USING GRID SAMPLED SOIL TEST DATA TO PREDICT WHOLE-FIELD NUTRIENT RECOMMENDATIONS

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Soil testing is recognized as the best method of determining crop nutrient (P, K, and lime) need prior to planting. The routine soil test relies on a soil sampling approach that is intended to identify a single rate of nutrient application for a field that optimizes crop yield and economic return, with limited risk of loss that might degrade water quality. It is recognized that the soil within a field is intrinsically variable because of natural factors (e. g. soil forming factors and natural processes) and past management (e. g. nutrient application, crop management, erosion, field consolidation, and drainage) (Brown, 1993). A soil sampling protocol should account for this variability, but cannot be so intensive and complicated that it will not be accepted in practice. This issue is especially important because of the need to provide appropriate recommendations to meet nutrient management planning criteria.

James and Wells, 1990 describe three of categories of soil test variability, namely micro-, meso-, and macro-variability. This variability arises between samples taken < 2 in., 2 in. – 6 ft., and > 6 ft. apart, respectively. Micro-variability exists because of the heterogeneity of the soil matrix. Different concentrations of nutrients develop in close proximity within peds and in soil pores in response to soil processes such as water movement, especially when nutrient amendments are broadcast. Meso-variability can result from the uneven treatment typical to row crop cultivation from management practices such as fertilizer banding. Macro-variability is the result of variability in landscape or gross fertilization and whole-field management differences. It may be impractical to account for all sources of variability in a sampling scheme. For example, 25 – 30 cores per sample may be needed to manage micro-variability. These cores would have to be thoroughly mixed and subsampled. Similarly, if meso-variabity were an issue because of fertilizer banding, it would be best to separate samples consisting of many cores from banded and non-banded areas in proportion to the volume of soil affected by fertilization. Finally, macro-variability might be managed by subdividing a field into cells with similar characteristics (previous management, soil type, topography, etc.). These cells may be of different sizes or their boundaries may be irregular and indistinguishable making routine sampling difficult. No two fields would be alike.

Recently, management of macro-variability has been approached by grid-point or zone sampling methods. Nutrient levels can then be managed variably within the field using GPS to navigate and identify field location. This

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management method has not been shown to be cost effective for a number of reasons even though it is reasonable to expect that the practice would control variability (Mallarino and Wittry, 2000). It is expected that most producers will continue to apply one rate of fertilizer or lime to a field based on an average of several soil samples collected from the field that best represents the needs of the crop to be grown. An application rate based on an average value will result in over-application to parts of the field and under-application to other areas.

A soil sampling procedure for single-rate fertilizer and lime application has three considerations: 1) the size of the cell or field area represented by one sample; 2) the number of soil cores taken per sample; and, 3) the pattern with which the samples are taken. The UWEX soil sampling guidelines in Bulletin A2100 (Peters and Bundy, 1997) for "uniform" fields recommends one sample for every five acres, consisting of a minimum of five cores taken in a zigzag pattern over the cell area. Crop advisers recognize that the majority of Wisconsin fields have never been sampled at this intensity, mainly because of cost and time considerations. This publication is currently under revision with the recommendation to increase the cell size gradually as the field size increases. The number of cores per sample would be increased to a minimum of ten per sample. The minimum number of samples for any field would be two. These changes will result in a more intensive sampling of small fields, and fewer samples from large fields. It is expected that field mean will be better expressed for all fields by collecting more cores per sample. This technique will do little to change within-field nutrient variability.

If there is a desire to manage soil test variability fields must be grid-point sampled. Management boundaries are interpolated by kriging and are set into maps showing the level and distribution of nutrients. This information could be used to determine the extent of responsive and non-responsive areas in the field and whether it might be economical to treat these areas with variable-rate versus field-average treatment.

The objective of this paper is to use existing grid-point sampled data to estimate the field-average soil test by simulating various sampling schemes on soil test maps interpolated from grid data. Several practical soil sampling strategies will be simulated to determine if there is optimum field area represented by a sample and number of cores per sample.

Procedure

Grid-sampled soil test data has been collected for several studies over the past five years from fields of varying sizes. These fields were grid-point sampled on a one-acre spacing (~200 x 200 ft) using GPS to establish sampling points placed on a modified uniform grid pattern. Six to eight cores were collected per sample from the plow layer within a five ft radius of each sample point. Standard care was taken to avoid sampling crop rows or non-uniform areas such as headlands, furrows, and small topographic anomalies. Six fields of at least 50 acres in size were selected for this evaluation so that each could be divided into cells of 5, 10, and 15 acres. A list of the fields, their approximate size, and the average, minimum and maximum soil test P, K, and pH calculated from the grid samples are shown in Table 1. The Caldwell, Stone Corp, Watzke, and Faulkner fields contain Subsoil Group A and B soils, and the FPD and Hart fields contain Subsoil Group D soils (Kelling et al., 1998).

A semivariogram analysis was conducted on the grid-sampled data to verify the existence spatial relationship for each soil test parameter. An interpolated surface on a grid of 50 by 50 ft was created for each field where the point sample test data were spatially related. One field was removed from consideration because the point soil test data was not spatially related. A simulated surface with a grid was created for pH, P, and K, based on the interpolated values and the corresponding interpolation error variances. An overall grand mean soil test value for each factor in all fields was calculated by averaging all the values for each of the 50 ft grids. This value would be considered analogous to one that might be derived by continuous measurement with a sensor.

A zigzag sampling pattern was superimposed on cells of 5, 10, and 15 acres, and values were selected from the surface grid according to the zigzag patterns to simulate samples consisting of 5, 10, and 20 cores. Results from the individual cores were averaged to produce the average soil test for a sample representing a 5, 10, or 15 acre cell. Field averages were calculated from these cell samples, either by using all samples or by dropping high testing outlier cells using the protocol described in UWEX Publication A2809 (Kelling et al, 1998). This protocol permits the dropping of one (three or four samples per field) or two (five or more samples per field) sample results in situations where P or K exceed the initial calculated mean by more than 5 ppm or 20 ppm, respectively. It is expected that this procedure provides a more realistic field-average soil test because it removes high testing results that are likely the result of a sample becoming contaminated by unusually high nutrient levels (e.g. starter bands, manure piles, fertilizer spills, etc.).

Results and Discussion

The average, minimum, and maximum soil test values for each field calculated from the grid-point samples is shown in Table 1. The average values calculated from the grid-point samples are very close to the average of the gridded data. These data show that all fields, except the Faulkner field, have average soil pH values that would be considered adequate for corn and soybean production. Most would require small amounts of lime if alfalfa were in the rotation. The Faulkner field was quite acidic and should receive several smaller applications of lime over a period of years. The range in pH suggests considerable variation in soil pH in all fields with the Watzke field having the largest range of 2.4 units. In actuality this variability would have a relatively small effect on liming as only 13 of the 77 samples were low enough to receive a lime recommendation for a corn/soybean rotation (<6.1).

Table 1. Soil test characteristics of the fields selected for the sample size evaluation.

Field	Field	pH			P			K		
Name	Size	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
	acres				--------- ppm --------			--------- ppm --------		
Caldwell	65	6.5	5.8	7.5	64	21	200	220	130	645
Stone Corp	66	6.5	5.9	7.0	39	20	100	177	110	360
Watzke	76	6.5	5.3	7.7	50	12	195	198	95	440
Faulkner	74	5.5	4.9	6.2	43	17	95	174	115	320
FPD	146	6.6	5.8	7.4	39	8	208	188	62	464
Hart	135	6.7	5.8	7.6	86	33	200	157	40	369

Values calculated from the initial one-acre grid sampling data.

The average soil test P and K of all fields were above the excessively high range for these nutrients, with the exception of P for the FPD field which was just below that category for a Group D soil. The range of both P and K in the FPD field was great, but like pH it represented only a very small number of the grid sample results. In the FPD field, 22 and 2 % of the P and K soil test values, respectively were below the optimum soil test category. Thirty-one and 75 % of the P and K soil test values, respectively in the FPD field were in the excessively high category.

An example of the gridded surface for soil test P for the Faulkner field is shown in Figure 1. As this figure is oriented, P soil test levels were lower in middle foreground and somewhat higher along either side in the background. These data represent the interpolation of values on the 50 x 50 ft grid and spatially estimate soil test P. The data are not smoothed, as would be done to create a contoured management map. A zigzag sample pattern was over-laid on the grid surface in combinations of cell sizes of 5, 10, and 15 acres with 5, 10, and 20 cores per sample. As previously described field average soil test values were calculated using all values and the UW method that remove specific numbers of high testing outliers.

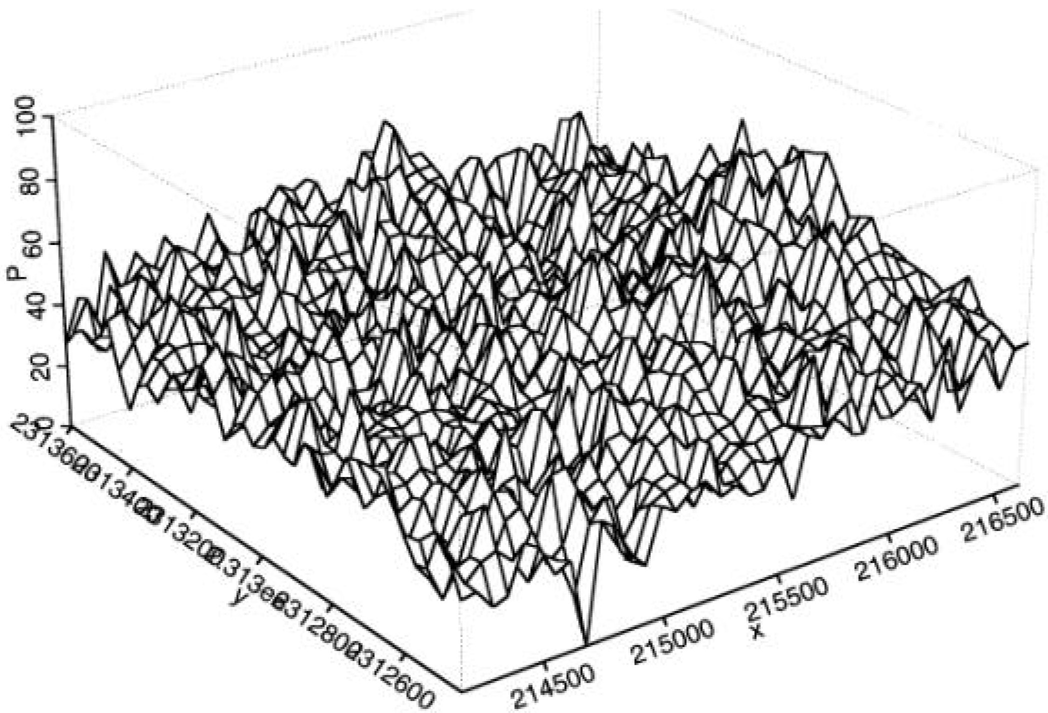

Figure 1. Gridded surface for soil test P for the Faulkner field.

The simulated effect of cell size and core number for soil test P, K, and pH for the six fields is shown in Tables 2-4. The soil test for a given sampling scheme was compared to the grand mean for the field which was the result of averaging the values of all the 50 x 50 interpolated grid cells. This grand mean was considered to be the best estimate of the field average soil test and hence was used as the fixed true average value. An asterisk indicates whether the calculated mean is different from the grand mean at the p=0.05 level. Because the number of degrees of freedom varies by cell size similar numbers may not always be statistically different if the cell size is different. Therefore, absolute comparisons of soil test values should not be made.

Table 2 shows the effect of cell size and core number on the average soil test P for the six fields. The implementation of the UW method of removing outliers lowered the average soil test and thereby increased the number of statistical differences with the grand mean. Removing the outliers showed the greatest difference in the Caldwell and Watzke fields, and resulted in minimal change in average soil test P in the other fields. Regardless of averaging method, the average soil test P levels remained within the same interpretation category (high for FPD and excessively high for the other fields). There was not a consistent trend that would suggest one sampling scheme was superior to another determine average soil test P, although the coarser schemes (10 or 15 acres/5 cores) resulted in lower values in the Caldwell and Stone Corp fields that may have placed the values in a different soil test category if the distribution of soil test values for these fields had been shifted lower. This may also be an issue if a high demanding vegetable crop or potato were grown. The result in that situation would have been the recommendation for fertilizer where it likely wasn't needed. None of the comparisons showed the opposite result – a soil test higher than the field-average such fertilizer would be omitted when it actually was needed.

Table 3 shows the similar comparison for soil test K. The implementation of UW method of removing outliers also lowered the soil test K level in most fields. The average soil test K levels of all the fields were so high that there was limited risk of the average values falling into a lower soil test category. The selection of a sampling scheme was important in some fields and a non-issue in others. Like P, the 15 acre with 5 cores per sample scheme resulted in lower soil test K levels in the Caldwell and Stone Corp fields, however these values were still in the excessively high soil test category.

Table 4 shows the field average soil pH values calculated by the different cell size and core number comparisons. The average soil pH was relatively unaffected by the soil sampling scheme and where a difference was significant it was relatively small. The significant differences tended to show with the larger cell sizes and smaller number of cores.

Summary

This study used grid-sampled soil test data to simulate the impact of various soil sampling schemes on the resulting field-average P, K, and lime recommendations. The UW recommendation program that drops one or two high testing outliers resulted in lower field-average P and K soil test levels. Because of the high soil test levels that exist in the study fields there were no changes in soil test category for P and K due to the UW program. Lower testing fields, or situations where high P and K demanding crops are to be grown, may have resulted average soil test values appearing in different soil test categories. The departure of the estimated field-average soil test from the grand mean as affected by sampling scheme varied between fields, presumably because of the inherent soil test variability of each field. Sampling density for P and K determination appeared to be important in two fields where a large cell size with few cores was inferior to denser schemes. In general, a 15-acre cell with 20 cores produced values similar to a five-acre cell with five cores. Field-average soil pH measurement was affected very little by sampling scheme. The simulated sampling schemes tended to under-estimate the actual field average and if anything, would result in the application of a relatively small amount of un-needed fertilizer.

Table 2. Effect of number of samples per field and cores per sample on the un-adjusted and adjusted field average soil test P for six Wisconsin fields.

Cell Size	No. of Cores	Caldwell		Stone Corp.		Watzke		Faulkner		FPD		Hart	
		All	UW	All	UW	All	UW	All	UW	All	UW	All	UW
Acres	/sample	ppm											
Grand Mean		63		38		51		44		39		88	
5	5	64	50*	40	38	45	38*	42	40	40	37	87	85
	10	64	48*	40	39	49	41*	42	39*	38	36	91	89
	20	62	44*	37	36*	50	42*	43	40*	38	36	87	86
10	5	43*	39*	38	36	42	33*	40	36	38	35	85	82
	10	49*	45*	37	36	46	35*	37	32*	39	36	87	85
	20	51*	47*	39	38	49	40	36*	40*	39	37	87	84
15	5	46*	41	30*	30*	52	41	43	39	37	34	90	86
	10	60	48	38	35	45	38*	44	39	37	34*	85	81*
	20	66	55	40	40	50	38*	43	37	39	36	84	81*

All=average of all estimated values; UW=high testing outlier omitted (>5 ppm P or 20 ppm K; up two samples for 5 and 10 acre cells, one sample for 15 acre cells).
Grand Mean=Average of all 50 x 50 ft interpolated grid cells.
* = value is significantly different from grand mean at p=0.05.

Table 3. Effect of number of samples per field and cores per sample on the un-adjusted and adjusted field average soil test K for six Wisconsin fields.

Cell	No. of	Caldwell		Stone Corp.		Watzke		Faulkner		FPD		Hart	
Size	Cores	All	UW	All	UW	All	UW	All	UW	All	UW	All	UW
Acres	/sample	ppm											
Grand Mean		218		173		201		176		189		158	
5	5	226	200	178	174	188	175*	178	164	190	182	159	154
	10	226	196*	178	175	199	182*	179	163*	187	180	166	163
	20	219	189*	171	171	199	183*	179	165	187	179	159	156
10	5	170*	170*	175	171	177	162*	166	158*	188	177	156	148
	10	187*	180*	171	168	189	174*	160	149*	189	178	160	154
	20	192*	183*	176	176	196	179*	167	162*	190	179	159	153
15	5	179*	179*	151*	151*	202	182	179	160	187	173	167	159
	10	207	190*	170	170	185	167*	182	160	185	169*	156	146
	20	220	205	178	178	196	179	178	155	189	172	154	146

All=average of all estimated values; UW=high testing outlier omitted (>5 ppm P or 20 ppm K; up two samples for 5 and 10 acre cells, one sample for 15 acre cells).

Grand Mean=Average of all 50 x 50 ft interpolated grid cells.

* = value is significantly different from grand mean at p=0.05.

Table 4. Effect of number of samples per field and cores per sample on the un-adjusted and adjusted field average soil pH for six Wisconsin fields.

Cell Size Acres	No. of Cores /sample	Caldwell	Stone Corp.	Watzke	Faulkner	FPD	Hart
Grand Mean		6.5	6.5	6.5	5.5	6.6	6.7
5	5	6.5	6.5	6.5	5.5	6.6	6.8
	10	6.5	6.5	6.6	5.5	6.6	6.8*
	20	6.5	6.5	6.6	5.5	6.6	6.8
10	5	6.3*	6.5	6.3*	5.5	6.6	6.7
	10	6.4	6.5	6.5	5.4	6.6	6.8
	20	6.5	6.5	6.5	5.5	6.6	6.8
15	5	6.4	6.4*	6.5	5.5	6.6	6.8
	10	6.5	6.5	6.5	5.5	6.6	6.7
	20	6.5	6.5	6.5	5.5	6.6	6.7

Average of all estimated values.
Grand Mean=Average of all 50 x 50 ft interpolated grid cells.
* = value is significantly different from grand mean at p=0.05.

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