SITE-SPECIFIC NITROGEN MANAGEMENT

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INTRODUCTION

Applying only the amount of nitrogen fertilizer needed for a crop at a particular point in the field makes intuitive sense - and is hard to argue against conceptually. However, in practice site-specific nitrogen (N) management is quite challenging. That is to be expected, since routine, uniform N management is often more challenging than is management of other nutrients. Because of nitrogen's mobility in soil, the fact that it is subject to a wide range of transformations and loss processes, and is needed as a supplemental nutrient in greater quantities than any other for most crops, N is not easy to manage. Site-specific, or variable rate, management of N has the potential to clarify or further confuse the overall issue of efficient use of N fertilizers.

The initial focus of variable rate technology (VRT) has been on non-mobile nutrients - primarily phosphorus (P) and potassium (K). Successful commercial adoption of VRT in parts of the Corn Belt was based on these nutrients. Interest in site-specific N management lagged somewhat, probably because of the added complexity in general of N management, but has had considerable interest over the past five years as a potential best management practice (BMP) to further protect water quality. In order for VRT application of N to be worth doing, it will need to be either economically or environmentally attractive - preferably both. Several studies have been initiated over the past 3-4 years to investigate both issues.

THE APPLICATION MAP

An effective evaluation of VRT N application must begin with an accurate application map. In most cases, existing uniform N recommendations based on expected yield and measures of soil N availability are adopted spatially (Gotway, et al, 1996; Snyder, et al, 1996; Kitchen, et al, 1994). Surely some of the uncertainty regarding the benefits of VRT N application can be related to the uncertainty upon which our uniform rate recommendations are based. However, these recommendations are the best that we currently have, and likely provide a reasonable basis upon which the merits of site-specific N management can be evaluated. Various approaches have been used to attempt to quantify the yield and N supply potential of fields spatially. These can be

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generally divided into four categories: grid sampling, soil series - topography, yield mapping, and remote sensing. These categories can be further described in terms of their information extent and spatial density. Grid soil sampling has the potential to provide very extensive information about the chemical and perhaps physical characteristics of the soil at selected points, but the spatial density of this information is likely to be limiting because of the expense of collecting and analyzing soil samples. For the most part, the other methods provide spatially dense, but not very extensive, information about the field.

GRID SOIL SAMPLING

This method of generating rate maps is, in may areas, the most commonly used method for P and K, and has been used for N rate maps as well. When commercially practiced, the sampling density is most often one sample for every 3-4 acres, usually representing a composite of several soil cores collected around a grid point. Grid density can have a major influence on the accuracy of the N application map. Figure 1, from Ferguson, et al, 1996, illustrates this point. At this site, in Lincoln county, Nebraska, two sampling densities, both much denser than commonly used commercially, provide substantially different maps. The coarser density misses a systematic pattern present in soil residual nitrate levels, most likely resulting from patterns of livestock fencing in the past. Forty five percent of the field received a different recommendation with the coarser grid.

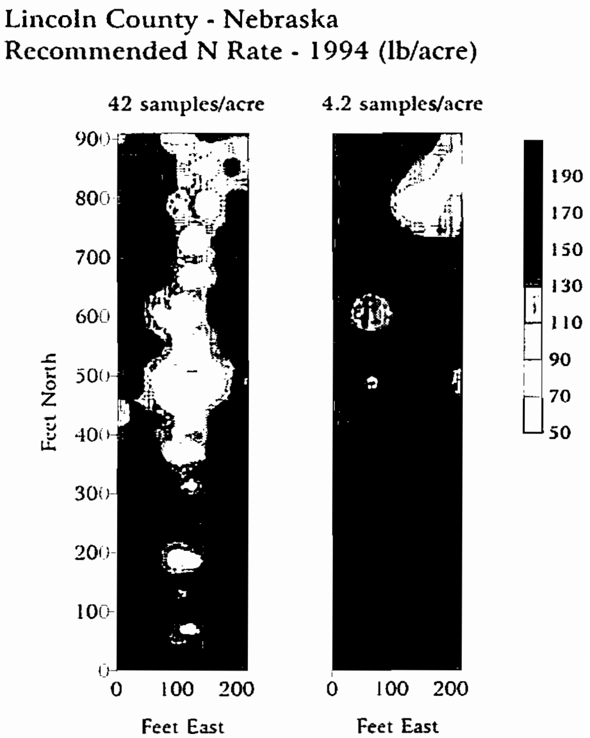


Figure 1

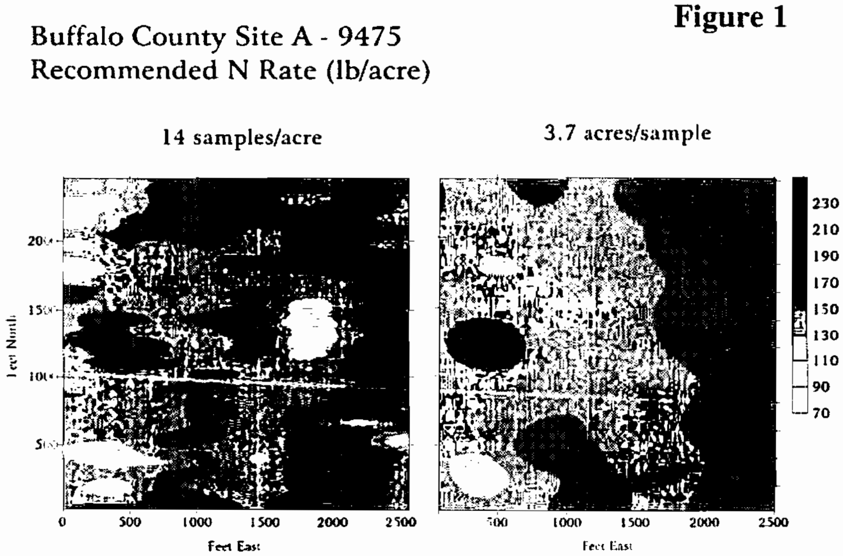


Figure 2

However, coarser grid densities can provide acceptably accurate maps, as illustrated in Figure 2. At this site, a grid density similar to that used commercially provides an acceptable map at a density many times less than actually collected in the study. The area of the field which received a different recommendation at the lower density grid was only 17.6%. The dilemma is that it is currently difficult to predict the minimum grid size necessary to provide an acceptably accurate map. Further, grid sampling annually to detect nitrate levels in soil is not likely to be a realistic management option, due to cost and labor constraints.

SOIL SERIES - TOPOGRAPHY

Nitrogen rate maps based on soil series or field topography take advantage of spatial information which is already well known, and in some areas of the U.S. is becoming available electronically. Several researchers have found topography-based N rate maps to be effective (Solohub, et al, 1996). Others have found topography or soil series based application maps to provide similar results to grid sample based maps (Thompson & Robert, 1994), while still others have found relatively low spatial correlation between crop response to N and soil map units

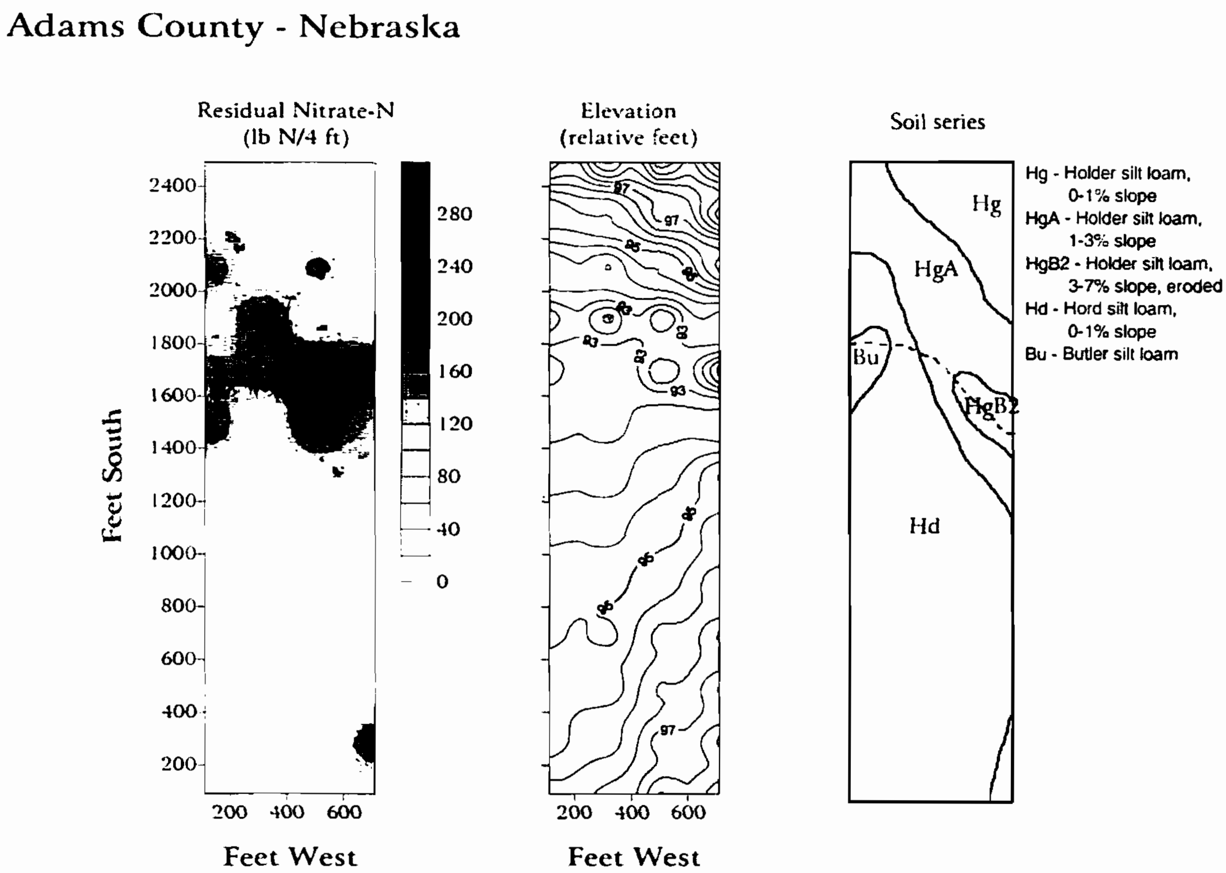
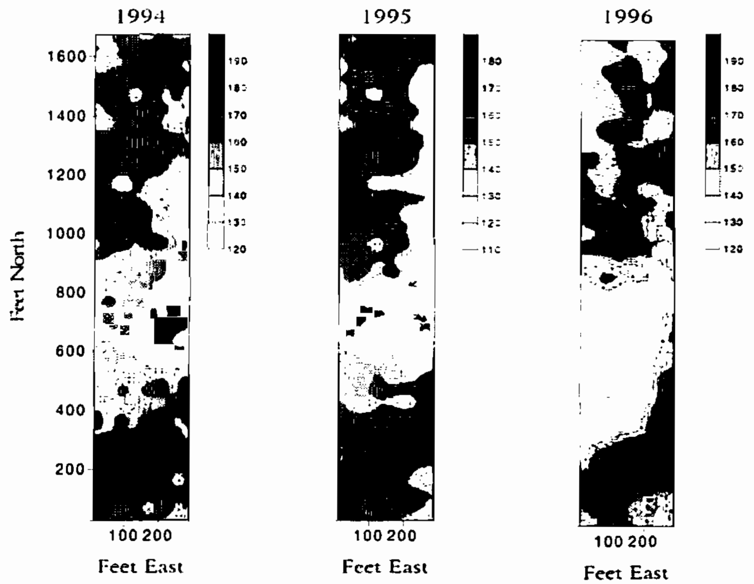


Figure 3

(Everett & Pierce, 1996). Figures 3 and 4 illustrate both situations. Figure 3, from a field in Adams county, Nebraska, illustrates a situation where the soil residual nitrate map, here developed from grid sampling, is closely correlated with relative elevation and soil series in the field. At this site, residual nitrate-N is highest in the lowest area of the field, which also corresponds to the less productive Butler and eroded Holder soils. In this case, residual nitrate-N is higher where crop yield and consequently crop removal was less the preceding year. Figure 4 illustrates a situation, from Clay county, Nebraska, where the entire field is mapped as one series, and yet substantial variation in N rate is recommended from grid sampling - the recommended N rate in most years ranges from 120 to 190 lb N/acre, within one soil mapping unit.

One criticism of grid sampling is that it ignores what we already know about fields. Currently available soil surveys contain spatial information which we appear to ignore when we arbitrarily impose fixed grid patterns for soil sampling on a field. On the other hand, arbitrary grid sampling may often expose things we did not know about fields which have resulted from prior

Clay County - Nebraska
Recommended N Rate (lb/acre)



Soil series

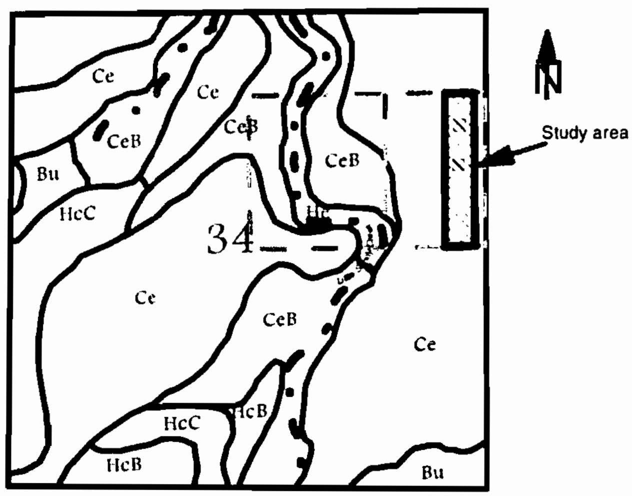


Figure 4

management and are unrelated to soil series or topography. Figure 5 illustrates the location of the residual effects on soil P from a farmstead animal lot described by grid sampling a field in Clay county, Nebraska. The existence of this area of high phosphorus concentration was unknown prior to grid sampling. This pattern of P in the field has persisted for over 30 years - the tenure of the current owner, who has never applied manure or pastured livestock in the field - and likely much longer. The systematic pattern of residual N and resulting N fertilizer recommendation in Figure 1 is a similar example of significant patterns in a field undetectable by any means other than grid sampling.

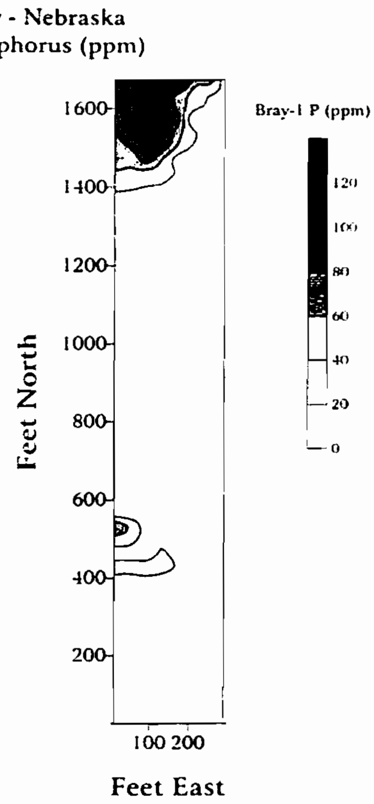


Figure 5

YIELD MAPPING

The most rapidly growing area of site-specific management is yield monitoring and mapping. Consequently, there is considerable interest in using yield maps as management tools. One potential application of yield maps is providing the basis for VRT application of fertilizers. A yield map, assuming it accurately represents the yield from the field, can reflect crop removal of nutrients on a spatial basis. It uses the plant as an integrator of soil parameters which might more reasonably reflect nutrient availability than a soil test. Kitchen, et al (1994) found productivity trends in fields which persisted over years and crops, but suggested that the use of yield maps to identify areas of relative productivity in fields should be based on an accumulation of as many years of mapped yields as possible. Davis, et al, 1996, found yield levels from unfertilized plots were more accurate predictors of spatial patterns of N requirement than were yield levels from well-fertilized plots (150 lb N/acre). These results point out that producers are likely to have difficulty using yield maps produced from adequately fertilized fields to determine areas within fields having different N requirements, emphasizing the need for tools in addition to yield maps that can be used to determine these areas. Many factors will influence yield other than N availability - in most cases, N will not be the yield limiting factor. Consequently, yield maps may not very accurately portray N availability to the crop, or predict N requirement for the coming season. Figure 6, from Clay county, Nebraska, illustrates factors influencing grain yield in three subsequent years. In 1994, high wind damage to the crop in July effectively masked any soils influence on yield patterns, with the exception that the area of lower yields tended to be where stalk breakage was greatest, which was in the higher organic matter area of the field where plant growth was occurring most rapidly. In 1993, the yield pattern was related to organic matter, but was also heavily influenced by high wind damage as well. In 1995, the yield map was well correlated to organic matter in the field. In only one year of three was the pattern of soil attributes the *primary* factor influencing the yield map.

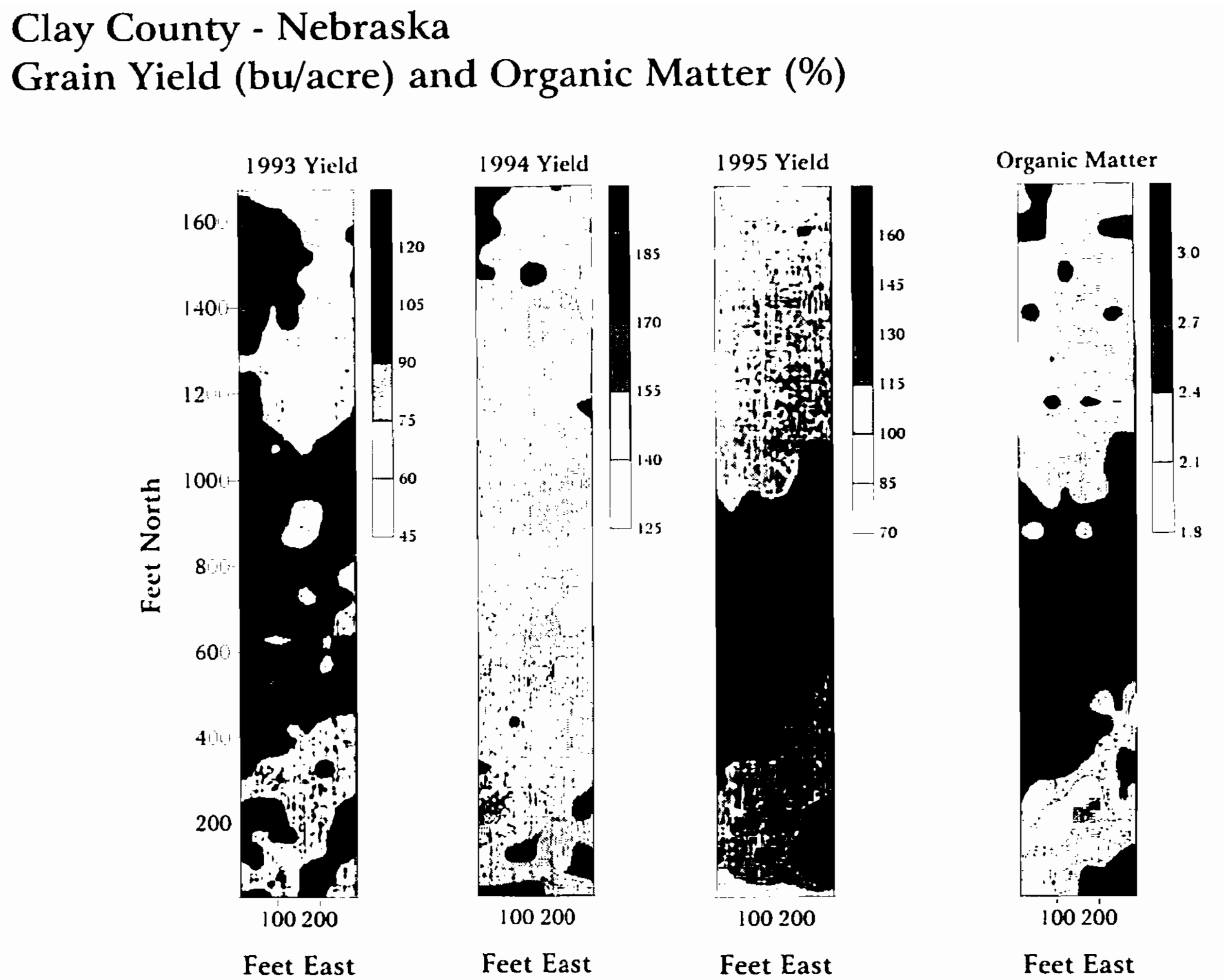


Figure 6

REMOTE SENSING

Like the yield map, remotely sensed images can use the crop as an integrator of soil nutrient availability. Remote sensing has considerable potential to monitor crop N status and also provide an application map if N deficiency is detected. Two primary remote sensing approaches are under investigation - real-time, ground based sensing and aerial or satellite sensing. Ground-based sensors, located on high clearance equipment or center-pivot sprinkler systems, may have the capability to detect crop N stress and apply N as necessary at the same time. Aerial or satellite sensors have the potential to detect developing crop N stress, and provide a N rate map for sidedressing or high clearance application. Remotely sensed images can correlate well with other spatial sources of information, as shown in Figure 7. At this site, a remotely sensed image collected in July, 1995 correlates visually with a map of organic matter and yield in 1995 (Figure 6). However, without the prior existence of the organic matter map, the cause of patterns observed in remote-sensed images may be a matter of speculation. Considerable research is needed in ground-truthing sensor technology - relating observations at specific spectral bands to

Remotely sensed image, Clay county site, July 1995.

Resource21™ Enhanced Vegetation Map

Figure 7

specific stresses in crops. Currently, commercial availability of remote-sensing data is relatively limited. This is likely to change rapidly, as several partnerships have plans to install satellite remote sensing systems within the next few years.

AN INTEGRATED APPROACH

It is most likely that future, successful implementation of VRT N application will rely on some combination of the above methods for generating the application map. The spatial density available from yield maps, remotely sensed images, and soil series/topography sources will be coupled with the extensive information available from soil sampling. In many cases, yield maps and remotely sensed images will be used to facilitate directed sampling, in which areas of fields most likely to contain different organic matter or other nutrient levels are identified for sampling. It may be likely, in cases where prior management has the potential to significantly influence non-mobile nutrient levels in the soil, that an initial grid sampling at some determined optimum density will be collected, followed by N application based on a combination of crop removal, N stress detection, and soil supplying capability.

ECONOMIC AND ENVIRONMENTAL BENEFITS

The economic benefit of site-specific N management is still unknown. Some investigators show that VRT N application can be economically feasible in some years (Snyder, et al, 1996; Malzer, 1996), while others show no economic gain (Kitchen, et al, 1994). Summarizing field comparisons of variable to uniform N application in Nebraska, we find generally no significant reductions in the total amount of N applied with variable application. Averaged over 19 site/years, variable rate application resulted in the application of 3% less total N (Table 1). Malzer, 1996, noted that factors currently used in making N recommendations, including expected yield, cropping history, organic matter and residual nitrate-N only predicted a portion of the potential benefit of site-specific N management, suggesting that additional factors will need to be considered to maximize profitability of site-specific N management.

The environmental benefit of site-specific N management is more difficult to quantify, and consequently few studies to date have addressed this question. Kitchen, et al (1994) documented a decrease in root zone NO_3-N with variable N application. Redulla, et al, 1996, found similar residual NO_3-N levels remaining in soil with uniform or variable N application. In Nebraska, we have measured significant reductions in residual NO_3-N with variable application compared to uniform in two of six site/years (Hergert, et al, 1996). Generally, reductions in leachable nitrate with site-specific management noted to date are relatively small.

Table 1. Comparison of variable to fixed rate N application at Nebraska research locations.

Year	Location (county)	Treatment	Average N Rate (lb/acre)	Ratio of Variable to Fixed
1992	Adams	Fixed (F)	180	1.017
		Variable (V)	183	
1993	York	F	138	0.935
		V	129	
	Lincoln	F	174	0.943
		V	164	
1994	Polk	F	146	0.938
		V	137	
	Clay	F	148	0.993
		V	147	
	Buffalo B	F	96	1.042
		V	100	
	Lincoln	F	147	0.986
		V	145	
	Buffalo A	F	95	0.989
		V	94	
1995	Clay	F	183	1.027
		V	188	
	Buffalo B	F	139	0.957
		V	133	
	Buffalo A	F	142	0.972
		V	138	
	Polk	F	126	0.810
		V	102	
	York	F	119	0.849
		V	101	
	Hall	F	145	0.938
		V	136	
1996	Buffalo A	F	134	0.978
		V	131	
	Clay	F	125	0.992
		V	124	
	Lincoln	F	145	0.952
		V	138	
	Buffalo B	F	116	1.155
		V	134	
	Hall	F	139	0.942
		V	131	
	Means	F	139	0.969
		V	134	

SUMMARY

Site-specific nitrogen management conceptually makes sense. Theoretical considerations, applying equations to existing datasets of spatial information, indicate that, at least part of the time, site-specific N management is both profitable and can reduce N loss to the environment. However, when site-specific N management has been actually compared to uniform application in the field, real differences economically or environmentally are often quite small or non-existent. With seemingly small but real benefits from site-specific N management both economically and environmentally, it will be essential that procedures be developed to generate accurate application maps inexpensively. If variable rate N application from a map is to be practical, it must not cost much more to produce the application map than it costs to produce a recommendation for uniform N application. From this standpoint, real-time remote sensing on an applicator or irrigation system has an advantage, since no rate map is needed - the applicator simply responds to the crop status at the time of application. However, real-time application of N according to crop N status, if it ultimately becomes practical, will not be an option for some cropping situations. Site-specific N management is also likely to be most useful in highly variable cropping situations. Additional work is needed on identifying those soils and cropping systems which are most likely to reflect positive benefits, either economically, environmentally, or both, to site-specific N management.

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