SOIL TEST PHOSPHORUS SAMPLING STRATEGIES TO OPTIMIZE MANURE APPLICATION IN AGRICULTURAL FIELDS

E. M. Pena-Yewtukhiw, J.H. Grove

The authors are **Eugenia M. Pena-Yewtukhiw,** Postdoctoral Scholar, and **John H. Grove,** Associate Professor, Department of Agronomy, University of Kentucky, Lexington, Kentucky. **Corresponding author: Eugenia M. Pena-Yewtukhiw**, Agronomy Dep., N-122 Agricultural Science North, Univ. of Kentucky, Lexington, KY, 40546-0091; phone: 859-257-2467; fax: 859-257-3655; e-mail: epena0@uky.edu.

ABSTRACT. *Phosphorus (P) is necessary for plant productivity, but excessive P can have a negative environmental impact. Manure application to fields can raise the possibility of P contamination of water bodies. That P contamination potential is related to management, especially the bioavailable soil test P (STP) level. Environmental indices to guide applications of animal waste are based, in large part, on STP. As STP rises, the manure rate should decrease. Field-average rates may result in excessive manuring of environmentally sensitive areas, but site-specific application depends on spatial sampling strategy/quality. In-field variation must be well described. Two fields under no-tillage management were chosen, and one (112) had been fertilized, while the other (950) had been both fertilized and manured. Three risk levels (low, medium, high) were defined according to a laboratory STP versus water-soluble P relationship. As sample grid size increased, both areal extent and location of risk levels changed. In 112, doubling grid size increased low risk area and decreased medium risk area. In 950, doubling grid size increased both low and high risk area at the expense of medium risk area. The number and location of samples influenced future manure management. Sampling research is needed for greater environmental benefits to site-specific manure application.*

Keywords. Spatial analysis, soil test phosphorus (STP), soil sampling.

INTRODUCTION

Though phosphorus (P) is necessary for plant production, its excess has negative environmental impact. Animal agriculture creates waste, but manure application to fields can raise the potential for P movement to surface waters. Potential P contamination is related to management (rate, method, and timing of manure application; bioavailable soil test P (STP) and field characteristics. New indices are proposed to guide manure applications, indices based on STP. As STP rises, recommended manure P rates decrease. Site-specific manure application should put waste on less sensitive field area, but depends upon greater soil sampling. The vagaries of sampling are important issues with site-specific management (McBratney and Webster, 1983). Site-specific sampling strategies include both the number and geometry of sample sites. The geometry is related to the distribution of samples in space, perhaps as a regular (square, rectangular) or triangular grid (McBratney and Webster, 1981). Sample number is related to the error acceptable to spatial prediction, and will depend on variation of the property in the field. Systematic sampling (grid sampling) can increase the precision of interpolation or decrease the maximum kriging variance (Burgess et al., 1981). Theory indicates that the estimation variance decreases, while the precision of the interpolation increases, as sample number (and associated sampling and analytical costs) increase.

A field-average STP interpretation causes uniform manuring of the whole field, resulting in applications to more sensitive field areas, unless the field is itself entirely uniform. Site-specific management implies knowledge of the spatial context for a field characteristic. Maintaining the spatial identity (location) of STP creates its spatial context. Grid sampling creates the spatial identity. When STP is used to guide manuring, it becomes necessary to deal with in-field STP variation, which must be described in a useful way. The objective of our study was to compare alternative approaches for generating manure application recommendations, based on comparing the field-average STP to that derived from sampling at three different intensities.

MATERIALS AND METHODS

Two fields were used, 112 (20.8ha) and 950 (17.7ha). Both fields were in a corn, corn, wheat-doublecrop soybean rotation where complete no-tillage management had been used since 1991. The soils in these fields were Paleudalfs, Hapludults and Fragiudalfs. Both contain mostly well-drained soil, but also contain significant areas of fragipan soil. Field 112 had a history of uniform chemical fertilizer application, while 950 had a history of liquid swine manure and chemical fertilizer N applications. Three sampling strategies were compared against the field-average recommendation. Sampling strategies were: A) high intensity sampling on a 54.7m x 60.8m grid; B) medium intensity sampling on a 109.4m x 121.6m grid; and C) low intensity sampling on a 164.1m x 182.4m grid.

Composite soil (8 cores to a 10cm depth around each grid point) samples were taken after harvest, and locations were recorded using a CMT manual GPS unit. Each was analyzed for bioavailable P (Mehlich III). Semi-variograms for each sampling strategy, for each field, were used to characterize spatial variation in STP, and were calculated using GS+ 5.1.1 (Gamma Design Software, 2001) and Vesper 1.6 (Whelan et al., 2001). The best interpolation method (kriging or inverse distance power) was used to predict STP values at unsampled locations. Maps of STP were plotted using Surfer 7.0 (Surfer, 1999). The average of all STP values for a field was used to arrive at the field-average STP.

Comparison between estimated STP maps was performed using the goodness-of-prediction criterion G (Kravchenko, 2003). G is calculated as:

$$G = (1\text{-}MSE/MSE_{average})^{*}\ 100\%\ ,$$

where MSE is the mean square error calculated, in this case, by cross-validation, and $MSE_{average}$ is the mean square error obtained from the field-average values as an estimate for all test data. Negative G values indicate that the field-average predicts the values at unsampled locations better that the grid sampling estimates. Positive G values would favor grid sampling over the field-average. In this report, G was used to compare not only between any grid sampling intensity and the field-average, but also among the different grid sampling intensities.

Three manure P management risk levels (low, medium, high) were defined, based on the water soluble P versus STP relationship for 20 Kentucky soils (D’Angelo et al, 2001). The STP at low, medium and high risk levels was less than 70, between 70 and 200, and greater than 200 lb/acre, respectively. Risk levels were quantified as a percentage of the total field area. Changes in areal extent and location for these risk levels were described for each field, at each grid sampling intensity.

RESULTS AND DISCUSSION

The field-average STP for 112 was 54 lb/acre, lower than the 147 lb/acre found for 950. The coefficient of variation for STP in 112 was higher (57.4%) than that for 950 (43.8%). Field 112 was classified as a low risk for releasing water soluble P, while 950 was a medium risk. The number of sampling points, determined by grid size, differed for the two fields. High, medium and low sampling intensity resulted in 70, 35 and 24 samples, respectively in 112 and 52, 16 and 9 samples, respectively, in 950. Table 1 gives the variogram characteristics for each sampling strategy, within each field.

Table 1. Summary of variogram characteristics for the different STP sampling intensities used in fields 112 and 950.

Field – Sampling Intensity	Model	Nugget	Total Sill	Range (m)	Nugget / Total Sill	R^2
112 - high	Exponential	371	1100	80	0.34	0.28
112 - medium	Exponential	143	1200	70	0.12	0.11
112 - low	Spherical	1	943	80	0.10	0.96
950 - high	Spherical	1720	6373	710	0.27	0.82
950 - medium	Exponential	10	5130	100	0.20	0.95
950 - low	Linear	4255	4255	330	-	0.95

Variogram models changed as the sampling intensity (grid size) changed. The total sill (maximum semivariance) was greater for 950 than for 112, due to the higher STP in the first field. The range was larger in 950, indicating a higher correlation with distance between STP values than found in 112. The nugget to sill ratio was generally below 0.6, indicating that spatial structure was present, at the selected sampling intensities, in both fields (Kravchenko, 2003).

Cross-validation was applied to compare the measured values to those estimated from the selected variogram models (Isaaks and Srivastava, 1989). The MSE was calculated from the observed and estimated STP. Table 2 gives the cross-validation summary for each field.

Table 2. Cross-validation and G index summary for fields 112 and 950.

Field- Sampling Intensity	R^2	MSE	$MSE_{average}$	G
112 - high	0.08	914	944	3.2
112 - medium	0.01	1380	1119	-23.4
112 - low	0.03	818	841	2.7
950 - high	0.33	2705	4048	33.2
950 - medium	0.51	2262	4038	44.0
950 - low	0.02	4957	4000	-23.9

Results of the cross-validation for 112 (lower average STP) found that the selected variogram models did not estimate STP at the sampling points in a satisfactory manner (low R^2) at any level of sampling. However, in F950, both high and medium intensity sampling gave a significant correlation. In 112, the G criterion indicated that maps of STP derived from either high or low intensity sampling were only slightly better in quality than using the field-average STP value across the entire field. For

950, both high and medium intensity grid sampling yielded a better map of STP than using the field-average STP value. Neither the medium intensity sampling of 112 or the low intensity sampling in 950, resulted in STP maps of quality greater than that assuming a uniform field-average STP value.

Using STP to predict risk of soluble P loss in 112, decreased sampling intensity (increasing grid size) increased low risk area from 83 to 93% of total field area, with equivalent loss of medium risk area (data not shown), and some underestimation of soluble P loss risk. The lowest sampling intensity in 112 caused medium risk area to not be coincident to that found with more intense sampling (not shown). Changes in extent and location of the different risk level areas were also found in 950 (Fig. 1). Medium intensity sampling tripled low risk area, decreasing both medium and high risk areas, and raising potential underestimation of P loss. However, the lowest sampling intensity gave the greatest high risk area. In 950, field-average STP underestimated both low and high risk area.

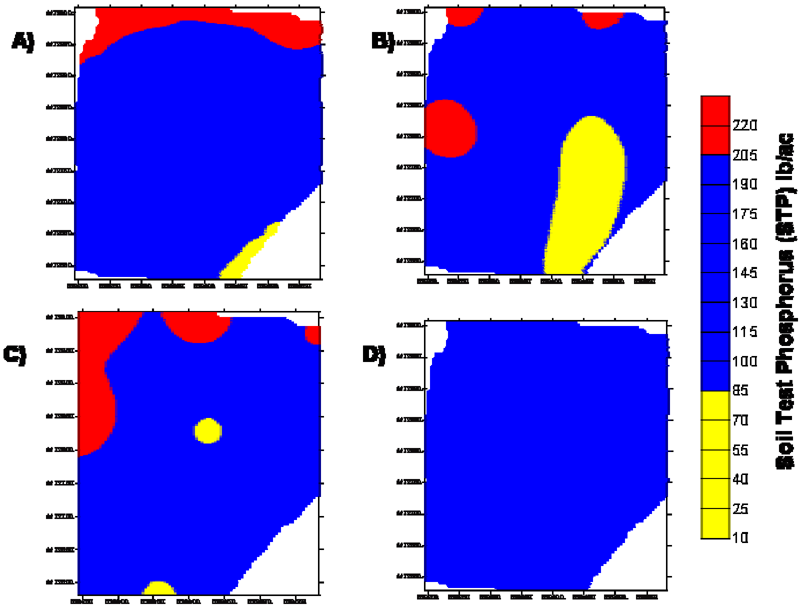

Figure 1. Soluble P loss risk maps for field 950: A) high intensity sampling; B) medium intensity sampling; C) low intensity sampling; D) field-average STP.

CONCLUSIONS

The number of samples affected the “location” of areas at greater risk of greater soluble P loss, which could impact site-specific manuring. Sampling STP in order to guide future manure applications is sensitive because of its inherent impacts on environmental quality and agricultural productivity. A site-specific approach has the potential to minimize P’s environmental impact and farmer cost due to premature loss of field area for waste application, only if the spatial distribution of STP is understood.

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