SHORT-TERM STABILITY OF SOIL TEST PHOSPHORUS IN AGRICULTURAL FIELDS

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Abstract

The spatial and temporal stability of soil test values is important to the use of soil testing for nutrient management. A study was conducted to evaluate the spatial and temporal stability of soil test phosphorus (P). Five sites ranging in size from 9.1 to 10.8 acres were soil sampled in the same locations in a 60 X 60 ft. grid either three or four times over a two year period. Bray 1-P values were similar or decreased over time while Olsen-P values at two of five sites decreased. One site showed no pattern and two sites had cyclic patterns where the spring sample values were greater than the fall. The spatial pattern of soil test values during a two year rotation for Bray 1-P and Olsen-P was very stable. The changes in distribution in soil test P categories over a two year period resulted in a shift to lower soil test categories. The decreases in soil test P were probably caused by plant P uptake in combination with no application of P fertilizer during the study.

Introduction

Nutrient management has become more important for producers with the increasing prices of inputs. Soil testing is an important component in a nutrient management plan. Large concerns exist about how nutrient values change across the landscape with time and if the shape of the nutrient map change with time. Currently it is common for producers in a corn - soybean rotation to apply fertilizer P once every two growing seasons. The immediate concerns point to short term changes in soil test P and nutrient map shape.

Researchers have documented that soil test values are extremely variable within a field. Most of the early studies on spatial variability of soil nutrient status had an objective of developing a procedure for obtaining a soil sample that was representative of a whole field (Reed and Rigney 1947; Cline 1944). Kunkel et al. (1971) reported that soil test P in the top 30 cm for experimental plot areas in Washington that were less than 3.2 acres in size had coefficients of variation (CV) from 12 % to 91 %. In a 90 acre field in Iowa, Cambardella et al. (1994) reported that soil test P varied from 0.9 to 250 ppm. In Illinois, soil test P variability for a field ranged from 2.2 ppm to 100 ppm (Franzen and Peck 1995). Franzen et al. (1998) measured soil test P that varied from 4 to 55 ppm in a 40 acre North Dakota field. These research results document the variability of immobile nutrients such as P within fields across a wide portion of the North Central United States. Cameron et al. (1971) found that CVs for soil test P in fields formed on lacustrine, glacial till, and alluvial parent material were 44 %, 60 %, and 40 %, respectively. These data indicate that variability occurs in soils having a wide range of parent materials.

Researchers have reported that various soil test parameters have different spatial characteristics. Cahn et al. (1994) and Gotway et al. (1996) suggested that nitrate-N was more variable than soil organic matter content or soil organic carbon. Soil test P, K, and soil water content were intermediate in variability compared to nitrate-N (high variability) and soil organic carbon (low variability) (Cahn et al. 1994). Assmus et al. (1985) found that the spatial characteristics for soil test P changed from field to field in South Dakota glacial till soils.

Soil test values can change with time. Cahn et al. (1994) measured differences in the spatial nature of soil nitrate-N changed with time. Liebhardt and Teel (1977) reported that soil test K values were affected by sampling date. The changes were cyclical throughout the year with the soil test K values increasing to the highest values in the spring, declining during the growing season and increasing again during the following spring. They attributed this change to the slow release of K from K-feldspars found in the Delaware soils and subsequent utilization by the crop during the growing season. Peterson and Krueger (1980) and Nyborg et al. (1992) indicate that in addition to soil test K, soil test P also exhibits cyclical patterns. Lochman and Molloy (1984) suggested, that because of the cyclical nature of soil test values for P and K, a fall sampling was preferred for these nutrients.

In order to improve accuracy in soil testing for P, it is important to understand the spatial and short term temporal variability of soil test P in agricultural fields. In addition, to facilitate the collection of the increased number of soil samples needed to support variable rate fertilizer application, it is important to explore opportunities for expanding the window of time for sample collection into the growing season.

However, research which has focused on both spatial and temporal stability of soil test P on a field scale basis is limited. Therefore, this study was conducted to evaluate the spatial and short term temporal stability of soil test P in five agricultural production fields.

Materials and Methods

Five experimental sites in south central Minnesota (F, M, RA, RM, and S) were established as part of a larger P fertilizer management study in farmer fields with soils derived from glacial till material. A typical landscape for these fields is gently rolling in topography. The soils are classified as predominantly udolls or aquolls. The clay mineralology of these soils is predominantly montmorillitic. These landscapes and the soils within them are characteristic of a large part of the corn and soybean production area in Minnesota and Iowa. Studies were conducted in a corn-soybean rotation. Both of the crops were planted by farmer cooperators in 30 inch rows. Recommended production practices were used with regards to seeding rate, pest control, and application of nutrients other than P.

The short term P stability study utilized samples collected from the control treatments of a larger P fertilization study. The control strips were 15 ft. wide and 990 to 1320 ft. in length. These control strips at each location were arranged so that the centers of the strips were approximately 60 ft. apart (Figure 1). Within each strip, samples were collected at 60 ft. intervals. This sampling procedure produced a grid cell size of approximately 60 ft. by 60 ft. Spring samples were collected following planting, and fall samples were collected after harvest. For each sampling, sites were located by measuring from benchmark locations established at the initiation of the study. This procedure produced samples taken from the same location on each sampling date. At each location, nine cores

(0.875 in. dia) taken within a circle having a dia of 24 in. were taken to a depth of 6 in. and composited. All soil samples were dried at 95 degrees F and ground to pass through a 2 mm sieve. The soil samples were analyzed for P by both the Bray and Kurtz #1 (Bray 1-P) and Olsen procedures as outlined by Frank et al. (1997).

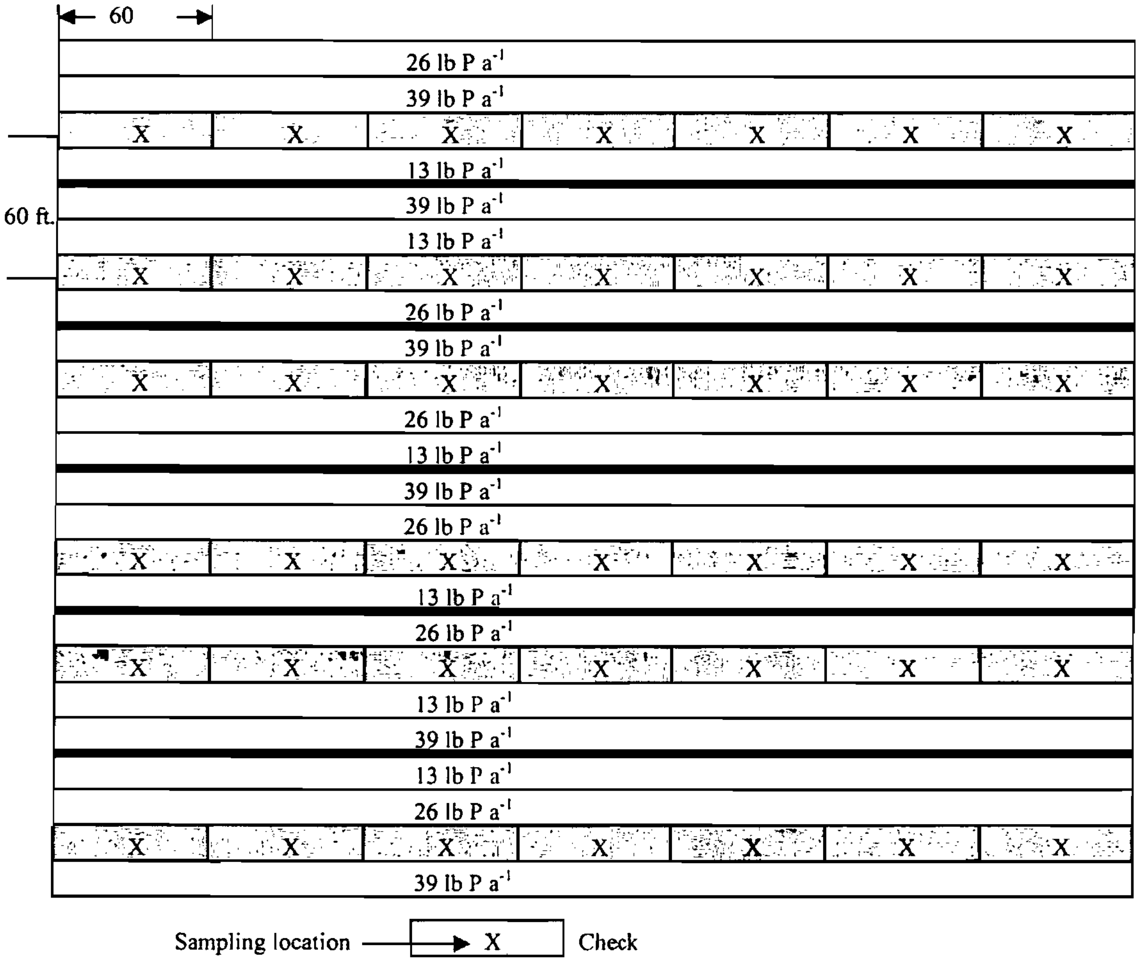

Figure 1. The general layout of sampling study.

The data were characterized by calculating the mean, median, minimum, maximum, standard deviation, and standard error of the mean using the MEANS procedure of SAS (SAS Institute 1996). The normality of the distribution for soil test values for each sampling time at each site was determined by the Shapiro-Wilk test (Bilisoly et al. 1997). Since the distribution of all soil test values for each site and sampling time were not normally distributed, the differences between sampling times for pH, Bray 1-P, and Olsen P soil test values were tested using a nonparametric Wilcoxon statistical test (Bilisoly et al. 1997). Both of these statistical tests were determined with PROC UNIVARIATE (SAS Institute 1996).

The data were analyzed for spatial stability using two different methods. The first method used a geostatistical analysis of semi-variance. Semivariograms were produced for data from each sampling time at each site. The range, sill, nugget, nugget ratio and model were calculated and used in a procedure similar to the one described in Cambardella and Karlen (1999). This analysis was conducted using GS+ geostatistical software from Gamma Design Software, St. Plainwell, MI. (Robertson 1998).

The second method used Spearman ranked correlations from PROC CORR (SAS Institute 1996). Soil test data were analyzed for stability over sampling times by using ranked correlations similar to the statistical analysis used in plant breeding research to test stability of genotypic traits over different years and locations (Falconer 1981). For simplicity, plant breeders will use this analysis to determine whether plant performance for a selected trait measured from field studies conducted in one location is similar at other locations. If the genotypes are similar (stable) in each environment, then the interaction of genotype and environment would be small. In the plant breeding example, there is replication of genotypes and thus an error term to test the genotype x environment interaction. To adapt this analysis to soil test stability, a location in the field is analogous to a genotype and sampling time is the environment. An error term for the interaction of location and sampling time is not available in this adaptation. If the location (genotype) term is highly significant, then the soil test values would be considered stable since the interaction is used as error. Since there is no error term to test the interaction between location and sampling time, ranked correlation of soil test values by sampling time was performed. The higher the correlation, the more stable soil test measurements will be in the field between the sampling times compared (Lamb et al. 1997).

Results and Discussion

Bray 1-P

Summary statistics for Bray 1-P are provided in Table 1. The differences between the maximum and minimum Bray 1-P soil test values ranged from 20 ppm on the Fall Year 1 sampling at the M site to 120 ppm on the Spring Year 1 sampling at the S site. The standard deviations indicate that the least variability across the site occurred at site M and the greatest amount at site S. The Bray 1-P soil test values range was substantial at each site. In Minnesota, Bray 1-P soil test values are categorized for making recommendations. Bray 1-P values of 0 - 5 ppm are very low, 6 - 10 ppm are low, 11- 15 ppm are medium, 16 - 20 ppm are high, and 21 + ppm are very high (Rehm et al. 2001). Spatial variability caused measured values to vary from very low to very high at each site and sampling period.

Table 1. Descriptive statistics for Bray 1-P (ppm) at five sites over time.

	Site F			Site M			Site RA				Site RM			Site S			
	Spring Yr1	Fall Yr1	Fall Yr2	Spring Yr1	Fall Yr1	Fall Yr2	Spring Yr1	Fall Yr1	Spring Yr2	Fall Yr2	Fall Yr1	Spring Yr2	Fall Yr2	Spring Yr1	Fall Yr1	Spring Yr2	Fall Yr2
N	128	128	128	128	128	128	114	114	114	114	110	110	110	132	132	132	132
Mean	11.1	9.1	7.9	11.5	11.5	11.5	15.3	12.8	13.0	12.4	20.5	23.4	20.6	28.2	26.7	25.4	27.3
Median	7.0	5.0	5.0	11.0	12.0	10.0	14.0	11.0	9.5	10.5	17.0	19.5	17.0	16.0	24.0	23.5	27.0
SD	13.9	11.9	10.6	7.0	6.3	5.8	12.7	11.0	12.2	11.4	12.0	14.6	14.2	22.6	20.7	17.8	17.3
Minimum	1	1	1	1	1	1	1	1	0	1	1	2	1	0	0	1	1
Maximum	95	95	75	34	31	26	59	46	56	50	58	78	65	120	110	80	70
Range	94	94	74	33	20	25	58	45	56	49	57	76	64	120	110	79	69
SE	1.7	1.5	1.3	0.9	0.8	0.7	1.7	1.5	1.6	1.5	1.6	2.0	1.9	2.8	2.5	2.2	2.1

The mean Bray 1-P values decreased from 11.1 ppm in Spring Year 1 to 7.9 ppm in Fall Year 2 at the F site (Table 1). This decrease changed the overall soil test category for the entire experimental area from medium to low. Site M Bray 1-P soil test values were the same at the Spring Year 1 and Fall Year 1 sampling dates and decreased significantly by a small amount from Fall Year 1 to Fall Year 2. The fall Bray 1-P values (Fall Year 1 and Fall Year 2) were less than the values measured in the samples from the previous spring (Spring Year 1 and Spring Year 2) at the RA site. The general trend during the two years of sampling at this site was a reduction of Bray 1-P from 15.3 ppm in Spring Year 1 to 12.4 ppm Fall Year 2. At the RM site, the Bray 1-P soil test for the spring sampling was greater than either of the fall Bray 1-P values. The mean Bray 1-P values for both fall sampling dates were equal. Mean Bray 1-P soil test values at the S site were the same for the first (Spring Year 1), and last (Fall Year 2) sampling times. The mean Bray 1-P soil test value decreased from Spring Year 1 to Spring Year 2, then increased to a value similar to the one measured at the beginning of the sampling study. In general, Bray 1-P soil test values were either the same as or less than the initial value over time.

The geostatistical evaluation of the spatial properties for the Bray 1-P soil test values indicate very large nugget ratios at four of the five experimental sites. These ratios indicate that a strong spatial relationship existed for all sampling dates at the F, M, RA, and S sites. The nugget ratio at the RM site was less than the other sites indicating a moderately strong spatial relationship. When spatial parameters at each site were compared, the range, nugget ratio, and best model of fit were similar over sampling dates. The only exception was at the S site where the model that fit the semivariance was exponential in shape for Bray 1-P for the Spring Year 1 sampling date; whereas a spherical model best described the data for the other three sampling dates at this site. This is not a large difference because the shape of the exponential model is similar to that of the spherical model.

The Spearman ranked correlations for Bray 1-P were large for all comparisons. Because of the similarities in both the geostatistical parameters and the ranked correlations at each of the five sites, the Bray 1-P soil test values were considered to be spatially stable over time.

Olsen-P

As observed with the Bray 1-P values, there was a considerable amount of variability in Olsen-P values at each site (Table 2). The difference between minimum and maximum Olsen-P values varied from 19 ppm on Fall Year 2 at the M site to 119 ppm on Spring Year 1 at the S site. The standard deviation for Olsen-P values range from 3.7 ppm on Fall Year 2 at M site to 16.2 ppm Spring Year 1 at the S site. The Olsen-P soil test values were found not to be normally distributed by the Shapiro-Wilk statistical test at any sampling date, so a Wilcoxson sign ranked test was used to determine if the means between sampling dates at each site were statistically different. Comparing sampling times for each site, all but two mean comparisons for Olsen-P were statistically different.

Table 2. Descriptive statistics for Olsen-P (ppm) at five sites over time.

	Site F			Site M			Site RA				Site RM			Site S			
	Spring Yr1	Fall Yr1	Fall Yr2	Spring Yr1	Fall Yr1	Fall Yr2	Spring Yr1	Fall Yr1	Spring Yr2	Fall Yr2	Fall Yr1	Spring Yr2	Fall Yr2	Spring Yr1	Fall Yr1	Spring Yr2	Fall Yr2
N	128	128	128	128	128	128	114	114	114	114	110	110	110	132	132	132	132
Mean	13.7	10.8	8.6	11.4	11.7	7.8	14.3	10.7	14.1	11.8	15.5	17.0	14.0	20.6	21.2	19.7	23.9
Median	9.0	7.0	6.0	10.0	10.0	7.0	12.0	9.0	12.0	10.0	13.0	14.0	11.5	17.0	18.0	15.0	20.5
SD	9.5	8.8	7.2	5.4	5.2	3.7	6.5	5.7	7.2	6.4	10.8	10.7	10.1	16.2	14.9	14.6	14.8
Minimum	2	2	2	5	4	3	6	4	5	5	3	4	3	4	5	5	6
Maximum	60	65	52	45	28	22	38	31	41	38	58	61	50	123	118	104	103
Range	58	63	50	40	24	19	32	27	36	33	55	57	47	119	110	99	97
SE	1.2	1.1	0.9	0.7	0.7	0.5	0.9	0.8	1.0	0.8	1.5	1.4	1.4	2.0	1.8	1.8	1.8

Mean Olsen-P values decreased from 13.7 ppm on Spring Year 1 to 8.6 ppm on Fall Year 2 at site F. Olsen-P soil test values at the M site remained the same from Spring Year 1 to Fall Year 1 and then decreased from Fall Year 1 to Fall Year 2. In Minnesota, Olsen-P soil test values like the Bray 1-P values are categorized for making recommendations. Olsen-P values of 0 - 3 ppm are very low, 4 - 7 ppm are low, 8- 11 ppm are medium, 12 - 15 ppm are high, and 16 + ppm are very high (Rehm et al. 2001). Therefore, at both site F and M, the decrease in Olsen-P values during the study changed the overall mean value for each site from the medium to the low soil test category. At the RA and RM sites, Olsen-P values for the spring sampling dates were greater than the preceding fall values. The mean Olsen-P soil test value in Spring Year 1 for the RA site was the same as in Spring Year 2, while the Fall Year 2 mean value was greater than the preceding fall (Fall Year 1). At the S site, Olsen-P means were significantly different at each date. No pattern over time was observed.

Geostatistical analysis indicates that all sampling dates at the F, M, RA, and S sites had strong spatial correlations. The RM site had a moderate spatial correlation over all sampling dates. Except for the M site, the semivariance for all sampling times at each site fit the same model type. The spherical model was the best at the F, RA, and S sites, while a linear model was best at the RM site. On Spring Year 1 and Fall Year 1 sampling dates, the exponential model fit the semivariances best at the M site while a spherical model was best fit for the Fall Year 2 data. The semivariance ranges were similar among the sampling dates at each site except for the M site. The range, which is the distance at which the data between two points are spatially independent, at site M increased from 210 ft. on Spring Year 1 to 460 ft. on Fall Year 2. This would indicate a change in spatial structure between sampling dates.

The Spearman ranked correlations for Olsen-P at the M and RA sites were not as large as at the other sites. This confirms the conclusions reached from the geostatistical analysis indicating a lack of stability over time at the M site. The smaller ranked correlations for the RA site in most cases, were caused by a difference in the spatial structure of the Spring Year 2 sampling. Olsen-P values were spatially stable at the F, RM, and S sites.

Summary and Conclusions

Significant differences in soil test measurements from one sampling date to another occurred frequently. Bray 1-P values were similar or decreased over time while Olsen-P values at two of five sites decreased, at one site no pattern in the soil test value changes while at two sites cyclic patterns occurred where the spring sample values were greater than the fall. The decreases which occurred between the spring and fall sampling dates, were probably caused in part by P uptake by the crop. Since no P fertilizer was applied to the area where soil samples were obtained during the two years of the study at each site, the decrease in soil test values between the spring and fall sampling dates was expected. The positive changes from fall to spring sampling dates may be caused by the release of P from the soil as it comes back into equilibrium after crop use from the previous year. The analysis for spatial stability over time was done by using a geostatistical approach which utilized an analysis of semivariance of each measurement at each sampling date and a Spearman ranked correlation. There was strong agreement between these two approaches. The distance over which autocorrelation occurs was greater than the 60 ft. interval that the soil samples were obtained. In the geostatistical analysis for Bray 1-P, the spherical model was the best fit for the relationship between the lag distance and the semivariance for 10 of 17 sampling dates. This was similar to results in a Iowa study (Cambardella et al. 1994, Cambardella and Karlen 1999). The best model for four of the 17 sampling dates was exponential while the linear model was used for three sampling dates. The best fit model for Olsen-P values on 13 of 17 sampling dates was also spherical.

Spearman ranked correlations for Bray 1-P were stronger than for Olsen-P. In general, soil test parameters measured in this experiment were spatially stable over time.

In general, the soil test P categories decreased over the study period. The decrease was probably caused by plant P uptake in combination with no application of P fertilizer. Because of the changes in soil test measurements between spring and fall sampling dates, a soil sample should be obtained at the same time of year consistently from year to year and from the same locations in the field. The nutrient maps developed from the soil samples taken at most soil sampling times at all sites were found to be similar in shape over time by two different methods. The similarity in shape of soil test P distribution of these nutrient maps over time indicates that in the short term the maps are viable to use for locating the variability of soil test P in a production field.

A producer using good nutrient management for P can feel confident that a site specific P map obtained within two years of the last the last soil sampling is useful for site specific P application and reliably maps the variability of P in soils formed in a glacial till landscape.

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