THE INFLUENCE OF DIFFERENT APPROACHES FOR IDENTIFYING N AND P MANAGEMENT ZONE BOUNDARIES

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ABSTRACT

The effectiveness of the nutrient management zones approach rests on locating zonal boundaries. Once identified, soil samples can be collected, analyzed, and recommendations developed. The objective of this study was to determine the influence of different approaches for identifying N and P management zone boundaries on nutrient variability and fertilizer recommendations. Research was conducted in three fields located in eastern South Dakota. Data included in the analyze were an order 1 soil survey map, aerial photographs collected between 1950 and 1960, elevation, apparent electrical conductivity (EC_a), and soil nutrient concentrations. Soil samples collected on at least a 60 by 60 m grid were analyzed for Olsen-P and NO_3-N. Techniques for locating management zone boundaries included blocking areas by size, classification using the equal interval option in a geographic information system (GIS), and classification using cluster analysis. Pooled variances (s^2_p) were calculated for each sampling approach. A F test was used to determine if the sampling approach reduced nutrient variation. Generally, sampling old homesteads separately from the rest of the field reduced soil Olsen-P and NO_3 –N s^2_p. The s^2_p could be reduced further by block sampling (3.5-4 ha in size). The impact of blocking on s^2_p was attributed to homesteading subdividing the fields into areas that were 4 to 8 ha in size. Characterization based on soil attribute information had a mixed impact on s^2_p. Findings from this study suggest that areas are not physically connected should not be composited into a single sample, and that both intrinsic and prior management must be considered in developing nutrient management zone boundaries.

Keywords: Management zone, Nitrogen, Phosphorus, Nutrient variability, Fertilizer recommendation.

INTRODUCTION

Large areas of fields can be under- and over-fertilized when whole field fertilizer recommendations are followed (Chang et al., 2000). A key precision agriculture concept is that fertilizer recommendations can be improved by accounting for in-field nutrient variability. Selecting a sampling approach that reduces error and improves profitability is not a trivial problem because the value of the information must be balanced against the cost of obtaining the information.

Commonly used strategies for obtaining spatial information are grid, block, and soil attribute sampling. In grid sampling, samples are collected from specific points within fields and kriging is used to estimate values at unknown points (Chang et al., 1999). Grid sampling provides excellent information if the grid points are close enough to assure spatial dependence. Some researchers prefer grid sampling because it eliminates personal bias. Land managers have been using grid soil sampling to obtain spatial nutrient information. Problems with grid sampling are that it ignores unique or unusual topographic fertility areas that occur between sampling points, and it is labor intensive.

Management zone sampling is an alternative strategy that may reduce sampling costs with a minimal loss of information (Fleming et al., 2000). Management zones can be based on intrinsic variability or prior management. Management zone demarcation based on intrinsic variability relies on the observation that fields are a mosaic of habitat types with each having unique characteristics that influence soil properties (Doerge, 1999). The success of the management zone approach rests on the ability to locate zone boundaries. Once boundaries are identified, samples from each zone can be collected, analyzed, and used for management recommendations. Information layers that have been used for identifying management zones include: soil type, yield maps, topography maps, soil drainage, soil apparent electrical conductivity (EC_a), soil color, soil organic matter, remote sensing data, and moisture content (Doerge, 1999). Franzen et al. (1998) compared topography-based sampling with grid sampling. They reported that NO_3-N and P concentrations from management zone demarcation based on topographic information were correlated to values calculated on a 60-m grid. Fleming et al. (1999) used aerial photographs as templates for farmer developed productivity management zones in two center pivot irrigated fields near Wiggins, Colorado. High nutrient concentrations (NO_3^-, K, and Zn) and yield were observed in high productivity zones. Soil organic matter, % clay, and EC_a were significantly correlated with yield. Franzen et al. (2002) compared order 2, order 1, topography-based, and grid sampling approaches. Franzen et al. (2002) reported that published order 2 surveys should not be used for identifying N management zones, unless the soil patterns are verified with other zone development tools.

Computerized classification can be used for delineating management zone boundaries. Fridgen (2000) and Fridgen et al. (2000) used cluster analysis to identity zone boundaries. Information layers that can be considered in the analysis includes yield, EC_a, elevation, soil type, soil test results, slope, aspect, and remote sensing data. This approach has had some success and in Missouri, approximately 54% of the yield variation was explained using cluster analysis of EC_a, elevation, and slope information.

Management zones can also be on prior management. Prior management information can be obtained from old aerial photographs or by interviewing landowners. During homesteading, many quarter sections were split into rectangular blocks that ranged in size from three to eight ha. In prior management sampling, each previous subdivision is sampled separately. Advantages with prior management sampling are that zone sampling negates the need for interpolation and the sampling costs are less than grid sampling costs. A disadvantage with prior management sampling is that it is difficult to ascertain all the subdivisions that may have occurred over a 100-150 year period. Given all the different approaches available for identifying management zones, producers have asked, what is the best approach for identifying nutrient management zones? It is likely that the answer is dependent on interactions between prior management, climatic conditions, intrinsic soil variability, and the type and quality of information available for classification. The objective of this study was to determine the influence of different approaches for identifying N and P management zone boundaries on reducing nutrient variability and fertilizer recommendations.

MATERIALS AND METHODS

Study Fields and Soil Samples

This research was conducted at the Moody (65-ha), Brookings (65-ha), and Beresford (40-ha) sites. All of the sites were located in eastern South Dakota and the rotation was corn followed by soybean. The Moody field was located at 44.17^{o}N latitude and 96.62^{o}W longitude. The Brookings field was located at 44.23^{o}N latitude and 96.65^{o}W longitude. The Beresford site was located at 43.05^{o}N latitude 96.89^{o}W longitude. Soil information for these fields is available in Clay et al. (2001). Soil samples from the 0-15 and 15-60 cm depths were collected at Moody from a 30 by 30 m grid in 1995. At Brookings and Beresford, soil samples from the same depths were collected from a 60 by 30 m grid and 60 by 60 m grid, respectively in 1997. Each grid sample consisted of 15 individual cores. The sampled points were located by latitude, longitude, and elevation using a carrier phase frequency differential Global Positioning System (DGPS). The vertical error of the system was ±2 cm (Johansen et al., 2001).

Soil samples were prepared for analysis by air-drying (35^{o}C) and grinding to less than 2 mm. Inorganic N was extracted from samples collected at the 0-15 and 15-60 cm soil depths with 1.0 *M* KCl using a 10:1 solution to soil ratio and analyzed on a Astoria Analyzer 300 (Astoria-Pacific Inc., Clackamas, OR) using the Cd reduction method (Maynard and Kalra, 1993). Olsen-P was extracted from samples collected from the 0-15 cm soil depth with 0.5 *M* $NaHCO_3$ at a pH value of 8.5 (Olsen and Sommers, 1982). The soil extract was filtered, a color reagent containing ascorbic acid and molybdate was added, and color development was measured on a colorimeter set at 882 nm.

Apparent electrical conductivity (EC_a) was measured with an EM38 (Geonics, Ltd., Mississauga, ON, Canada) using the approach described by Clay et al. (2001). Aerial black and white aerial photographs of the sites (1950-1965) were obtained from county United States Department of Agriculture National Soil Resource Conservation Service Offices (USDA-NRCS). Order 1 soil survey maps (scale < 1:12,000) were developed by the USDA-NRCS staff at Moody and Brookings (Soil Survey Staff, 1993). An order 1 soil survey was not available at Beresford.

Locating Management Zone Boundaries

Techniques for locating management boundaries were: (i) based on previous management (field boundary demarcations and old homestead locations); (ii) based on soil attribute (EC_a, elevation, and aspect) and distance between sampling points using the equal interval option in ArcView (ESRI, 1996); (iii) based on soil attributes using cluster analysis; and (iv) based on an the order 1 soil survey map.

Zones based on previous field boundaries

Old aerial photographs (1950-1965) showed that the fields had been subdivided into small fields with sizes that ranged from 3 to 16 ha. An aerial photograph taken of Brookings field in 1956 demonstrates typical subdivision of many South Dakota fields (Fig. 1). In the three fields, an area containing an old home site or area where animals were grazed were identified. Identifying all of the subdivisions that occurred over a 125- year period was not possible, therefore, the fields were split into square blocks. At Moody, the field was split into 16, 9, and 4 square blocks that were 4, 7, and 16-ha in size, respectively. At Brookings, the field was split into 14 and 8 square blocks that were 3.5 and 6.6-ha in size, respectively. At Beresford, the field was split into 10, 6, and 3 square blocks that were 4, 7, and 13-ha in size, respectively.

Equal Interval Classification

The equal interval option within ArcView GIS (ESRI, 1996) was used to characterize soil attribute information into different management zones. Ten EC_a-elevation zones were identified by: (i) separating the field into five different

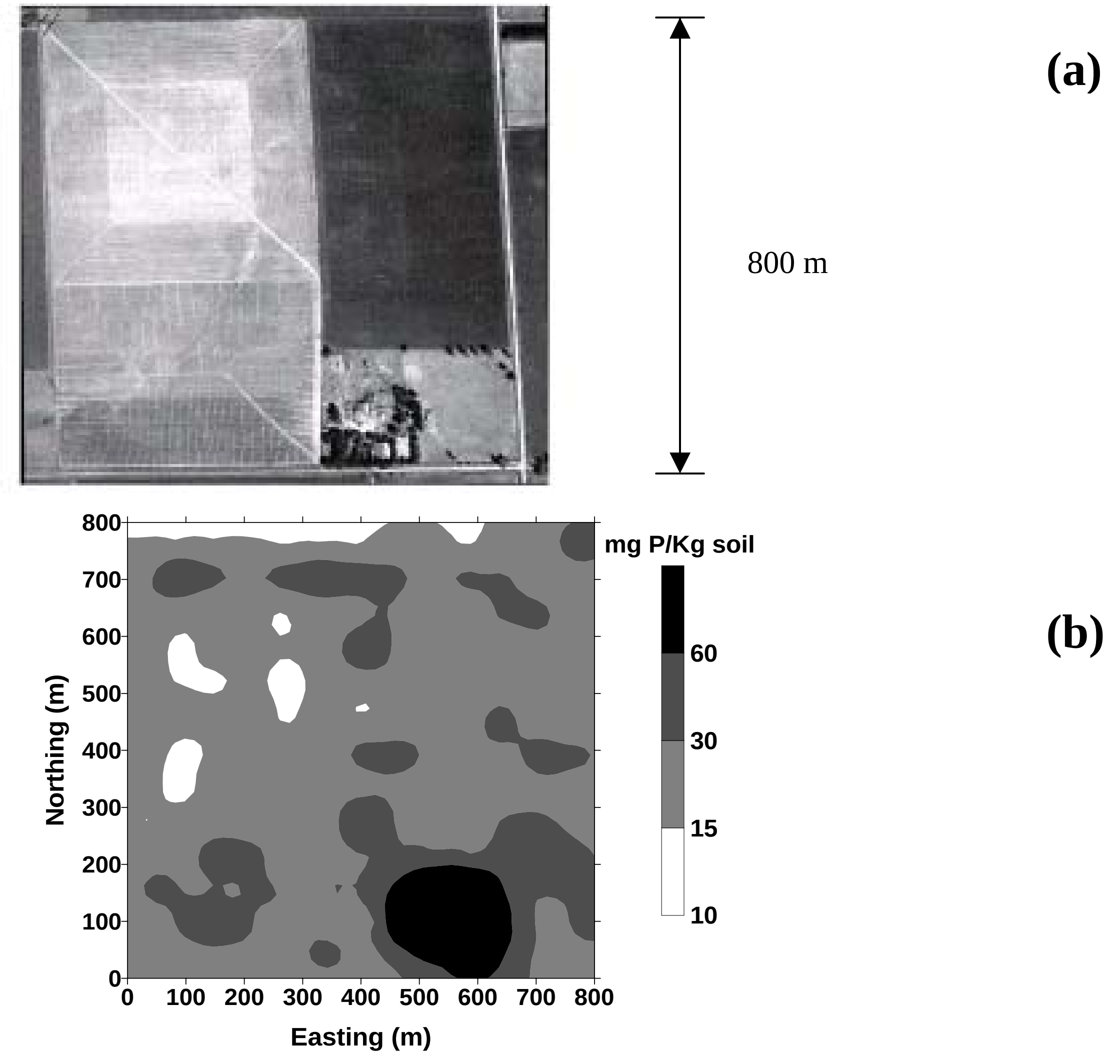

Figure 1. (a) An aerial image collected in 1956, and (b) Olsen P contour map of the Brookings field in 1998.

elevation zones, and (ii) subdividing the 5 areas into areas with less than or greater than the average EC_a value. For classification based on EC_a and distance information, the fields were separated in five different EC_a classes. These large groups were further subdivided into areas that were connected or not-connected. If they were connected, then they were identified as a single zone. If they were not connected, then they were characterized as two zones. For classification based on EC_a and aspect, the fields were separated in five different EC_a classes. These zones were further subdivided by four different aspects (316^o to 45^o, 46^o to 135^o, 136^o to 225^o, and 226^o to 315^o).

Cluster Analysis Classification

Mahalanobis distance and fuzzy *c*-means unsupervised clustering algorithms were used to identify different clusters (Johnson, 1998). These algorithms are available within Management Zone Analyst (MZA) (Fridgen, 2000). The combinations of three variables (EC_a, elevation, and aspect) were used for MZA. The number of management zones was determined by the minimum number of Normalized Classification Entropy (NCE) and Fuzziness Performance Index (FPI) (Fridgen, 2000).

Statistics and Calculations

Summary statistics, skewness values (Ott, 1977), and semi-variograms for Olsen-P and NO_3-N were determined. The models used to describe the relationship between sampling distance and the semi-variances were exponential, spherical, and linear. The model that accounted for the most variation was the criteria for selecting a given model.

Once management zone boundaries were identified, the mean and variance of each zone (s^2_i) was calculated. These variances were used to calculate pooled variances (s^2_p) using the equation:

$$s^2_p = \sum_{i=1}^{z} (n_i - 1)s_i^2 / [\sum_{i=1}^{z} (n_i) - z] \qquad [1]$$

where z was the number of sampling zones, n_i was the number of samples within zone *i*, and s^2_i was the variance within zone *i* (Steel and Torrie, 1980). A F-test (s^2_{field} / s^2_p) at p=0.1 was used to determine significant differences.

The P recommendation for corn (*Zea mays* L.) from each zone was calculated using the equation:

$$\text{P recommendation (kg P ha}^{-1}) = (0.7 - 0.044 * \text{STP}) * \text{YG} * 9.58 \qquad [2]$$

where STP was the soil test P (mg P kg^{-1}) and YG was the yield goal (8.8 Mg ha^{-1}) (Gerwing and Gelderman, 1998). The N fertilizer recommendation for corn was calculated using the equation:

$$\text{N recommendation (kg N ha}^{-1}) = 25.78 * \text{YG} - \text{STN} - \text{PCC} \qquad [3]$$

where STN was NO_3-N contained in the surface 60-cm of soil and PCC was the previous crop credit (legume credit, 44.8 kg N ha^{-1}) (Gerwing and Gelderman, 1998).

RESULTS AND DISCUSSION

Field Characteristics

Olsen-P and NO_3-N concentrations at the three sites had skewness values greater than 0 and medians less than the means (Table 1). Kravchenko and Bullock (1999) had similar results for fields located in Illinois, Indiana, and Iowa. Soil P concentrations were higher in the old homestead areas than the rest of the field (Table 1). A comparison between the 1956 aerial photograph and 1997 P contour map demonstrates the relationship between old homesteads and high P concentrations (Fig.1). Findings from the Brookings site showed that very high P concentrations can be associated with old homestead, even after 30 to 50 years of continuous cropping (Fig. 1). Franzen et al. (1998) had similar results in a field located in Valley City, North Dakota, where P level patterns were consistent between years, and very high P levels were observed where livestock were fed until 1960. No evidence of the pasture boundaries remain today in both North Dakota and South Dakota fields. Chung et al. (1995) showed that the direction of farming practices and applying fertilizer, i.e. north to south and east to west, also influence soil nutrient variability.

In all fields, soil P and nitrate concentrations were spatially dependent. The nugget to sill ratios ranged from 0.09 for Olsen-P at Brookings to 0.40 for NO_3 – N at Beresford. The nugget to sill ratio has been used as an indicator of spatial dependence (Cambardella et al., 1994). Spatial dependence is weak if the ratio is greater than 0.75, moderate if the ratio is between 0.75 and 0.25, and strong if the ratio is less than 0.25.

Soil Olsen-P

At Moody, removing the sampling points within the old homestead from the whole field data set reduced the field variance (Table 2). Splitting the field into 4-ha blocks or using EC_a-distance information to define P management zone further reduced s^2_p. Using cluster analysis or the order 1 soil survey to characterize management zones did not reduce s^2_p.

At Brookings, sampling the old homestead separately from the whole field reduced s^2_p (Table 3). Pooled variance was further reduced by splitting the field into 3.5-ha blocks. Cluster analysis or sampling by the order 1 soil survey did not reduce s^2_p.

At Beresford, sampling the old homestead separately from the whole field and block sampling (4 and 7-ha) reduced s^2_p (Table 4). Pooled variance values were further reduced by subdividing the field into 4 and 7 ha blocks. Classification based on soil attribute information had mixed results. When the data set contained the old homestead, s^2_p was reduced using the equal interval (EC_a-elevation, EC_a-aspect, and EC_a-distance) and cluster analysis (EC_a-aspect) approaches. When the homestead was sampled separately, soil attribute sampling did not influence s^2_p.

At Moody, Brookings, and Beresford sampling the homestead separately from the rest of the field reduced the field variance 37, 63, and 95%, respectively Lower variances indicate that sampling approach reduced the sampling error (Table 1). The equation:

$$n_{est} = t_p^2 * s^2 / d^2 \qquad [4]$$

where n_{est} is the estimated sampling requirement, t_p is the student T value associated with a specific probability level, s^2 is the variance, and d is allowable population mean range (Clay et al., 1997) shows that a reduction in s^2 results in lower sampling requirement and more accurate laboratory results.

Table 1. The means, minimums, maximums, medians, variances, skewnesses of the whole field, whole field without the homestead, and old homestead locations. The exponential (exp), spherical (sph), and linear (lin.) models were used to develop the semi-variograms.

	Moody’95		Brookings’97		Beresford’97	
	Olsen P	NO_3^-	Olsen P	NO_3^-	Olsen P	NO_3^-
	------------------------------ mg Kg^{-1} --------------------------------					
Whole field						
Mean	13.3	12.3	18.1	4.4	25.4	10.2
Median	11.0	9.2	15	3.9	12	8.0
Variance	60.8	72.6	268	8.1	1611	54
Skewness	1.69	1.1	6.2	3.6	4.22	4.16
# of samples	536		352		100	
Field w/o homestead						
Mean	12.3	12.6	16.4	4.3	13.9	9.4
Median	11.0	9.4	15.0	3.8	11.0	7.7
Variance	39.2	74.6	97.6	6.3	86.9	18.1
Skewness	1.4	1.0	4.5	2.8	1.9	1.2
Homestead						
Mean	33.1	6.9	61.3	7.4	114	16.6
Variance	62.1	4.6	2775	42.5	4778	301
Area (ha)	4		2.3		5.3	
			Semi-variogram			
Nugget	27.1	23.5	21.4	3.9	25.1	8.0
Sill	74.9	101	248	9.1	120	20.0
Range (m)	795	784	1572	824	420	320
Nugget/sill	0.4	0.2	0.1	0.4	0.2	0.4
Model	Exp.	sph.	sph.	lin.	sph.	sph.

Table 2. The influence of sampling approach on Olsen P pooled variances (s^2_p) at Moody.

			Old homestead			
Sampling		Number	Sampled separately		Not sampled separately	
Methods	Classes (n)	of zones	Pooled var.	F-test	Pooled var.	F-test
Block						
4-ha block	16	16	32.7	1.198	42.5	1.430
7-ha block	9	9	36.7	1.067	50.5	1.204
16-ha block	4	4	37.1	1.057	51.8	1.174
Equal interval						
EC_a-Elev.	10	29	36.2	1.081	53.5	1.136
EC_a-Aspect	18	62	35.3	1.110	50.4	1.204
EC_a-Distance	15	15	33.9	1.157	45.1	1.348
Cluster						
EC_a-Elev.	4	10	38.8	1.009	57.5	1.057
EC_a-Aspect	2	19	39.2	0.998	57.1	1.064
EC_a-Elev.-Aspect	5	8	39.2	0.998	60.9	0.998
Soil types	16	40	38.2	1.026	59.4	1.024
Whole field	1		39.2		60.8	

s^2_p value was significantly different from the whole field variance at $p=0.1$. The degrees of freedom for the numerator were equal to 536. The degrees of freedom for the denominator were 536-n.

For example, if d is 2 mg kg^{-1} and t_p is 2.00, then the whole field sampling would be for population with s^2 values of 50 and 25 would be 50 and 25 cores, respectively. These results show that simply sampling old homesteads separately from the rest of the field will improve fertilizer recommendations.

In the three fields, when the homestead was sampled separately, splitting the field into 4-ha blocks further reduced s^2_p. Spatial dependence and prior management may have interacted to produce these results. In two fields strong spatial dependence was observed and in one field moderate spatial dependence was observed. Strong and moderate spatial dependence indicates that has the sampling points become further away, the P values became less similar. The maximum distance between the sampling points in the 4 ha block sampling was 282 m. The other approaches did not have maximum distances. The 4 ha block sampling may also have matched up with the way the fields were originally farmed.

At Moody, including the homestead in the data set reduced the whole field P recommendation and increased the amount of the field that was under-fertilized. Splitting the field into 4-ha blocks increased fertilizer rates when compared to the whole field recommendation. When the homestead was sampled separately, splitting the field into 4 ha blocks reduced over-fertilized areas from 31.5 to 27.8 % and reduced under-fertilized areas from 57.1 to 45.0% (Table 5). Similar improvements were observed when the old homestead was not sampled separately.

Splitting the field into 4-ha blocks increased fertilizer rates when compared to the whole field recommendation. When the homestead was sampled separately, splitting the field into 4 ha blocks reduced over-fertilized areas from 31.5 to 27.8 % and reduced under-fertilized areas from 57.1 to 45.0% (Table 5). Similar improvements were observed when the old homestead was not sampled separately.

Table 3. The influence of sampling approach on Olsen P pooled variances (s^2_p) at Brookings.

			Old homestead			
			Sampled separately		Not sampled separately	
Sampling Methods	Classes	Number of zones	Pooled var.	F-test	Pooled var.	F-test
	(n)					
Block						
3.5-ha block	14	14	71.7	1.360	189	1.418
6.6-ha block	8	8	81.0	1.205	211	1.269
Equal interval						
EC_a-Elev.	9	24	87.7	1.112	251	1.066
EC_a-Aspect	13	56	94.2	1.036	251	1.067
EC_a-Distance	10	10	91.0	1.072	248	1.082
Cluster						
EC_a-Elev.	8	34	91.3	1.068	251	1.069
EC_a-Aspect	9	67	90.3	1.080	244	1.101
EC_a-Elev.-Aspect	8	38	90.0	1.084	249	1.077
Soil types	8	37	92.3	1.057	264	1.017
Whole field	1		97.6		268	

s^2_p value was significantly different from the whole field variance at p=0.1. The degrees of freedom for the numerator were equal to 352. The degrees of freedom for the denominator were 352-n.

Table 4. The influence of sampling approach on Olsen P pooled variances (s^2_p) at Beresford.

			Old homestead			
			Sampled separately		Not sampled separately	
Sampling Methods	Classes (n)	Number of zones	Pooled var.	F-test	Pooled var.	F-test
Block						
4-ha block	10	10	57.6	1.507	1326	1.214
7-ha block	6	6	63.1	1.376	1292	1.247
13-ha block	3	3	83.5	1.041	1561	1.032
Equal interval						
EC_a-Elev.	8	14	77.0	1.128	1256	1.283
EC_a-Aspect	11	35	81.9	1.061	1108	1.454
EC_a-Distance	11	11	69.9	1.243	1241	1.298
Cluster						
EC_a-Elev.	8	19	78.1	1.112	1452	1.109
EC_a-Aspect	5	20	71.3	1.219	930	1.731
EC_a-Elev.-Aspect	9	22	77.4	1.122	926	1.740
Whole field	1		86.9		1611	

s^2_p was significantly different from the whole field variance at p=0.1. The degrees of freedom for the numerator were equal to 100. The degrees of freedom for the denominator were 100-n.

At Brookings the whole field P recommendation was 0 kg P ha^{-1}. Block sampling increased P fertilizer rates. The net effect of block sampling at Brookings was to increase the percentage of the field over-fertilized and reduce the percentage of the field under-fertilized. At Beresford, sampling the old homestead separately from the whole field increased the whole field recommendation. Block sampling further increased the P recommendation, and reduced the percentage of land both under and over fertilized.

Nitrate-N

A similar analysis for nitrate-N was conducted (data not shown). The complete data set is available in Chang (2002). At Moody, sampling the old homestead separately from the rest of the field did not influence the field variance. When compared to the whole field variance of 74.6 ,4, 7, and 16 ha block sampling reduced s^2_p, 49, 35, and 41%, respectively. Cluster analysis or classification based EC_a and elevation or EC_a and aspect did not reduce s_p^2.

Table 5. The influence of sampling the homestead separately from the rest of the field and separating the field into 3.5 to 4 ha blocks on the percentage of the three fields that would have been over and under fertilized with P fertilizer. Area within 5 kg P ha^{-1} of the recommendation were considered correctly fertilized.

	Old homestead					
	Sampled separately			Not sampled separately		
	Areas of fertilized			Areas of fertilized		
Sampling Methods	Over	Under	P Recom.	Over	Under	P Recom.
	-------- % -------		kg field^{-1}	-------- % -------		kg field^{-1}
Moody						
4-ha block	27.6	45.0	764	23.1	46.1	708
Whole field	31.5	57.1	720	31.7	63.6	516
Brookings						
3.5-ha block	25.1	37.6	228	25.1	37.8	220
Whole field	0	55.2	0	0	55.2	0
Beresford						
4-ha block	16	39	749	14	40	629
Whole field	30	63	401	0	72	0

At Brookings, sampling the old homestead separately from the whole field reduced the NO_3-N field variance from 8.1 to 6.34. s^2_p was further reduced to 5.38 by 3.5-ha block sampling. Classification based on soil attributes did not reduce nitrate-N s^2_p.

At Beresford, sampling the homestead separately from the rest of the field reduced the variance from 54 to 18. When the homestead was sampled separately from the rest of the field, 4-ha block sampling reduced s^2_p from 18 to 13.9. In Brookings and Beresford, sampling the homestead separately reduced s^2_p 22 and 67%, respectively. In all fields, the only approach that consistently produced further reductions in s^2_p was block sampling (3.5-4 ha). Classification based on soil attribute information using either equal interval or cluster analysis had a mixed or no impact on nitrate-N s^2_p.

The net effect of block sampling at Moody was to increase the N recommendation. In spite of this increase, the amount of N fertilizer applied to over-fertilized areas was highest (582 kg N field^{-1}) for the whole field and lowest (371 kg N field^{-1}) for the 4-ha block sampling. When old homestead was sampled separately, splitting the field into 4-ha blocks reduced under-fertilized areas from 63.3 to 34.8 % and increased over-fertilized areas from 30.0 to 32.6 %. These results show that the net effect of block sampling at Moody was to reduced under-fertilized areas with a minimal impact on over-fertilized areas. The amount of land over- and under-fertilized was similar when the old homestead was included or not included in the data set.

At Brookings, removing the old homestead from the data set had a relatively small impact on total N applied (<3%). Block sampling (3.5 ha) reduced the percentage of land over- and under-fertilized. At Beresford, when the old homestead was removed from the data set, block sampling (4 ha) reduced under-fertilized areas from 51.5 to 36.4 %, and did not influence total N recommendation or the percentage of the areas over-fertilized.

SUMMARY

This study investigated the importance of considering soil intrinsic characteristics, methods for identifying management zone boundaries, and prior management in identifying N and P management zone boundaries. Single and multiple soil attributes are a model system for considering the importance of intrinsic soil variability. Block sampling and separating data from old homestead sites from the entire field data sets were model systems for considering prior management. When compared to the whole field, soil sampling based on the order 1 soil survey did not reduce the Olsen-P and NO_3-N s^2_p. The inability of the order 1 soil survey to reduce N and P s^2_p was attributed to prior management.

Generally, combining data within 4-ha blocks had the lowest Olsen-P and NO_3-N s^2_p. The net effect of 4 ha block sampling when compared to whole field sampling was to reduce the percentage of the land under-fertilized. These results were attributed to two factors. First, Olsen-P and NO_3-N had strong spatial dependence in all fields (Table 1). Spatial structure was important because in block sampling, distance is the only criteria used for identifying the zones. Management zones based on block sampling (3.5 and 4-ha) had shorter distances between all the sampling points within an area than any other technique used for defining management zone boundaries. For example, a 4-ha block samples that were within 100 to 140 m from the center of the block were included in the block, and samples that were farther than 100 to 140-m were not included in the block.

Second, prior to becoming a single 65-ha field, the fields had been farmed as smaller individual fields. Results from this study indicate that events of 30 to 50 years ago still impact spatial variability of soil nutrients today. Whatever the cause, these results suggest that in fields where prior management influenced soil chemical properties, the distance between sampling points is important. Although not always significant, management zones based on EC_a-distance information generally had lower s^2_p than classification approaches that did not consider distance. These results were attributed to EC_a-distance classification separating areas with similar EC_a values that were not physically connected to each other into two different zones. These results point out the importance of distance between sampling points, and suggest that similar landscape positions that are not physically connected should not be combined.

Generally, sampling the old homestead separately from the rest of the field reduced s^2_p. Based on Equation [4], reductions in s^2_p result in reduced composite core sampling requirements and improved fertilizer recommendations. To determine management boundaries for soil nutrients (Olsen-P and NO_3-N), simple block sampling was better than soil attribute sampling. These results were attributed to human activities which impacted nutrient spatial variability. Findings from this study suggested that: (i) areas that are not physically connected should not be composited into a single sample; and (ii) the soil nutrient variation can be substantially reduced by considering prior management.

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