfate S values than the 220 ft grid, but more highly correlated than the 330 ft, 5 acre grid, and point-based topography sampling (Table 2). In 1995, the 220 ft grid sampling was better correlated than other methods for sulfate S. Point-based topography sampling was less correlated than area-based topography sampling, but more highly correlated in 1994 and 1996 than the 5 acre grid.

Chloride

Chloride levels in 1994 and 1995 showed similarities to soil nitrate N patterns and strongly revealed similar patterns, such as the horsehead shape, with nitrate N in 1996 (Fig. 5). Correlation of area-based topography sampling in 1994 was superior in correlation with 110 ft grid chloride values than with other sampling methods. Area-based topography sampling was not as highly correlated as point-based topography sampling to the 220 ft grid in 1995 and 1996, but was more highly correlated than the 330 ft and 5 acre grids. In 1995, the 220 ft grid was more highly correlated than other methods, while in 1996, point-based topography sampling was better correlated than all other methods.

General Observations

When nutrient values were variable within landscape zones, such as nitrate N in 1994, or 1994 to 1996 sulfate S, or 1994 chloride levels, point-based topography sampling was not highly correlated compared with most other methods and area-based topography was more highly correlated. When levels within a landscape zone were more uniform,

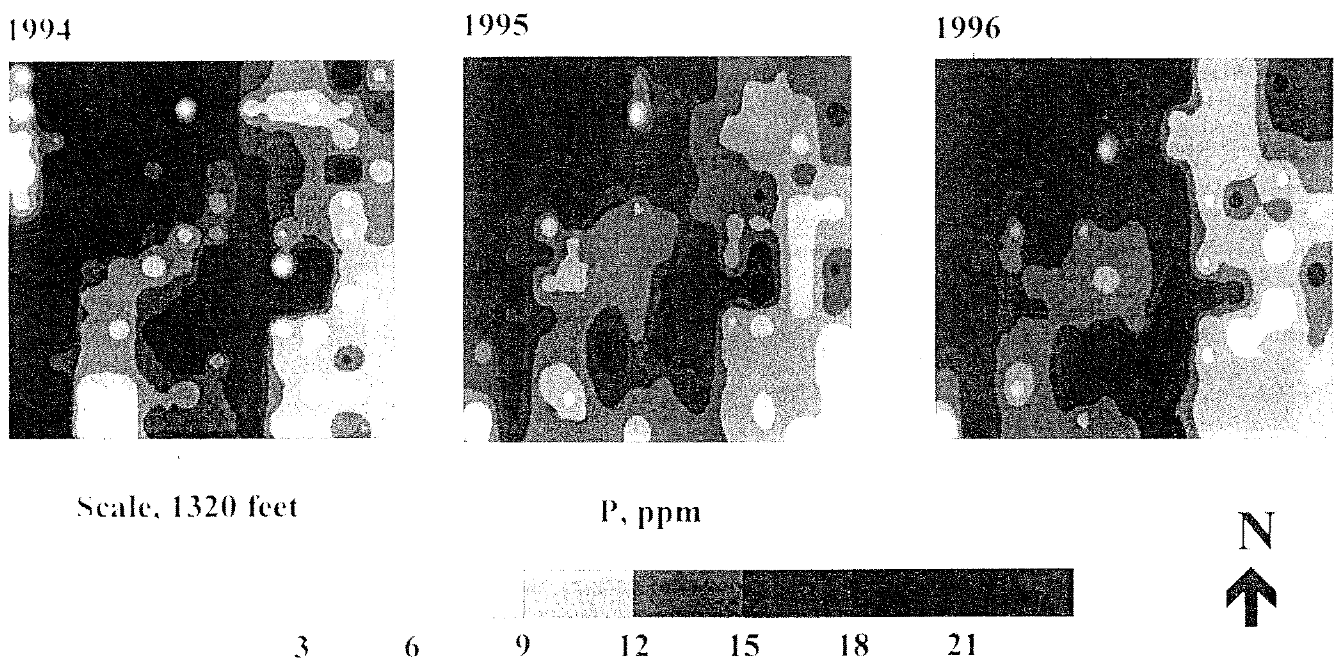

Fig. 3. P levels, 1994–1996.

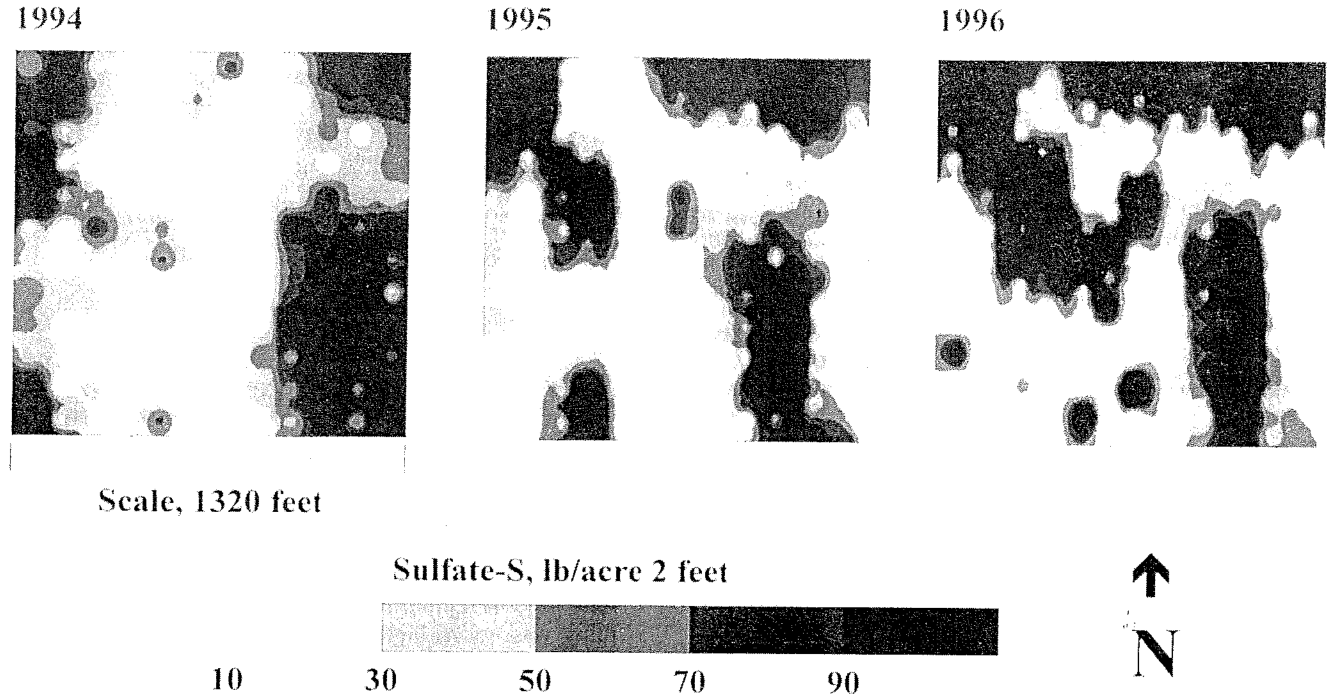

Fig. 4. Sulfate S levels, 1994–1996.

such as P levels in all years, or chloride levels in 1995 and 1996, the difference in correlation between point-based and area-based topography sampling was small. The 5 acre grid was consistently poor in correlation with the 110 ft grid values for all nutrients, with only three of 12 comparisons showing significance. The 330 ft grid was most highly correlated in comparing P levels, where more uniform levels of that nutrient were positioned in large block-shaped areas. The 220 ft grid size was most consistent of all sampling patterns, including topography based, with superior correlation in six of 12 comparisons. However, some type of topography sampling was most highly correlated in four of 12 comparisons, with low correlation only in 1995 with the highly variable sulfate S levels. Area-based topography sampling was most highly correlated in three of 12 comparisons, while point-based topography sampling was most highly correlated in one of 12 comparisons. Both area-based topography sampling and the 220 ft grid sampling was signifi-

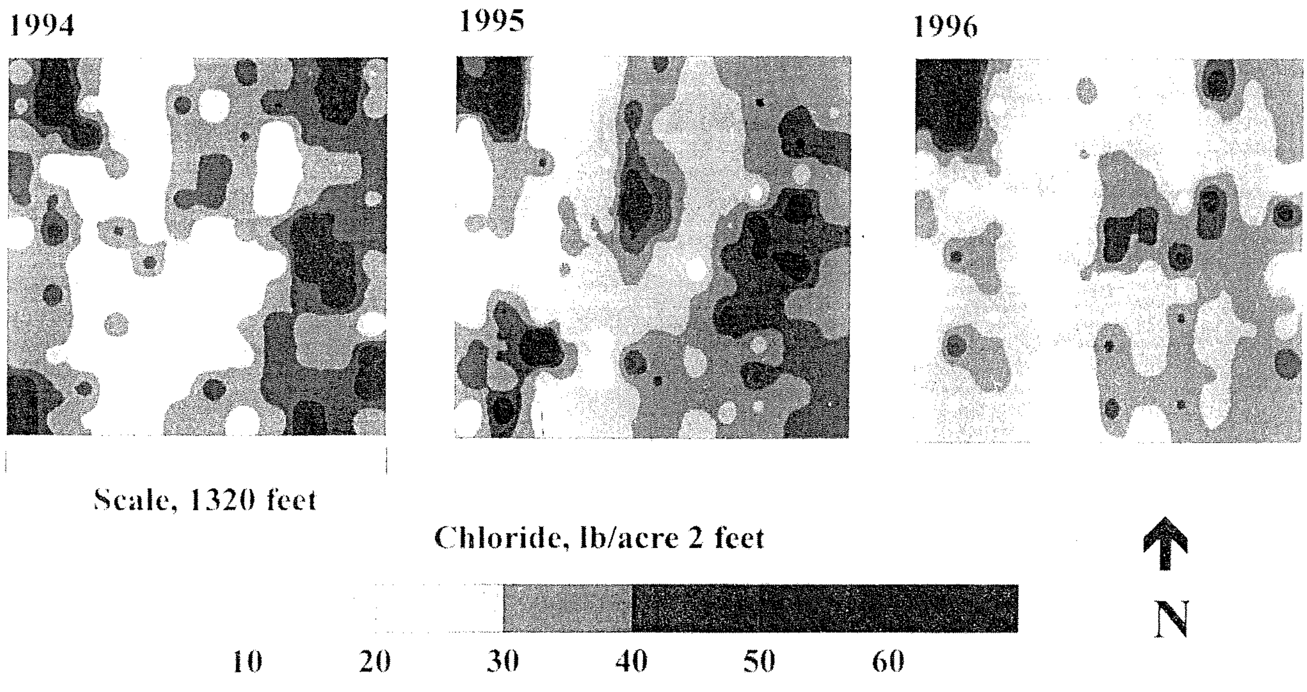

Fig. 5. Chloride levels, 1994–1996.

cantly correlated in 11 of 12 comparisons. The high correlation of topography sampling compared to grids was accomplished with the use of only five of six samples, compared with 36 sample locations for the 220 ft grid.

Pattern Representation of Topography-Based Sampling Compared with Grid Sampling

Although high correlation with field nutrient levels may be important, it is also important to represent fertility level boundaries. Figure 6 shows nitrate N levels in 1995 from the 110 ft grid sampling. The map shows the horsehead shaped high nitrate N level area in the central part of the field and the high nitrate N levels in the northwest, northeast, and southeast. The map from the 220 ft grid sampling shows the high nitrate N area in the northwest and northeast, but the boundary areas in the central part of the field are distorted from the original. The 330 ft grid shows the high nitrate N levels in the west and southeast, but the boundaries are again distorted. The 5 acre grid map shows little resemblence to field levels. However, using five sampling points and delineating landscape zones, such as the low landscapes in the west and northeast, and the long level slope in the horsehead pattern in the south to central part of the field, nitrate N levels from point-based topography appear similar to the 110 ft grid. Although in the correlation comparison the 220 ft grid was superior to the topography, the fertility boundaries important for future investigations were much clearer and

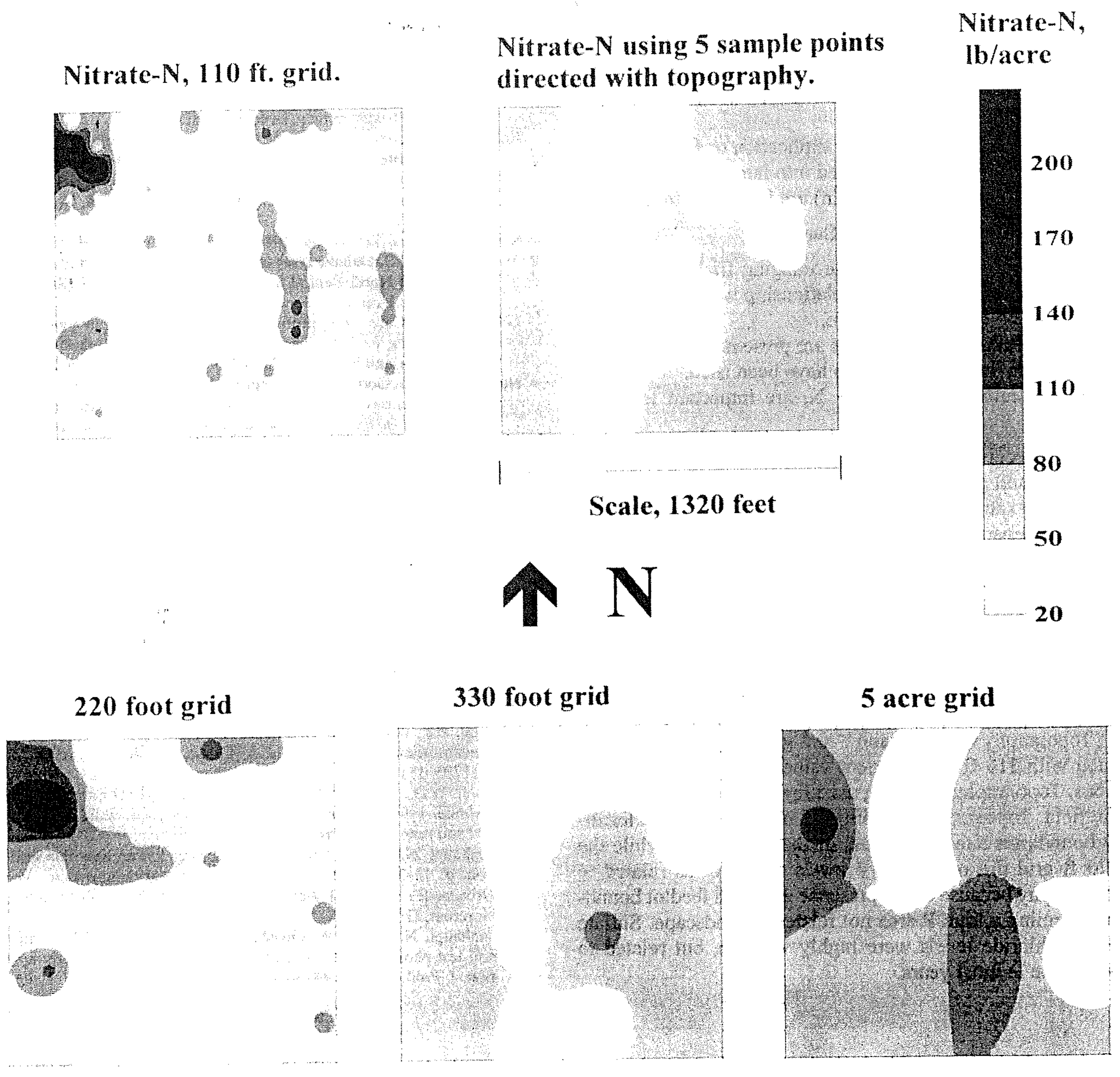

Fig. 6. Comparison of nitrate N levels using selected grids and point-sampled topography, 1995.

more accurately portrayed with a map developed using topography-based sampling.

Topography-based sampling, however, has certain limitations. If human activity has changed the variability of nutrients across a landscape, a purely topography-based sampling system may not be effective. One example of this is in the P levels, where the old feedlot influence forms a large high P area not evident in the nitrate N mapping.

Based on work from this study and associated work published in various proceedings regarding effects of buildup fertilizer application and the use of remote sensing and yield monitor data, (Franzen and Peck, 1996; Franzen et al., 1997) the following guidelines are offered for determining whether fields are candidates for grid sampling or topography sampling.

Candidates for Grid Sampling

- The field history is unknown.
- Fertility levels are high, or high rates of fertilizer or limestone have recently been applied, such as buildup rates of P.
- There is a history of manure application or feedlots.
- Small fields have been merged into larger ones.
- Nonmobile nutrients (P, K, Zn) are important to map.

Candidates for Topography Sampling

- Yield monitor data or remote imaging from satellites or aerial photography show a relationship with landscape.
- There is no history of manure.
- Relatively low fertility levels are present or low fertilizer rates (less than maintenance) have been used.
- Mobile nutrients, especially N, are important to determine.

It is conceivable that a combination of both topography sampling and grid sampling could be used within a single field. For example, an area with an old feedlot may be grid sampled separately from the remainder of a field where topography sampling has been shown to be superior. The choice may not be either/or. Both methods may be superior in certain situations.

SUMMARY

Topography sampling and 220 ft grids were highly correlated with 110 ft grid nutrient values in 11 of 12 comparisons. Topography sampling used fewer samples to describe the field. Topography sampling for nitrate N formed fertility boundaries similar to those of the 110 ft grid, while the 220 ft grid did not. Field P levels were not as related to topography because of the presence of an old feedlot boundary, forming a high P area not related to landscape. Sulfate S and chloride levels were highly variable, but related to landscape in most years.

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