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Precision Farming Protocols. Part 2. Comparison of Sampling Approaches for Precision Phosphorus Management

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ABSTRACT

Research is needed to compare the different techniques for developing site-specific phosphorus (P) recommendations on a field-wide basis. The objective of this study was to determine the impact different techniques for developing site-specific P recommendation maps on yield and profitability. Enterprise analysis combined with a crop simulation model and detailed field characterization was used to estimate the value of spatial P information in a system where N was not limiting. The systems evaluated were continuous corn (*Zea mays*) and corn and soybean (*Glycine max*) rotations where sampling and fertilizer applications were applied annually and semi-annually, respectively. The sampling techniques tested were: (i) an unfertilized P control; (ii) whole field; (iii) whole field plus historic information (feedlot); (iv) landscape positions; (v) soil type; (vi) soil type plus historic information (feedlot); and (vii) 90-m grid sampling. The finding of this study were based on soil samples collected from a 30 by 30-m grid. The value of the spatial information was dependent on the crops response to P, the accuracy of the different sampling techniques, crop rotation, and the length of time between sampling dates. All of the sampling techniques produced different application maps. The recommendation map based on a single composite sample under fertilized 56.5% of the field. Increasing the sampling density reduced the percentage of under-fertilized land. If corn had a low P response, then simulation/enterprise analysis indicated that applying P did not increased profits. For all scenarios tested: (i) the soil type + historic sampling approach had higher potential profits than the 90 m grid sampling approach; and (ii) there was no economic benefit associated with the 90-m grid sampling. However, if research shows that amortization of sampling and analysis costs over 3 or 4 years is appropriate, then it may be possible to derive economic benefit from a 90-m grid sampling. For a corn/soybean rotation, where fertilizer was applied when corn was planted and N and P was not applied to soybeans, enterprise/ simulation analysis (2.8 Mg ha^{-1} soybean yield goal and a moderate P model) showed that soil + historic sampling approach increased profitability \$3.74 ha^{-1} when compared to the uniform P treatment.

INTRODUCTION

Grid and soil property-based sampling often are used to obtain spatial information required for precision nutrient management. In grid sampling, soil samples are collected from grid points with a specified distance between adjacent samples (Crepis and Johnson, 1993). Following sample collection, samples are chemically analyzed and nutrient contour maps constructed (Isaaks and Srivastava, 1989). Studies using grid sampling show that if grid distances are close enough, then grid sampling provides excellent information about intrinsic and management induced variation, however if grid distances are too large, then important attributes may be missed (Cambardella et al., 1994; Chang et al., 1999; Ferguson et al., 1996; Franzen and Peck, 1995; Froment et al., 1996; Hergert et al., 1995; Mohamed et al., 1996; Mallarino, 1996). Because grid sampling is expensive, selected grid distances often are too long to be of practical use.

Soil property-based sampling uses soil color by remote sensing, soil series maps, landscape position, and surveyed or digital elevation maps for characterizing soil management zones (Frazier et al., 1997; Franzen et al., 1998). Property-based sampling may balance sampling costs with information value. However, soil-property-based sampling is not recommended when: (i) field histories are unknown; (ii) fertility levels are high or high rates of fertilizer have been applied; (iii) manure was applied; (iv) the field contained a feedlot; (v) small fields were merged into a larger one; and (vi) nonmoble nutrients are important to map (Franzen et al., 1998). Given potential advantages of soil property-based sampling, research is needed to compare different techniques for identify management zones. The objective of this study was to determine the impact different techniques for developing site-specific P recommendation maps on yield and profitability.

MATERIALS AND METHODS

A 65 ha no-tillage field located in east central South Dakota (latitude 44.17°N and longitude 96.62°W) with a corn (*Zea mays*) and soybean (*Glycine max*) rotation was used for this case study. In 1995, total nitrogen (N), P, and zinc (Zn) applied was 124, 25.9, and 2.24 kg ha^{-1}, respectively, and grain yields were measured by a differential corrected global positioning systems (DGPS) equipped yield monitoring combine.

Soil samples (0-15 and 15-60 cm depths) were collected from a 30- by 30-m grid in May 1995. Each composite sample contained 15 individual cores (Clay et al., 1997a). Soil series at each grid point was determined following standard NRCS methods (Soil Survey Staff, 1993). Soil samples were air dried (35°C), ground with a ball mill, and analyzed for NO_3-N, Olsen P, potassium (K), Zn, and pH (North Central Regional Publication, 1988).

Means, variances, and semivariograms of the whole field were calculated using Geo-eas 1.2.1 (Englund and Spark, 1991). Nutrient contour maps, corn yields, and semivariograms were reported in companion papers (Clay et al., 1997b; Chang et al., 1999). A related study conducted at this site demonstrates an approach that uses electromagnetic magnetic (EM) information to locate old feedlots.

Sampling Approaches

Sampling and fertilizing approaches tested were: (i) a 0 P control, (ii) P uniformly applied based on a single composite sample; (iii) P variably applied to landscape positions based on composite samples collected from the different landscape positions, (iv) P variably applied to management zones identified by a level 1 soil survey (soil type), (v) P variably applied to management zones identified by a level 1 soil survey plus historical information (soil type +), and (vi) P variably applied to the field based on two different 90-m grid maps.

Landscape positions were determined by calculating concavity and slope for each grid point (Chang, 1997). Concavity was calculated by the following equation:

$$\delta y^2/\delta x^2 = (Z_1+Z_3-2Z_2)/L^2 \qquad [1]$$

where Z_2 was the center of a 3 by 3 grid matrix, Z_1 and Z_3 were elevations at uphill and downhill corners, and L was the horizontal distance in the direction of most slope. The slope was calculated by the following equation:

$$\delta x/\delta y = (Z_1-Z_3)/L \qquad [2]$$

The toeslope was defined as areas where concavity was greater than zero and slope was less than 3%. Footslope was defined as areas where concavity was greater than zero and the slope ranging from 3 to 5%. The lower backslope were defined as areas where concavity was greater than zero and slope was greater than 5%. The upper backslope was defined as areas where concavity was less than zero and slope was greater than 5%. The shoulder was defined as area where concavity was less than zero and slope was ranged from 3 to 5%. The summit was defined as areas where concavity was less than zero and slope was less than 3%.

Management zones identified by soil series plus historical information were located by combining historical records with soil survey information. The P concentrations within each landscape position or soil series were calculated by averaging all grid points within an area. In order to avoid the inference of a higher accuracy level than actually observed, the Olsen P soil test results were grouped into very low (0-3 mg Olson P kg^{-1}), low (4-7 mg Olson P), medium (8-11 mg Olson P kg^{-1}), high (12-15 mg Olson P kg^{-1}), and very high (>16 mg Olson P kg^{-1}) categories. The mean value of a category was used to make fertilizer recommendations.

Crop Simulation Model

The simulation model estimated corn and soybean yields based on soil P (mg Olson P kg^{-1}), fertilizer added, and yield goal, and P response model. The model systems were the continuous corn and the corn followed by soybean rotations. Simulated corn yields were 5.5, 7.7, and 10 Mg ha^{-1}, while the simulated soybean yield was 2.8 Mg ha^{-1}.

Three different P (low, medium, and high) models were used to simulate the effect of P fertilizer on corn and soybean yields. The low (5% maximum yield gain from P fertilizer for soil with an Olsen P concentration of 1.5 mg Olson P kg^{-1}), medium (15% maximum yield gain from P fertilizer in soil with an Olsen P concentration of 1.5 mg Olson P kg^{-1}), and high (35% maximum yield gain from P fertilizer in soil having an Olsen P concentration of 1.5 mg Olson P kg^{-1}) response models were derived by combining the P fertilizer recommendation model with equations relating yield to soil P. The low, medium, and high P equations relating corn yields (yield goal 7.7 Mg ha^{-1}) to soil P, when P fertilizer was not added, were:

$$\text{Low: yield (Mg ha}^{-1}) = 6.89 + 0.02658 * (\text{mg P kg}^{-1}) \quad [3]$$
$$\text{Medium: yield (Mg ha}^{-1}) = 5.98 + 0.123 * (\text{mg P kg}^{-1}) - 0.0023 * (\text{mg P kg}^{-1})^2 \quad [4]$$
$$\text{High: yield (Mg ha}^{-1}) = 4.17 + 0.31 * (\text{mg P kg}^{-1}) - 0.0071 * (\text{mg P kg}^{-1})^2 \quad [5]$$

For the three models when Olsen P was less than 16 mg Olson P kg^{-1} the maximum fertilized yield was 95% of the yield goal and when P was greater than 16 $\mu g\ g^{-1}$, the calculated yield was equal to the yield goal. The corn P recommendation (CPFR) model was:

$$\text{CPFR (kg P ha}^{-1}) = [(0.7 - 0.044 * (\text{mg P kg}^{-1}) * \text{YG (Mg ha}^{-1}] * (9.58) \quad [6]$$

where, STV was the soil test value in μg P g $soil^{-1}$ and YG was yield goal (Gerwing and Gelderman, 1996). The soybean P recommendation (SPER) model was:

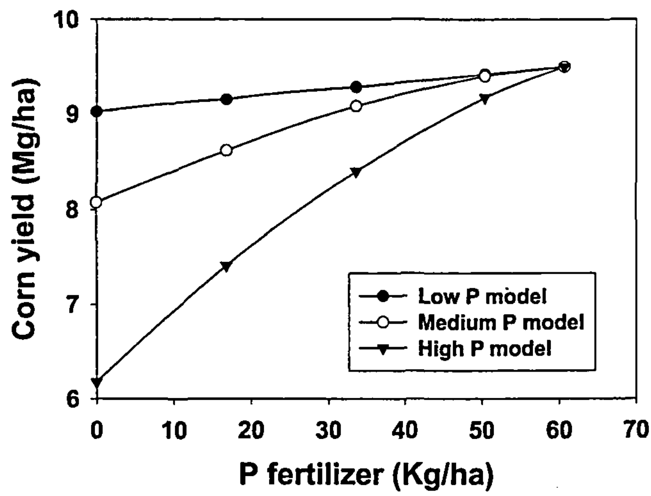

FIGURE 1. The relationships between corn yield and P fertilizer for the low, medium, and high P response models.

$$\text{SPER} = (\text{kg ha}^{-1}) = [1.55\text{-}0.14 * (\text{mg P kg}^{-1})] * \text{YG (Mg ha}^{-1}) * 0.0246 \quad [7]$$

The amount of N fertilizer applied to corn was adjusted for the amount of N contained in the P fertilizer. Examples of the derived low, medium, and high P response models for the 10 Mg ha^{-1} yield goal are shown in Figure 1.

The nitrogen recommendations, for the different yield goals, were based on university recommendations (Gerwing and Gelderman, 1996). For all simulations, inorganic N was assumed to not limit yield. Current N fertilizer recommendations are a function of yield goal, amount of nitrate-N contained in the surface 60 cm of soil, and N credits from soybeans or manure. The simulation analysis did not consider the impact of landscape position on N mineralization, denitrification, volatilization, immobilization, or leaching and assumed that within a simulation the field had uniform yield. A second assumption was that 45 kg N ha^{-1} of residual nitrate-N was available at all sampling points. The amount of residual N was consistent with the N recommendation for unsampled fields (Gerwing and Gelderman, 1997). This simplification was made because: (i) in South Dakota in a corn and soybean rotation when university N recommendations are followed the amount of residual nitrate contained in the soil two years after the last N fertilizer application has been shown to be equal to approximately 45 kg N $^{-1}$ (Clay et al., 1997a, 1997b); (ii) when sampled on a 90 m grid, nitrate N typically shows weak spatial dependence (Clay et al., 1997a, 1997b); and (iii) due to transient nature of soil nitrate, many consultants only make site specific P recommendations and estimate N requirements using the approach described above.

Enterprise Budgets

The profitability of the different sampling techniques was estimated using enterprise analysis (Wollenhaupt et al., 1997; Lowenberg-DeBoer and Swinton, 1997). The enterprise analysis assumptions were that: (i) 100 Kg of corn at 0% moisture sells for $9.82 (US); (ii) the yield goal was the maximum yield within a simulation and P fertilizer could increase yield to 95% of the yield goal; (iii) uniform fertilizer application costs were $12.30 ha^{-1}; (iv) variable rate fertilizer application plus information expenses (software training and obtaining detailed soil maps) were $18.50 ha^{-1}; (v) the diammonium phosphorous (DAP: 18-46-0) cost was $275 Mg^{-1} [$275/(1000 kg * 0.46 * 0.44) = $1.35 kg P^{-1}] and urea cost was $0.50 $(kg\ of\ N)^{-1}$; (vi) sampling and analysis costs were estimated at $20 for each sample; (vii) the N contained in the DAP was equivalent to N contained in the urea and, therefore, DAP-N was subtracted from the N recommendation; (vi) university N and P fertilizer recommendation models were correct; and (vii) expenses for yield monitors and other equipment were identical for precision and conventional treatments.

The appropriateness of sampling cost amortization in fields where P is variably applied is beyond the scope of this paper, and therefore to avoid this issue, amortization was not conducted. The alternative to amortization was to mimic sampling and fertilization strategies used by land managers. The model systems mimicked were: (i) the continuous corn rotation where fertilizer applications and sampling is conducted annually, and (ii) the corn followed by soybean rotation where fertilizer applications and sampling is conduced biannually. In a general sense, increasing amortization length increases the profitability associated with precision farming.

Incorrect Management Zone Characterization

The percentages of land incorrectly characterized by the different sampling techniques were determined by comparing the 30-m grid recommendation map to the recommendation maps defined by each sampling approach. Yield losses due to incorrect characterization were determined by comparing calculated yields for the 30-m grid with calculated yields for the different sampling approaches.

RESULTS AND DISCUSSION

Uniform Phosphorus Application

Field P, K, Zn, and pH values of the surface 15-cm of soil were 13.1 mg kg^{-1}, 193 mg kg^{-1}, 1.30 mg kg^{-1}, and 6.5 (-log[H^+]), respectively (Chang et al., 1999). Potassium and Zn levels were sufficient for corn and soybeans (Gerwing and Gelderman,

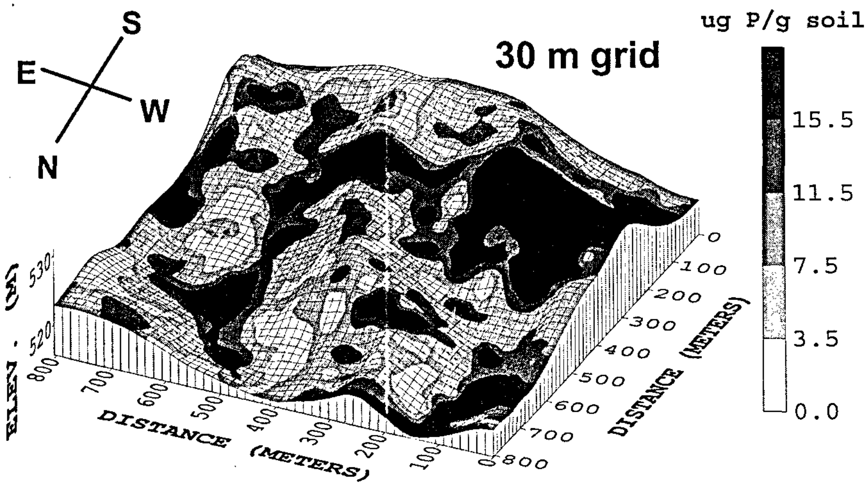

FIGURE 2. The Olsen P contour map based on the 30-m grid sampling.

1996). However, 7.9 kg of P ha^{-1} was recommended as an uniform application. A comparison between the 30-m grid and the uniform P application recommendation map showed that 56.5% of the field was under-fertilized by the uniform P application treatment.

An area located in the west central part of the field had very high P concentration (Figure 2). A historical search revealed that this area was the location of a feedlot during the 1930s. If this area was sampled separately from the rest of the field, then the field and feedlot would have been characterized as high and very high, respectively. Sampling the feedlot separately would have reduced over-fertilized land by 8% when compared to conventional treatment. A simulation analysis, using a yield goal of 7.7 Mg ha^{-1} and the high P model, indicated that for both of these treatments the corn yield was 0.44 Mg ha^{-1} less than the 30 m grid. If P was not applied, the simulation analysis showed that corn yields would have been reduced 0.71 Mg ha^{-1}. It is important to point out that a less responsive soil would have had smaller losses, while a more responsive soil would have had larger losses.

Soil Property-Based Sampling: Landscape

Toeslope areas had the lowest total N and upper backslope areas had the highest total N concentration, respectively (Table 1). In all landscape positions, P was in the high range, K was in the very high range, and Zn was in the high or very high range. This sampling approach had an identical P fertilizer recommendation map as

TABLE 1. The mean and 95% confidence interval (CI) for total N, total organic C, $\delta^{13}C$, NO_3-N, Olsen P, K, Zn, pH, and yield for soil collected from the different landscape positions.

	N	C	$\delta^{13}C$	NO_3-N	P	K	Zn	pH	Yield
	-- g mg^{-1} --		‰	-------- mg kg^{-1} --------					Mg ha^{-1}
Toeslope (32% of the field)									
Mean	2.48	29.5	-17.0	12.7	12.9	198	1.30	6.90	5.34
CI	0.04	0.58	0.18	1.44	0.96	7.04	0.10	0.14	0.24
Footslope (10 % of the field)									
Mean	2.45	30.3	-16.9	12.4	13.9	194	1.33	6.26	5.84
CI	0.06	0.96	0.16	1.12	2.2	13.8	0.14	0.12	0.46
Lower backslope (13% of the field)									
Mean	2.41	30.7	-16.8	13.2	14.1	190	1.37	6.23	6.09
CI	0.06	0.80	0.12	2.14	1.88	13.0	0.14	0.10	0.30
Upper backslope (7 % of the field)									
Mean	2.24	28.6	-16.7	11.3	14.5	186	1.44	6.12	5.97
CI	0.08	0.76	0.24	2.40	3.38	18.0	0.44	0.18	0.30
Shoulder (12% of the field)									
Mean	2.32	28.4	-16.7	9.97	11.9	178	1.12	6.27	5.90
CI	0.06	0.78	0.20	1.12	1.36	12.0	0.12	0.14	0.26
Summit (26% of the field)									
Mean	2.38	28.8	-16.9	12.7	13.4	208	1.35	6.35	5.85
CI	0.04	0.56	0.12	1.56	1.46	12.4	0.18	0.12	0.20

the uniform P application treatment, and under-fertilized approximately 57% of the field. Predicted yield loss, relative to the 30-m grid, was identical to the uniform P application treatment.

Soil Property-Based Sampling: Soil Series

The level 1 soil survey identified 16 different soil series in the field. Of the 16 soil series, eight represented less than 2% of the field and are not considered in the following discussion. The Cubden silty loam (Cu) and Waubay silty loam(WaA) soil series were located in toeslope areas (Figure 3) and had similar total N, Olsen P, K, total organic carbon (C), and Zn concentrations but were dissimilar in pH, and $\delta^{13}C$ values (Table 2). One explanation for higher $\delta^{13}C$ and pH values in Cu than WaA surface soil may be that Cu had higher carbonates than WaA.

The soils in lower backslope and footslope areas were the Doland loam (DoB) and Kransburg silty loam(KrA). These soils had similar total N, total organic C, and pH, while Olsen P, K, and Zn were higher in KrA than DoB. Soil in the upper backslope positions were the Kranzburg silty loam(KrB) and Waubay silty loam(WaB). These soils had similar chemical properties and grain yields. In summit

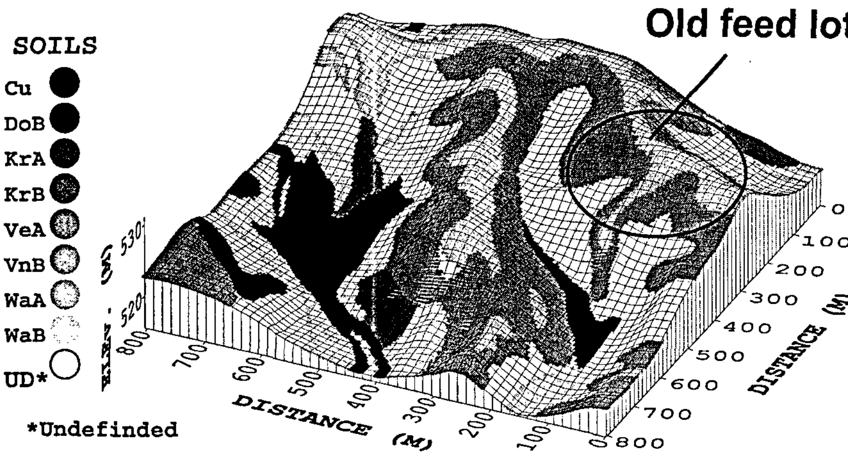

FIGURE 3. The relative locations of the different soil series and feedlot.

and shoulder areas, Venagro loam(VeA) and Vienna silty loam(VnB) had similar total N and Olsen P concentrations, while VeA had lower total organic C, K, Zn, and pH values than VnB.

The soils located in toe and upper backslope positions (Cu, KrB, WaB, WaA, VnB) had high P and represented 90% of the field. The remaining 10 % of the field (KrA, DoB, and VeA) had medium P (Table 3). Using the soil series classification and a yield goal of 7.7 Mg ha^{-1} as input for the high P simulation model, the simulation model predicted a yield loss of 0.32 Mg ha^{-1} when compared to the 30 m grid.

If the old feedlot was sampled separately, then soils located in the summit, shoulder, and upper backslope (KrA, DoB, VeA, VnB, KrB, and WaB) had medium P values, while soils in the foot and lower backslope (Cu and WaA) had high P values. Based on this characterization, the field was split into three zones where: (i) the P concentration was very high (old feedlot); (ii) the P concentration was medium (summit, shoulder, and upper backslope); and (iii) the P concentration was high (foot and lower backslope). When compared to the uniform P treatment, the soil + historic recommendation increased the amount of P applied to summit and shoulder areas and reduced P rates in foot and lower backslope positions. Based on this classification (soil series plus historic information), 33.5% of the field was under-fertilized. Using the soil series plus historic information classification approach and a yield goal of 7.7 Mg ha^{-1} as input for the high P model, the simulation model predicted a yield loss of 0.19 Mg ha^{-1}.

TABLE 2. The mean and the 95% confidence interval for total N, total organic C, $\delta^{13}C$, NO_3-N, Olsen P, K, Zn, pH, and yield for the different soil series.

	N	C	$\delta^{13}C$	NO_3-N	P	K	Zn	pH	Yield
	-- g mg^{-1} --		‰	--------- mg kg^{1} ---------					Mg ha^{-1}
Cubden silty loam (Cu; 9% of the field, toeslope)									
Mean	2.65	30.5	-17.0	10.4	12.8	211	1.07	7.77	6.03
CI	0.09	1.1	0.24	1.56	1.91	10.6	0.15	0.15	0.35
Waubay silty loam (WaA; 13 % of the field, footslope)									
Mean	2.59	29.8	-17.6	15.5	14.2	190	1.41	6.98	4.48
CI	0.08	0.87	0.23	1.89	1.69	9.44	0.17	0.21	0.41
Kransburg silty loam (KrA; 4 % of the field, footslope)									
Mean	2.36	28.6	-17.0	13.6	9.5	187	1.15	7.04	4.54
CI	0.09	1.27	0.25	3.97	1.96	17.3	0.29	0.32	0.67
Doland loam (DoB; 3% of the field, lower backslope)									
Mean	2.44	25.8	-17.3	11.3	8.06	136	0.88	6.15	4.77
CI	0.126	1.13	0.20	2.41	1.12	12.6	0.15	0.30	0.69
Kranzburg silty loam (KrB; 33% of the field, upper backslope)									
Mean	2.34	29.7	-16.6	10.7	13.5	198	1.35	6.15	6.12
CI	0.04	0.37	0.08	1.05	1.42	9.8	0.12	0.06	0.15
Waubay silty loam (WaB; 22% of the field, upper backslope)									
Mean	2.45	30.2	-17.0	13.5	14.0	198	1.45	6.30	5.87
CI	0.04	0.64	0.1	1.62	1.19	7.0	0.10	0.10	0.29
Vienna silty loam (VnB; 13% of the field, shoulder)									
Mean	2.24	27.6	-16.6	13.3	13.7	204	1.29	6.33	5.62
CI	0.07	0.80	0.23	2.48	2.03	18.0	0.30	0.12	0.24
Venagro loam (VeA; 3% of the field, summit)									
Mean	2.25	22.7	-17.3	10.2	8.63	120	0.78	5.69	5.36
CI	0.17	1.27	0.12	1.91	1.70	6.5	0.11	0.07	0.78

Grid Sampling

The two 90 m contour maps shown in figure 4 were obtained by varying where the first grid sample was collected (Chang et al., 1999) (Figure 4). A P fertilizer recommendation based on Figure 4A under-fertilized 23.6% of the field (Table 4), and using the model parameters described above was estimated to reduced corn yield 0.14 Mg ha^{-1}. The fertilizer recommendation map for figure 4B under-fertilized 40.9% of the field, and was estimated to reduce yield 0.31 Mg ha^{-1}. These findings show that the ability to convert information into increased yield was dependent where the first sample was collected.

Enterprise Budgets: Continuous Corn

For the uniform P treatment, N and P recommendations for a 7.7 Mg ha^{-1} yield goal were 88 and 7.9 kg ha^{-1}, respectively (Table 3). If diammonium phosphate

TABLE 3. The influence of sampling technique on the percentage of soil testing in very low, low, medium, high, and very high P categories.

Sampling technique	Very low <3.5	Low 3.5-7.5	Medium 7.5-11.5	High 11.5-15.5	Very high >15.5
	Soil test categories and soil P concentration range				
	% of the 65 ha field				
Field				100	
Field+feedlot				92	8
Landscape position				100	
Soil type			10	90	
Soil type+feedlot			64.9	22.0	13.1
Grid maps					
90 m (Fig. 4A)		20.6	36.6	14.9	27.9
90 m (Fig. 4B)		3.1	25.2	32.5	39.2
90 m ave.[1]	0.0 (0.79)	22.8 (4.35)	31.7 (5.50)	19.7 (3.68)	25.1 (4.73)
60 m ave.[1]	0.5 (0.55)	22.6 (1.46)	29.2 (5.54)	22.0 (5.62)	25.9 (1.15)
30m	0.7	23.6	32.2	16.5	27.0

[1]The 60- and 90-m grid means have 4 and 9 replicates, respectively. Values in parentheses are standard deviations.

(DAP) was the P source, then the amount of N contained in the DAP reduced the N requirement. For this treatment the investment for soil sampling, N and P fertilizer, and applying the fertilizer was $4,146 (Table 5).

By considering the 0P treatment as the control, the potential profitability of several different sampling approaches were estimated. Sample calculations and results from the simulation analysis for a yield goal of 7.7 Mg ha^{-1} and high P response model are shown in Table 5. As discussed below, expenses were not amortized over several years. In a general sense, amortization increased the profitability associated with the precision treatments (data not shown). The ability to convert spatial information into increased profits were influenced by crop value, yield goal, fertilizer cost, soil P level, P model, and rotation (Table 6). Generally, reducing P fertilizer costs, increasing corn value, or P response increased precision farming profitability.

Yield goal had a mixed impact on calculated profitability because increasing yield goals increased fertilizer costs, but also increased expected yield gains (Table 6). For the low P response model, increasing yield goal or applying P reduced profitability for all sampling approaches. For the medium P response model increasing the yield goal increased profitability with the uniform P treatment having the highest calculated profits. For the high P response model, the soil type + historic sampling approach had the highest profits.

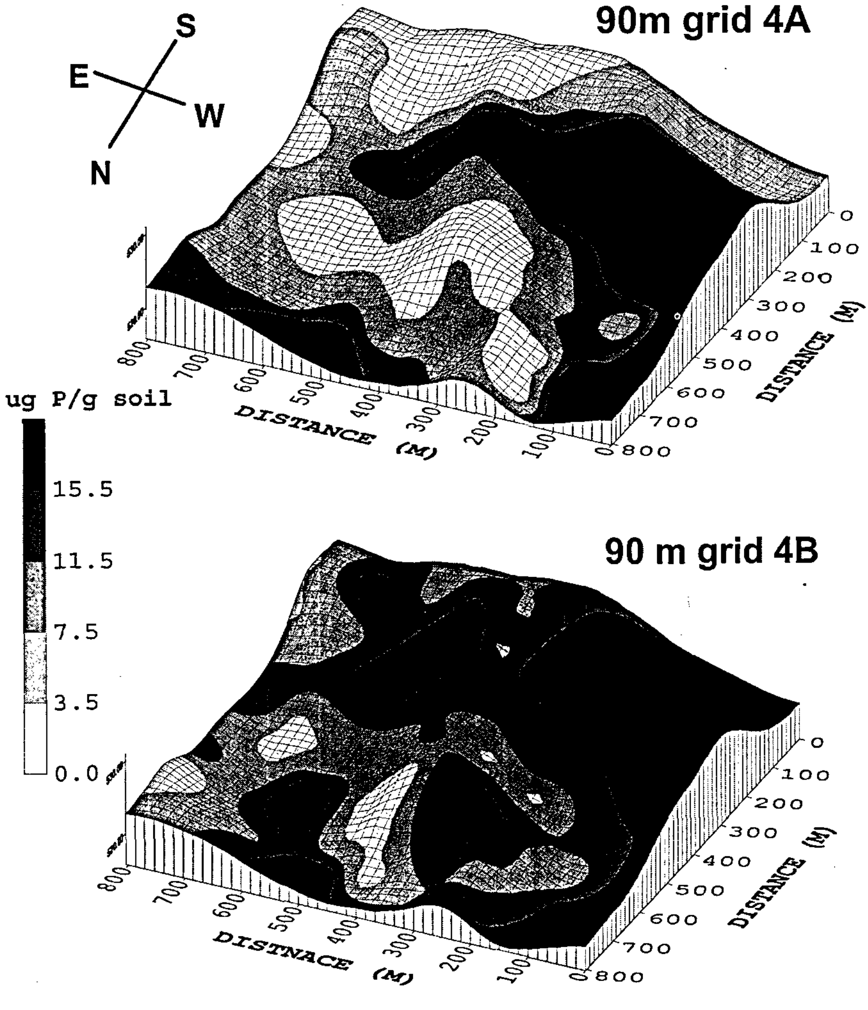

FIGURE 4. Two of the possible 9 Olsen P contour maps with a 90-m grid distance.

Calculations in tables 5 and 6 were based on using variable rate equipment plus information expenses which, relative the conventional application approach, increased costs \$6.15 ha^{-1}. If variable rate equipment was not used, then information plus application costs would have been much lower, which in turn would have increased the soil + historic profits. It is important to point out the entire field did not fit any one of the criteria in Table 6, and that depending on the climatic

TABLE 4. The ha of land, relative to the 30-m grid, under-fertilized by the soil + historic and 90 m grid sampling approaches.

Sampling approach	Classified as	P concentration mg kg^{-1}	Correct classification based on the 30-m grid High	Medium	Low
			---------- ha ----------		
Soil + historic	High	12-15		6.37	2.34
	Medium	8-11			13.00
90-m grid 4A	Very high	>16	3.84	2.91	0.34
	High	12-15		3.84	1.77
	Medium	8-11			2.66
90-m grid 4B	Very high	>16	3.32	7.28	2.54
	High	12-15		7.35	1.89
	Medium	8-11			4.88

conditions the yield goal for the different areas may change. For example, the footslope areas during the cool wet year of 1995 had low corn yields and during the hot summer of 1998 had high yields. The crops response to P may also vary within a field. For example, Malzer et al. (1999) reported that areas with poor drainage may be the most responsive to added P.

Enterprise Budgets: Corn/Soybean Rotation

In the corn/soybean model system, resampling occurred every two years and the spatial information was obtained using the soil + historic sampling approach. The simulation analysis (7.7 Mg ha^{-1} corn yield goal, 2.8 Mg ha^{-1} soybean yield goal, and moderate P response model) showed that precision P management increased profitability \$3.74 ha^{-1} relative to the uniform or zero P treatments. The profitability was increased by precision P management, because based on composite soil sample for the uniform P treatment, additional P was not recommended for soybeans. Again profits, as previously discussed for the continuous corn rotation, were directly related to P response model, yield goal, crop value, and fertilizer cost.

CONCLUSIONS

In conclusion, this paper investigated the potential profitability associated with different sampling approaches and using historical information to identify management zones. The value of the spatial information was dependent on the crops response to P, the ability the different sampling techniques to accurately classify the field, crop rotation, the length of time between sampling dates, and the ability to locate P hot spots prior to sampling. In a related paper a technique for identifying P hot spots prior to sampling is discussed (Clay et al., 2000). All of the

TABLE 5. An example showing how profitability was calculated. In this example, a yield goal of 7.7 Mg ha^{-1} was used as input for the high P simulation model. The different columns represent: (i) analysis and sampling costs (analy & sampling), (ii) information plus fertilizer application costs (infor. & appl.), (iii) DAP and urea fertilizer costs, (iv) the expected return from the fertilizer investment as estimated by the simulation model, (v) investment differences, and (vi) expected return from the investment. The 90-m grid calculations are for grid maps shown in Figure 4A (a) and 4B (b).

Sampling Approach	#	Analy & sampling	Infor. & appl.	Fertilizer[1,2] DAP	Fertilizer[1,2] Urea	Total N&P Invest	Return[3] from P fert	Return[3] Prec-0 P	Invest Prec-0 P	Profit
		US$/65 ha field								$/ha
Contol 0P		0	0	800	0	2860	3660	0		
Uniform P	1	20	800	695	2631	4146	1765	1765	486	9.67
Uniform P+H	2	40	1200	619	2656	4515	1765	1765	855	14.00
Landscape	6	120	1200	695	2631	4646	1765	1765	986	11.98
Soil type	8	160	1200	809	2594	4763	2514	2514	1103	21.70
Soil type+H	9	180	1200	1338	2419	5137	3349	3349	1477	28.80
90 m (a)	60	1200	1200	1378	2406	6184	3663	3663	2524	17.53
90 m (b)	60	1200	1200	775	2600	5775	2818	2818	2119	10.76
Column	A	B	C	D	E	F	G	H	I	J
Column calculation		A*$20				$\sum B_iE_i$		G_i-G_1	F_i-F_1	(H-I)/65

[1]DAP=diammonium phosphate (18-48-0) cost calculated at 1.35 kg^{-1} of P. Urea cost calculated at $0.50 Kg^{-1} of urea-N and the amount of urea needed was adjusted for the amount of N contained in the DAP.

[2]To calculate the Kg of P added to the 65 ha field divide the fertilizer-DAP by 1.355.

[3]Expected returns were calculated using the high response model, which had a maximum gain from fertilizer of 35%.

TABLE 6. The influence of P response model, yield goal, and sampling approaches (soil, soil + historic, and 90-grid sampling) on estimated profitability when P fertilizer is applied and sampled annually to a continuous corn rotation. Profitability was estimated following the procedure demonstrated in Table 5.

Sampling technique	Yield goal Mg ha^{-1}		
	5.5	7.7	10.0
	------- Profit $US/ha year -------		
Low P model (max 5% yield increase)			
Control +P	-1.35	-2.91	-3.84
Soil type	- 9.04	-10.25	-11.10
Soil type + historic	-11.10	-13.62	-15.60
90 m grid 3A	-26.60	-28.66	-30.70
90 m grid 3B	-24.10	-25.00	-25.90
Moderate P model (max 15% gain)			
Control +P	4.33	4.46	6.08
Soil type	-1.11	0.04	2.93
Soil type + historic	-1.32	0.11	1.97
90 m grid 3A	-15.90	-14.10	-10.90
90 m grid 3B	-16.40	-13.50	-11.30
High P model (max 35% gain)			
Control +P	16.76	19.67	24.48
Soil type	15.62	21.70	25.77
Soil type+ historic	22.44	28.80	38.10
90 m grid 3A	7.45	17.53	27.75
90 m grid 3B	1.12	10.76	16.40

different sampling techniques produced different application maps and were not as accurate as the 30-m grid map. The recommendation map based on a single composite sample under fertilized 56.5% of the field. Increasing the sampling density reduced the percentage of under-fertilized land. If corn had a low P response, then simulation/enterprise analysis indicated that applying P did not increase profits. For all scenarios tested, the soil type + historic sampling approach had higher potential profits than the 90 m grid. For a corn/soybean rotation, where fertilizer was applied when corn was planted and N and P was not applied to soybeans, enterprise/simulation analysis (2.8 Mg ha^{-1} soybean yield goal and a moderate P model) showed that soil + historic sampling approach increased profitability $3.74 ha^{-1} when compared to the uniform P treatment.

REFERENCES

Cambardella, C.A., T.B. Moorman, J.M. Novak, T.B. Parkin, D.L. Karlen, R.F. Turco, and A.E. Konopka. 1994. Field scale variability of soil properties in central Iowa soils. Soil Sci. Soc. Am. J. 58:1501-1511.

Chang, J. 1997. Soil spatial variability as influenced by landscape position and soil sampling strategy. M.S. thesis, South Dakota State University, Brookings, SD.

Chang, J., D.E. Clay, C.G. Carlson, J. Lee, D.D. Malo, S.A. Clay, and M.M. Ellsbury. 1999. Selecting precision farming soil sampling protocols. Part 1. Grid distance impact of semivariograms and estimation variances. Precision Farming 1:227-289.

Clay, D.E., C.G. Carlson, and S.A. Clay. 2000. A lesson learned in identifying P management zones. Precision Agric. (in press).

Clay, D.E., C.G. Carlson, K. Brix-Davis, J. Oolman, and B. Berg. 1997a. Soil sampling strategies for estimating residual N. J. Prod. Agric. 10:446-452.

Clay, D.E., J. Chang, S.A. Clay, M. Ellsbury, C.G. Carlson, D.D. Malo, D. Woodson, and T. DeSutter. 1997b. Field scale variability of nitrogen and delta 15-N in soil and plants. Commun. Soil Sci. Plant Anal. 28:1513-1527.

Crepis, J. and R.L. Johnson. 1993. Soil sampling for environmental assessment. pp. 5-18. In: M.R. Carter (ed.), Soil Sampling and Method of Analysis. Canadian Soil Science Society, Lewis Publisher, Ann Arbor, MI.

Englund, E. and A. Sparks. 1991. GEO-EAS1.2.1: Geostatistical Environmental Assessment Software User's Guide. Environmental Monitoring Systems Laboratory, Office of Research and Development, US-EPA, Las Vegas, NV.

Ferguson, R.B., C.A. Gotway, G.W. Hergert, and T.A. Peterson. 1996. Soil sampling for site-specific nitrogen management. pp. 13-22. In: P. Robert, R. Rush, and W.E. Larson (eds.), Proceedings of the 3rd International Conference on Precision Agriculture, June 23-26, Minneapolis, MN. American Society of Agronomy, Madison, WI.

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

Franzen, D.W., L.J. Cihacek, V.L. Hofman, and L.J. Swenson. 1998. Topography-based sampling compared with grid sampling in the northern Great Plains. J. Prod. Agric. 11:364-370.

Frazier, B.E., C.S. Walters, and E.M. Perry. 1997. Role of remote sensing in site-specific management. pp.149-160. In: F. Pierce and Sadler (eds.), The State of Site Specific Management for Agriculture. American Society of Agronomy, Madison, WI.

Froment, M.A., A.G. Chalmers, S. Peel, and S.J. Dawson. 1996. The use of grid soil sampling to measure soil nutrient variation within intensively managed grass fields in the UK. pp. 227-236. In: P. Robert, R. Rust, and W.E. Larson (eds.), Proceedings of the 3rd International Conference on Precision Agriculture, June 23-26, Minneapolis, MN. American Society of Agronomy. Madison, WI.

Gerwing, J and R. Gelderman. 1996. Fertilizer Recommendation Guide. January 1996. Cooperative Extension Service, South Dakota State University, Brookings, SD.

Hergert, G.W., R.B. Ferguson, C.A. Shapiro, E.J. Penas, and F.B. Anderson. 1995. Classical statistical and geostatistical analysis of soil nitrate-N spatial variability. pp.175-186. In: P. Robert, R. Rust, and W.E. Larson (eds), Proceedings of Site-Specific Management for Agricultural Systems 2nd International Conference, March 27-30, 1994, Minneapolis, MN. American Society of Agronomy, Madison, WI.

Isaaks, E.H. and R.M. Srivastava. 1989. An Introduction to Applied Geostatistics. Oxford University Press, New York, NY.

Lowenberg-DeBoer, J. and S.M. Swinton. 1997. Economics of site-specific management in agronomic crops. pp. 369-306. In: J. Pierce and S. Sadler (eds.), The State of Site Specific Management for Agriculture. American Society of Agronomy, Madison, WI.

Mallarino, A.P. 1996. Spatial variability patterns of phosphorus and potassium in no-tilled soils for two sampling scales. Soil Sci. Soc. Am. J. 60:1473-1481.

Malzer, G.L., D.J. Mulla, and T.S. Murrell, 1999. Getting specific with site-specific nutrient management. In: D.E. Clay (ed.), Site Specific Management Guidelines. SSMG 23. Potash and Phosphate Institute, Bern Switzerland.

Mohamed, S. B., Evans, E.J., and Shiel, R.S. 1996. Mapping techniques and intensity of soil sampling for precision farming. pp. 217-226. In: P. Robert, R. Rust, and W.E. Larson (ed), Proceedings of the 3rd International Conference on Precision Agriculture, June 23-26, 1996, Minneapolis, MN. American Society of Agronomy, Madison, WI.

North Central Regional Publication. 1988. Recommended Chemical Soil Test Procedures for North Central Region. Publ. No. 221. North Dakota State University, Fargo, ND

Soil Survey Staff. 1993. USDA Handbook #18: Soil Survey Manual. NRCS, Washington, DC.

Wollenhaupt, N.C., R.P. Wolkowski, and H.F. Reetz. Jr. 1997. Variable rate fertilizer application: Update and economics. In: R.M. Vander Hewel (ed.), Information Gathering: Precision Agriculture and Intensive Soil Sampling. Cenex Land O'Lakes, Agronomy Technical Services/Agrisource Laboratories, Inner Grove Heights, MN.