NCERA 13 Workshop

February 22-23, 2011
Bettendorf, Iowa

Tuesday, February 22, 2011

1:00 Welcome and Introductions – John Peters/Antonio Mallarino

1:10 Managing variations in soil test K levels in Southeast Kansas – Dave Mengel

1:40 Temporal K variation over time and reasons for variation and testing alternatives – Antonio Mallarino (page 3)

2:30 Soil testing for N in the Plains States – Dave Franzen (page 15)

3:00 Break

3:20 The IPNI soil test summary – Scott Murrell

Soil test summaries across the region:
Ohio – Robert Mullen (page 18)
Illinois – Fabian Fernandez (page 23)
Michigan – Jon Dahl (page 43)
Wisconsin – John Peters (page 47)
K across the Midwest – Bob Miller

4:50 Using the web soil survey – Matt Ruark (page 51)

5:10 Short presentation by sponsors

5:30-6:30 Social Hour

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Wednesday, February 23, 2011

6:30 Continental Breakfast

7:30 Individual State Sessions

8:00 Effect of sample depth on soil test levels - Dick Wolkowski (page 52)

8:30 Soil sampling variability – grid point uncertainty – Bob Miller (page 60)

9:00 Change in soil tests over time from long-term nutrient applications – Anthony Bly and Ron Gelderman (page 67)

9:20 Does using ICP affect results for K, secondary and micronutrients? – Byron Vaughan (page 72)

10:10 Break

10:30 NAPT Update – Grant Cardon

11:00 MAP Update – Jerry Floren (page 74)

11:20 Challenges in managing a lab across state borders 1 – Steve Peterson, AgSource
Challenges in managing a lab across state borders 2 – Lois Parker, A&L Great Lakes

12:00 Wrap up and adjourn

Factors Determining High Temporal Soil-Test Potassium Variation and Soil Sampling and Testing Alternatives

A.P. Mallarino, P.A. Barbagelata, M.W. Clover, C.X., Villavicencio, and L.B. Thompson
Department of Agronomy, Iowa State University

Introduction

There has been extensive research on potassium (K) fertilization and soil testing in Iowa since the 1960's. From the middle 1990s until the early 2000s, more than 200 conventional or on-farm strip trials were conducted. Results of this research have been summarized in several extension and journal articles, and have resulted in updated Iowa State University (ISU) K recommendations in 1999 and in 2002, and recommendations continue to be evaluated at the present time. In spite of significant advances on soil-test calibration, fertilizer placement methods, and fertilizer rates, these research demonstrated a great deal of uncertainty about K management in soils testing low to optimum in K, a very poor capacity of soil and plant testing to predict K sufficiency for crops, and unexplained very high soil-test K (STK) variation over time. The high temporal variability of STK is well known by farmers and crop advisors that have used soil testing for K during many years. An example for five long-term Iowa trials is shown in Fig. 1. Potassium is present in the soil in water-soluble, exchangeable, non-exchangeable, and mineral or fixed K forms. An estimate of soil exchangeable K with the ammonium-acetate or Mehlich-3 tests from air-dried or oven-dried soil samples is the most widely used methods to predict plant-available K. These two methods provide comparable K test results, and are suggested methods for soils of the north-central region of the USA by the North-Central Regional Committee for Soil Testing and Plant Analysis (Warncke and Brown, 1998).

In spite of extensive research, predicting plant available soil K by soil or plant testing has proven to be a difficult task, however, due to the complexity of the dynamic equilibrium among these various forms of soil K and the many factors that influence crop availability of K and plant K uptake. This article summarizes recent and ongoing research to study these problems and work to improve soil K testing and management. This includes study of sampling date effects on soil test K results and prediction of yield response, impacts of soil sampling drying and K extraction methods, and impacts of K recycling with crop residues.

Soil Sampling Date for Potassium

An Iowa Corn-Soybean Initiative on-farm research project was developed since 2006 until 2009 to study soil sampling dates for K and the within-field variation of STK and the yield response of corn and soybean to K fertilization. This section provides an overview of preliminary yield and STK results from 2006 and 2008 (some of the 2009 results have not been summarized at this time). Soil samples were taken from the top 6 inches of soil before applying K in the fall using a dense grid-point sampling approach (cells 0.2-0.5 acres in size). Samples were also collected from cells of the control strips in spring (April) before planting the crops and again in early summer (June). Soil samples were dried at 35-40 ºC and analyzed for K with the ammonium-acetate (AAK) and Mehlich-3 K tests, but only results for the AAK test are shown. Grain yield was measured with yield monitors and GPS, and data was imported into GIS computer software.

Yield maps were subdivided into small cells defined by the soil sampling cells and strips to study yield response variation along the strips.

The project indicated moderate and inconsistent effects of the time of soil sampling on STK results. Observation of data in Fig. 2 indicates that the average STK differences between the three sampling dates were very small in southeast Iowa but larger in the other regions. However, there was no consistency across regions as of what sampling date resulted in lower or higher STK. An interesting result (which we cannot explain at this time) was that except for the eastern Iowa fields, the June sampling date resulted in smaller range of STK values. Relationships between yield response and STK across sites indicated no clear difference in critical levels or ranges for the three sampling dates (not shown), which agrees with inconsistent results for STK shown in the previous figure. An arrangement of STK and response values into current Iowa interpretation classes (Fig. 3) show, however, that the June sampling date was more effective at classifying soils with high yield response into the Low interpretation class, mainly compared with the fall sampling date. Therefore, results for each region or all trials showed no clear or conclusive differences between sampling dates, although seems that the June sampling date was slightly more effective. Obviously, an inconvenience of sampling in June sampling date is that crops already are planted, which is a major problem if there was a deficiency. Because in-season K fertilization is not effective for annual crops, the information would be useful only for the next crop, but also has there is the problem of how to account for removal by the current crop when deciding the fertilizer rate for the next crop. The results of this study do not necessarily indicate that sampling date is not part of the problem of high year-to-year unexpected variation in STK as indicated in Fig. 1, because the set of factors involved could not be the same in all fields and may not affect STK in the same way across fields or regions.

Sample Drying and Soil Testing for Potassium

The effect of drying soil samples on STK measurements is well known. Decades old research has shown that wetting-drying and freezing-thawing cycles influence transformations of K between non-exchangeable, exchangeable, and solution fractions. Soils initially high in exchangeable K may fix K upon drying while those with initially very low exchangeable K levels tend to release K upon drying. Freezing of moist soils often has a similar effect to drying the soil. The equilibrium between these soil K pools also is affect by K additions and plant K removal from the soil. Therefore, the time of sampling interacting with these factors in the field or during the sample handling at the laboratory may partly account for high temporal variation of STK. Iowa research in the 1960s and 1970s showed that soil K extracted with the ammonium-acetate solution from field-moist samples was better correlated with crop K uptake than K extracted from air-dried or oven-dried soil samples. A method for testing field-moist soil samples for P, K, and other nutrients based on a slurry was developed and implemented in Iowa until 1988, and procedures were among those suggested by the North-Central Region NCR-13 soil testing committee (Brown and Warncke, 1988; Eik and Gelderman, 1988). Field correlations for corn and soybean for this slurry K test from long-term Iowa experiments were published by Mallarino et al. (1991a, 1991b). However the Iowa State University Soil and Plant Analysis Laboratory discontinued analyzing samples with the slurry test in 1988 because no private laboratory adopted it citing impractical procedures (mainly soil moisture determination and the slurry preparation). Therefore, based on comparisons of amounts of soil K extracted using dried (35 to

40 ºC) or moist soil samples (not field calibrations), the soil-test interpretation categories for the slurry K test were increased by a factor of 1.25 for Iowa recommendations published in 1988 and 1996. Testing for P is not affected by drying at 35-40 C, so soil-test P interpretations were not changed. The old database for the slurry K test and a 1.25 factor continued to be used for AAK and Mehlich-3 K test in recommendations updated in 1999. However, new field calibration research (Mallarino et al., 2002) revealed the inadequacy of this adjustment for the dry-based tests (it over-estimated crop available K) and results were used to make fundamental changes in STK interpretations for the last update in 2002 (Sawyer et al., 2002).

A study was conducted from 2001 until 2006 (151 site-years of data) to assess the impact of sample drying on soil K extraction from several Iowa soil series, study correlations between K tests, and to develop field calibrations with corn and soybean for the commonly used test based on dried samples and a modified direct-sieving field-moist samples for the extraction. As smaller set of representative samples were used to compare the old slurry K test with the modified direct-sieving moist test. The amount of soil K measured by the two moist-based tests (not shown) was highly and linearly correlated (r = 0.99), but the slurry K test on average measured 17% more K than the direct-sieving moist K test (hereon referred to as the moist K test). The most likely reason for this difference was an incomplete destruction of soil aggregates with the direct-sieving moist K test. Observation of sediment after filtering sometimes indicated the presence of small soil aggregates after shaking soil for the moist K test but none for the slurry test. This difference was not clearly different for the soils included in this set of samples, which varied greatly in initial moisture and texture. The results suggest that the slurry test provide a less variable K measurement than the quicker and simpler direct-sieving moist test, however, and that any critical level determined in this study for the moist test used would be 17% lower than would have been for the slurry test.

Soil K extracted with the dry test was higher than for the moist test but the difference decreased with increasing soil K level (Fig. 4). The difference increased significantly by increasing the drying temperature form air-drying to 50 C (not shown). Also, the sampling drying effect varied greatly between soil series (Fig. 5). Other NCERA-13 committee research has shown that the effect of soil temperature varies across soils (R. Elliason and G. Rehm, University of Minnesota). Therefore, no single simple factor can be used to relate the dry and moist K test results because. The moist K test correlated better with corn and soybean yield response and showed a better defined critical K concentration range compared with the dry test (Figs. 6 and 7). The results showed that different calibrations may be needed for different soils and (or) growing conditions for the dry test, but not clearly for the moist test. Critical concentration ranges defined by Cate-Nelson and linear-plateau models across all soils (6-inch sampling depth) for corn were 144 to 201 ppm for the dry test and 62 to 76 ppm for the moist test; while critical concentrations ranges for soybean were 121 to 214 and 52 to 90, respectively. According to the almost 1:1 correlation found in this study between the old slurry and moist K tests but a 17% higher test result for the slurry test, the critical concentration range for the slurry test would be 73 to 89 ppm for corn and 61 to 105 for soybean. These values are very close to critical concentration ranges calculated for the last available relationships between the slurry K test and either crop response to K fertilization (Mallarino et al., 1991b), and also to the Optimum (called to Medium before) Iowa old interpretation class for the slurry test (68 to 100 ppm). Therefore, this study indicated that a K test based on field-moist samples (based on a slurry or direct-sieving sample handling method) predicts crop response to K fertilizer significantly better than the commonly used test based on dried samples, and that the magnitude of the improvement may justify more laborious laboratory procedures for the field-moist test.

Some evidence suggests that the measurement of exchangeable K by dry or moist tests may not be the most reliable index of plant-available K for some regions and crops. Cox and Joern (1996) showed that the AAK dry test predicted plant-available K poorly in soils where non-exchangeable K contributed significantly to K nutrition in winter wheat. Therefore an ideal soil-test for K may need to measure exchangeable K but also a proportion of non-exchangeable K that may potentially become crop available before or during the growing season. A modified version of the sodium tetraphenylboron extraction method developed in Iowa in the 1960s to assess non-exchangeable K has received attention as a potential method to estimate plant-available K. Cox et al. (1996) modified the method by using Cu^{2+} instead of Hg^{2+} to destroy the phenylboron anion and recover precipitated K. Cox et al. (1999) modified the method further by decreasing the extraction time to facilitate its potential use as a routine soil-test for K (hereon referred to as TB). Results of field calibrations using the response trials mentioned above did show that the amount of TB-extractable K was significantly higher than amounts measured by the AAK or Mehlich-3 K tests based on dried samples, and that difference increased with increasing soil K levels and decreased as the Ca and Mg to K ratio increased. However, the TB test did not show a consistently superior capacity to predict corn and soybean response to K (not shown). Critical STK concentration ranges defined by the CN and LP models across all soils for the TB test were 421 to 641 ppm for corn and 473 to 556 ppm for soybean. The results for this test do not support adoption of the TB in production agriculture as a routine K test because its correlation with crop response is not consistently better than for the dry or moist tests and the laboratory procedure is much more laborious and expensive.

Equilibrium between Soil K Pools

Potassium is present in the soil in water-soluble, exchangeable, non-exchangeable, and mineral or fixed K forms. Distribution of K among these forms also occurs as K is added to soil as fertilizer, manure, or crop residues. Plants take up K from soil solution, which is readily replenished by soil exchangeable K. Some non-exchangeable K can become exchangeable when solution and exchangeable K are depleted by plant removal, leaching, or exchange reactions with other cations. Potassium additions quickly increase the solution and exchangeable K pools, and can also increase the non-exchangeable over a difficult to predict extent and time frame. We postulated that at least part of the high temporal STK variation could be explained by not recognized or under-estimated equilibrium between exchange K (which the pool estimated by routine soil test methods) and the so-called non-exchangeable K. Ongoing research is confirming our hypothesis and, furthermore, is showing that these effects vary greatly across Iowa fields and years due to factors that we are studying at this time. Figure 8 shows (as examples) results for two contrasting Iowa sites. In a northwest Iowa soil, the high K application increased post-harvest STK compared with the control and a lower rate because the K applied exceeded removal and K remaining in residue, but non-exchangeable K as measured by the tetraphenylboron test remained approximately constant or decreased slightly compared with the no application or the lower K rate. At a central Iowa site, however, post-harvest STK was not increased by fertilization (in fact decreased slightly) but the non-exchangeable K increased significantly. The yield responses and removal data from these and other sites (not shown) are suggesting that much of the increased non-exchangeable K is available for the next crop. Clearly, these processes can explain much of the unexpected variation in STK and also often unexpected relationships between STK, yield response, and K removal as some shown in Fig. 1.

Potassium Recycling with Residue

Evidence from the studies summarized above and others strongly suggest that the degree of K recycling to the soil as affected by the uptake and leaching to the soil with rainfall also could explain part of the high temporal STK variation. Since plant K is inorganic and highly soluble, rainfall patterns combined with uptake amounts and distribution within the plant could greatly affect the patterns of K return to the soil from crop physiological mature into the next year. From fall 2008 we had been studying these processes at various corn and soybean field trials. At physiological maturity and during the harvest time we harvested and analyzed separately the above-ground portion of plants (grain and the rest of the plant). We also collect and weighed residue, and left it on the ground to collect samples for P and K analyses at five dates from harvest until April of the next year (before planting the new crop).

In this article we share average results for two cornfields and five soybean fields (Fig. 9). The trends were approximately similar for corn and soybean. One clear result for both crops was a very sharp decrease in the amount of K remaining in vegetative tissue from physiological maturity until harvest, a period of only about four weeks on average. This sharp decrease in the amount of K in the plant vegetative parts between physiological maturity and the time of harvest can be explained by some K remaining in dropped leaves (which we did not collect at grain harvest time when they were contaminated with soil) and leaching to the ground from standing biomass. Other clear results for both crops was that there was another sharp decrease during fall, amounts changed little during winter (with snow and frozen ground), and there was another small decrease in spring. There were significant variations in the patterns of K release from plant and residue that most likely were related to rainfall amounts and distribution. However, we have not completed the study of rainfall data together with the results at this time.

Summary Conclusions

The combination of ongoing studies of the effects of sampling date, testing of dry or moist samples, equilibrium between different soil K pools, and residue recycling have great promise to understand processes that determine high temporal variation in STK and often poor relationships between STK, yield response, and K removal. Although the studies are not completed and it is unclear how the new knowledge can be considered in recommendations, the preliminary results already are useful to crop advisors and farmers. Even a general knowledge of suggested factors that may affect a K soil-test result can help interpret better test values that sometimes seem illogical given a good sampling approach, testing by a certified laboratory, previous soil-test results, yield levels, and fertilization rates. For example, information about rainfall from a few weeks before harvest to the time of soil sampling may be used to help decide about fertilization rates when a K test result seems too low or too high according to the previous history. Although sampling and laboratory errors always are a possibility, we feel that in most cases the processes discussed here are largely responsible for unexpected results from soil K testing.

Acknowledgements

These studies were or are being supported in part by the Iowa Soybean Association, the International Plant Nutrition Institute, and the Iowa State University Corn-Soybean Initiative.

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Figures

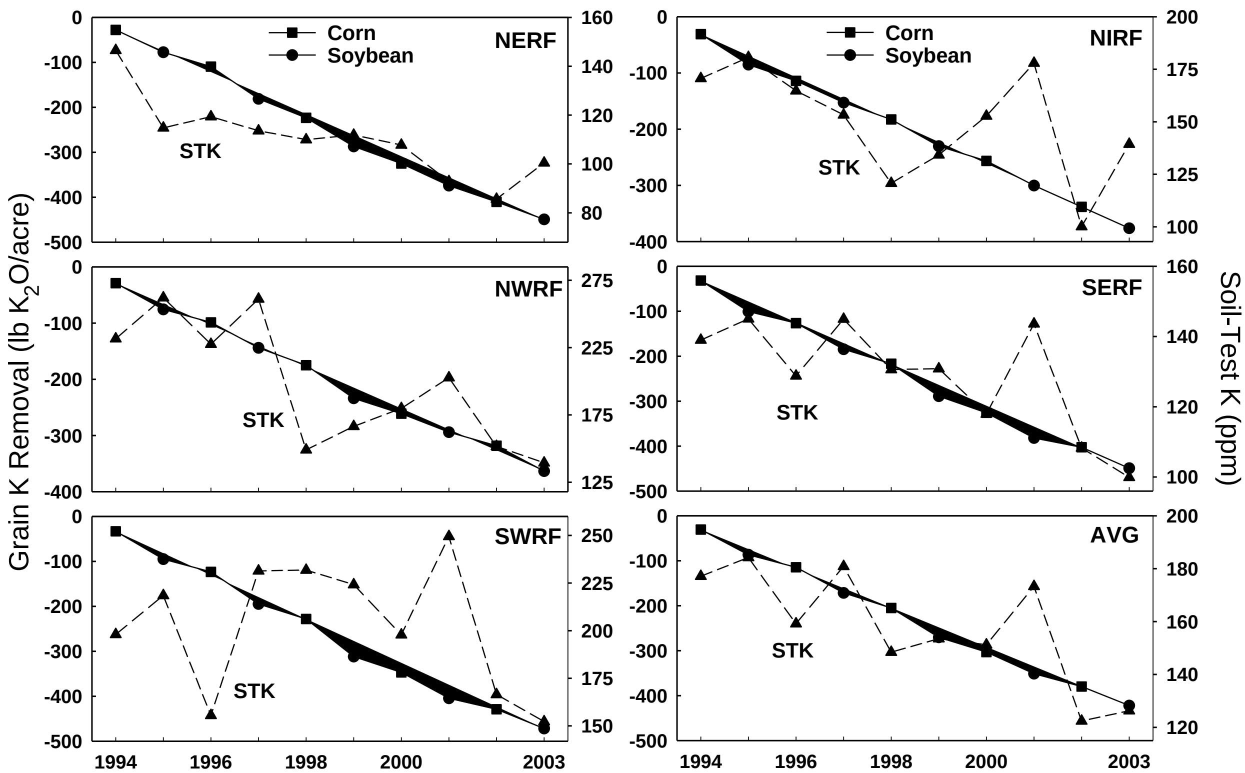

Fig. 1. Soil-test K (STK) and cumulative K removal long-term trends for five Iowa sites (northeast, north, northwest, southeast, and southwest research farms). Averages of three replications for plots 825 to 1,200 sq-ft across sites and 12 cores per composite soil sample (Mallarino and M. Valadez-Ramirez, 2005, unpublished).

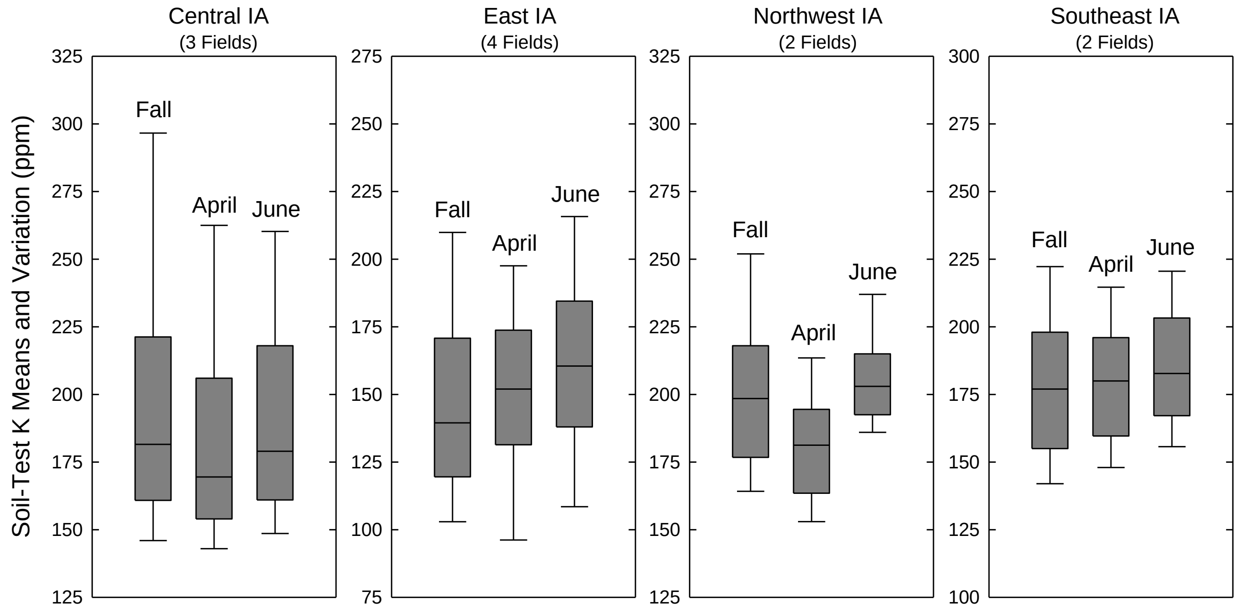

Fig. 2. Median and percentile distributions for soil-test K results for grid soil samples taken in the fall, April, and June from eleven Iowa fields. No fertilizer or manure was applied between the sampling dates.

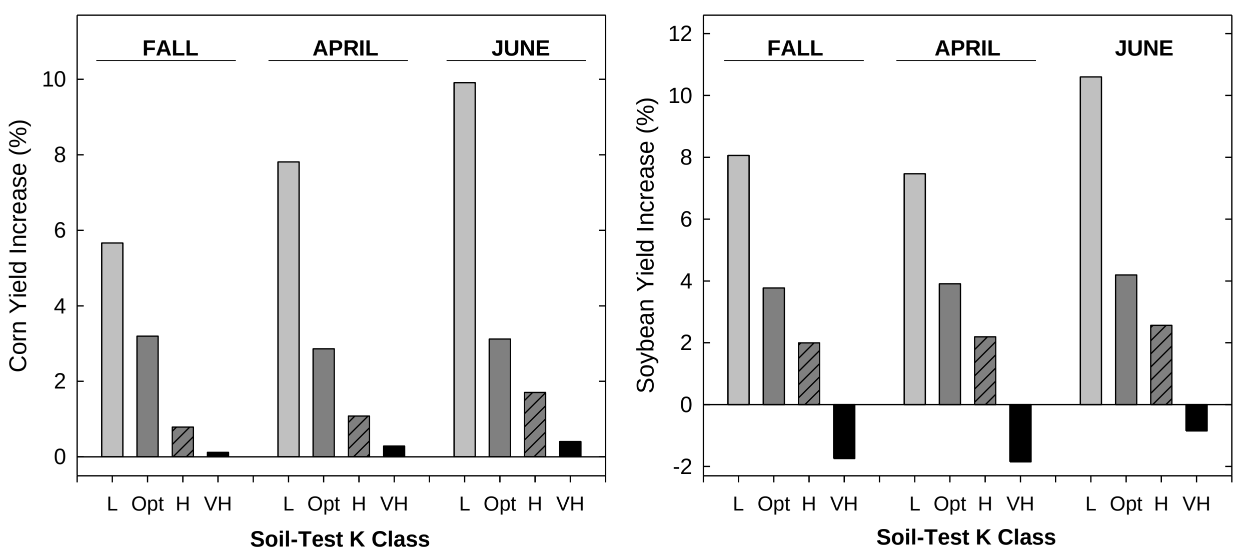

Fig. 3. Relationships between relative yield response and soil-test K (STK) from different sampling dates from Iowa on-farm, replicated strip-trials managed with precision agriculture technologies (13 site-years for corn and 9 sites-years for soybean). GIS was used to consider responses for field areas testing within different interpretation classes across all fields and years (very few soils testing Very Low that were merged with the Low class).

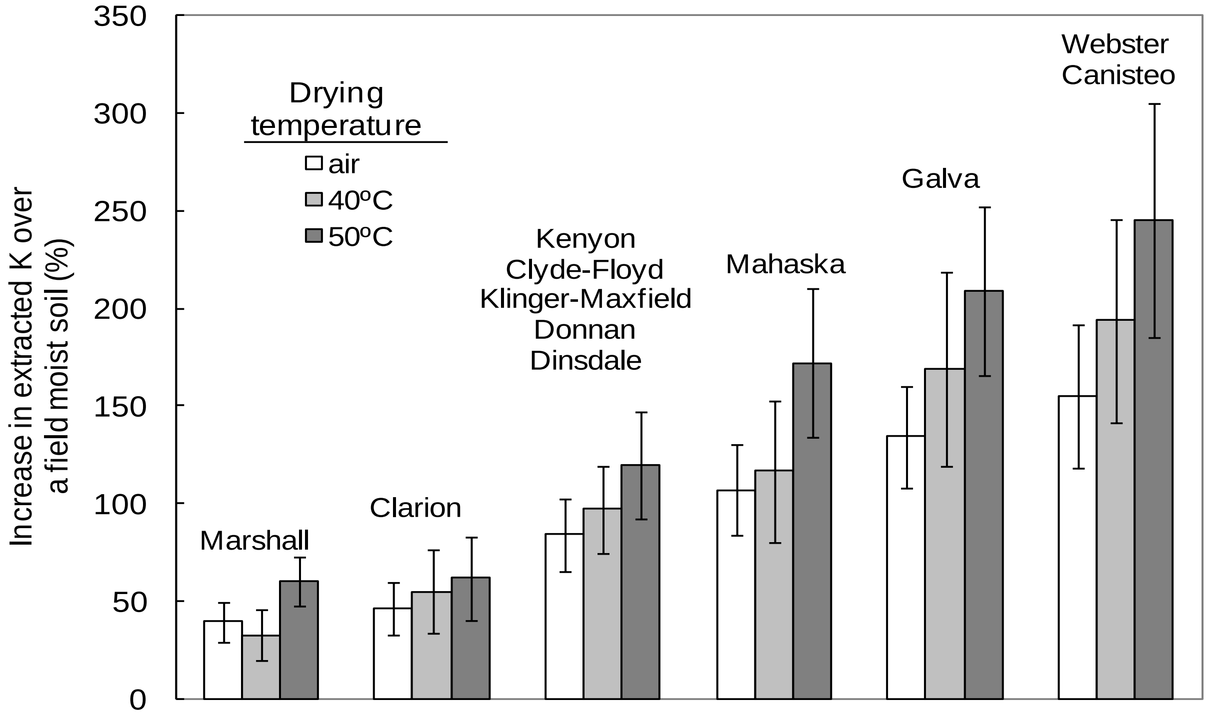

Fig. 4. Effect of sample drying temperatures on ammonium-acetate soil-test K relative to K measured on field-moist samples for typical Iowa soil series (vertical bars represent standard deviations).

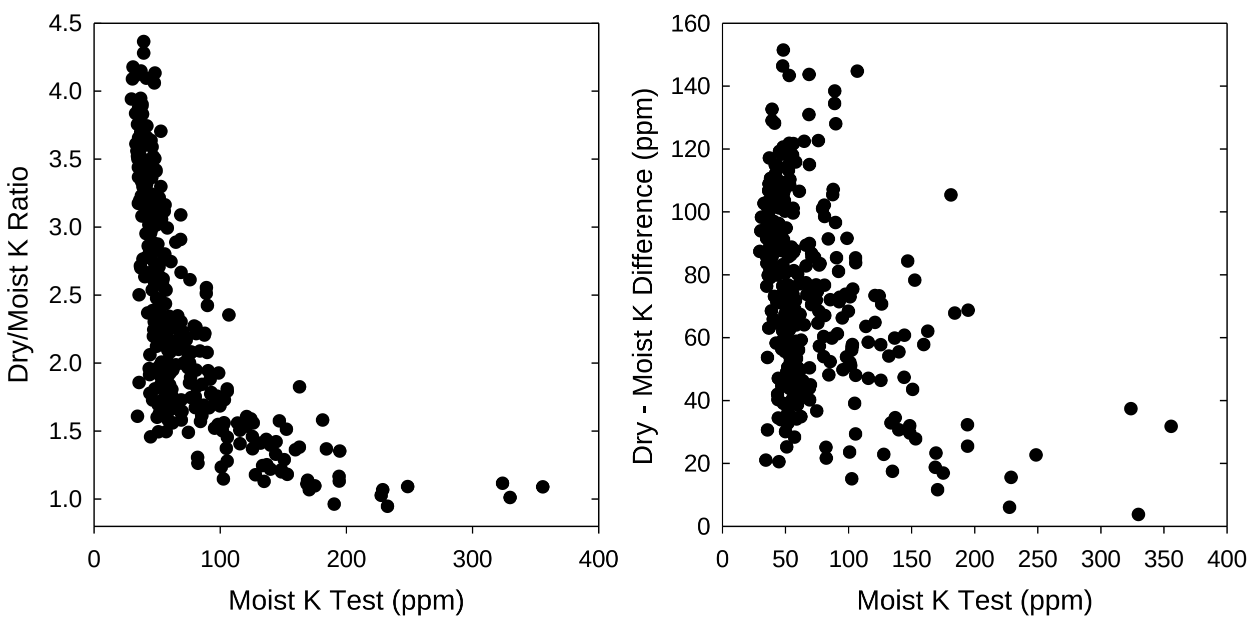

Fig. 5. Relationships between ammonium-acetate soil-test K based on field-moist soil samples and the relative or absolute difference between measurements based on dried (35-40 C) or moist samples.

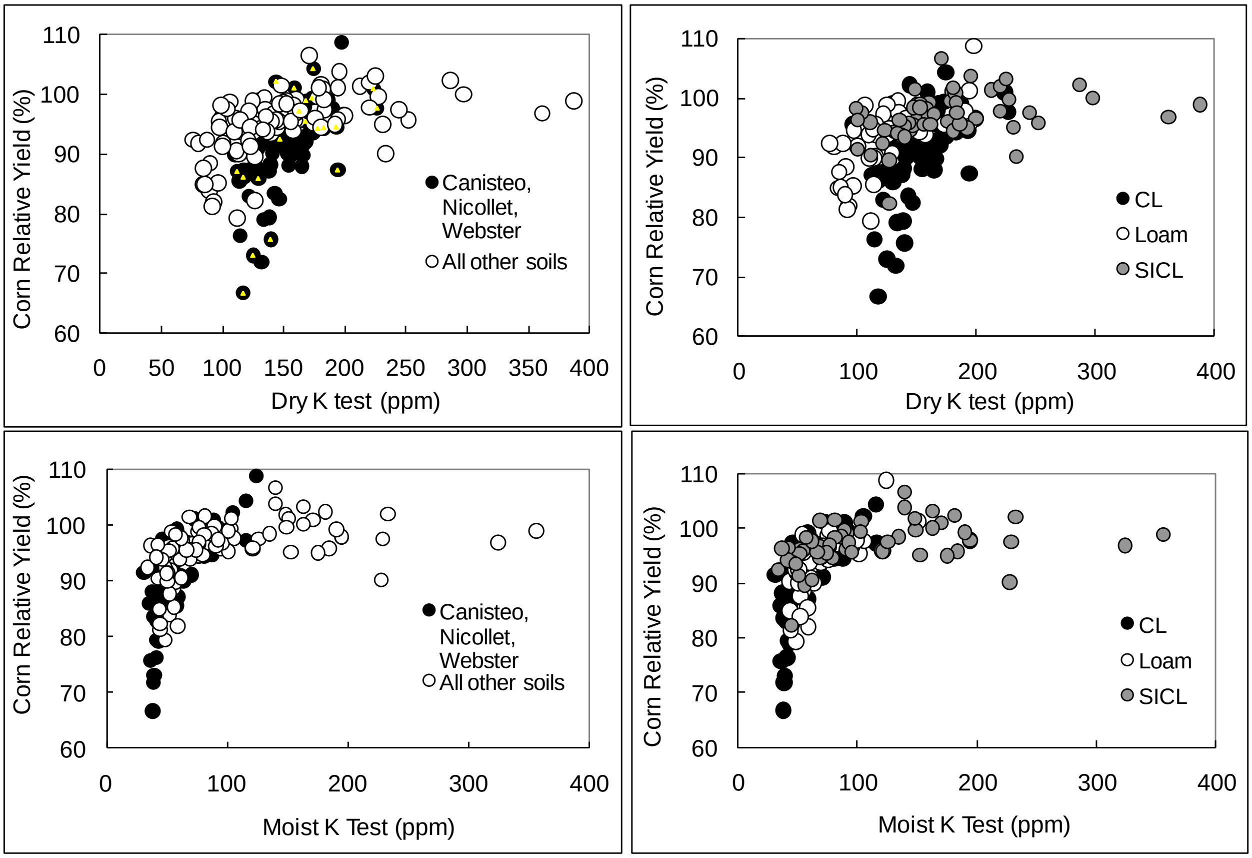

Fig. 6. Relationship between relative corn yield response to K fertilization and ammonium-acetate soil-test K based on dried (35-40 C) and field moist samples.

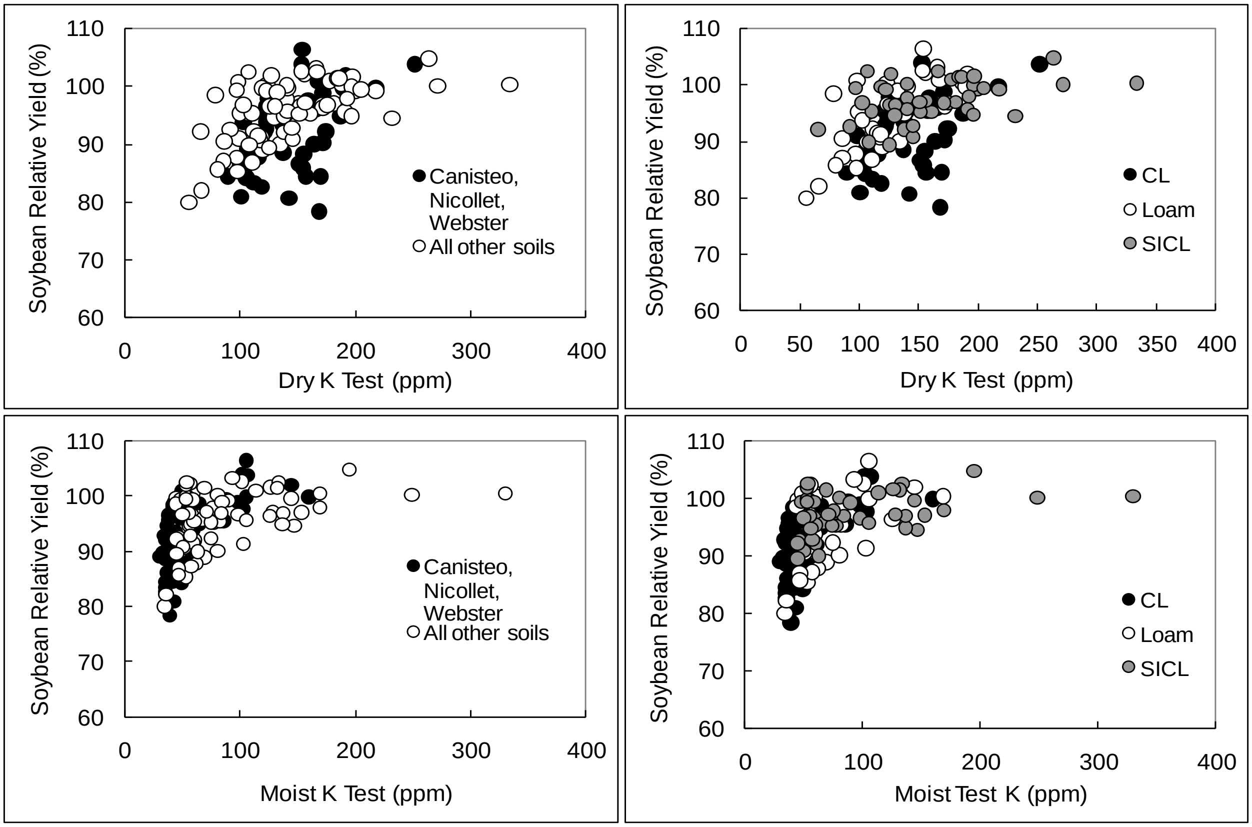

Fig. 7. Relationship between relative soybean yield response to K fertilization and ammonium-acetate soil-test K based on dried (35-40 C) and field moist samples.

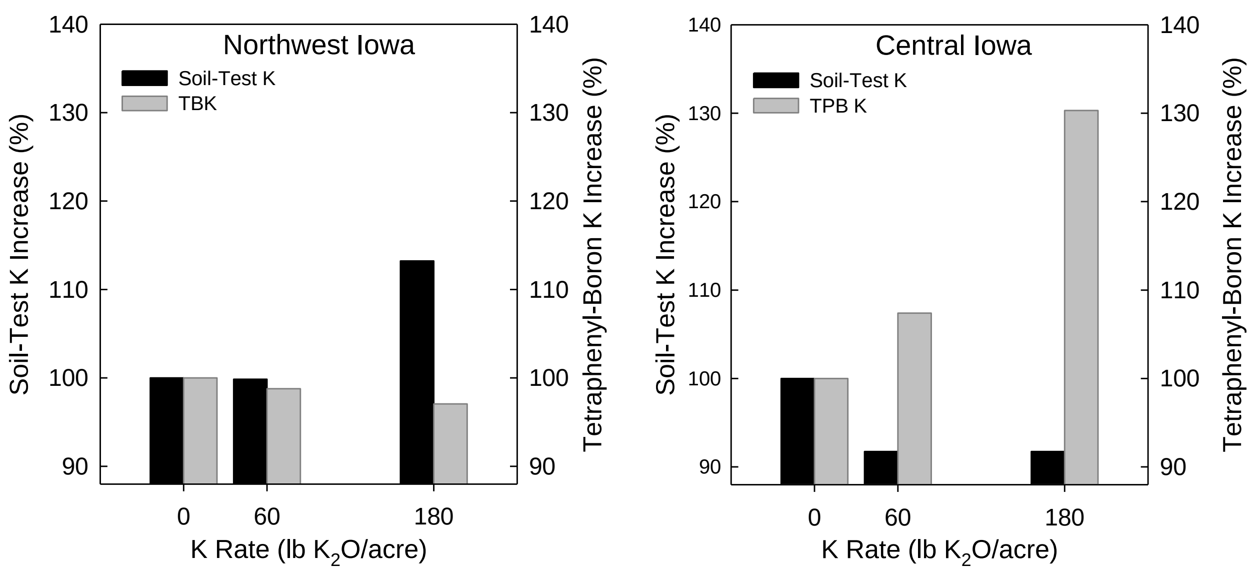

Fig. 8. Post-harvest soil-test K and non-exchangeable K (tetrapehnylboron (TPB) test) when similar K fertilizer rates were applied for corn at two Iowa sites.

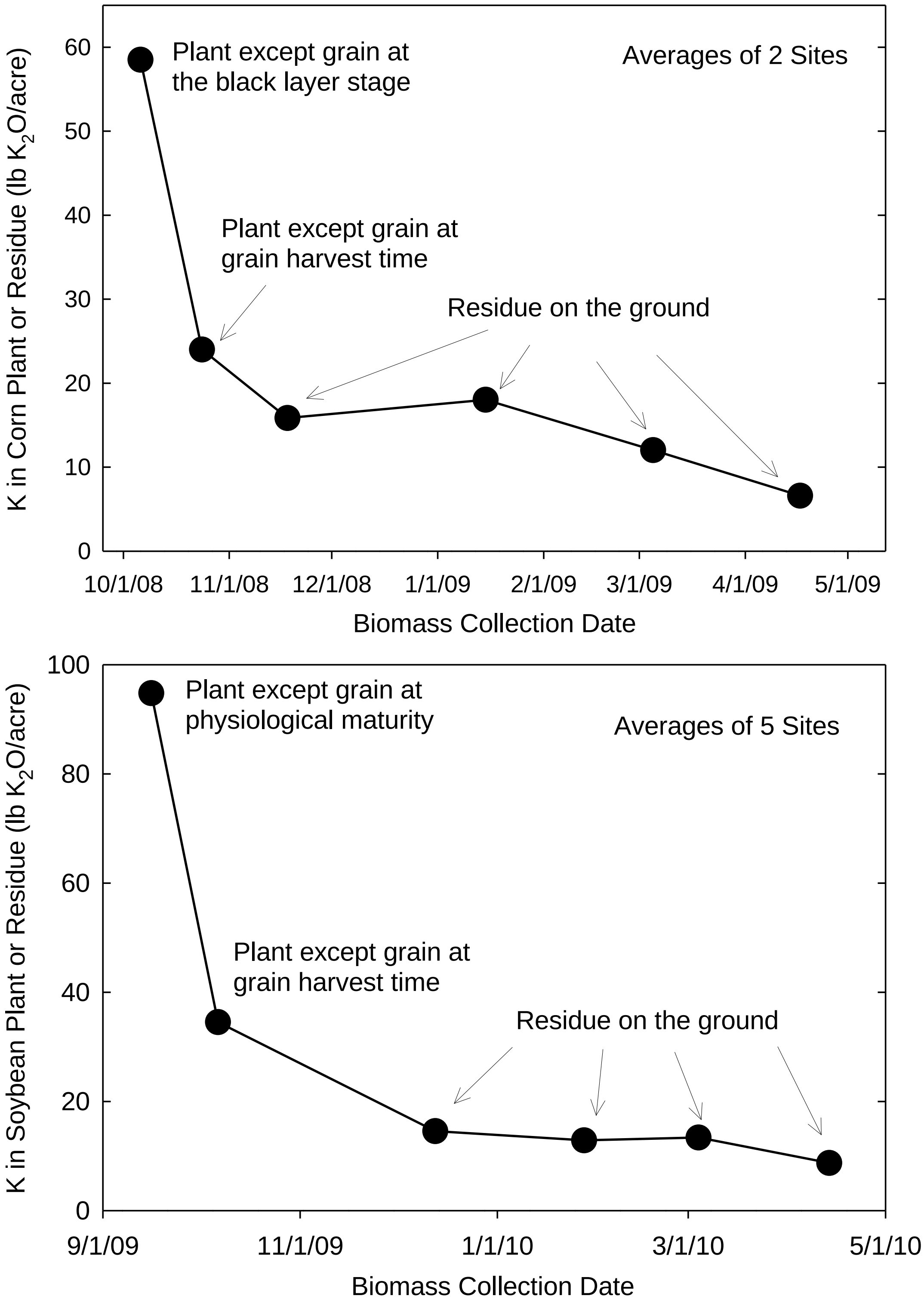

Fig. 9. Amount of potassium remaining in corn and soybean plants except grain and in after harvest residue from physiological maturity until spring.

Nitrate Soil Testing in the Northern Plains

Dave Franzen
North Dakota State University

The unique climate of the Northern Great Plains offers a chance to use fall sampling for residual soil nitrate as a factor in determining N rate for the next crop. In Fargo, for example, it may snow temporarily from mid-September through October, but usually by November the snow falls and stays until late March of April. Locals call this snow “the keeper”. By November, soil temperatures lower to at most 32 degrees, and by December the soil is often frozen at least 2 feet deep. Frost is often still in the soil to a depth of 2 feet until spring wheat and barley seeding is well underway. Because soil nitrate is in a frozen environment and soil water movement essentially stops in the rooting zone for about 4 months, residual fall nitrate is considered stable, and as useful as a spring nitrate analysis.

Use of residual soil nitrate levels to include in N recommendations for crops in the Northern Great Plains is a relatively modern consideration. As late as 1965, it was thought that soil nitrate was too capricious to use effectively in the modifying N rates (Scarsbrook, 1965). However, Soper and Huang (1971) demonstrated that residual nitrate was useful in determining the N requirements of spring barley. By 1971, the soil nitrate test was incorporated into the N recommendation formula for crops in North Dakota (Torkelson, 1972). A series of subsequent studies showed the value of the soil nitrate test in sugar beets (James, 1971; James et al., 1971; Reuss and Rao, 1971; Hills and Ulrich, 1976). By 1980, Moraghan writes that the use of the 0-2 foot soil nitrate test was commonly used in the Red River Valley. Today, more than 90% of projected sugarbeet acres are tested for at least 0-2 foot and often 0-4 foot nitrate in Red River Valley sugar beets. Based on numbers of analysis made by Agvise Laboratories at Northwood, ND (John Lee, personal communication) and the NDSU Soil Analysis Laboratory in Fargo, more than 200,000 soil samples are analyzed for nitrate in the state of North Dakota. These numbers represent about 6 million acres of cropland, or about 25% of the total crop acreage in the state. Additional acres are guided (or misguided) by the use of county average soil tests, and sometimes by using benchmark soil nitrate analysis from a grower’s field to estimate the levels in others with a similar history.

Although the nitrate soil test is recommended for use in Montana, its use is not as widespread as in North Dakota. Many growers assume that residual nitrate levels are low and fertilize accordingly. In northwest Minnesota, the use of the soil nitrate test for sugarbeet is as high in the Red River Valley as in North Dakota. For spring wheat the use of the soil nitrate test is similar to North Dakota, but a factor of 60% is used when the soil nitrate test is used for corn in the western part of the state.

Recently, the use of the soil nitrate test was reexamined in North Dakota. The results suggested that the soil nitrate test is very useful in the N recommendation process and should be included into the N recommendation formulas (Figures 1 and 2).

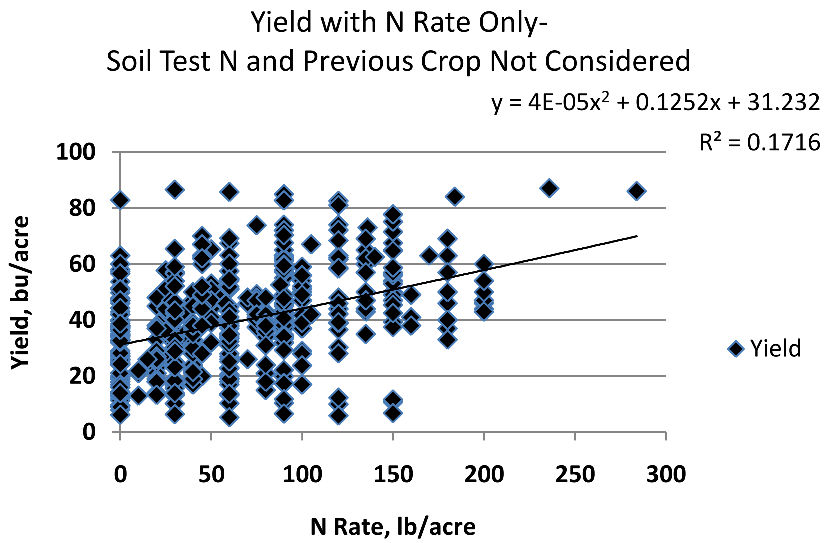

Figure 1. Relationship of North Dakota spring wheat yield and N rate only without regard for soil test nitrate and previous crop credit.

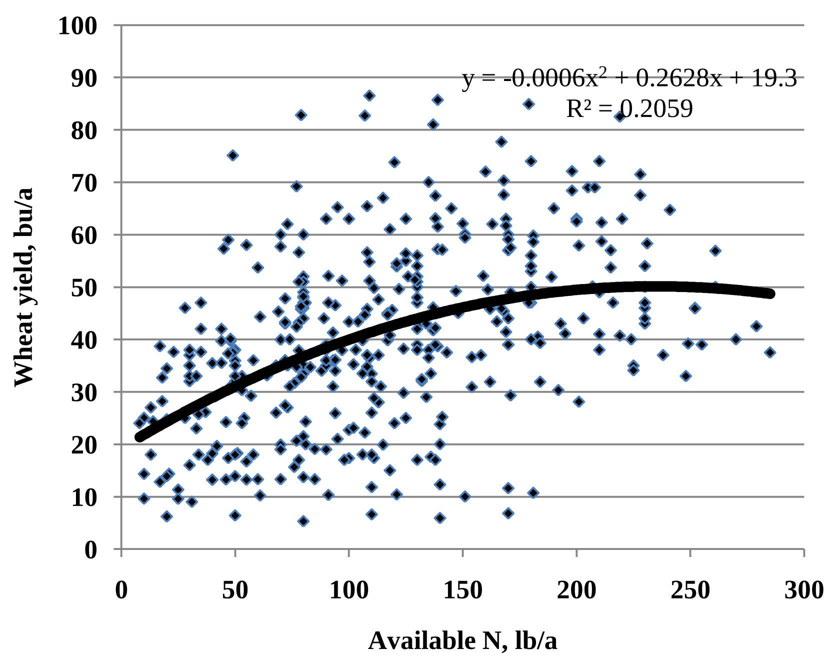

Figure 2. Relationship of spring wheat yield and N rate with soil test nitrate and previous crop credit considered.

A compelling argument for the use of the soil nitrate test in spring wheat and durum is that at the zero N rates, yields range from below 10 bushels/acre to over 80. This range is not reasonable. The relationship with soil nitrate considered in Figure 2 still has considerable yield variation at higher available N levels. However, this variability is reduced when factors such as western ND vs. eastern ND, no-till vs. conventional till, and an unusual state region (the Langdon area) are separated into their own unique data sets.

At smaller laboratories, the colorimetric determination of soil nitrate is still used (Cataldo et al., 1975; Vendrell and Zupancic, 1990). However, larger laboratories use cadmium reduction determination.

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SOIL TEST PHOSPHORUS TRENDS IN OHIO

Melissa C. Herman, Robert W. Mullen, and Elizabeth Dayton
School of Environment and Natural Resources, Ohio State University, Ohio Agricultural Research and Development Center, Wooster, OH 44691

Abstract

Agriculture is often cited as the primary factor for high phosphorus (P) loads contributed to Ohio surface waters including Lake Erie, but its exact contribution is not known. It has been reported that the amount of dissolved reactive phosphorus (DRP) measured in agriculturally dominated watersheds has been increasing since the mid-90s. In an effort to identify the factor driving the reported increase, this project evaluated historical soil phosphorus (P) trends in the state of Ohio by collecting historical soil test data from the three largest commercial laboratories servicing Ohio to determine if P levels at a county resolution are changing. This helps address to what extent widespread over-applications of fertilizer P (either commercial or organic) are contributing to the reported high P loads. Of the 50 counties evaluated, trends did not show any county to have an increasing average P level, and 11 counties showed downward trends. Data was also evaluated for percentage of samples showing a P level above 60 ppm; only four counties in Ohio had soil test levels >60 ppm occurring greater than 40% of the time. The reported increase in DRP does not appear to be the result of widespread over application of fertilizer P, based upon observations in soil test levels.

Introduction

Eutrophication in Lake Erie has been a concern since the late 1960's (Richards et al., 2002a). In 1972, the US and Canada signed the Great Lakes Water Quality Agreement (GLWQA). Laws were enacted to regulate point source polluters, and the municipal P load declined from >15,000 Mg P in 1972 to approximately 3,000 Mg P in 1981 (Dolan, 1993). Agricultural practices were also addressed, and no-till farming became adopted voluntarily by approximately 45% of corn and soybean farmland in Northwest Ohio (Richards et al., 2002b). Despite continual declines in total P loads, there are rising concerns regarding dissolved reactive phosphorus (DRP) levels in Lake Erie, which are believed to be increasing and the cause of recent algal blooms in Lake Erie's Western Basin (Baker, 2008).

Agricultural systems are often pointed to as the primary source of these increased P loads in Ohio's waterways (Baker, 2008), but our understanding of just how much of the total P load could be attributed to agriculture and what is driving it (over-application, poor application methodologies, etc.) is not entirely clear. Baker and Richards (2002) calculated a P balance for the Sandusky and Maumee watersheds from 1975 to 1995. This study concluded that P fertilizer inputs, which accounted for more than 75% of applied P, declined 39 and 30% in the Maumee and Sandusky watersheds, respectively. Likewise, manure inputs were estimated to have decreased by 13 and 28%. Accompanied by continual increases in P removal at harvest, it would be expected for the total amount of P in the soil to have declined. More comprehensively, Bruulsema et al. (2011) conducted a P balance study for Ontario, Michigan, and Ohio from 1955 through 2008. This study found that, prior to 1990, there was a net P surplus in all three regions. More recently, P applications (both commercial fertilizer and organic manure sources) roughly equaled the amount of P leaving the field every year in harvest grain and biomass (Figure 1). This "balance" can be attributed to increased yields over the past few decades, decreases in P applications, and lower animal numbers (Bast et. al, 2009).

To truly confirm this calculated P balance, STP data needed to be evaluated, as it would be expected for STP to decline with a negative balance between P inputs and outputs. This study compiled the digital soil test databases from Ohio's three largest analytical laboratories and evaluated the STP data from 1995 through 2008 to determine if STP, evaluated at a county resolution, were generally following the calculated Ohio P balance.

Methods

Soil test information was collected from the digital databases of the three largest soil testing labs that service Ohio producers: A&L Laboratories, Brookside Laboratories, and Spectrum Analytic. In total, there were just over 1,000,000 data points collected going back to 1992, provided at a county level resolution. The information was delineated into years by county. Although soil test information was available for every county in Ohio, the only counties evaluated were the 50 that had significant sample numbers (>100) since 1995. The data was not coming from a true randomized sampling; however, it was conclude that the data was still a fair representation of Ohio's soils at a county resolution because there were often over 1,000 samples for any given county per year. A greater variation in the data was observed when sample numbers were low, especially less than 500. For such situations, extreme points which seemed to be more related to a low sample number, than a true reflection of the county average soil P level, were not considered when determining trends in soil P levels over time.

All soil test P information was reported as Mehlich III extractable P in mg kg^{-1}. Only lab data from agronomic fields was reported. Thus, garden and turf soil analytical information was not provided for evaluation of soil test trends. A county was considered to be experiencing either an increase or decrease in soil test P level if a change in P was greater than 10 ppm when examining the P levels over time. In addition, if the trend in mean STP met the above criteria, but the median trend was not relatively parallel to the mean, the change in mean STP was not considered to be changing.

Results and Discussion

Across the entire state of Ohio, mean and median soil test P levels did not increase from the period of 1995 through 2008 (Fig. 2). In fact, many counties have begun to show gradual declines in mean and median soil test P levels during this time period. Out of the 50 counties evaluated, 11 showed evidence of declining soil test P levels: Columbiana, Crawford, Darke, Defiance, Fulton, Henry, Medina, Miami, Paulding, Ross, and Van Wert. The remainder of counties revealed unchanging soil test P levels. There were no counties that showed an increasing soil test P trend.

To better understand the spread of STP levels in each county, STP data was also delineated into five ranges: <15, 15-30, 30-45, 45-60, and >60 ppm Mehlich-III. Although the groups are somewhat arbitrary, sixty ppm was used as the upper bound because this is where Ohio State University P recommendations approach a zero recommendation. Of the fifty counties evaluated, nineteen had soil test levels >60 ppm occurring less than 20% of the time, 28 had soil test levels >60 ppm occurring between 20 and 40% of the time, and only 4 had soil test levels >60 ppm occurring greater than 40% of the time. The four counties with the highest percentage of soils with levels greater than 60 ppm were Columbiana, Mercer, Muskingum, and Wayne County, which are among the top six in the state in animal numbers. Across the state as a whole, soil test phosphorus levels that are >60 ppm occur only 30% of the time (Fig.3).

Conclusion

The historical data provided by the analytical laboratories for this study shows that soil test P concentrations have not increased at the large, countywide scale. For some counties in Ohio, soil test P levels are actually declining. Trends of decreasing soil P levels can be expected considering the decreasing trend of P sales and animal numbers and improved agronomic productivity resulting in greater P removal. Soil P levels would not be expected to drop dramatically in conjunction with decreases in P sales, but soil P levels can be expected to decline over time if P sales continue to stay low. This study is not able to evaluate the possibility of poor nutrient management practices that might lead to excessive P loading into waterways, but it does show that at the county level, P is not being over applied. Small scale, isolated areas of high soil test P and loss of recent fertilizer applications cannot be discounted as significant contributors to increased DRP in Ohio watersheds, but it does not appear that it is the result of gross over-application on a widespread basis.

Acknowledgements

We would like to thank the Lake Erie Commission and more specifically the Lake Erie Protection Fund for providing financial support for this research effort. We would also like to thank A & L Laboratories, Brookside Laboratories, and Spectrum Analytic for access to their historic soil test information.

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Figure 1. Calculated P balance per acre for the state of Ohio from 1975 to 2007 (based on data from Bruulsema et al., 2011).

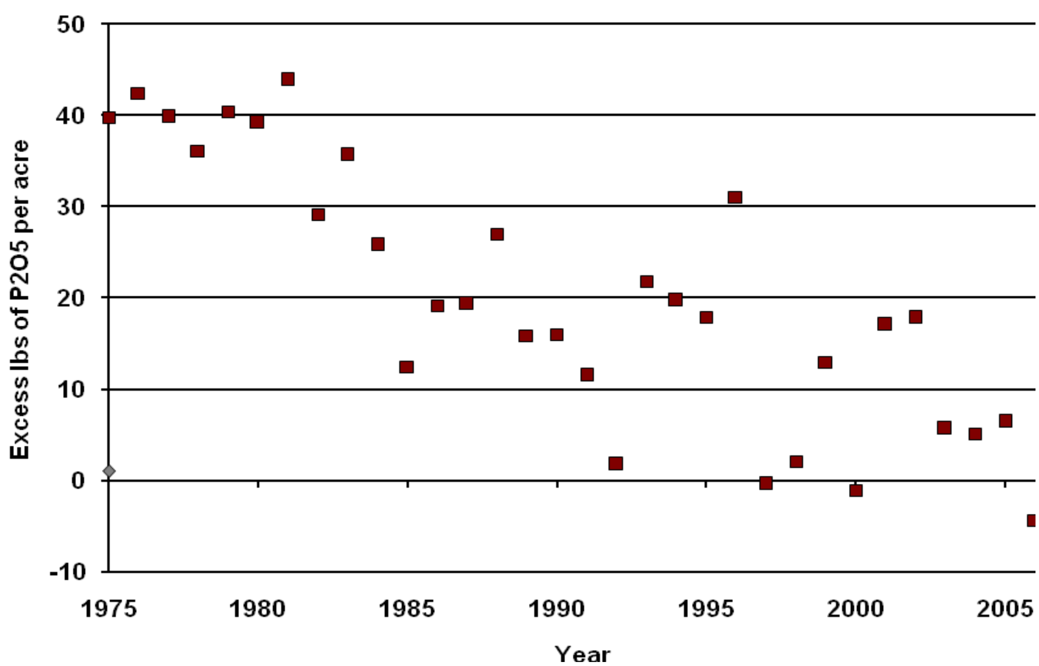


Figure 2. Soil test average and median P levels and number of soil samples (n) across the entire state of Ohio, 1995-2008.

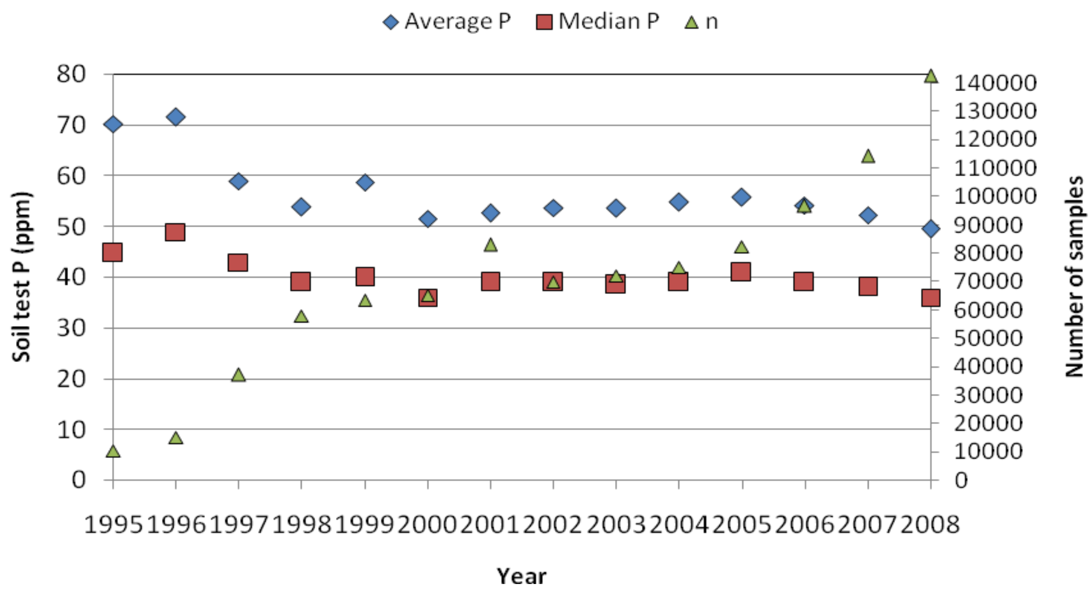
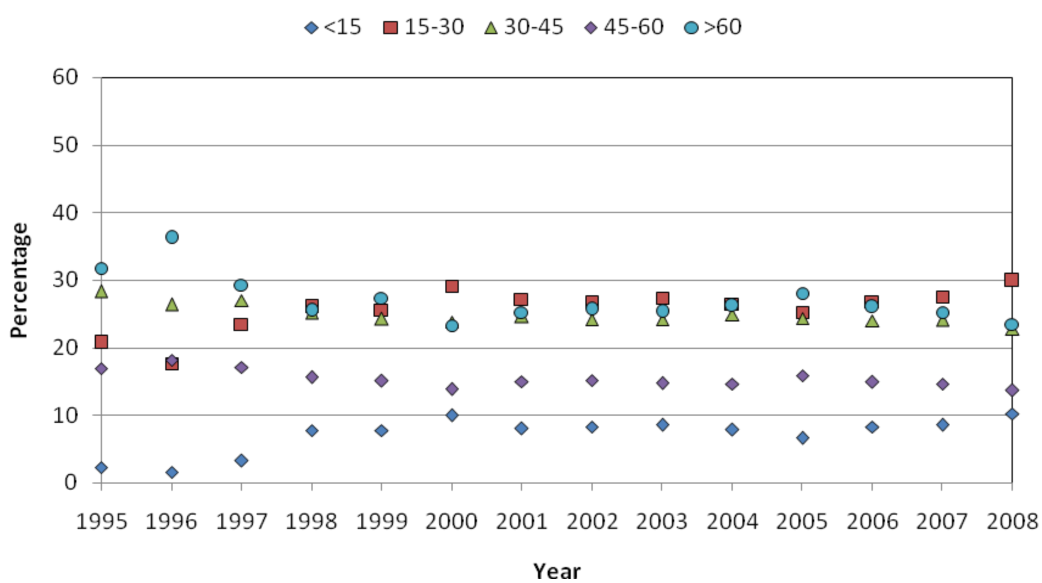


Figure 3.Percentage of soils testing within specified soil test P ranges (<15, 15-30, 30-45, 45-60, and > 60 ppm) across the state of Ohio, 1995-2008.



Crop-Nutrient Status of Soils in Illinois and Perceptions on Soil Fertility Recommendations

Fabián G. Fernández

ABSTRACT

Adequate soil fertility is critical to ensure high-crop productivity. Our objective was to determine the general fertility of soils in Illinois, including the degree of nutrient vertical stratification and to assess the perception of the agriculture industry on university soil fertility recommendations. Volunteers conducting the annual European Corn Borer Survey collected soil from the 0-8 and 8-18 cm depths at 547 random fields in 51 counties prior to corn (Zea mays L.) harvest. Samples were analyzed for phosphorus (P), potassium (K), pH, calcium (Ca), magnesium (Mg), and organic matter (OM). Perception on soil fertility recommendations was assessed using TurningPoint® during a conference series with approximately 1,100 attendees. The soil survey represented the soil fertility status of Illinois and revealed that 18 and 46% of samples were below P and K critical levels (CL) and 59 and 27% of samples were above the soil P and K levels requiring no additional fertilization, respectively. Mean soil pH, Ca, and Mg were at adequate levels and organic matter (OM) was well correlated (R2=0.690) with mean-county corn grain yield. Comparison with an earlier survey (1967-1969) indicated that P and pH levels have increased, but K levels are approximately the same. Surface to subsurface concentration ratios were 2.4:1 for P and 1.5:1 for K indicating little soil disturbance by tillage. While 89% of producers conduct regular soil analysis and 55% of them agree with university recommendations, many fields with higher-than-needed P levels and below CL for K indicate an opportunity for improvement in fertilizer management.

INTRODUCTION

Illinois has over 10 million hectares of cropland producing an estimated $8.6 billion value to the state (2000-2009 mean) (USDA-NASS Quick Stats, 2010). A substantial portion of this area has some of the most productive soil in the world. Most of this land is dedicated to corn (Zea mays L.) and soybean [Glycine max (L.) Merr.] production. Flanking the impressive entrance of Davenport Hall, formerly known as the Agriculture Building, in the main campus of the University of Illinois there is a quote by A.D. Draper (University President from 1894 to 1904) proclaiming “The wealth of Illinois is in her soil and her strength lies in its intelligent development.” Even though many soils in Illinois are highly productive, their productivity is closely related to their nutrient levels. To maintain adequate fertility levels for crop production, it is critical to regularly conduct soil sampling and analysis to determine the need for fertilization.

Illinois has a set of recommendations for P, K, and limestone applications to help guide producers on the fertilizer and lime inputs needed to maximize productivity while minimizing potential negative impacts to the environment (Fernández and Hoeft, 2009). Fertilizer recommendations for the application of P and K fertilizers in Illinois were developed by soil test data and yield response curves generated from fertilizer rate studies. The yield response curve can be divided into three major categories: 1) the critical level (CL) is defined as the point at which near maximum yields are achieved; 2) A test level at which additional application of P and K is very unlikely to produce an increase in yields; and 3) a maintenance level range which falls between the previous two points. Producers are encouraged to maintain test levels within the maintenance range by applying an amount of P and K equal to what is removed by the harvested portion of the crop. This strategy ensures adequate fertility to maximize productivity. When soil test levels are below the CL, additional fertilizer applications, beyond what the crop will remove from the harvested portion, are needed to build the soil test levels. This is recommended to prevent yield loss due to inadequate nutrient availability. When soil test levels are above a point at which additional P and K applications are not likely to increase yield, it is recommended to stop additional applications to drawdown soil test levels to the maintenance range. This strategy is designed to improve the return on the fertilizer investment, and to prevent excessive soil test levels that can pose environmental risks or adversely affect other nutrients in the system.

The state is divided into three major P regions associated with the P-supplying power of the soil (Fernández and Hoeft, 2009). The critical soil test levels are 15, 20, and 23 mg P kg-1 for the high-, medium-, and low-P supplying region, respectively. It is not recommended to apply additional P fertilizer when soil test levels are above 30, 33, 35 mg P kg-1 for the high-, medium-, and low-P supplying region, respectively. The state is also divided into two major K-supplying power regions associated with the cation exchange capacity (CEC) of the soil. The low-K supplying power region has soils with CEC below 12 meq. 100g-1 and the high-K supplying power region has CEC values ≥12 meq. 100g-1. Some soils with high sand content also fall within the low CEC category. The critical soil K levels are 130 and 150 mg kg-1 for the low- and high-K supplying power region, respectively. It is not recommended to apply additional K when soil test levels are above 180 and 200 mg kg-1, for the low- and high-K supplying power region, respectively. It is recommended to maintain soil pH for corn and soybean production between 6.0 and 6.5. Additional limestone applications to raise pH above 6.5 are not recommended because the yield increase would not pay for the added cost of the material.

While having accurate information for a specific field is critical to guide fertilizer applications in that particular field, knowing the fertility status of soils across Illinois can be important to help target state-wide efforts to enhance nutrient management both in terms of agricultural production and environmental considerations. Similarly, assessing the level of adoption of fertilizer recommendations and identifying potential roadblocks hindering effective use of such recommendations is critical for Land-Grant Universities in order to effectively address concerns and improve nutrient management. High price of fertilizers in recent years, especially autumn season 2008 and 2009, induced many producers to reduce or eliminate application of P and K in their farms. This strategy was used by many to reduce costs in the short-term and to allow time for the market to return back to more traditional prices. While some producers could afford to produce a few crops without replenishing nutrients and see no yield penalty, others were likely at soil test levels that would not allow them to reduce application rates without paying a yield-reduction penalty. During such challenging times having current soil fertility information can be extremely valuable to help producers prioritize their resources into those inputs with greatest potential for return on investment.

Finally, it is well known that farmers in Illinois are increasingly using more conservation or reduced tillage practices (Illinois soil conservation transect survey summary, 2006) and these practices can result in vertical stratification of some nutrients in the soil profile (Crozier et al., 1999; Holanda et al., 1998; Howard et al., 1999). Stratification can have important consequences in terms of nutrient availability and can create challenges in obtaining accurate soil test information if soil samples are not collected from the appropriate depth (Bordoli and Mallarino, 1998; Fernández et al, 2008; James and Wells, 1990; Kaspar et al., 1989; Koenig et al., 2000; Yin and Vyn, 2002).

Despite all these important issues, currently there is no state-wide information on the degree of nutrient stratification, the fertility status of soils, or the perception of producers and others closely associated with crop production on Land-Grant University fertilizer recommendations. Thus, the objectives of this study were to determine the general fertility of soils in Illinois, to determine the degree of vertical stratification of crop nutrients within the recommended sampling depth, and to assess the perception of producers and others linked to crop production on the current soil fertility recommendations from the Land-Grant University.

MATERIALS AND METHODS

The soil survey was conducted by-in-large by volunteers conducting the annual European Corn Borer Survey. This survey has taken place for more than 60 years in Illinois. Soil samples were taken from 547 randomly-selected fields in 51 of the 102 counties in Illinois during the fall of 2007 and 2008. Sample locations are overlaid in a map of the phosphorus- and potassium-supplying power regions of

Illinois in Figure 1. The sampling density ranged from 1 to 25 samples per county with median and mean value of 10.0 and 10.7 samples per county, respectively. Samples were collected prior to harvest of the corn crop during September and October. This approach prevented sampling fields with very recent fertilizer applications. A 6-core (2 cm diameter) composite sample was taken from each field within a 3-meter diameter area that was georeferenced at the time of sampling. Each sample was divided into the 0-8 and 8-18 cm soil depth increment. Unfortunately, a few samples were not partitioned into the two depth increments; therefore, those samples could not be included in some of the datasets. Samples were air-dried and ground to pass through a 1-mm sieve. Samples were analyzed for Bray P1 (Bray and Kurtz, 1945); ammonium acetate-extractable K, calcium (Ca), and magnesium (Mg) (Warncke and Brown, 1998); pH (1:1v:v) (Thomas 1996); and organic matter (OM) by loss of weight on ignition (LOI) at 360°C (Schulte and Hopkins, 1996).

Soil classification information for each sample location was obtained from the USDA-NRCS Web Soil Survey database (2010b). Historic information on number of cattle and swine production by county was obtained from USDA-NASS Quick Stats (2010).

An audience survey to determine perception on current soil fertility recommendations was conducted during the Corn and Soybean Classic Conference series (January, 2009) in which there were approximately 1,100 attendees. Responses were obtained using the TurningPoint® audience response system (©2002-2008 Turning Technologies, LLC). During the Corn and Soybean Classic Conference series in 2010, a follow up to the 2009 survey was conducted to determine the knowledge base of the audience regarding the actual values used in the recommendation system. In 2010 there were approximately 1,000 attendees. Using registration information from the conference we estimated approximately 59% of attendees in 2010 were also present in 2009. The survey questions and answer choices are listed in Table 1. Prior approval on these questions was obtained from the Institutional Review Board for the protection of human subjects (IRB).

Descriptive analysis of the data was conducted using the MEANS procedure and comparison of soil analyses for the 0-8 and 8-18 cm soil depth was performed using the T-test procedure of SAS ((SAS Institute, Inc. 2000). Regression analysis was used to determine various relationships.

RESULTS AND DISCUSSION

How representative is the 2007-08 survey?

Soil fertility surveys typically gather information from soil samples submitted to testing laboratories. This approach has the benefit of generating a large database at relatively low cost since it does not require sample collection from the field or chemical analysis by the investigator. One of the potential drawbacks of this approach is the bias that can be introduced by the fact that the person submitting the samples is likely interested in maintaining adequate fertility in the field and understands the importance of regular assessment of soil fertility. One of the unique aspects of the survey presented here is that, since the soil survey was done in random fields selected for a purpose other than the evaluation of soil fertility, the main focus was the European Corn Borer Survey, the survey should provide an excellent source of unbiased information that should closely represent the actual soil fertility status of Illinois. One possible bias of this survey is that samples were collected only from fields with corn growing during the years of the survey and many farmers applying P and K fertilizers in a biennial basis in a corn-soybean rotation would have applied sufficient levels for two successive crops on the year of sampling. Another potential bias is that soil samples might not fully represent field conditions since corn was still standing at the time of the survey and it was difficult to sample far from the edge of the field.

Approximately 45% of the soils in Illinois are Mollisols, 45% are Alfisols, 7% are Entisols, and 2% Inceptisols (USDA-NRCS, 2010a). In our soil survey 67, 28, 3, and 2% of the samples were Mollisols, Alfisols, Entisols, and Inceptisols, respectively. The survey represented 165 soil series out of the more than 600 series that have been recognized in Illinois (USDA-NRCS, 2010a). The soil series with most samples (number of samples between parenthesis) in our survey occurred in the order Drummer (32)> Ipava (24)> Flanagan (22)= Osco > Elliott (15)> Sable (13)> Fayette (12)= Virden > Cisne (11) = Hoyleton = Rozetta. Drummer is also the most extensive soil series in Illinois covering approximately 648,000 ha. In ideal natural conditions (no erosion to slightly eroded soils with 0 to 2% slopes), productivity of Illinois soils under average management ranges from 43 to 130 (Olson, et al., 2000). Soils in our survey (adjusted for erosion and slope conditions below ideal natural conditions) had a productivity index ranging from 67 to 130.

Our survey represents a sampling density of 15,678 hectares per sample for the state (547 samples over an average corn and soybean harvested area of 8,575,875 hectares during 2007-08 [USDA-NASS Quick Stats, 2010]). The Potash and Phosphate Institute (PPI) (2005) conducted a survey of 515,745 samples (mean of samples analyzed for P, K, and pH) from Illinois submitted for analysis to commercial laboratories and representing conditions for the 2005 growing season. Their survey represented a sampling density of 17 hectares per sample (the average corn and soybean harvested area in Illinois for 2004 was 8,707,500 hectares [USDA-NASS Quick Stats, 2010]). Our survey had median values 8 and 6% lower than the PPI survey for P and pH, respectively, and 15% greater than the PPI survey for K (Figure 2). The surveys also showed 97% of 119,455 samples and 95% of 547 samples were above 100 mg Mg kg-1 for the PPI and the 2007-08 survey, respectively (Data not shown). While our survey represents a lower sampling density than the PPI survey, these comparisons would indicate that the results of our study could be broadly applied and likely represent an accurate measurement of the soil fertility status of the soils in Illinois.

Soil Phosphorus

Overall, in Illinois it is recommended to maintain soil P values between 15 and 35 mg kg-1 to maximize crop production (Fernández and Hoeft, 2009). Across the state, mean (51 mg kg-1) and median (39 mg kg-1) P values in our survey were above recommended maintenance (Table 2). The number of samples testing below the CL increased from the high- to the low-P supplying regions while the number of samples that tested above maintenance increased from low- to high-P supplying regions (Table 3). Also, mean P values for each of the P-supplying regions were above the recommended maintenance level and maximum, median, and mean values increased from low- to high-P supplying regions (Table 4). These results could indicate that P supplying power in the high-P region is actually higher than what was suspected when P recommendations were established, thus leading to over-application of P overtime and causing an increase in test levels. Also, it might be possible that some of the inherent soil P present below the standard 18-cm sampling depth has been mined overtime by crops and deposited on the soil surface in the form of crop residue. Another possibility is that over application of P in the western region (high-P supplying region) and under application in the eastern part of the state (low-P supplying regions) may be related to greater access and lower price of fertilizer near the Mississippi River in the west from which much of the fertilizer used in the state and the region comes. However, this is not likely the case since 78% of the surveyed counties scattered across the state, regardless of P-supplying region, had P mean levels above NA and only two counties (Shelby and Tazewell), both located in the medium P-supplying region, had median P levels below the CL (Figure 3a). We found no evidence of differential P management on the basis of potential crop yield since there was no correlation between soil productivity index (defined by Olson et al. 2000) and P test levels (data not shown).

Wide adoption of conservation tillage systems across Illinois in which minimal soil disturbance occur can induce vertical stratification with higher levels in the surface layer when P is broadcast-applied. This stratification in conservation tillage systems was observed by others (Crozier et al., 1999; Howard, et al., 1999). In our survey P showed a surface (0-8 cm) to subsurface (8-18 cm) stratification ratio of 2.4:1 (Table 5). This high ratio of stratification is likely an indication that most soils in Illinois are not being mixed extensively by tillage operations. Correlation analysis of surface and subsurface P levels showed a positive linear relation (R2= 0.782) (Figure 4a) which indicates a concomitant increase in the subsurface layer as the P levels increase in the surface. Also, it was observed that the ratio of stratification increased from the high- to the low-P supplying power region. While it is a possibility that more tillage is being done in the high-P supplying region, most likely, the high-P supplying soils have greater inherent P availability in the subsurface compared to low-P supplying soils. The greater inherent P availability in the subsurface is likely reducing the surface to subsurface ratio. Further, consistent stratification ratios across the P-supplying regions for soil K levels also indicate that changes in P stratification for the different regions are not the result of changes in tillage practices across the regions. Finally, it was observed that P levels were not affected by the different K-supplying power regions since this delineation is not related to soil conditions affecting P supply.

A similar soil fertility survey to the one conducted in this study was done between 1967 and 1969 in Illinois (Walker et al., 1968, 1969, 1970). While the sampling depth may be slightly different and the time of collection and locations may not match our survey, a comparison of soil test values provides insight on the state-wide soil fertility changes that have occurred over approximately 40 years. Phosphorus levels have increased overtime (Figure 5a).The mean P level in the 1967-69 survey was 31 mg P kg-1 which is 20 mg P kg-1 lower than the current survey. In the earlier survey, 30% of the samples were below CL (≤15 mg kg-1) for P compared to only 11% in the recent survey. While both surveys show slightly over 50% of samples near the critical levels to somewhat above maintenance (16-50 mg kg-1), the new survey shows a greater percentage of samples at the higher end of the range. In the recent survey, 19% more samples were in the very high (>50 mg kg-1) soil P level category compared to the earlier survey.

It is not clear which factor or factors have contributed to the high soil P test levels observed in our survey. It is possible that P levels have increased as crops are continually removing nutrients from subsurface layers below the standard soil sampling depth and depositing nutrients in the form of crop residue on the soil surface. Another possibility is that soil tests levels have built by frequent manure applications. However, a scatter plot showing the relationship of number of swine and cattle produced since the earlier survey in the late 1960's and the mean soil P level by county showed no clear evidence to substantiate this possibility (Figure 6). Other such relationships accounting for animal production at various time intervals yielded similar results (Data not shown). Finally, another possibility is that less than expected P removal rates during marginal-yielding years or higher rates of application than those needed to maximize production have overtime built up test levels.

Soil potassium

Current recommendations across Illinois indicate maximum crop production can be obtained when soil K levels are maintained between 130 and 200 mg kg-1 (Fernández and Hoeft, 2009). Soil K values across the state showed mean (172 mg kg-1) and median (152 mg kg-1) values within maintenance levels (Table 2). While all three K-supplying regions had a large number of samples testing below CL, the low-K supplying region had the most with 60% of the surveyed fields testing below CL (Table 3). Mean and median soil K levels were above the CL for the high- and low- (sand) K supplying power regions of the state, but mean and median values were below the CL for the low K-supplying power region (Table 4). This would indicate that in general, the southern one-third portion of the state (Figure 1B) would benefit from a buildup management approach in which K fertilizer applications are designed to be higher than the amount removed by harvested seed. It is possible that some soils might be lower than the recommended K value because their mineralogy prevents them from buildup (increase plant-K availability), but these soils are not common in the state. For K, only 18% of the surveyed counties had mean K levels above NA and 7 counties (14%) were below the CL (Figure 3b). Also, there was no clear evidence indicating that very high testing soils were the result of greater fertilization in high productivity index soil (as defined by Olson et al, 2000) (data not shown). Similarly, soils testing below CL were not limited to soils with low productivity indices.

The distribution of values for K was similar between our survey and the earlier survey conducted in the late 60's (Walker et al., 1968, 1969, 1970). While the mean K level for the earlier survey was 175 mg kg-1 (only 3 mg kg-1 higher than the current survey), our survey shows slightly more samples at the maintenance range or slightly above it (151-250 mg kg-1) (Figure 5b). The 1967-69 survey had 56% of the samples testing at or below the CL compared to 48% of samples for the 2007-08 survey. These data may indicate that overall there is improvement in soil K fertility, but more drastic measures are likely needed to increase overall K fertility in the state.

Similar to P, K is a slowly mobile nutrient in the soil. Broadcast applications of K on the soil surface without intensive tillage to incorporate the nutrients likely resulted in the measured 1.5:1 surface (0-8 cm) to subsurface (8-18 cm) ratio (Table 5). This ratio was smaller than for P, likely because K is more mobile in soil relative to P. Holanda et al. (1998) also found greater stratification ratios for P than K under conservation tillage systems relative to conventional tillage. Stratification ratios for K were not affected by the different K supplying regions since the regions are delineated by CEC and not by soils' native K reserves as is the case for P in Illinois. Correlation analysis of surface and subsurface K levels showed a positive linear relation (R2= 0.804) (Figure 4b).

Soil pH

Soil pH median and mean values for the state were at 6.7 (Table 2). In soils where limestone applications are required, it is recommended to maintain soil pH between 6 and 6.5 for corn and soybean production (Fernández and Hoeft, 2009). Increasing the pH above 6.5 is not recommended purely from an economical, not agronomical, standpoint. An average pH of 6.7 across the state indicates that, in general, producers understand the importance of maintaining adequate soil pH and are managing it correctly. Soil pH was not stratified within the top 18 cm of the soil as were P and K concentrations (Table 5). However, correlation analysis of surface and subsurface pH levels were not as well correlated as for P and K (R2= 0.653) (Figure 4e). Further, soil pH levels were not influenced by P- or K-supplying regions (Table 4). This likely indicates that soil acidity is being controlled by management rather than natural soil conditions. Further, lack of stratification is an indication that limestone applications are being done regularly, allowing the material to reduce soil acidity at depths even when soils are not being intensively mixed. This agrees with Woodard and Bly (2010) who also observed that surface-applied limestone in conservation tillage systems overtime reduces acidity in deeper layers of the soil.

In comparison to the earlier survey conducted in the late 60's (Walker et al., 1968, 1969, 1970) our survey shows overall better soil pH levels (Figure 5c). Earlier, 35% of the sites were at or below pH 6, whereas now only 15% of the sites are in that category. Currently 61% of the samples collected are testing above pH 6.5 compared to only 35% during the former survey. This would indicate that producers are more actively managing soil acidity.

Soil Calcium, Magnesium, and Organic Matter

Current recommendations indicate that Ca values of 200 to 400 mg kg-1 and Mg values of 30 to 100 mg kg-1 are sufficient for crop production in Illinois (Fernández and Hoeft, 2009). The survey data indicates that there is an abundant supply of both Ca and Mg and the application of these nutrients will not be needed in the foreseeable future (Table 2 and Table 4). Across the state, SOM median (3.2%) and mean (3.3%) values indicate that many soils in production agriculture in the state are not low in SOM. Soil organic matter is an important indicator of soil productivity. Our SOM data explained 69% of the variability in county-mean corn yield for the combined 2007 and 2008 growing seasons (USDA-NASS Quick Stats, 2010) (Figure 7). We determined that yield was maximized at 11.9 Mg ha-1 when SOM was 3.8%. Other soil parameters were not as well correlated with yield. There was no correlation with P or pH, and 32, 39, and 35% of the county-mean yield variability was explained by K, Ca, and Mg, respectively (Data not shown). Calcium, Mg and SOM showed increasing levels from the high- to the low-P regions (Table 4). This was expected since P-supplying regions were primarily determined by parent material and degree of weathering, which also influences these parameters. Soils in the high P-supplying region tend to be deeper and calcium- and magnesium-carbonate also tend to occur deeper (below 100cm) than the other P-supplying regions. We also observed lower Ca, Mg, and SOM mean values in the low- compared to the high-K supplying regions (Table 4). As with the P-supplying regions, this is indicative of native soil conditions influencing these parameters. The low CEC soils of southern

Illinois are older and generally less fertile than soils in central and northern Illinois. Calcium and Mg concentrations were not stratified within the top 18 cm of soil (Table 5). This is likely because the soil has an ample supply of these elements and concentrations have not been influenced by applications of these nutrients as in the case of P and K. Also, correlation analysis of surface and subsurface Ca and Mg showed a high positive linear relation ($R2= 0.913$ and 0.946 for Ca and Mg, respectively) (Figure 4c,d). Also, SOM was highly correlated ($R2= 0.822$) (Figure 4f) but SOM levels were slightly higher in the 0-8 cm compared to the 8-18 cm depth. This is likely the result of greater organic matter inputs from roots and above-ground crop residues being deposited on the top layer of the soil relative to the subsurface.

Audience Survey

Our study indicated that only 22 and 27% of the surveyed fields were within maintenance levels for P and K, respectively (Table 3). Since soil P and K levels are largely influenced by management, the fact that, generally speaking across the state, 59% of samples were above NA for P and 46% of samples were below CL for K seems to indicate there is greater emphasis in P fertilization relative to K. This imbalance with more number of samples testing high in P and low in K can be observed when soil samples are partitioned into the different categories of the yield response curve (Table 6). For example, for P, 19% and 13% of samples were testing above maintenance (above NA) and at maintenance, respectively, at the same time that K levels were below maintenance (below CL). On the other hand, only 4% of samples had P levels below maintenance when K levels were at or above maintenance levels. Across the state, the mean recommended maintenance value for soil K is 165 mg kg-1 (130 to 200 mg kg-1 range) while the mean recommended maintenance value for soil P is 26 mg kg-1 (15 to 35 mg kg-1 range). It follows that the recommended mean K:P ratio is 6.3:1. Even though measured K and P values in our soil survey were not strongly correlated ($R2=0.512$) this correlation indicates a K:P ratio of 3.4:1 (Figure 8). This represents a 46% reduction compared to the recommended mean ratio. This is surprising given the fact that an audience survey showed that a majority (55%) of producers agree with the current P and K recommendations (Table 7). While slightly more responses from the agricultural support groups indicated that recommended P and K levels were “too low” (and less of them responded that they were “about right”) relative to producers, overall responses were similar across the participating groups.

There seems to be disagreement between the audience survey and the soil survey if we equate belief in the recommendation system to following the recommendations. Of course, there are factors, such as economics, that may influence management. For example, P and K fertilizer prices during the audience survey were at a record-high, and while 38% of the producers indicated that they would make no changes to their fertilizer applications, 53% of the producers agreed that they would reduce P and K application for the 2009 crop (Table 7). A recent survey of samples from Illinois submitted to soil testing laboratories showed that median P levels compared to 5 years ago (2005) have declined 10 mg kg-1 [International Plant Nutrition Institute (IPNI), 2010]. Relative to the 2005 survey (PPI, 2005), the 2010 IPNI survey showed a decline in frequency of samples for soils testing between 26 and 150 mg kg-1 and an increase in the frequency for soils testing below 26 mg kg-1. While a reduction in the number of very high testing soils is desired, the fact that more soils are also testing below CL is a concern and seems to indicate a reduction of P fertilization regardless of soil testing level. This change in P levels is likely the result of a combination of high fertilizer prices and late harvests and wet soil conditions following harvest for some of the years for the period 2005-2009. While these and other factors, such as errors in application rates and over- or under-estimation of actual removal, can result in changes in soil fertility. They do not explain the discrepancy between recommended levels and our measured soil test levels. Eighty-nine percent of producers in the audience survey indicated that they are testing their soils at least every 4 years. Soil test information should provide a means to correct problems that might have developed due to misapplications. These surveys seem to indicate that while most producers have updated soil test information, that information is not being interpreted or utilized correctly.

Another possible explanation as to why soil P and K values are not following current recommendations is that fertilizer users overall do not know what should be the correct soil test level.

However, our data would suggest that this is likely not the case. In 2010, questions were asked to determine the knowledge of producers and other agricultural groups relative to the actual P and K test values in the recommendations (Table 1). By and large the audience knew what the recommended levels were (data not shown). For P and K, 60 and 57% of the participants, respectively, provided the correct answer. Only 12 and 18% of the participants believed the recommended CL was below the actual value for P and K, respectively. Also for P and K, 18 and 15% of the participants, respectively, believe they needed greater test levels than recommended to maximize yields. It would seem that the effect of nutrient management leading to over- or under- application by these two groups would nearly cancel out in overall soil fertility levels. This audience likely represents the more progressive sector of Illinois farmers, and while it is not possible to make inferences from these audience surveys to understand the results from the soil survey, the surveys illustrate the need to continue to educate fertilizer users on the benefits of following sound crop-nutrient management practices. Whatever the factors may be that causes the discrepancy between the audience and soil surveys, it is clear that many producers or their advisors are not following current Land-Grant University recommendations to manage their P and K. In general, P is being over-applied and K is being under-applied. Both situations can lead to a reduction in investment, and in the case of P, to greater potential for environmental degradation.

In Illinois, increasing P and K test levels by 1 mg kg-1 requires on average an application of 20 kg P2O5 ha-1 and 9 kg K2O ha-1, respectively (Fernández and Hoeft, 2009). Using the fertilizer rate values needed to increase test levels, the percent of samples below CL and mean soil test below CL from our survey, and the average number of hectares (8,575,875) under corn and soybean production in the state in 2007 and 2008 (USDA-NASS Quick Stats, 2010) we determined that it would be necessary to apply 247,160 tons of P2O5 and 1,350,477 tons of K2O in Illinois to buildup soils to the CL. These estimates do not account for the maintenance (crop removal) rates that would be needed in addition to the buildup rates.

Conversely, the soil survey indicated that some soils are testing very high and could produce maximum yields without P and K application for several years. Mallarino and Borges (2006) and data presented by Fernández and Hoeft (2009) indicate that it would take approximately 6 years of crop removal without P fertilization to reduce the current (71 mg P ha-1) mean testing level above NA to the upper limit of the maintenance level. Using the percent of samples in the survey testing above NA, the mean 2007-2008 number of hectares (8,575,875) and mean corn (11.1 Mg ha-1) and soybean (3.0 Mg ha-1) yield produced in the state (USDA-NASS Quick Stats, 2010), the amount of nutrient removal (7.68 and 14.17 g P2O5 kg-1 seed-1for corn and soybean, respectively) (Fernández and Hoeft, 2009), and assuming fields testing above NA currently receive maintenance rates equal to the amount of nutrient removal in seed, we estimated that P applications could be reduced by 1,961,526 tons of P2O5 over a 6-year period. For K, drawdown values are not as readily available due in part to the large variability observed for such measurements (Randall et al., 1997). However, Fernández and Hoeft (2009) indicated that it is very unlikely for a high-testing soil to drop 50 mg K kg-1 over a 4-year period when no K is applied in a corn-soybean rotation. Using this conservative approach, it would be safe to say that crop removal without K fertilization to reduce the current (257 mg K ha-1) mean testing level above NA to the upper limit of the maintenance level would take approximately 6 years. Using the same approach as with P, but with the amount of nutrient removal for K (5.00 and 21.67 g K2O kg-1 seed-1for corn and soybean, respectively) (Fernández and Hoeft, 2009), we estimated that K applications could be reduced by 845,009 tons of K2O over a 6-year period.

Overall our data would indicate the need to increase K fertilization while temporarily reducing or eliminating P fertilization to bring soil P and K levels to the maintenance range. Not accounting for maintenance rates that would be applied over all hectares testing below the NA level, over a 6-year period Illinois could reduce P2O5 usage by 1,714,366 tons (difference between 247,160 tons to buildup and 1,961,526 tons to drawdown) while K2O usage should be increased by 505,468 tons (difference between 1,350,477 tons to buildup and 845,009 tons to drawdown) over the same time period. This shift in P and K applications would overall not necessarily imply added cost to producers since resources currently used for P fertilization could be reallocated toward K fertilization. In turn, increasing the current low K test levels could overall increase crop productivity and profitability.

CONCLUSIONS

The soil survey represents the fertility status of agricultural land in Illinois. In general, across the state soil P levels are high and K levels are low relative to the recommended for maximum corn and soybean production. While P levels have increased since the late 1960's, K levels have remained approximately constant. Soils in Illinois are not being tilled extensively, judging by the amount of vertical stratification of P and K. Both nutrients are stratified, with P being more highly stratified than K. Soil pH levels are adequate for corn and soybean production and showed no vertical stratification within the top 18 cm layer. Similarly Ca and Mg levels in the soil are at adequate concentrations for crop production and the survey indicates there is an ample supply of these nutrients present in the soil. Producers and agriculture support groups by and large know the recommended P and K test levels and agree that the recommendations are useful for crop production. Further, most people sample their soils to determine fertility levels on a regular basis. However, the soil survey and the audience surveys seem to indicate that while people have the necessary information to make correct fertilization decisions, in general terms P is being over-applied and K is under-applied. Our study indicates that overall more emphasis should be placed in K than P fertilization. Additionally, this study highlights the need to educate fertilizer users on how to more effectively utilize the soil fertility information they already have to guide fertilizer applications.

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Table 1. Survey questions and possible answers used during survey conducted in 2009 and 2010 to determine perception on current fertilizer recommendation in Illinois and knowledge base on actual recommendation values.

Survey conducted in 2009
A) Which of the following describes your primary occupation? 1) Producer, 2) Ag input supplier (retailer), 3) Ag chemical company representative, 4) Seed company representative, 5) Consultant, 6) Other
B) (For producers) In your operation, how many acres are dedicated to corn AND soybean production? 1) <500; 2) 500-1,000; 3) 1,001-2,000; 4) 2,001-5,000; 5) >5,000
C) (For suppliers/reps/consultants) How many acres do you assist with or have influence with? 1) 1 – 1,000; 2) 1,001-10,000; 3)10,001-50,000; 4) 50,001-100,000; 5)>100,000
D) What do you think about the critical levels for P recommended for corn and soybean production in Illinois? 1) Too low; 2) About right; 3) Too high; 4) Don't know
E) What do you think about the critical levels for K recommended for corn and soybean production in Illinois? 1) Too low; 2) About right; 3) Too high; 4) Don't know
F) How often do you soil sample for P, K, and pH? 1) Every 2 years at least; 2) Every 4 years; 3) Every 5-10 years; 4) Never
G) Do you plan on applying less P and K for the 2009 growing season? 1) Yes, by quite a bit; 2) Yes, by a little; 3) No change; 4) I will be applying more P and K
Survey conducted in 2010
H) What is the minimum phosphorus soil test range needed to produce near maximum corn and soybean yields? In other words, how low can you go and still produce near maximum yields? 1) <6; 2) 6-14; 3) 15-23; 4) 24-32; 5) 33-41; 6) >41 mg kg^{-1}
I) What is the minimum potassium soil test range needed to produce near maximum corn and soybean yields? In other words, how low can you go and still produce near maximum yields? 1) <108; 2) 109-129; 3) 130-150; 4) 151-172; 5) 173-193; 6) >193 mg kg^{-1}
J) In your opinion, what is the minimum phosphorus test range at which you don't expect to increase corn and soybean yield by adding more phosphorus fertilizer? 1) <16; 2) 17-22; 3) 23-29; 4) 30-35; 5) 36-42; 6) >42 mg kg^{-1}
K) In your opinion, what is the minimum potassium test range at which you don't expect to increase corn and soybean yield by adding more potassium fertilizer? 1) <136; 2) 137-157; 3) 158-179; 4) 180-200; 5) 201-222; 6) >222 mg kg^{-1}

Table 2. Descriptive statistics of various soil parameters for the top 18 cm of soil across 547 fields in Illinois.

Variable	Minimum	Maximum	Median	Mean
Phosphorus (mg kg^{-1})	1	576	39	51
Potassium (mg kg^{-1})	31	794	152	172
Calcium (mg kg^{-1})	404	6485	2047	2226
Magnesium (mg kg^{-1})	37	1107	329	366
OM (%)	0.9	8.9	3.2	3.3
pH	4.7	8.1	6.7	6.7

Table 3. Number of samples and percent of total number of samples below the University of Illinois recommended critical test level (CL), above the soil test level at which no additional fertilization is recommended (NA), or at maintenance soil test levels (between CL and NA) for the different phosphorus-supplying power regions (broadly defined based on parent material and weathering) and potassium-supplying power regions (broadly defined based on cation exchange capacity [CEC]).

		CL	NA	Below CL		Maintenance		Above NA	
Region	n	mg kg^{-1}	mg kg^{-1}	Samples	%	Samples	%	Samples	%
Phosphorus									
High	202	15	30	14	7	40	20	148	73
Medium	168	20	33	26	16	41	24	101	60
Low	177	23	35	60	34	41	23	76	43
Potassium									
High CEC	447	150	200	195	44	126	28	126	28
Low CEC	78	130	180	47	60	20	26	11	14
Low CEC (Sands)	22	130	180	7	32	4	18	11	50

Table 4. Descriptive statistics of various soil parameters for the top 18 cm of soil at the different phosphorus-supplying power regions of Illinois (broadly defined based on parent material and weathering) and different potassium-supplying power regions of Illinois (broadly defined based on cation exchange capacity [CEC]).

Variable	Min	Max	Median	Mean	Min	Max	Median	Mean	Min	Max	Median	Mean
	High-P region (n= 202)				Medium-P region (n =168)				Low-P region (n =177)			
Phosphorus (mg kg^{-1})	6	576	43	60	1	407	39	52	1	197	32	40
Potassium (mg kg^{-1})	43	639	152	179	49	701	165	178	31	794	146	158
Calcium (mg kg^{-1})	404	4653	1911	2056	711	5812	2074	2270	743	6485	2248	2380
Magnesium (mg kg^{-1})	37	857	273	298	59	1031	300	342	92	1107	471	467
OM (%)	0.9	6.6	2.7	2.8	1.2	6.2	3.4	3.4	1.7	8.9	3.6	3.8
pH	4.7	8.0	6.8	6.8	5.2	8.0	6.5	6.6	5.1	8.1	6.8	6.8
	High-CEC region (n= 447)				Low-CEC region (n =78)				Low-CEC (sands) (n =22)			
Phosphorus (mg kg^{-1})	1	576	38	51	3	150	44	48	3	168	52	63
Potassium (mg kg^{-1})	43	794	158	179	31	310	119	127	71	377	173	188
Calcium (mg kg^{-1})	711	6485	2141	2344	743	4498	1563	1658	404	3941	1756	1859
Magnesium (mg kg^{-1})	37	1107	376	400	59	524	152	175	52	857	334	362
OM (%)	1.2	8.9	3.3	3.5	1.3	5.2	2.4	2.5	0.9	6.1	3.4	3.2
pH	4.7	8.1	6.7	6.7	5.2	8.0	6.7	6.6	5.0	8.0	6.6	6.6

Table 5. Soil parameters at different depths and surface (0-8 cm) to subsurface (8-18 cm) ratio for the different soil phosphorus-supplying power regions of Illinois (broadly defined based on parent material and weathering), potassium-supplying power regions of Illinois (broadly defined based on cation exchange capacity [CEC]), and across Illinois.

Soil depth parameter	P	K	Ca	Mg	pH	OM
	---------------------------mg kg^{-1}--------------					%
High P region (n=202)						
0-8cm	71a†	214a	2027	297	6.9	3.0a
8-18cm	51b	152b	2078	299	6.7	2.7b
Surface:subsurface ratio	2.1	1.5	1.0	1.0	1.0	1.2
Medium P region (n=163)						
0-8cm	65a	213a	2193	329	6.6	3.6a
8-18cm	38b	146b	2304	346	6.6	3.2b
Surface:subsurface ratio	2.5	1.5	1.0	1.0	1.0	1.2
Low P region (n=177)						
0-8cm	56a	190a	2320	451	6.8	4.1a
8-18cm	28b	133b	2424	479	6.8	3.6b
Surface:subsurface ratio	2.8	1.5	1.0	1.0	1.0	1.2
High CEC region (n=442)						
0-8cm	63a	213a	2288	390	6.8a*	3.7a
8-18cm	40b	151b	2378	406	6.7b	3.3b
Surface:subsurface ratio	2.4	1.5	1.0	1.0	1.0	1.1
Low CEC region(n=78)						
0-8cm	66a	163a	1624	170	6.7	2.8a
8-18cm	35b	100b	1684	178	6.6	2.2b
Surface:subsurface ratio	2.7	1.7	1.0	1.0	1.0	1.4
Low CEC region (sands) (n=22)						
0-8cm	77a**	227a**	1795	350	6.5	3.3
8-18cm	52b	159b	1908	370	6.6	3.0
Surface:subsurface ratio	1.9	1.5	1.0	1.0	1.0	1.1
Entire region (State) (n=542)						
0-8cm	64a	206a	2173	357	6.8a*	3.5a
8-18cm	40b	144b	2259	372	6.7b	3.1b
Ratio	2.4	1.5	1.0	1.0	1.0	1.2

†Values followed by the same letter within column and region are not different by Mann-Whitney Rank Sum Test ($p>0.001$), values followed by * or ** indicate $p<0.1$ and $p<0.05$, respectively.

Table 6. Distribution of soil samples, percent of total number of samples, and number of hectares in Illinois that could be represented by the survey samples testing at the different combinations of yield response curve categories for phosphorus and potassium.

Phosphorus level	Potassium level	Number of sample	% of samples	Hectares in IL†
Above maintenance	Above maintenance	134	24	2,100,854
Above maintenance	Maintenance	87	16	1,363,987
Above maintenance	Below maintenance	104	19	1,630,514
Maintenance	Above maintenance	12	2	188,136
Maintenance	Maintenance	41	7	642,799
Maintenance	Below maintenance	69	13	1,081,783
Below maintenance	Above maintenance	2	0	31,356
Below maintenance	Maintenance	22	4	344,916
Below maintenance	Below maintenance	76	14	1,191,529

† Based on average number of hectares (8,575,875) under corn and soybean production in the state in 2007 and 2008 (USDA-NASS Quick Stats, 2010).

Table 7. Responses provided by producers and agriculture support groups during an audience survey conducted in 2009 to determine perception on current fertilizer recommendation in Illinois.

	Producers						Agriculture support groups					
	Response by farm size (hectares)						Response by group					
	<200	200–400	400–800	800–2000	>2000	All producer	Input supplier	Chem. Co.	Seed Co.	Consul-tant	Other	All
Categories	n=45	n=84	n=116	n=66	n=16	n=340	n=221	n=28	n=188	n=46	n=92	n=589
	---% of responses---											
<u>P recommendations</u>												
Too low	11	7	12	15	25	11	26	4	9	17	5	16
About right	60	61	54	47	63	55	52	32	47	50	43	48
Too high	4	8	9	12	0	8	7	14	4	17	7	7
Don't know	22	15	18	17	6	17	5	25	22	7	14	13
No response	2	8	7	9	6	8	11	25	18	9	30	17
<u>K recommendations</u>												
Too low	18	14	16	17	38	16	40	14	16	33	10	26
About right	53	60	59	50	44	55	42	29	45	50	38	42
Too high	9	11	7	12	0	9	4	14	5	4	7	6
Don't know	13	8	11	12	13	12	5	21	17	4	12	10
No response	7	7	6	9	6	8	10	21	16	9	34	16
<u>Soil test frequency</u>												
Every 2 years at least	18	11	5	8	0	10	5	7	10	13	10	8
Every 4 years	67	81	84	74	75	79	79	43	57	72	42	63
Every 5-10 years	9	6	5	15	19	7	3	4	1	2	2	2
Never.	2	0	0	2	0	0	2	4	4	0	2	3
No response	4	2	5	2	6	4	11	43	28	13	43	23
<u>Apply less P and K in 2009?</u>												
Yes, by quite a bit	16	19	18	29	19	19	18	11	13	11	13	15
Yes, by a little	20	37	35	41	38	34	26	4	16	22	12	19
No change	56	35	39	27	38	38	12	21	29	24	20	20
Applying more	7	1	0	0	0	1	3	4	3	4	1	3
No response	2	8	8	3	6	8	41	61	39	39	54	43

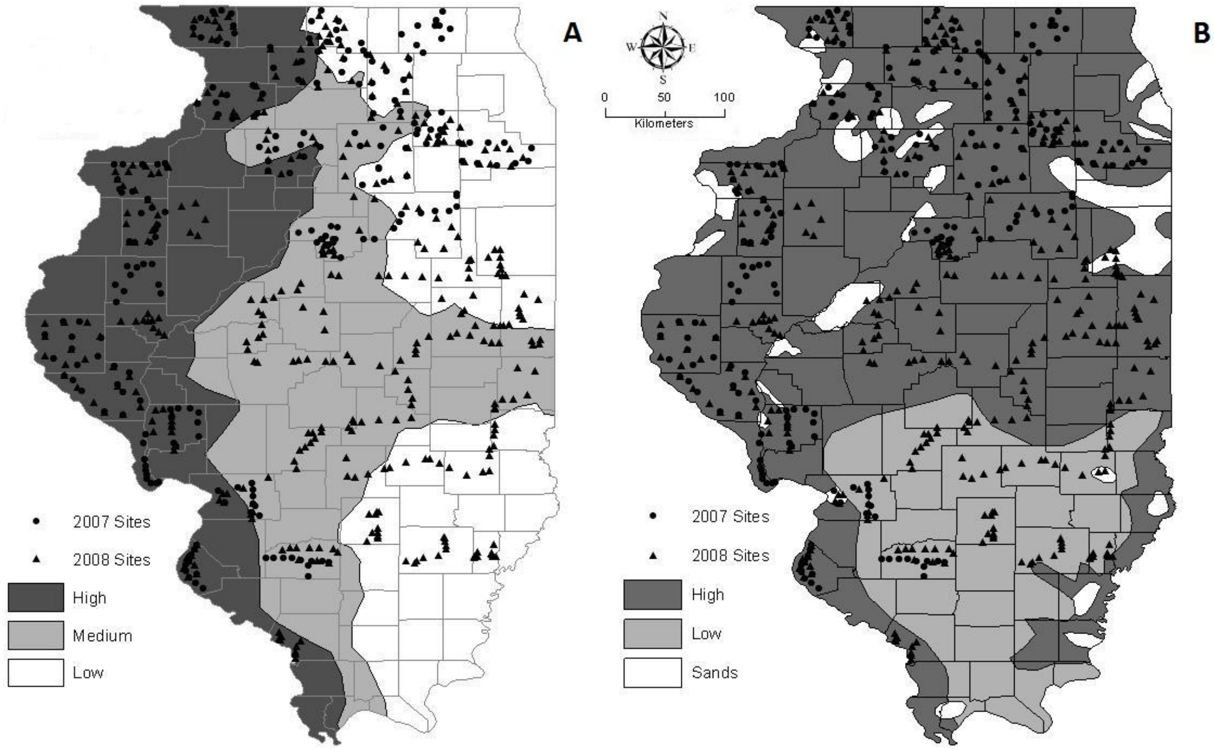


Figure 1. Illinois county map with sample locations surveyed in 2007 and 2008 and the corresponding phosphorus-supplying power regions broadly defined by parent material and degree of weathering (A) and potassium-supplying power regions broadly defined in function of soil cation exchange capacity (CEC) (B).

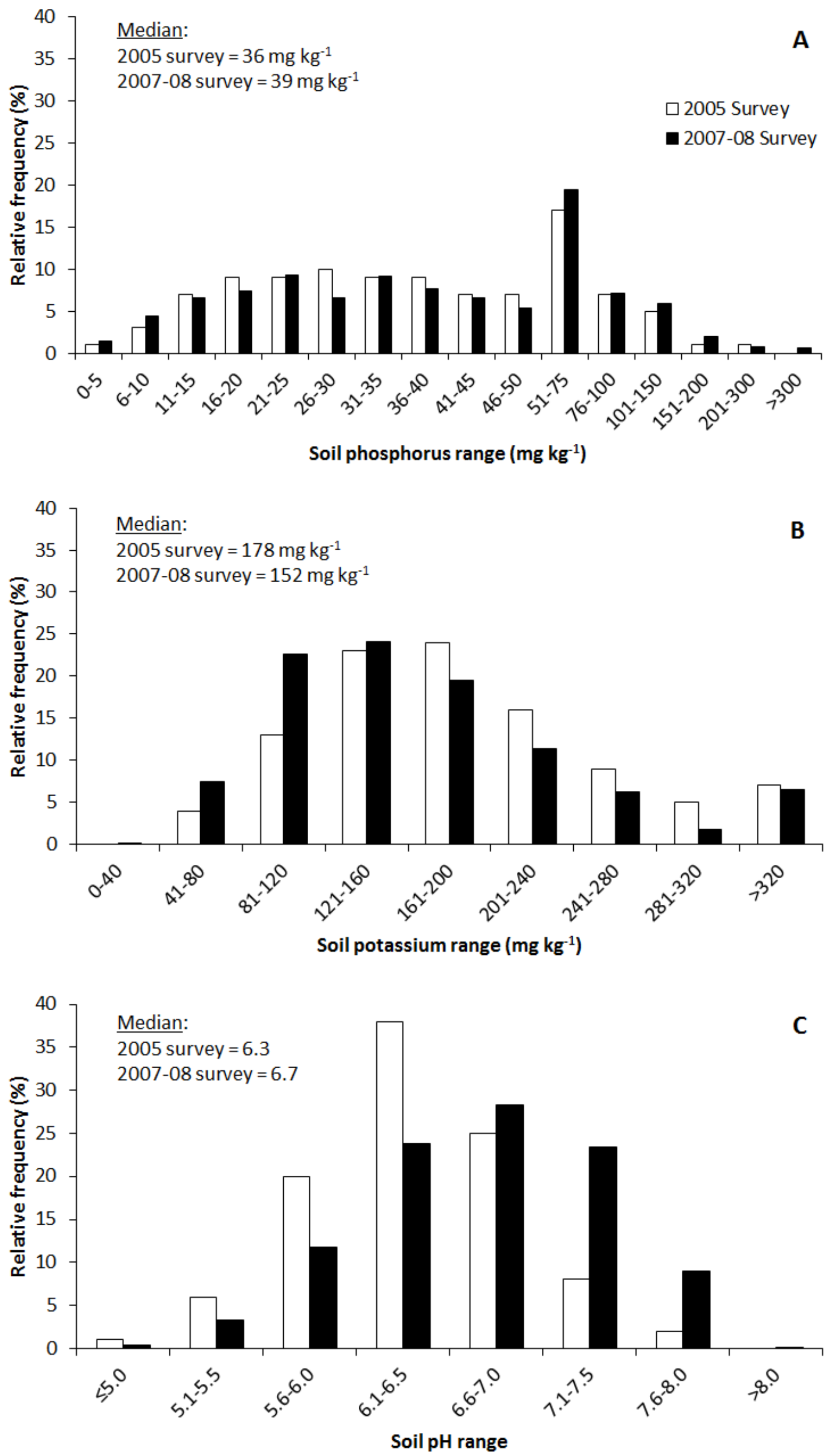


Figure 2. Relative frequency distribution of soil phosphorus (A), potassium (B), and pH (C) levels in Illinois as reported in the survey: *Soil test levels in North America, 2005* by the Potash and Phosphate Institute (PPI) and the Univ. of Illinois survey conducted in 2007-08. Total number of samples for the PPI survey was 534,904; 509,342; and 502,989 for phosphorus, potassium, and pH, respectively. Total number of samples for the Univ. of Illinois survey was 547 for each soil parameter.

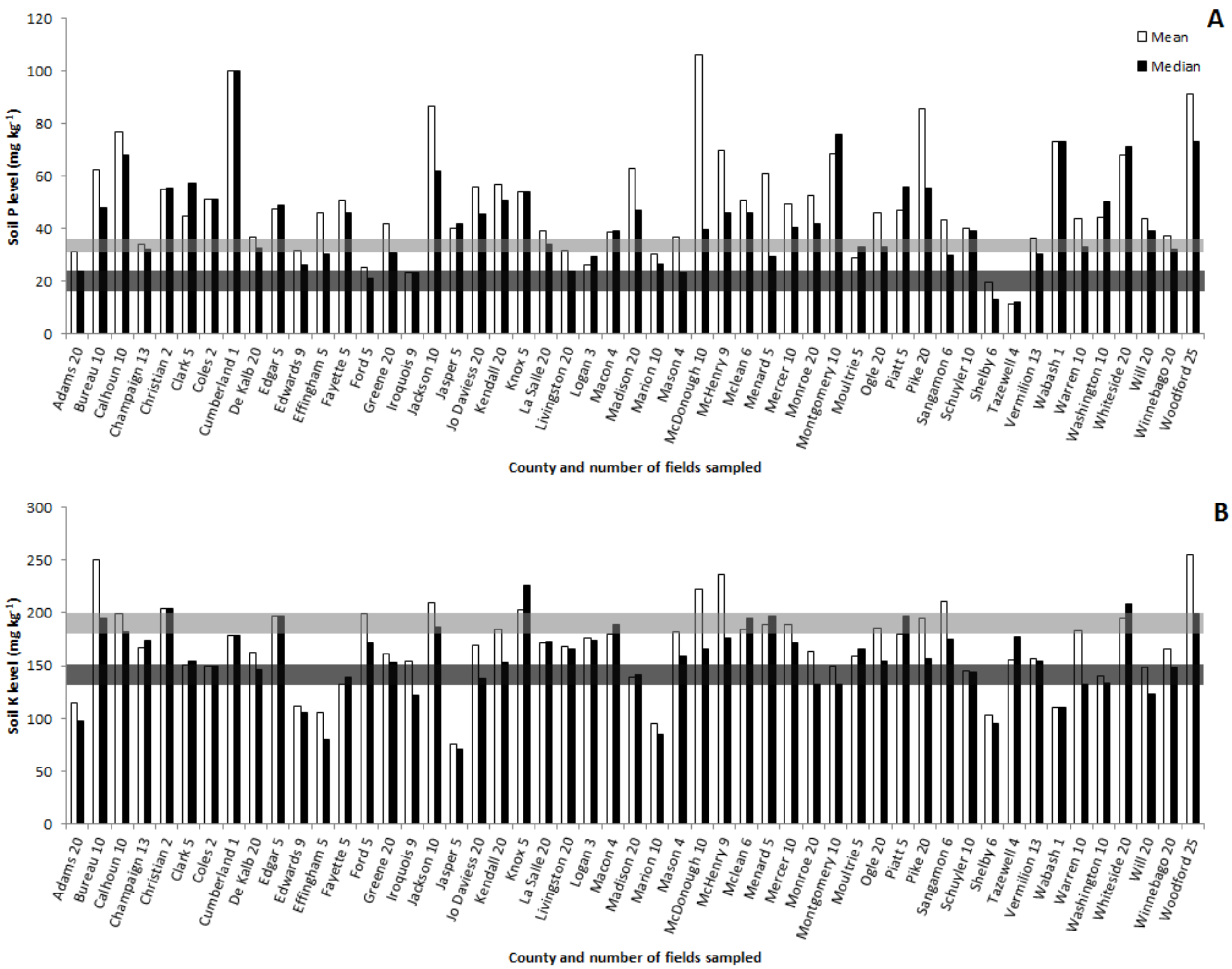


Figure 3. Mean and median phosphorus (A) and potassium (B) soil test levels at the 0- to18-cm depth increment for 51 counties surveyed during 2007-08. Numbers following the county name indicate number of samples used to calculate nutrient concentrations for the county. Dark-gray bands represent the range of critical levels across the different phosphorus-supplying power regions of Illinois (based on parent material and weathering) (A) and potassium-supplying power regions of Illinois (based on cation exchange capacity [CEC]) (B). Similarly, light-gray bands represent the range of levels at which additional application of phosphorus and potassium are not recommended for the various supplying power regions.

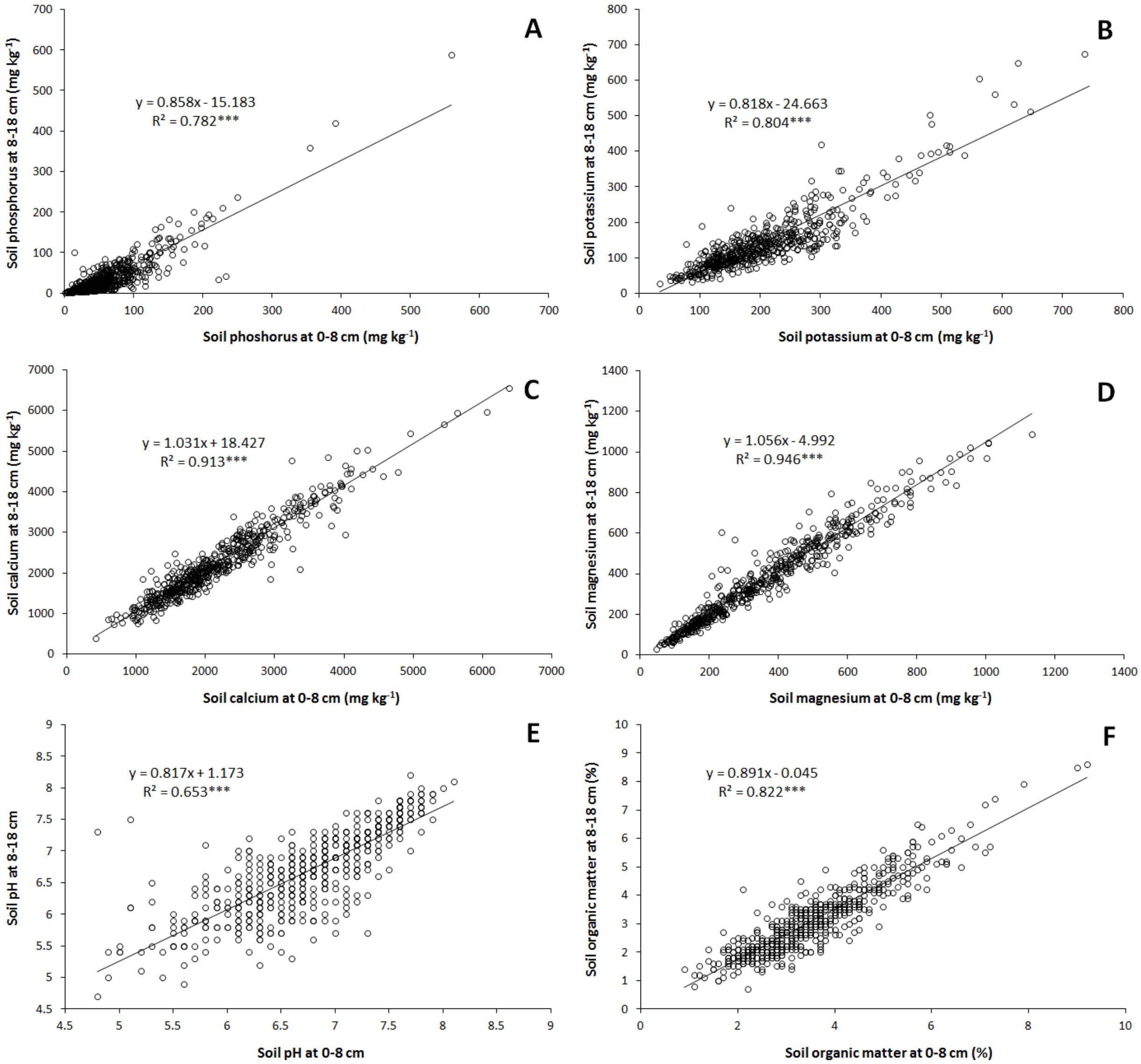


Figure 4. Relationship between soil test level in the 0- to 8-cm depth and the 8- to 18-cm depth for various parameters measured during the 2007-08 Illinois soil survey. *n*=542 for each plot. ***Significant *F* value for a regression at *P*<0.01.

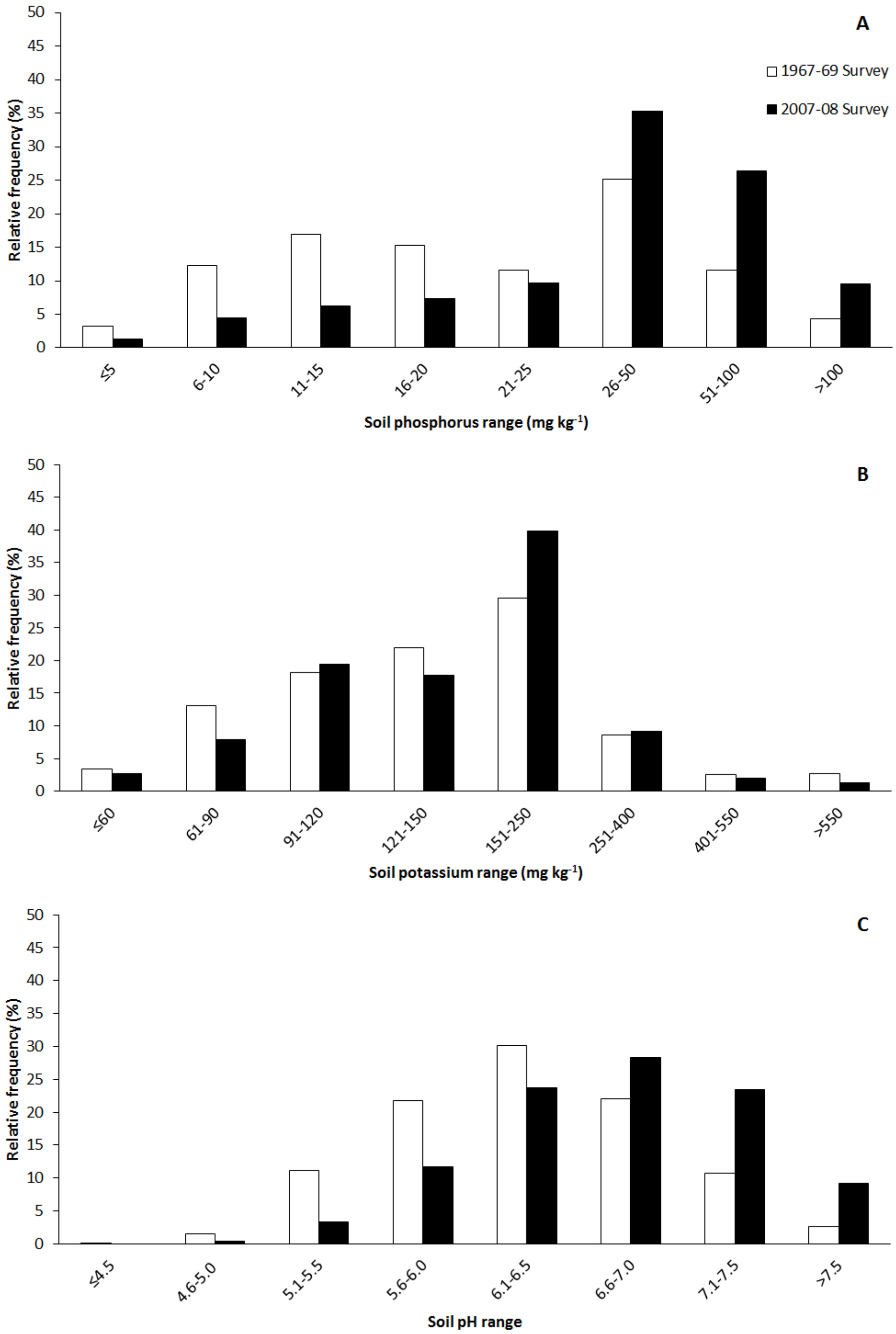


Figure 5. Relative frequency distribution of soil phosphorus (A), potassium (B) and pH (C) levels in Illinois as reported by two surveys conducted by the Univ. of Illinois in 1967-69 and in 2007-08. The 1967-69 survey had 1,701 samples collected from corn and soybean fields during the growing season from the 0-15 cm soil depth increment. The 2007-08 survey had 547 samples collected from corn fields in the fall prior to harvest from the 0-18 cm soil depth increment.

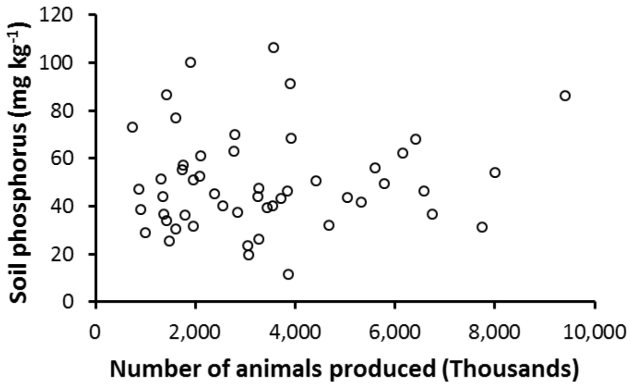


Figure 6. Relationship between total animal produced (swine and cattle) between 1970 and 2006 (USDA-NASS Quick Stats, 2010) and mean soil test phosphorus levels at the 0- to18-cm depth increment for 51 counties measured during the 2007-08 Illinois soil survey.

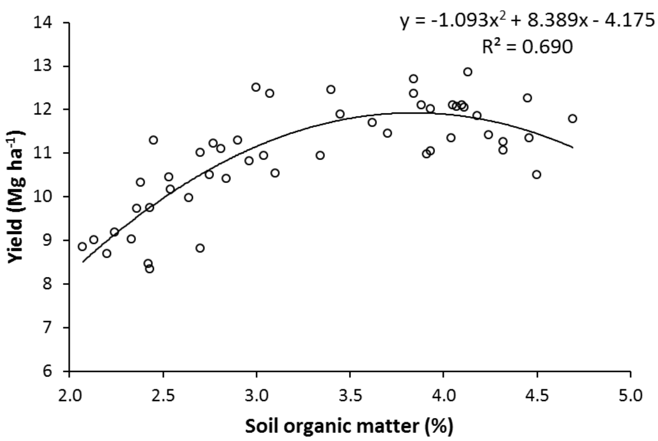


Figure 7. Relationship between mean soil organic matter at the 0- to 18-cm depth increment measured during the 2007-08 Illinois soil survey and mean 2007-08 corn grain yield (USDA-NASS Quick Stats, 2010) for the 51 counties surveyed.

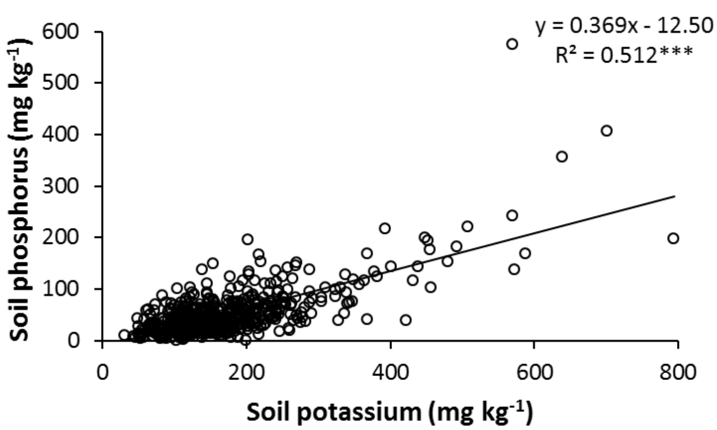
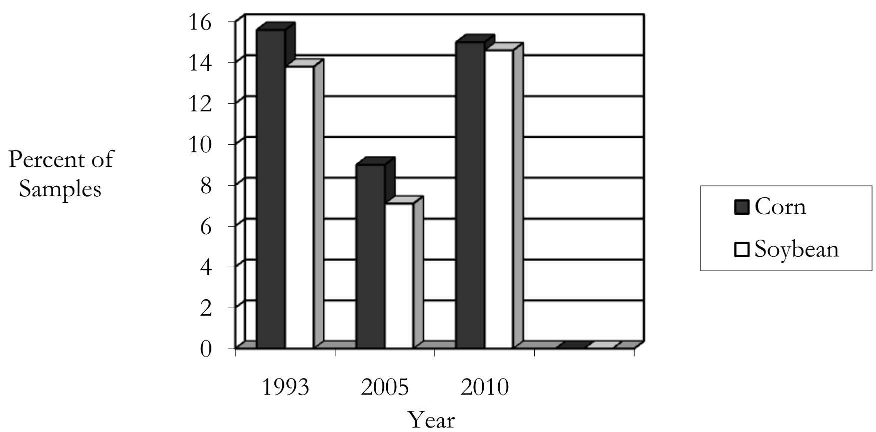


Figure 8. Relationship between soil potassium and phosphorus levels at the 0- to18-cm depth increment measured during the 2007-08 Illinois soil survey. *n*=547. ***Significant *F* value for a regression at *P*<0.01.

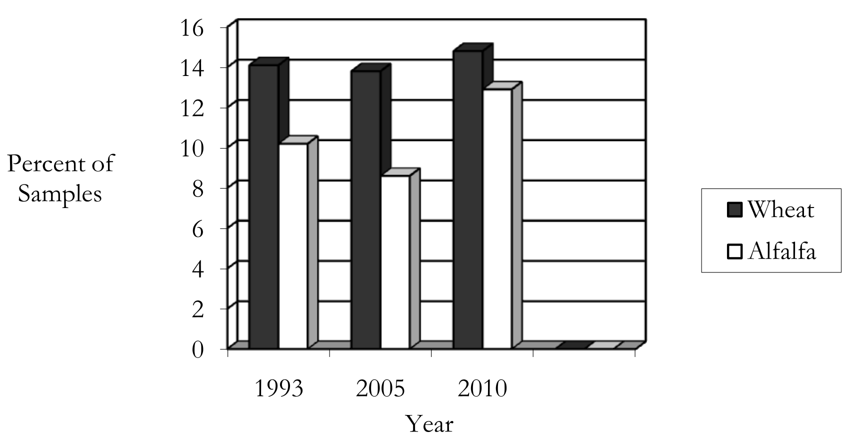
Michigan Soil Test Summary Information

Jon Dahl
Michigan State University

pH Summary Information Trends

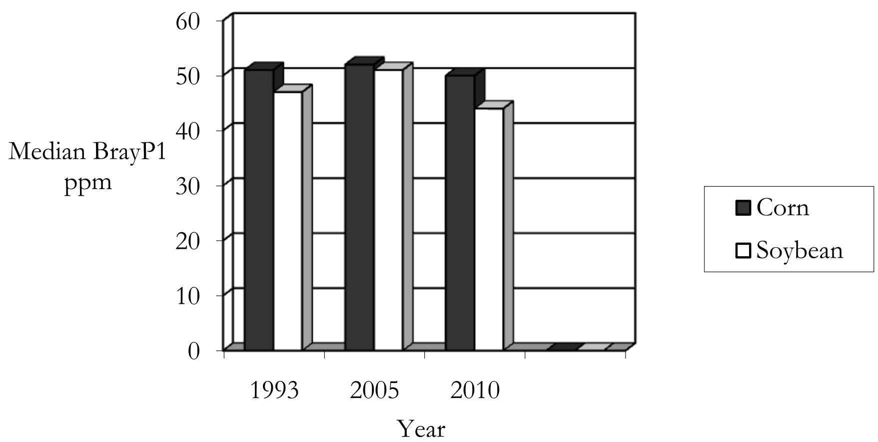


- Percent of samples needing 2.5+ tons lime per acre
- Number of samples: Corn 5388 (1993), 3316 (2005), 3839 (2010). Soybean- 1961 (1993), 1614 (2005), 1925 (2010).

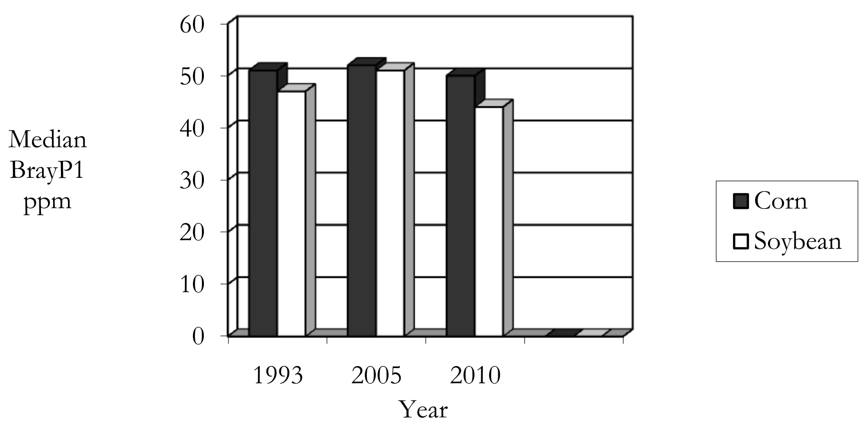


- Samples needing 2.5+ tons lime per acre
- Number of samples: Wheat -1277 (1993), 478 (2005) & 365 (2010). Alfalfa - 1263 (1993), 1126 (2005) & 1222 (2010).

MSU Lab Phosphorus (BrayP1) Summary Information

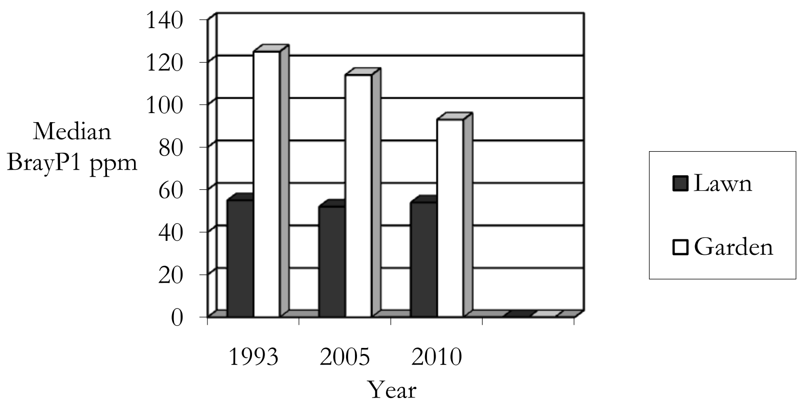


- Median values peaked out between 1995 and 2005 and appear to be coming down.
- Number of samples: Corn - 5388 (1993), 3316 (2005) & 3839 (2010). Soybean- 1961 (1993), 1614 (2005) & 1925 (2010).



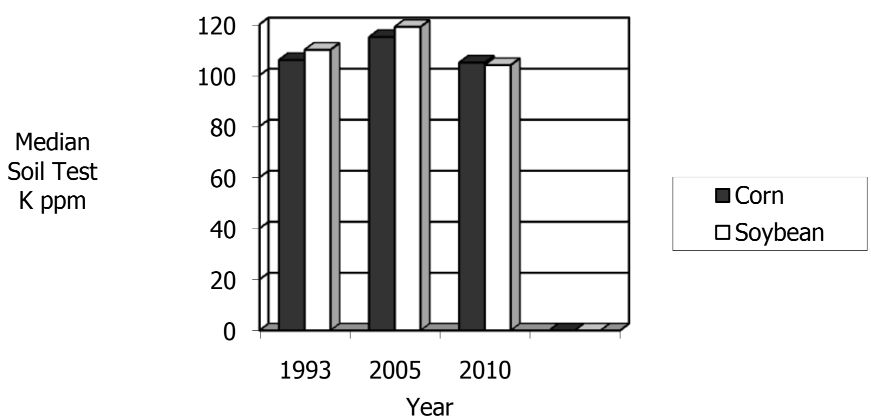
- Wheat following same trend as corn and soybeans.
- Alfalfa P has been lower than other crops, but now is trending up.

MSU Lab Homeowner Phosphorus Summary Information

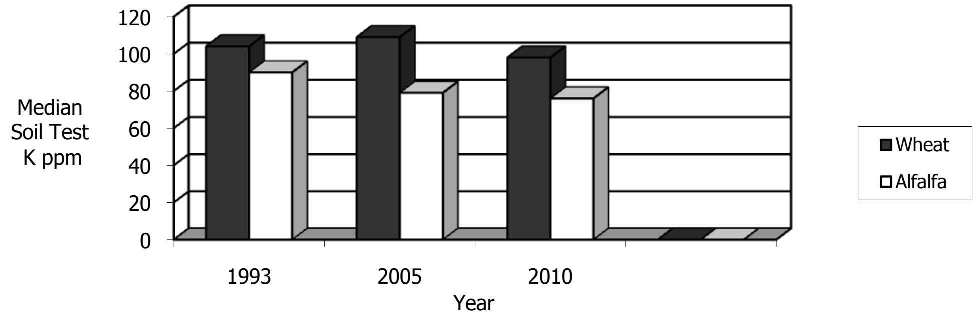


- New P legislation to take effect in 2012.
- 90% of lawn samples tested by MSU do not need additional P.
- Garden sample P coming back down into optimum range on average.

MSU Lab Homeowner Potassium Summary Information

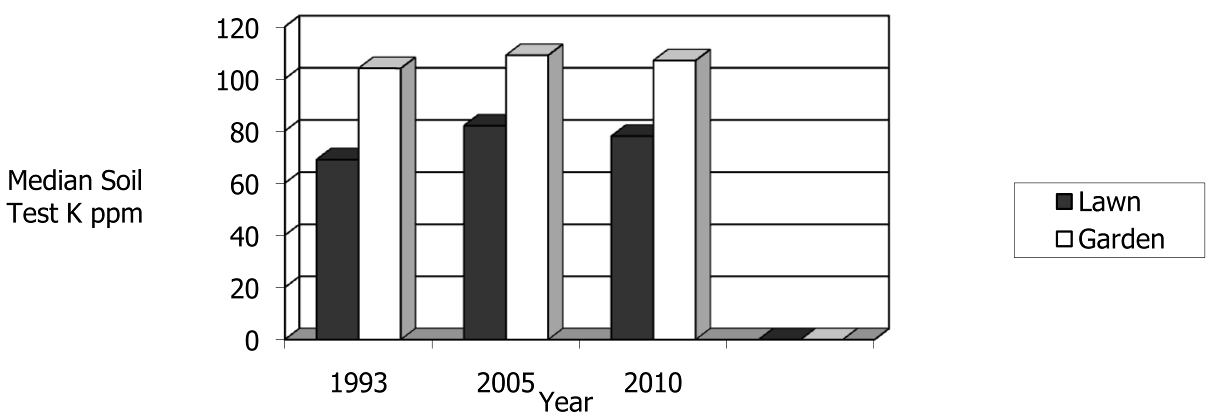


- Median K has dropped 10 ppm for corn and 15 ppm for soybean since 2005.



- Median K has dropped 11 ppm for wheat and 3 ppm for alfalfa since 2005

MSU Lab Potassium Summary Information



- Median K has only gone down slightly for lawns and gardens.
- Number of samples: Lawn -1419 (1993), 3458 (2005) & 3451 (2010). Garden - 1151 (1993), 3140 (2005) & 5559 (2010).

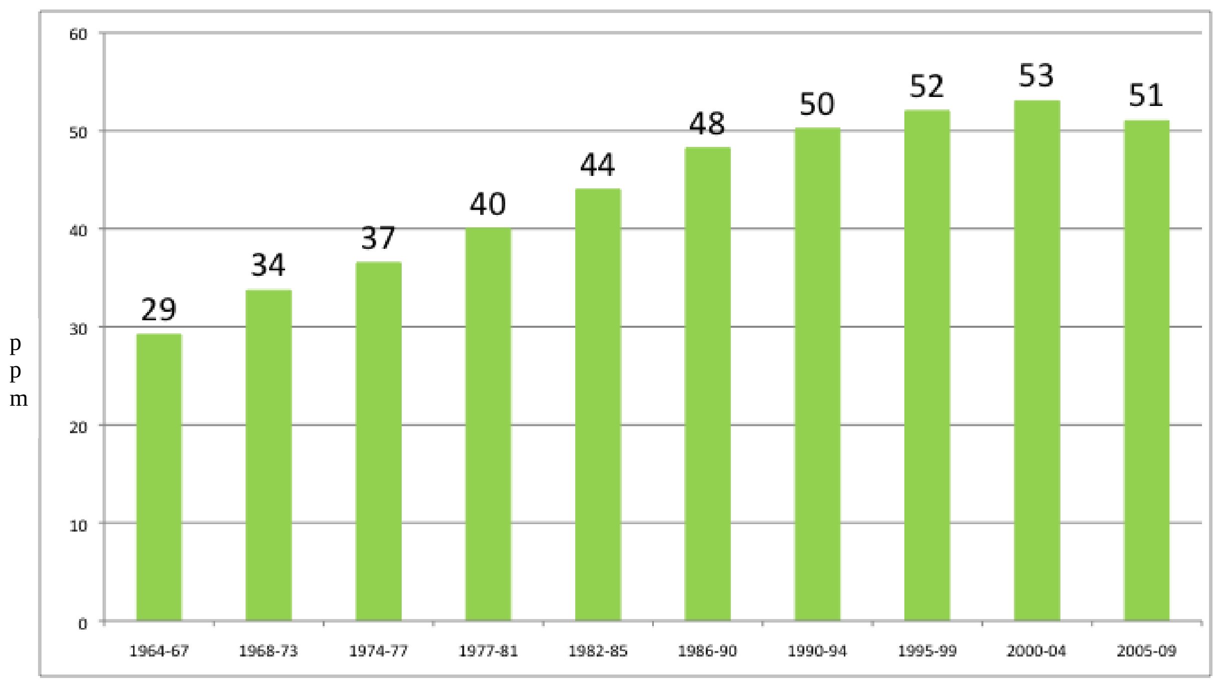
Wisconsin Soil Test Summary: 2005-2009

John Peters
Department of Soil Science
UW-Madison

Soil test data from over five million samples collected from Wisconsin farmland and analyzed by both public and private Wisconsin certified soil testing laboratories has been summarized every 3 to 5 years since 1964. Summary of soil test data is useful for not only identifying broad fertility trends, but also for evaluating fertilizer, lime and manure management practices, isolating areas of unique, localized fertility conditions requiring special management and for identifying soil areas having high environmental risk to water quality.

Available P and K (Bray-1), pH (water), organic matter (loss of weight on ignition) and secondary/micronutrient results are summarized for approximately 1,080,000 soils tested during 2005-2009. This represents approximately a 58% increase in samples compared to the 2000-04 summary period. Nearly 90% of these were in the medium and fine texture category and approximately 9% were coarse-textured soils. The balance was made up of organic soils and red soils from eastern Wisconsin.

Wisconsin Soil Test P Trends: 1964-2009

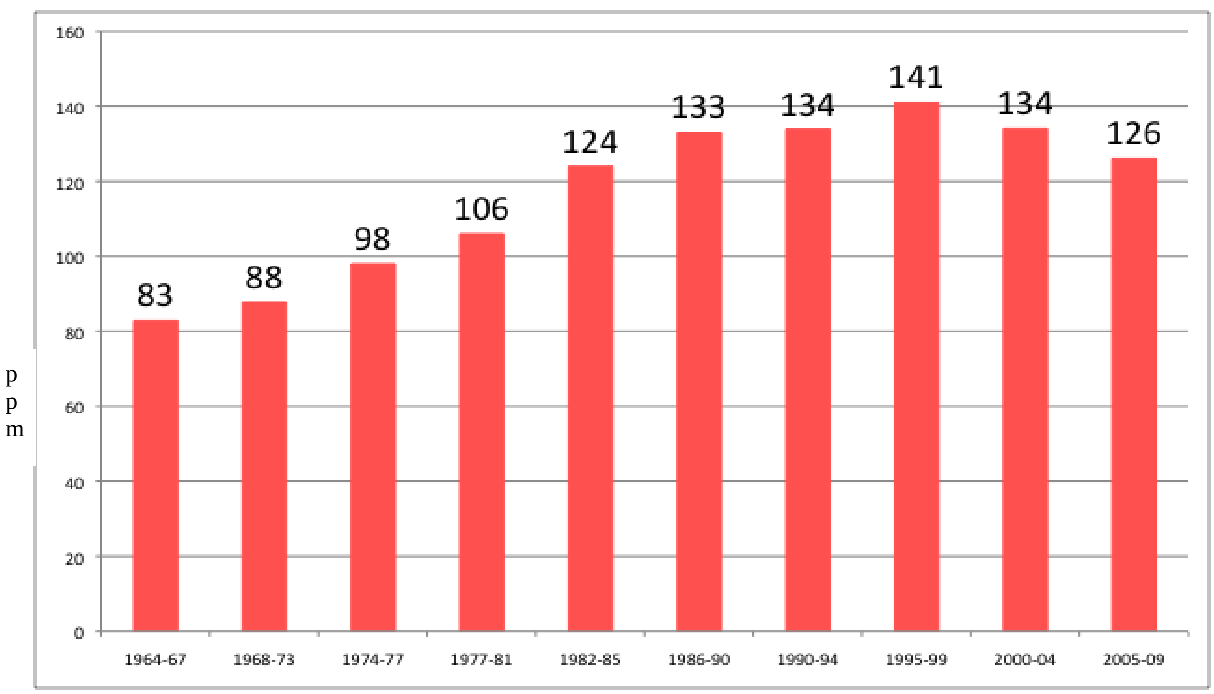


Phosphorus

Average soil test P for all Wisconsin farm soils decreased from 53 ppm in 2000-04 to 51 ppm in this 2005-09 summary period. Applying no more than recommended rates of phosphate fertilizer and/or crediting manure nutrients have become more common practices on Wisconsin farms and is reflected by this change in the long term trend of increasing soil test P levels. For the past five years, 54 of 72 Wisconsin counties had either no increase or a decrease in soil test P after regular upward trends in soil P levels since 1964.

The average soil test P for the coarse textured soils was 80 ppm as compared to the medium/fine-textured soils where the average was 50 ppm. The counties where soils are intensively managed for potato production had the highest soil P levels. Optimum soil test P levels required by potato and processing crops grown on coarse-textured soils can be considerably greater than for most other agronomic crops. Soil test P changes in counties that predominantly contain medium and fine textured soils were relatively minor (5-10 ppm) by comparison.

Wisconsin Soil Test K Trends: 1964-2009



Potassium

Soil test K for all soils summarized has decreased from 134 ppm in 2000-04 to 126 ppm in this 2005-09 summary period. This is the lowest average level since the 1982-85 summary period where the average was 124 ppm. At the time of the first summary forty-five years ago, average soil test K was 83 ppm. Increases in soil test K were relatively high (averaging 7 ppm per summary period) beginning with the 1964-67 summary period until the 1995-99 summary period. During the last two five year summary periods, the change has been of this same magnitude but in the opposite direction going from 141 ppm to 134 ppm and now to 126 ppm. Most counties have average soil K values on the upper end of the optimum level for corn (71-130 ppm) and alfalfa (71-140 ppm) production or somewhat above the optimum level. At optimum soil test levels, the amount of recommended potash is equivalent to crop removal. The average soil test K for coarse-textured soils of 103 ppm compared to 128 ppm for medium and fine textured soils, which reflects the lower CEC these soils have and the higher potential for rapid change under intensive cropping. Either a decrease or no change in average soil K level was seen in 63 of the 72 counties after regular upward trends until about ten years ago.

pH

Average pH for all soils in 2005-09 was 6.6, which is the same as was seen in the two previous summary periods. Overall, medium and fine textured soils used extensively for corn and alfalfa production have average pH values of 6.7, indicating that forage producers recognize the importance of liming to maintain optimum alfalfa yields. Liming soil to pH 6.8 if cropped in rotation with alfalfa or 6.3 if red clover is recommended. Coarse-textured and organic soils cropped mainly to high value vegetable crops have average pH values of about 6.3. Target pH for most high value vegetable and processing crops is 6.0 or less.

Organic Matter

Average soil organic matter for all soils tested in 2005-09 is 3.3% as compared to 3.2% in the previous summary period. Medium and fine textured soils had average organic matter levels of 3.2% while the coarse-textured soils averaged 1.4%.

Secondary/Micronutrients

Average results for secondary (Ca, Mg and SO_4-S) and micronutrients (B, Zn and Mn) have been summarized since the 1995-99 summary period. In addition, data exist from two earlier summaries including 1974-77 and 1982-85. It appears that there has been an increase in soil test Ca and a decrease in available Mn levels over the last 35 years, both of which are most likely related to liming practices. This is verified by the increase in statewide soil pH from 6.3 to 6.6 during that same time frame. The need for application of micronutrients is based on soil test level, soil type/texture and relative crop need. The need for sulfur amendments is based on a model that includes soil test SO_4-S as well as other significant sources of S.

Summary

The changes in soil test P and K show widespread adoption of good fertility management practices necessary for profitable crop production. Where high value crops such as potatoes and other processing crops are grown, high phosphate fertilization rates can bias county averages upward. The central sands are an example of this situation. The median value for all soils tested during 2005-09 was 35 ppm for soil test P and 110 for soil test K. These median values are substantially less than the average values of 51 ppm soil test P and 126 ppm soil test K, giving further evidence that there are some intensively managed areas biasing the average upward. Median soil test P values for the top ten soils show that most are below levels which are typically associated with the greatest amount of environmental concern. However there are certain soils and areas where extremely high soil test P may compromise environmental quality and require special management. The decreasing trend in soil test P and K shown in many counties is encouraging evidence that nutrient management planning is being implemented. Continuing to summarize soil test data can help educators and farm advisors develop strategies necessary for Wisconsin farmers to maximize crop production while recognizing and minimizing environmental problems. However, only good, representative sampling and testing of individual fields can provide growers with the data needed to make informed nutrient application decisions to achieve economically optimum yields while minimizing environmental concerns.

Using the NRCS Web Soil Survey

Matt Ruark, Assistant Professor and Extension Soil Scientist
Department of Soil Science,
University of Wisconsin-Madison; University of Wisconsin-Extension
Jennifer Krenz-Ruark, Soil Scientist, CH2MHill

There is a tremendous amount of information captured in NRCS soil surveys. This information has an even greater utility with the development of the NRCS Web Soil Survey. The NRCS Web Soil Survey is a web-based tool that can be used to extract soil survey data for an area of interest. Web Soil Survey requires no additional software and contains the most up-to-date soils information available, making it a useful alternative to the traditional hard copy soil surveys. It allows the user to create a custom report containing soils information for their area of interest and for their individual land use concerns.

Like many online tools, an interactive demonstration is often helpful for new users. Thus, the purpose of this presentation is to provide a guided tour through the NRCS Web Soil Survey. The walk-through will demonstrate how to delineate an area of interest, select soil survey and interpretation data and develop a report. According to the website, there are three main functions of the Web Soil Survey: (1) locate, (2) view/explore and (3) checkout. For the first function (locate), the presentation will include demonstrations of the ten methods that can be used to locate fields and using rectangle and polygon tools to delineate the area of interest (AOI). For the second function (view/explore), the presentation will demonstrate how to navigate through the "Soil Map" and "Soil Data Explorer" tabs. These tabs allow the user to identify not only soil type, but also all information that would be contained within the soil survey. Under the "Soil Data Explorer" tab, there are five subtabs: "Intro to Soils", "Suitabilities and Limitations for Use", "Soil Properties and Qualities", "Ecological Site Assessment" and "Soil Reports". And finally, the presentation will conclude with a demonstration of the checkout process. The website provides users the ability to develop a document that is both personalized and professionally styled.

Tillage Effects on Nutrient Stratification and Soil Test Recommendations

Dick Wolkowski
Extension Soil Scientist
University of Wisconsin

Soil testing is recognized as the best method of determining P, K, and lime need prior to planting. Conventional soil testing 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 nutrient loss. However, soil test values within a field are intrinsically variable because of natural factors (e.g., soil forming factors and erosion) and past management (e.g., nutrient application, crop management, field consolidation, and drainage). Soil sampling protocols are designed to account for spatial variability, both horizontally and vertically. While much emphasis has been given to addressing horizontal variability through grid soil sampling, cell size selection, and core number; often only casual attention is given to sample depth. Because P, K, and to some extent soil pH are immobile in soils nutrient and pH stratification will develop, especially when tillage intensity is low. Soil samples taken to inconsistent or improper depths may arguably cause more variability in fertilizer recommendations due to nutrient stratification than might be found due to variability across the extent of the field.

The causes of nutrient stratification are numerous. First, broadcast applications of immobile nutrients with no or incomplete mixing by tillage will increase nutrient concentration at the soil surface. Therefore, soil test P and K will be greater near the surface and typically pH will be lower from the hydrogen ions released by the nitrification of ammonium containing fertilizers or organic N sources. Another cause of nutrient stratification is the leaching of soluble nutrients from crop residues, especially at senescence or following a killing frost. Finally, tillage intensity has significantly decreased as more growers adopt conservation tillage systems. Even changing to sweeps instead of twisted shovels on a chisel plow increases the potential for stratification.

The soil sampling procedure for single-rate fertilizer and lime application has four considerations: (1) the size of the cell or field area represented by one sample; (2) the number of soil cores taken per sample; (3) the pattern with which the samples are taken; and, (4) the depth of the sample. With respect to tillage, UWEX soil sampling guidelines found in Bulletin A2100 recommend sampling moldboard plowed fields to the depth of tillage, chisel plowed fields to three-fourths the depth of tillage, and no-till to a depth of 6 inches. It is assumed that strip-tilled fields, or other high residue systems, should be sampled similarly to no-till. These guidelines offer some recognition of soil test stratification as it is suggested that long-term no-till fields should also be sampled at the 0- to 2-inch depth for soil pH.

Tillage practices for a given field are not always consistent because many farmers rotate tillage as they rotate crops (e.g., chisel tillage and no-till in a corn/soybean rotation). Forage stands that are maintained for multiple years actually become "defacto no-till" and may cause some confusion regarding sampling depth, especially if the dominant tillage is not known. Considering the amount of P and K that might be broadcast to alfalfa at optimum soil test levels it could be expected that nutrient stratification would develop in this scenario. Hay fields are commonly soil sampled prior to tillage, even though aggressive tillage management may occur in future years. Regardless of tillage management it should be obvious that soil sampling to a uniform depth is vital for obtaining accurate nutrient recommendations. The question of precision versus accuracy should favor precision such that sample depth and timing of sampling should be consistent over years. Thus, even if tillage is varied, a grower or consultant could monitor soil test, crop condition, and yield to determine if a proper indexing of nutrient availability based on soil test exists.

The objective of this paper is to examine the effect of tillage on nutrient stratification and the subsequent nutrient recommendation. Several fields that have been subjected to different tillage systems were incrementally sampled and recommendations were developed based on sampling to different depths.

Procedure

Soil samples were collected from field plots that had a history of various tillage practices at the Arlington and Lancaster Agricultural Research Stations. Samples were taken in increments of two in. to a depth of eight in. Samples were analyzed by the procedures of the UW Soil and Plant Analysis Laboratory for pH, organic matter, P, and K. From these soil test results, recommendations for phosphate, potash, and lime were developed for samples that hypothetically could have been collected at sampling depths of 0 to 4, 0 to 6, and 0 to 8 inches.

Samples were collected from the following studies using a standard soil probe.

1. Rotation x tillage x fertilizer placement study at Arlington — Corn/soybean and continuous corn rotation, with fall chisel with spring field cultivator, strip-till, and no-till. These treatments were established in 1997 and treatments of none, broadcast, or row-applied fertilizer as 200 lb 9-23-30/a were established in 2001. Soil samples were collected from all replications in the unfertilized and broadcast plots in June 2005. All plots to be planted to corn received 160 lb N/a broadcast as ammonium nitrate each year.

2. Tillage x K fertility study at Lancaster — This field had been in no-till corn and soybean production for at least the past 10 years. In the fall of 2003, tillage treatments including fall chisel with spring field cultivation and no-till were established for corn following soybean. Soybean was no-till planted into corn stubble. Therefore the chisel treatment was chisel plowed in the fall of 2003 and 2005. An adjacent area that had been continuously no-tilled was moldboard plowed in the fall of 2006. Three replications of soil samples were collected from the third replication of the unfertilized K control in the chisel, no-till, and the adjacent moldboard plowed area. All plots received 35 lb P_2O_5/a row applied phosphate and 120 lb N/a broadcast as ammonium nitrate in the corn years of 2004 and 2006.

3. Tillage x herbicide study at Arlington — This study is managed by Professor Dave Stoltenberg of the UW Department of Agronomy and has had tillage treatments of moldboard, chisel, and no-till for the past 20 years. Samples were taken from the continuous corn portion of the study. The site received row applied NPK fertilizer annually at crop removal for P and K, as well as 160 lb N/a as urea each year. Lime has not been applied over this period.

4. Production alfalfa field at Arlington — This field was in no-till corn in 2003 and received beef manure in the spring of 2004, which was subsequently disked and then field cultivated. It was then direct seeded and culti-mulched in the spring of 2004. The field received 250, 300, and 300 lb 0-0-60/a in November 2004, August 2005, and November 2005, respectively. The field was not fertilized in 2006 and has been managed for alfalfa hay until the fall of 2006 when it was fall-killed to rotate to corn. Sampling was conducted following killing, but prior to any tillage.

Results and Discussion

Table 1 shows the effect rotation, tillage, and fertilization on the routine soil test for the Arlington location where the rotation and tillage treatments have been in place since 1997 and 2001 for the fertilizer treatments. Rotation significantly affected pH in the 0- to 2-inch and 2- to 4-inch increments such that the pH was higher in soybean following corn. The pH was lowest in the continuous corn and intermediate in the corn following soybean. Presumably the N fertilization where corn was grown contributed hydrogen somewhat more rapidly than might have been expected in the corn following soybean. The only other soil test parameter that was affected by rotation was K in the 0- to 2-inch increment. This effect was significant at the $p=0.10$ level in the 2- to 4-inch layer and was apparent at deeper depths. The greater level in the surface was likely due to a combination of the accumulation from K leached from the crop residue and the greater removal of K expected for corn/soybean compared to corn.

Tillage significantly affected the organic matter, P, and K in the 0- to 2-inch increment being highest in the strip-till. Soil pH tended to be lower in the reduced tillage treatments. Tillage affected soil pH at the 2- to 4-inch and 4- to 6-inch depths with the chisel having the lower value due to mixing of surface acidified soil at this depth. As would be expected broadcast fertilization increased soil test levels in the 0-2 and 2-4 in. increments with this effect continuing to the depth of sampling.

This stratification would lead to different fertilizer recommendation if sample depth was not consistent with tillage. While lime is not needed in this field for corn or soybean the lime recommendation for alfalfa (pH 6.8) would vary substantially if samples were taken to 4, 6, or 8 inches. Recall that both the soil pH and organic matter are components of the lime requirement equation. Estimates show that in this field the chisel would have a lime recommendation of 3.4, 2.2, 2.6 tons/a 60-69 lime for the 0- to 4-, 0- to 6-, and 0- to 8-inch sampling depths, respectively. The lime requirement for no-till would be 3.6, 2.4, and 1.2 tons/a for the same depth increments.

The effect on K recommendations was not affected as significantly by tillage; however sample depth did affect the K recommendation. The 0- to 4-, 0- to 6-, and 0- to 8-inch sampling depths resulted in K soil test levels of 123, 107, and 98 ppm K, respectively in chisel and 122, 106, and 96 ppm K in no-till for these depths. If corn with a 180 bu/acre yield goal was the crop 20 lb K_2O would be the recommendation for the 0- to 4-inch increment and 50 lb K_2O/a would be recommended for the 0- to 6- and 0- to 8-inch depth. If alfalfa with a 6 ton/acre yield goal was the crop the 0- to 4-inch increment would call for 150 lb K_2O/a and the other increments would receive 300 lb K_2O/acre.

The incremental soil test data for Lancaster is shown in Table 2. These data were analyzed in a tillage x depth ANOVA. Samples at this site were taken from single adjacent tillage plots and not from all reps and treatments as was done at the Arlington Rotation x Tillage study. Also the tillage history at this site is much shorter, that being two recent chisel events and one moldboard event in a field that has a long no-till history. Because the site was moldboard plowed once, it is apparent that the surface layer was inverted creating a soil test that contrasts that of the no-till. Long-term moldboard tillage would be expected to resolve this anomaly.

Table 2. Effect of tillage on the incremental soil test, Lancaster, Wis., 2006.

	Moldboard				Chisel				No-till			
Depth	pH	OM	P	K	pH	OM	P	K	pH	OM	P	K
inch		%	---- ppm ----			%	---- ppm ----			%	--- ppm ----	
0 – 2	6.8	1.9	25	120	6.9	2.8	31	130	6.7	3.3	35	130
2 – 4	6.8	2.1	23	120	7.0	2.6	23	117	7.0	2.5	22	95
4 – 6	6.6	2.2	26	123	7.1	2.6	16	106	7.1	1.9	16	96
6 - 8	6.6	2.3	29	130	7.1	1.7	18	109	7.1	1.6	17	108

	Significance (Pr>F)			
	pH	OM	P	K
Tillage	<0.01	0.02	0.07	0.03
Depth	0.21	<0.01	<0.01	0.04
T * D	0.02	<0.01	<0.01	0.18

Regardless, these data show that the single moldboard tillage (with a light disking), removed most of the stratification that was apparent in both the chisel and no-till. Lime would not be recommended in this field, but depending on the crop and sample depth different P and K recommendations would be obtained if managed under different tillage systems.

The most unique opportunity in this exercise was the sampling of Dr. Stoltenberg's long-term tillage study which was established at Arlington approximately 20 years ago. This study has focused on herbicide interactions in tillage, receiving uniform tillage and nutrient management over this time. The site contains both a continuous corn and corn/soybean rotation. Only one replication of the continuous corn portion was sampled for this preliminary evaluation.

The data for the incremental soil test are shown in Table 3, from which several interesting observations can be made. First, the incremental soil test results were clearly more uniform with depth in the moldboard compared to the chisel and no-till. As was observed in the other data sets, chisel plowing does not remove stratification — or more properly chisel plowing results in stratification. Soil pH was lower in all tillage treatments in the 0- to 2-inch increment, likely reflecting the 2006 application of urea. The pH tended to be lower at depth in both the moldboard and chisel compared to no-till with the soil pH at depth in the no-till surprisingly high. Organic matter content was enriched in the surface of the chisel and no-till, which lends some credence to the support of enhanced C sequestration in conservation tillage systems, even chisel plowing. This site had excessively high soil test P and for the most part the analyses, although showing stratification, would still result in a non-responsive soil test P level. Soil test K clearly shows stratification in the chisel and no-till. The value in the 0- to 2-inch level is unusually high in the chisel, which may be an artifact of the small sample size. Statistically long-term tillage differences have created very highly significant differences in all the soil test parameters.

Table 3. Effect of tillage on the incremental soil test, Arlington, Wis., 2006.

	Moldboard				Chisel				No-till			
Depth	pH	OM	P	K	pH	OM	P	K	pH	OM	P	K
inch		%	---- ppm ----			%	---- ppm ----			%	--- ppm ----	
0 – 2	5.7	3.6	57	91	5.6	4.2	77	148	5.6	4.6	57	108
2 – 4	5.9	3.8	57	82	5.6	4.1	68	114	6.5	3.7	39	86
4 – 6	6.0	3.8	58	86	5.8	4.0	56	89	6.6	3.3	33	74
6 - 8	6.0	3.9	59	92	6.2	3.4	33	70	6.6	3.2	24	70

Significance (Pr>F)	pH	OM	P	K
Tillage	<0.01	<0.01	<0.01	<0.01
Depth	<0.01	<0.01	<0.01	<0.01
T * D	<0.01	<0.01	<0.01	<0.01

One obvious question is the effect that the soil test stratification has on soil test results, especially in a situation where samples were collected at inconsistent or improper depths. Assuming normal tillage depths, UWEX recommendations would suggest that the moldboard and possibly the chisel plot should be sampled to a depth of 8 inches and the no-till to a depth of 6 inches. What if conditions were very dry and the sample depth was just 4 inches or in contrast conditions were perfect and the sampler was “feeling their Wheaties” and sampled too deep? Table 4 shows the lime and K fertilizer recommendations for the Stoltenberg plots had the sampler consistently taken cores to 4, 6, or 8 inches. Recommendations were calculated for both corn and alfalfa at reasonable yield goals. Clearly because moldboard plowing resulted in the most uniform soil test levels it also resulted in very uniform lime and potash recommendations relative to sample depth. The lime recommendation for chisel tillage was considerably higher than that for either moldboard or no-till. Even though the no-till had a high organic matter and an acidic surface layer it had the lowest lime recommendation because of the higher pH found in the deeper increments. Chisel also had the unusually high soil test K in the surface layers, a result that may be an effect of the small sample size. Clearly sample depth did affect lime and K recommendations for both crops in this example.

Table 4. Effect of tillage and sample depth on soil test and subsequent lime and K recommendation, Arlington, Wis., 2006.

Tillage	Sampling depth	Soil test			Corn		Alfalfa	
		pH	OM	K				
	inch	------ ppm ------			T lime/a	lb K_2O/a	T lime/a	lb K_2O/a
MB	0-4	5.8	3.7	87 L	1.2	80	5.9	330
	0-6	5.9	3.7	86 L	0.6	80	5.3	330
	0-8	5.9	3.8	88 L	0.4	80	5.5	330
CH	0-4	5.6	4.2	131 H	2.7	20	8.1	150
	0-6	5.7	4.1	117 H	2.0	20	7.2	150
	0-8	5.8	3.9	105 O	1.2	50	6.2	300
NT	0-4	6.1	4.2	97 O	0	50	4.7	300
	0-6	6.2	3.9	89 L	0	80	3.7	330
	0-8	6.3	3.7	85 L	0	80	3.0	330

Recommendations calculated target pH of 6.0 for corn and 6.8 for alfalfa 180 bu/a corn and 6 ton/a alfalfa. LR (t 60-69 NI/a) = 0.16 x Δ pH x [OM x 10]

The final field that was sampled was a production alfalfa field at Arlington was seeded with modest tillage in 2004. In that time it has received 850 lb 0-0-60/a (510 lb K_2O/a). Prior to alfalfa establishment it was in no-till corn following 2 years of alfalfa. Thus it had been at least six years since it would have been chisel plowed.

If I were a crop advisor, I would prefer to sample this field prior to tillage for several reasons. First, it is simply much easier on the body and machine to traverse and sample an unplowed field. Furthermore, anyone who has sampled plowed fields knows the problems of sample tube plugging and inconsistent cores. If a soil test calls for lime or fertilizer it is more practical to apply it to the unplowed field where it can be distributed more uniformly and then incorporated. The soil test results for this alfalfa field are shown in Table 5. All soil test parameters show statistical differences with depth. Clearly the most obvious is the test for K where the soil test K level is three times higher in the surface 2 inches compared to the 6- to 8-inch depth. There is also a 50% difference in soil test P. Depending on crop and sample depth the interpretation for P would all have been low for all depths for alfalfa and the deeper depths for corn. The shallow sampling depth would have resulted in an optimum P test for corn. The K interpretation would all be excessively high for corn, but would range between excessively high, very high, and high for alfalfa for the 0-4, 0-6, and 0-8 in. depths, respectively.

Table 5. Effect of sample depth on routine soil test in a long-term alfalfa stand, Arlington, Wis., 2006.

Depth	pH	OM	P	K
inch		%	-------------------- ppm	------------------
0-2	7.4	4.1	20	265
2-4	7.3	3.6	12	150
4-6	7.4	3.4	11	99
6-8	7.5	3.2	11	90
Pr>F	0.02	<0.01	<0.01	<0.01
LSD	0.1	0.1	3	35

Summary

Soil sampling is the best and only method of determining crop nutrient need prior to planting. The fertilizer recommendation is based on good calibration data and lab methods, but it can clearly be argued that nutrient recommendations can be incorrect if samples are not collected to a proper and consistent depth. As conservation tillage systems become the norm, nutrient stratification will increase and it is extremely important that samples be collected to the depth of the most aggressive tillage system in the rotation. Chisel tillage does not remove nutrient stratification and actually increases it over moldboard plowing. The soil test remains a valuable to for providing an index of nutrient availability. The interpretation of that index, followed by monitoring plant analysis and crop yield with appropriate adjustments, will be the best method of providing an adequate, but non-excessive nutrient supply.

Table 1. Main effect of rotation, tillage, and fertilization on the incremental soil test, Arlington, Wis., 2005.

Treatment	0 to 2 inches				2 to 4 inches			
	pH	OM	P	K	pH	OM	P	K
		%	---- ppm ----			%	---- ppm ----	
Rotation								
CC	5.4	4.0	58	165	6.4	3.5	44	109
CSb	6.5	3.6	56	145	6.7	3.4	38	94
SbC	5.7	4.0	50	139	6.4	3.7	45	91
LSD	0.3	NS	NS	20	0.3	NS	NS	NS
Tillage								
Chisel	6.0	3.6	49	141	6.4	3.5	44	104
No-Till	5.7	3.9	59	150	6.7	3.5	42	93
Strip-till	5.9	4.1	68	176	6.7	3.5	45	99
LSD	NS	0.2	12	19	0.2	NS	NS	NS
Fert.								
None	5.9	3.8	43	127	6.5	3.5	38	89
Bdct.	5.8	3.8	67	171	6.5	3.5	47	106
LSD	NS	NS	5	11	NS	NS	3	7
Significance (Pr>F)								
Rotation	<0.01	0.25	0.26	0.04	0.05	0.42	0.34	0.07
Tillage	0.38	<0.01	<0.01	<0.01	<0.01	0.90	0.74	0.08
R*T	0.76	0.24	0.52	0.76	0.21	0.06	0.21	0.39
Fert.	0.09	0.26	<0.01	<0.01	0.59	0.28	<0.01	<0.01
R*F	1.00	0.19	0.04	1.00	0.99	0.77	0.24	0.76
T*F	0.80	0.22	<0.01	0.01	0.81	0.29	0.42	0.27
R*T*F	0.29	0.77	0.99	0.42	0.06	0.28	0.54	0.60

NS, not significant.

Treatment	4 to 6 inches				6 to 8 inches			
	pH	OM	P	K	pH	OM	P	K
		%	--- ppm ---			%	---- ppm ---	
Rotation								
CC	6.8	3.3	34	81	6.9	3.0	25	73
CSb	6.9	3.2	33	74	6.9	3.0	25	68
SbC	6.8	3.5	42	72	6.9	3.4	36	65
LSD	NS	NS	NS	NS	NS	NS	9	NS
Tillage								
Chisel	6.8	3.4	35	77	6.9	3.1	27	68
No-Till	6.9	3.4	38	74	6.8	3.2	29	68
Strip-till	7.0	3.3	40	75	7.0	3.1	32	71
LSD	0.1	NS	NS	NS	NS	NS	NS	NS
Fert.								
None	6.9	3.3	35	73	6.9	3.1	27	67
Bdct.	6.8	3.4	38	78	6.9	3.1	30	70
LSD	NS	NS	NS	4	NS	NS	NS	NS
Significance (Pr>F)								
Rotation	0.24	0.36	0.15	0.17	0.71	0.17	0.05	0.39
Tillage	0.03	0.76	0.81	0.21	0.14	0.73	0.70	0.06
R*T	0.24	0.04	0.22	0.03	0.41	<0.01	0.17	<0.01
Fert.	0.10	0.85	0.08	0.01	0.83	0.89	0.07	0.06
R*F	0.63	0.46	0.30	0.78	0.38	0.44	0.10	0.43
T*F	0.75	0.17	0.40	0.63	0.71	0.77	0.21	0.69
R*T*F	0.41	0.90	0.14	0.71	0.42	0.99	0.11	0.39

NS, not significant.

Grid Point Soil Sampling
Phosphorus and Potassium Uncertainty

Robert O. Miller, Ph.D., Affiliate Professor
Soil and Crop Sciences Dept, Colorado State University
Fort Collins, CO 80523

Soil testing is the foundation for the determination of nutrients for crop recommendations. The reliability of which is based on the collection of a representative field sample, appropriate test method, accurate laboratory analysis, and the nutrient recommendations. The success of the soil testing process is fundamentally dependent on the collection of a representative soil sample. For whole fields this entails a composite of multiple soil cores denoting the collection area, whereas for grid sampling cores are combined around the grid point.

Considerable research has been conducted across the Great Plains to address soil sampling techniques used to assess nutrient status. For whole field composite soil samples only the mean is measured with no estimate of the variance (Peterson and Calvin, 1965). Cameron et al., 1971 reported that 20 cores provided a mean estimate within 10% for phosphorus 70% of the time, but were inadequate on highly variable fields. Swenson et el., 1984 reported that 20 cores provided a mean estimate within 15% for nitrate 80% of the time. Work by Franzen and Peck 1993, has shown substantial spatial variability, and suggested sampling intensities of one sample per acre would be required to characterize nutrient variation in most fields in Illinois. Often high variability of immobile nutrients (P and K) of composite samples is associated with the fertilizer bands from previous nutrient applications. Fields that have high soil test values tend to have higher spatial variability (Mallarino, 1996 and Clodfelter, et. al., 2005). Increasingly fields are grid sampled in the region based on 2.5 acre grid approach, compositng 3-12 cores per grid point, however little information has been published on grid point nutrient variation.

Further complicating soil sampling are the impacts of soil tillage systems and application of livestock manures. With no-till and reduced tillage systems nutrients increasingly stratify near the surface, requiring accurate sample depth control (Wolkowski, 2002). If the sample is collected at a shallower depth, soil test results will over estimate the nutrient concentration of the sample. With regard to livestock manures, surface applications are often nonuniform resulting in high spatial variability.

The primary objective of this project was to estimate grid point sampling uncertainty for pH, P and K on fields on the Great Plains and Midwest.

Materials and Methods

Grid point soil samples were collected at sixty field sites across seven states in the fall of 2006 and 2009. Tillage practices ranged from no-till to conventional till and included sites where manure had been previously applied. Twelve individual soil cores, were taken in a structured pattern ranging from 2 to 10 feet from the center of a geo-referenced grid point. Sampling depths ranging from 0-6", 0-7" or 0-8" for dependent on location. At four locations soils were sampled to an additional depth of 6-12". At one location twenty four individual cores were sampled from 2 to 10 feet from the center geo-referenced grid point.

Grid point soil cores were dried, pulverized, thoroughly mixed and analyzed for pH, SMP buffer pH, Bray P1 phosphorus, ammonium acetate K, and DTPA extractable zinc, in triplicate. Laboratory quality control procedures included standard reference soils from the Agricultural Laboratory Proficiency (ALP) Program, blanks and duplicates.

Results

Spatial variability grid point of phosphorus (P), based on twelve core composites, indicated RSD values generally were between 10-30%, with the exception of twenty-five no-till sites (Table 1) which ranged 19 - 124%. The no-till sites were characterized by low to high Bray P concentrations (8-40 mg kg^{-1} P) and had received past band applications of P fertilizer materials. Results for K indicate RSD values ranged from 6.4-37%, with twenty-one of twelve fields averaging 12% for soils ranging from 124 to 458 mg kg^{-1} K. Three fields with highest variability, had received past band applications of K fertilizer. For soils ranging from pH 5.4 to 7.9 RSD values ranged from 3.0 to 12.0%. Across sites, no-till fields tended to have the highest spatial variability grid point pH.

Individual core results indicate that composite mean P concentration decreased going from 3 to 12 cores and overall improved precision. For site #15 the RSD value for a three core composite sample was 43.6%, while that for six cores was 40.9% and eight cores fell to 35.1%, resulting in an uncertainty of ±4.1 mg kg^{-1} P (Table 2). For site #43 a reduced tillage field the RSD value for three core composite was 38.1%, while that for six cores was 24% and eight cores fell to 21%, resulting in an uncertainty of ±6.2 mg kg^{-1} P. Generally no-till sites were characterized as having skewed populations (skewness >1.2) with one or two core subsamples high in Bray P1 concentration. Potassium results indicate composite mean concentrations and RSD values change only slightly going from six to twelve cores. For site #57 a no-till site with a mean K concentration of 490 mg kg^{-1}, the potassium RSD value for three core composite was 12.5%, while that for six cores was 14.0% and twelve cores 12.0%. No-Till sites tended to have the highest RSD values for K of all locations with or without prior application of K fertilizers. Lastly pH grid point variation, for soils ranging from pH 5.8 to 6.7, RSD values for six cores ranged 2.9-14.2% and for twelve cores ranged from 3.0 to 9.0%.

Individual core results for Bray P1 were further evaluated to assess sampling intensity. Bray P1 mean and RSD values were evaluated for 2 of 12, 4 of 12, 6 of 12, 8 of 12 and 11 of 12 core composites, based on all possible combinations. Results for field #15 (as shown in Table 3), indicate that sampling only two of twelve cores, consisting of all 66 possible combinations, resulted in a composite mean Bray P ranging from 13.2-25.3 mg kg^{-1} P and RSD values ranging from 0-57%. Increasing to six of twelve cores resulted in composite mean Bray P ranging from 14.2-19.7 mg kg^{-1} P and RSD values ranging from 4-36%. Soil core combinations (Figure 1) indicate a rapid convergence of composite mean soil Bray P1 values as the number of cores included increases from six to twelve cores for the field #15. Also worth noting is the skewness of the mean data associated with two cores of high Bray P1concentration. Overall, a minimum of eight core composites were required to obtain a range of mean core combinations within ±2.0 mg kg^{-1} P of that found for the twelve core composite. Similar results were found for Field #41 (Figure #2).

The number of grid point soil samples composited determines the accuracy and precision of the final result. Accuracy refers to the correctness to the true value, whereas precision is a measure of the reproducibility of the sample result for a given level of statistical confidence. Results of the grid point Bray P1 data were applied to the formula for calculating sample size:

$$n = (t^2 * s^2) / E^2$$

where *t* is the student *t*-values which equal's 1.27, 1.64, 1.96 for the 80%, 90% and 95% level of confidence respectively, E is the accuracy as percent allowable error and *s* is the population standard deviation. Bray P1 for grid point samples collected from a conventional tilled site (Field #31) with a mean of 45.1 standard deviation of 6.8 mg kg^{-1} P indicate a composite of seven cores would be required to obtain an accuracy of ±10.0% of the mean Bray P1 at 90 percent precision level (see Figure 2). Thus there would be only one chance in ten that a composite of seven cores would result in a value exceeding the mean by more than ±10%.

In contrast for a no-till location such as Field #15 with a mean of 16.6 and standard deviation of 4.8 mg kg^{-1} P a composite of twenty six cores would be required to obtain an accuracy of ±10.0% of the mean Bray P1 at a 90 percent precision level (see Figure 3). Reducing the precision level to 80%, would still require a composite of 16 cores to obtain an accuracy of ±10.0% of the mean Bray P1. Reducing accuracy to ±20.0% would still require six cores at a 90% precision level; however a level this low would be of little value for reliable fertilizer recommendations. Increasing the number of cores collected to twelve cores using 90% precision level would provide an accuracy of ±14.0%.

These results indicate that for Bray P1 soil sampling a grid point of manure and conventional tilled fields with RSD values of 12-16%, generally six to eight cores will result in an accuracy of ±8.0-11.0 % based on 90% precision level. For no-tilled fields and low testing fields with high variability (RSD 30%), 3-4 times more soil cores will be required to obtain an accuracy of ±10.0% of the mean Bray P1.

Summary

Results for twelve composited cores, indicates substantial improvement in grid point accuracy and precision going from two to twelve cores for phosphorus and to a lesser extent for potassium and pH. Although optimum precision was obtained with twelve core composites per grid point, generally for manure, conventional and reduced tillage sites, six to eight cores resulted in and Bray P1 RSD values of 11-19%. For no-till sites RSD values ranged from 19-124%. Increasing the number of cores composited for low testing and no-till fields substantially improved grid point precision for P, especially with fields where P fertilizers had been band applied previously. An estimate of accuracy indicates that twenty four to thirty cores are required to obtain an accuracy of ±10.0% on these fields.

The results of this research suggest that grid point sampling intensity be assessed for each field based on the nutrient test of primary interest, soil test levels, and field tillage management. For no-till and low testing soils consideration should be given to increasing the number of soil cores composited thereby improving the accuracy of the mean estimate, and providing more accurate nutrient recommendations. Lastly it is strongly suggested that grid point accuracy and precision estimates be periodically collected to assess grid point uncertainty and incorporated in the generation of nutrient maps.

Acknowledgment: Special thanks to: Greg Ikins, United Soil Testing and Tom McGraw of Midwest Samplers for their assistance in collecting soils. Thanks to United Soil Testing, Fairbury, IL and LGI, Laboratory, Ellsworth IA for providing analytical services.

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Table 1. Phosphorus Bray P1 content of grid point samples, five locations fall 2006 and 2007.

	Field #22	Field #31	Field #06	Field #15	Field #35
	Conv Till	Manured	Rd.-Till	No-Till	No-Till
Range (mg kg^{-1})	35 - 63	35 - 60	23 -52	12 - 30	16.3 - 59.0
Mean (mg kg^{-1})	51.7	45.1	41.9	16.6	29.8
Std Dev. (mg kg^{-1})	8.6	6.8	7.6	4.8	11.8
RSD %	16.6	15.0	18.8	29.4	39.8
Uncertainty – CI 95% (mg kg^{-1})	± 5.1	± 3.8	± 4.6	± 2.9	± 6.7

Table 2. Phosphorus Bray P1 grid point core variation, site Field #15 fall 2006.

Number of Cores	Mean Mg kg^{-1}	Stdev mg kg^{-1}	RSD %	Uncertainty (95%) ± mg kg^{-1}
3	20.0	8.7	43.6	9.9
6	16.5	6.7	40.9	5.4
8	16.8	5.9	35.1	4.1
12	16.6	4.8	29.0	2.8

Table 3. Core combination Bray P1 statistics, site Field #15 fall 2006.

<table>
<tr><th>Number of Cores</th><th>2 of 12</th><th>4 of 12</th><th>6 of 12</th><th>8 of 12</th><th>11 of 12</th><th>12 of 12</th></tr>
<tr><td>Combinations</td><td>66</td><td>495</td><td>924</td><td>495</td><td>12</td><td>1</td></tr>
<tr><td>Max Mean (mg kg^{-1})</td><td>13.2</td><td>13.6</td><td>14.3</td><td>14.7</td><td>15.0</td><td rowspan="2">16.6</td></tr>
<tr><td>Min Mean (mg kg^{-1})</td><td>25.2</td><td>22.2</td><td>19.7</td><td>18.7</td><td>17.4</td></tr>
<tr><td>RSD (%) Range</td><td>0 - 57</td><td>3 - 51</td><td>4 - 36</td><td>8 - 33</td><td>19 - 30</td><td>29.4</td></tr>
</table>

Figure 1. Range of mean core Bray P1, core combination for soil, site Field #15 fall 2006.

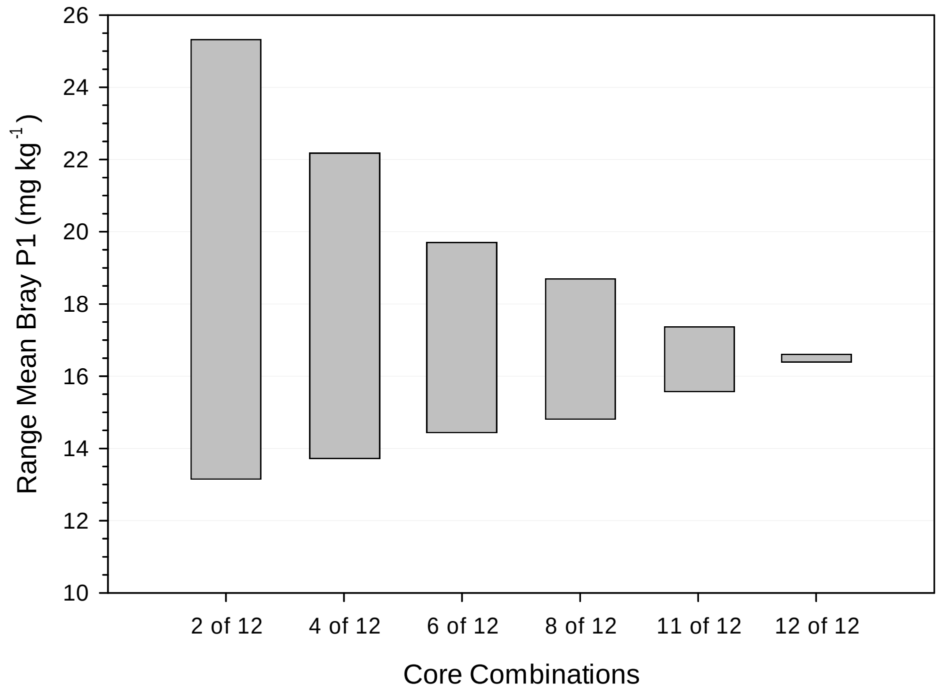


Figure 2. Range of mean core Bray P1, core combination for soil, site Field #41 fall 2006.

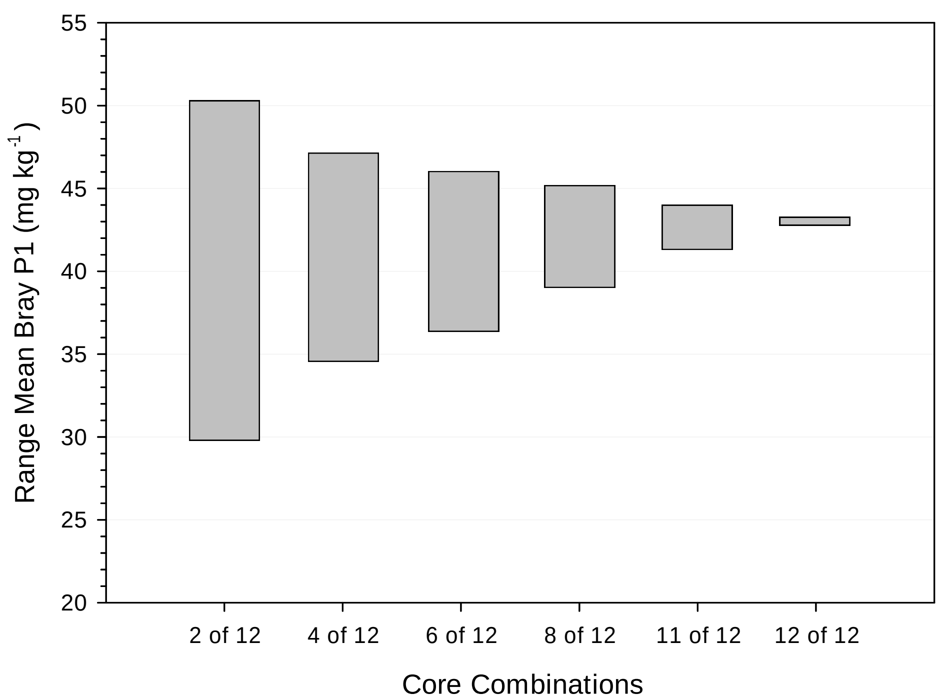


Figure 3. The number of subsamples required for grid point composite cores for soil Bray P1 at various levels of accuracy and three levels of precision, based on sampling RSD of 15%.

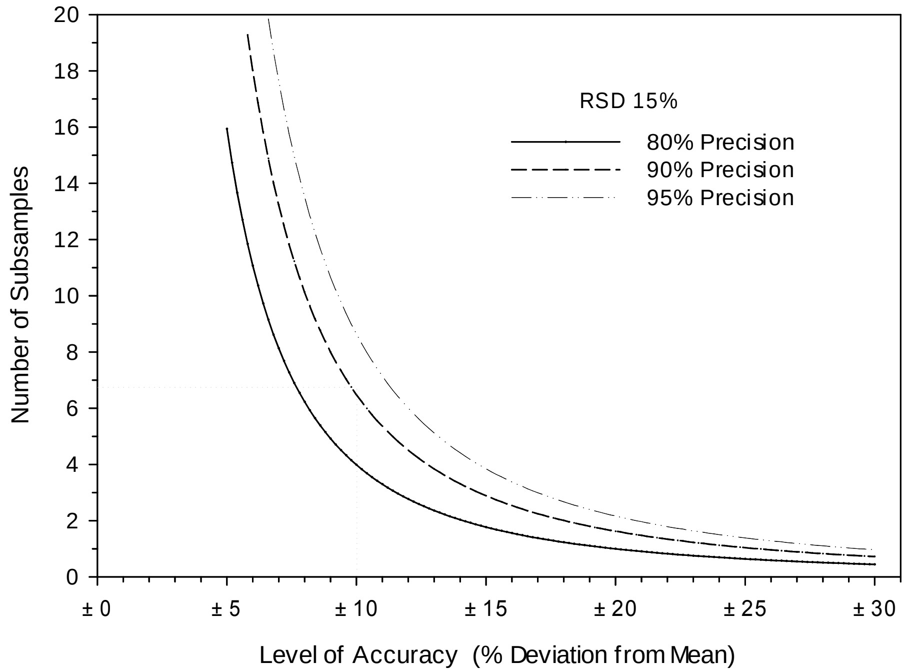
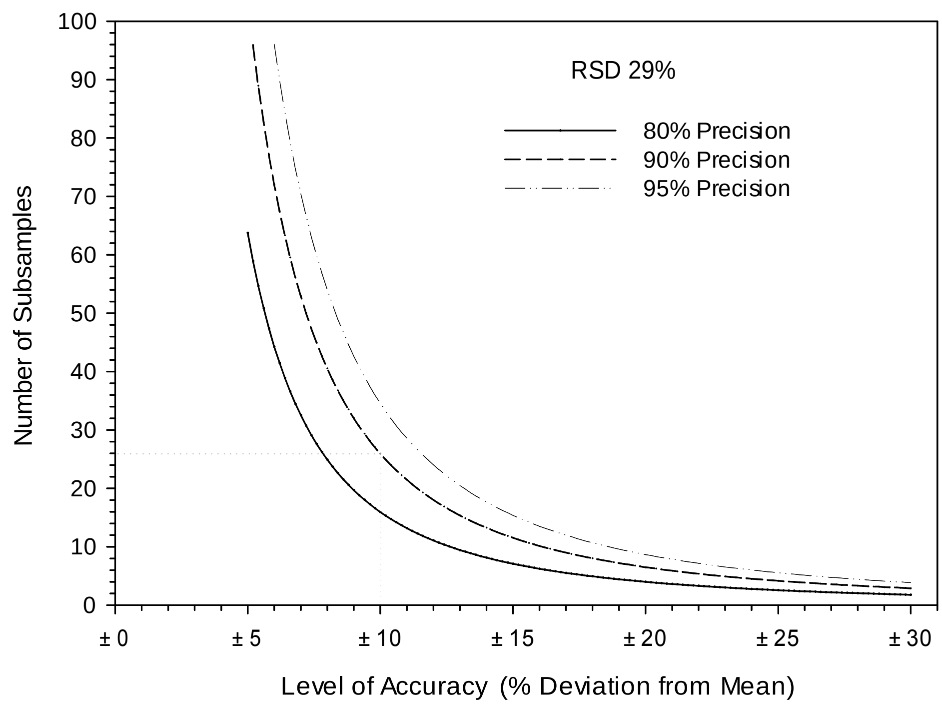


Figure 4. The number of subsamples required for grid point composite cores for soil Bray P1 at various levels of accuracy and three levels of precision, based on sampling RSD of 29%.



Soil Test Changes and Crop Response from Long Term Nutrient Additions

Anthony Bly, Ron Gelderman and Jim Gerwing
South Dakota State University

Objective: Evaluate and demonstrate the importance of soil testing in South Dakota.

Objective accomplished by using the following methods.
1. Determine the effect of added P, K, and Zn on soil test.
2. Determine the relationship of crop response (grain yield) to added P, K, and Zn.

Materials and Methods:

Table 1. Locations and dates of soil test demonstration research in South Dakota.

Location	City	Years conducted
SE Research Farm	Beresford	1991-2010
Agronomy Research Farm	Brookings	1991-2010
NE Research Farm	Watertown	1996-2010
Central Crops Research Farm	Highmore	1997-2006

Table 2. Nutrient rate treatments for soil test demonstration research in South Dakota.

Nutrient	Beresford	Brookings	Highmore	Watertown [1,2]
lbs/a				
check	N only[1] (corn)	N only[1] (corn)	N only[1] (wheat)	N P K Zn
P_2O_5	not tested	40	35	N – K Zn
K_2O	50	50	50	N P – Zn
Zn	5	5	5	N P K --

[1] N rate determined from soil test nitrate-N (0-2 ft), yield goal and legume credit.
[2] nutrient rates: P_2O_5 = 40, K_2O = 50, Zn = 5

Table 3. Cultural practices for soil test demonstration research in South Dakota.

Location	Crop Rotations	Plot Size (ft)	Tillage Method
Beresford	corn / soybean	15 x 65	conventional
Brookings	corn / soybean	20 x 40	"
Watertown	corn/soybean/spring wheat	15 x 60	"
Highmore	spring wheat/soybean	25 x 50	"

Table 4. Critical soil test level where no P, K, or Zn applications are recommended in South Dakota.

Crop	P	K	Zn
	----------------------------- ppm (0-6 inch) -----------------------------		
Corn	16	160	1
Soybeans	12	120	No recommendation
Spring Wheat	16	160	No recommendation

Results and Discussion:

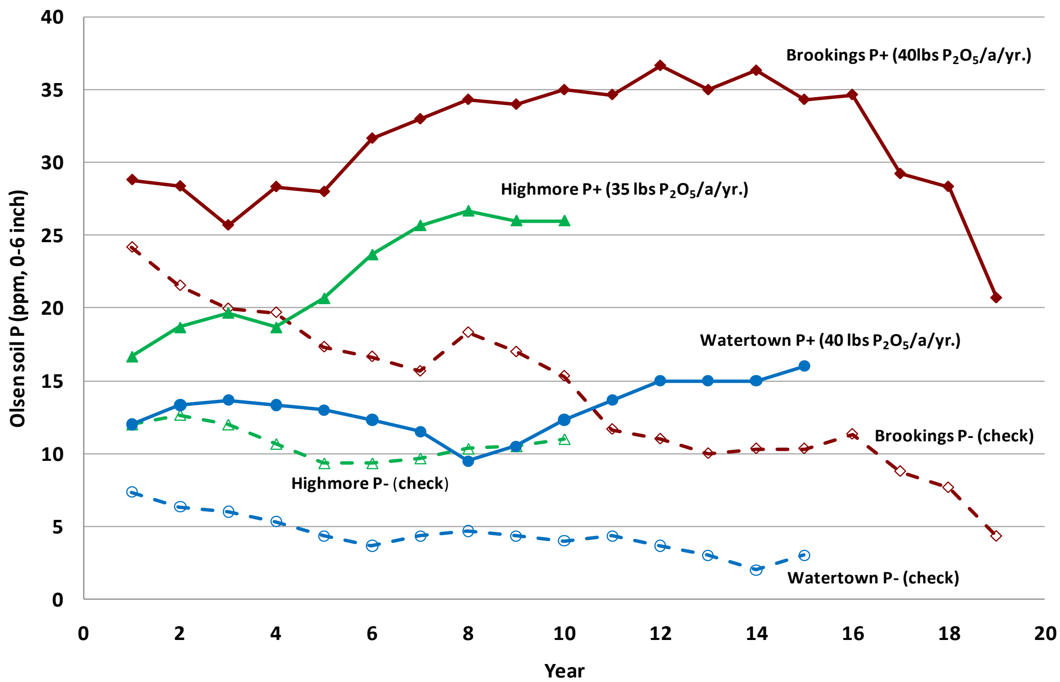


Figure 1. Influence of crop P removal and P fertilizer additions on Olsen P soil test at demonstration sites in South Dakota from 1991-2010.

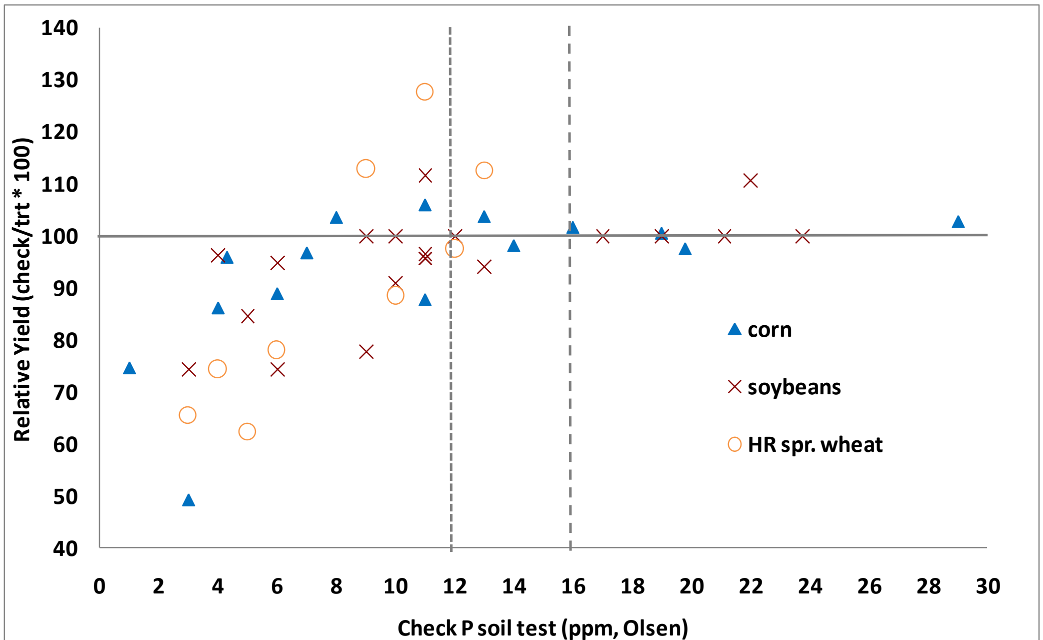


Figure 2. Crop grain yield response to P soil test at soil test demonstration sites in SD from 1991 to 2010.

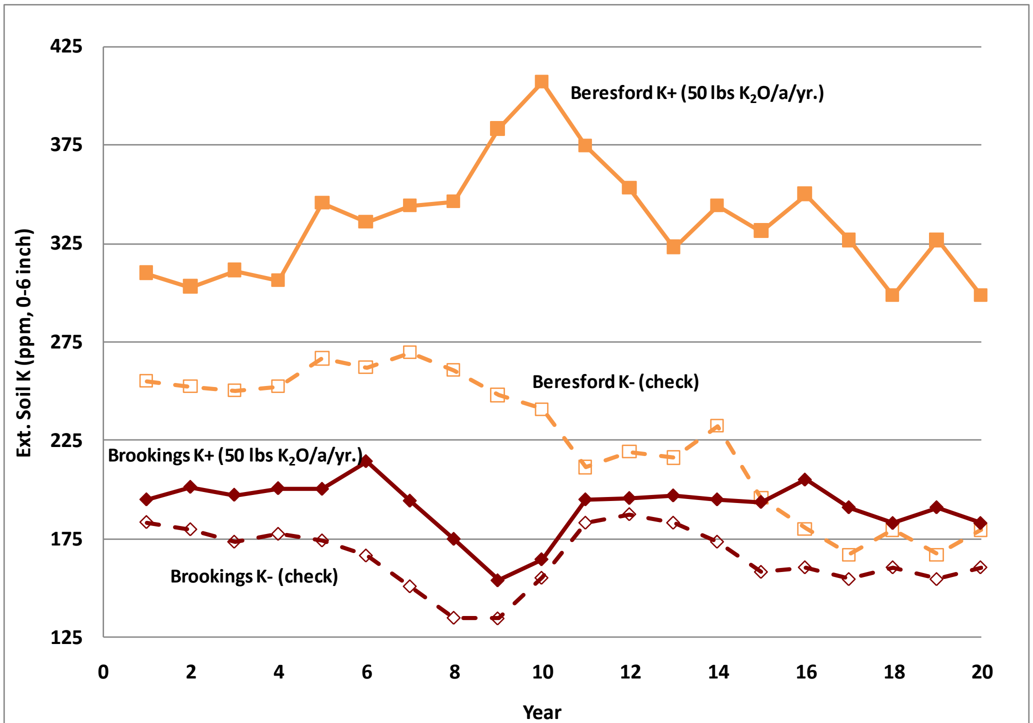


Figure 3. Influence of crop K removal and K fertilizer additions on extractable soil K at demonstration sites in South Dakota from 1991-2010.

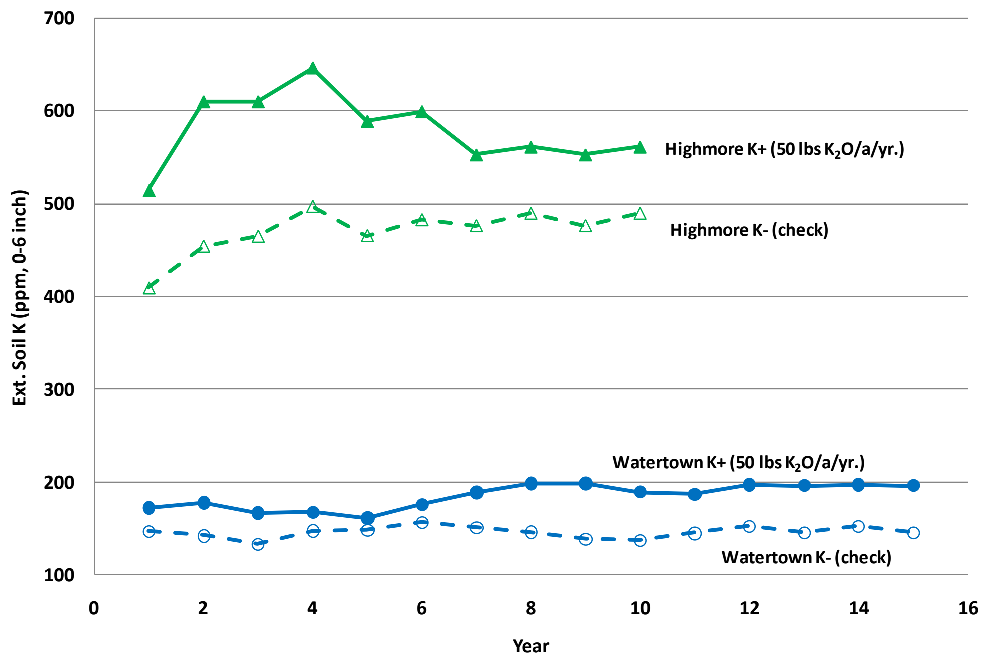


Figure 4. Influence of crop K removal and fertilizer K additions on extractable soil K at demonstration sites in South Dakota from 1991-2010.

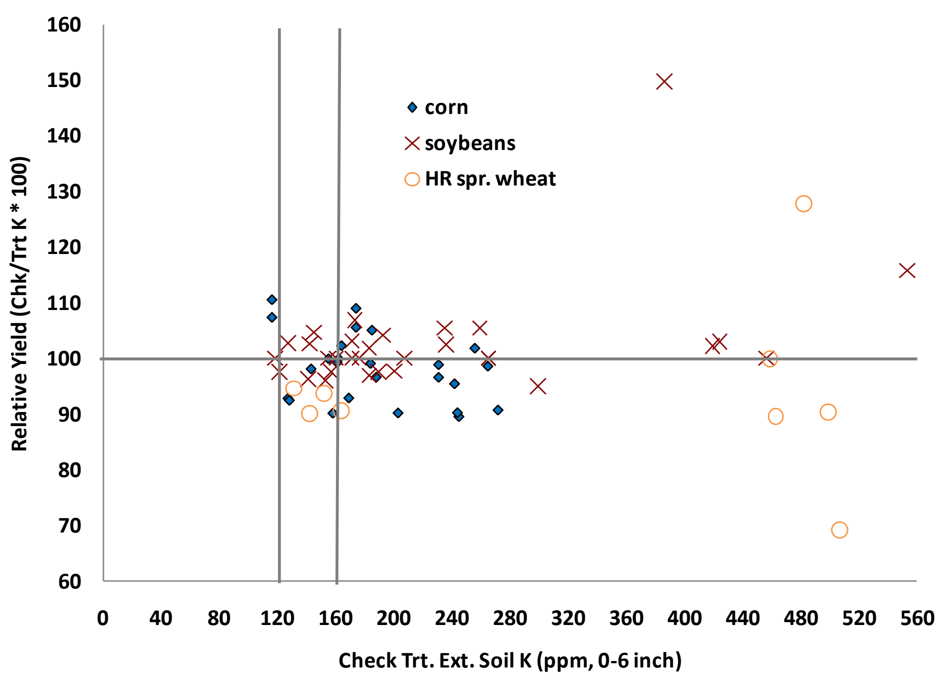


Figure 5. Crop grain yield response to extractable soil test K at demonstration sites in South Dakota from 1991 to 2010.

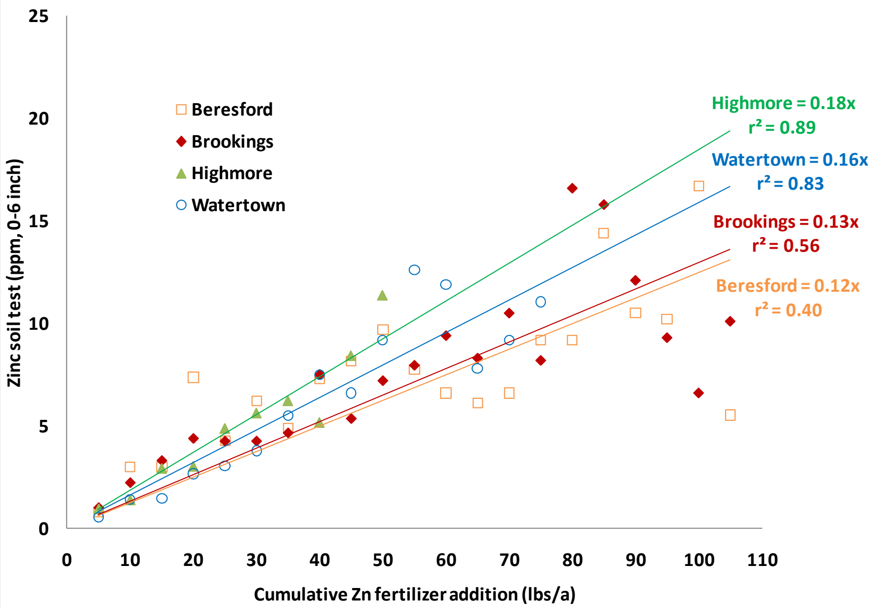


Figure 6. Influence of Zn fertilizer additions on soil test zinc at demonstration sites in South Dakota from 1991 to 2010.

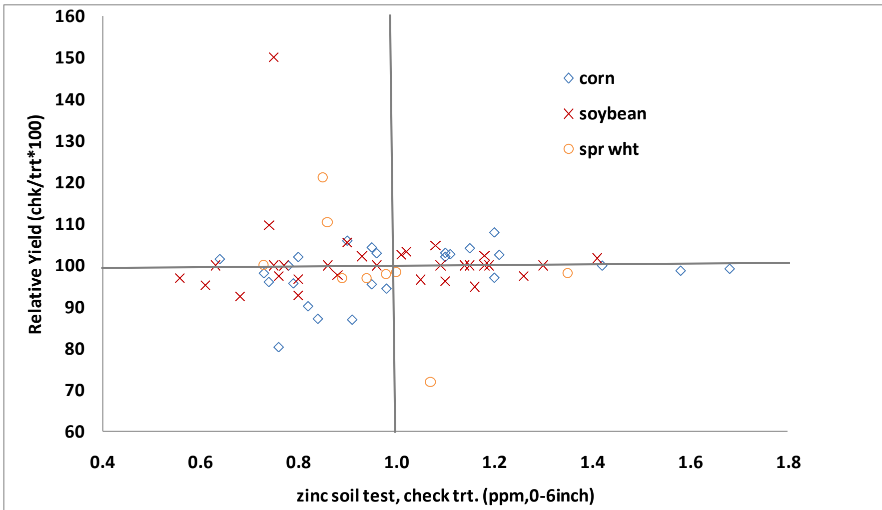


Figure 7. Crop grain yield response to zinc soil test at soil test demonstration sites in South Dakota from 1991 to 2010.

Summary:

These long term demonstration projects show that soil testing and fertilizer recommendations are good tools for managing crop fertilizer inputs and are supported by the following points.

1. Crop P responses measured below critical level of 16 ppm Olsen P.
2. Lack of crop response to K soil test which are mostly above the 160 (corn) and 120 (soybean) ppm critical levels.
3. Corn Zn responses measured below critical level of 1 ppm.

Does an ICP Affect Results for K, Secondary and Micronutrients?

Byron Vaughan
Independent Consultant, Chesterfield, VA

Many soil testing laboratories utilize an ICP for nutrient analysis. Like any analytical instrument, ICP has some quirks. A few key oddities that are noteworthy of discussing are P, K, S, and B.

Phosphorous determined by ICP is usually higher than colorimetric. Many researchers have evaluated the reason (soluble organic P, filter paper particle retention, manure history, etc.) for the elevated P levels and it is still unclear. A 10 to 15 ppm adjustment in Mehlich III interpretation is needed when an ICP is used. The ICP needs to be equipped with a cyclonic spray chamber and a concentric nebulizer to ensure that 1.0 P ppm method detection limits can be achieved.

ICP's can be equipped with the ability to view the plasma in a radial or axial mode. The axial mode provides more signal. The alkaline metals (Li, Na, K, Rb, Cs, and Fr) in column I of the periodic table have non linearity and matrix problems in the axial mode. This problem stems from alkaline metals self absorbing light in the tail of the plasma plume. It is critical to view the alkaline metals in the radial mode. If you own a axial ICP, the samples must be spiked with an ionization suppressant such as Li or Cs. This can be quite expensive for laboratory that analyzes hundred of thousand samples. The AA has better precision and detection limits than a ICP; however, the difference is analytical insignificant in a production soil testing laboratory.

Sulfur struggles with the same issues that affect P when analyzed by the ICP. Sulfur extractants have significant amounts of organic S. In my personal experience, I estimate 40% of the total S is organic. The challenge with S is that most soils have S values between 4 and 12 ppm. The narrow soil range gives little latitude for correction. The MCP extractant has a 2.5x dilution factor and the other more common procedures utilize a 10x dilution factor. The turbidimetric procedure has inadequate sensitivity for procedures with soil to extractant rations greater than MCP. The ICP is the only real choice for analyzing S in 1:10 extractants.

Boron has an affinity for ICP sample introduction system (spray chamber and torch). This creates a “memory” problem and elevated emission counts. This will elevate B soil test levels and lose low end detection. A 2% solution of HF or sorbitol will wash the B out of the ICP. The HF poses more health hazards and can etch your glassware. Sorbitol will not etch the glassware and is very effective washing B out of the ICP. A sorbitol solution can be prepared for the ICP rinse cup so that the ICP is cleaned out before and after calibration. The better setup is to fit a tee connection into sample line and continually pump a 2% sorbitol solution.

Beforehand knowledge of ICP quirks and possible solutions can greatly speed up the integration of ICP instrumentation into the laboratory. Overall, an ICP is one piece of equipment that every soil testing laboratory should own or plan to purchase.

Accuracy and Precision for Common Manure Analytical Tests

Jerry Floren
Soil Scientist, Minnesota Department of Agriculture

Abstract: A manufacturer for manure application equipment stated their company sent the same manure sample to several different labs and received very different results from each lab. We know the concentration of agricultural nutrients in manure is variable, but assuming different laboratories receive carefully split samples, what variation is expected in results? What variation is expected when the same laboratory analyzes carefully split samples on different days? Since 2003, the Manure Analysis Proficiency (MAP) Program has sent carefully split manure samples to approximately 60 labs participating in the MAP Program. These exchanges give insight to the variability found in manure analytical results.

Laboratories participating in the MAP Program receive shipments of three different manure samples with triple replicates (nine containers). Labs analyze the replicates on different days using the methods described in *Recommended Methods of Manure Analysis*[1]. From 2003 through 2006, participating labs received three shipments per year. From 2007 through 2010, labs received two shipments per year. The participating labs analyzed sixty different manure samples with triple replicates from 2003 through 2010.

Precision and Accuracy: Since labs analyze samples with triple replicates on different days, it is possible to evaluate both precision and accuracy. Precision is an intra-laboratory measurement of reproducibility of measurements within individual laboratories. In other words, how does the range of replicate results by an individual lab compare with the range of replicate results submitted by the other labs? Accuracy is an inter-laboratory measurement of variability for all laboratories submitting results for specific tests and samples.

Precision evaluation: Results submitted for sample replicates makes the evaluation of precision possible. How close are the results within an individual lab when they analyze the same manure sample on three different days? To evaluate precision, the mean of the three replicates is calculated for each lab submitting results for a particular sample and test. The standard deviation (SD) for the three reps is calculated next along with the Coefficient of Variation by dividing the SD by the lab's replicate mean and multiplying by 100 to give a percent value. This is denoted as Rp on the MAP reports. For each test and manure sample, the median of the Rp values is calculated and denoted as Rd on the MAP reports. Labs are flagged for precision if their individual Rp value exceeds three times the industry median Rd value.

Accuracy evaluation: For laboratory accuracy, the median and Median Absolute Deviation (MAD) are calculated for each sample and test. The median is the median of all replicate values submitted for the test and sample, not the median of the replicate means.

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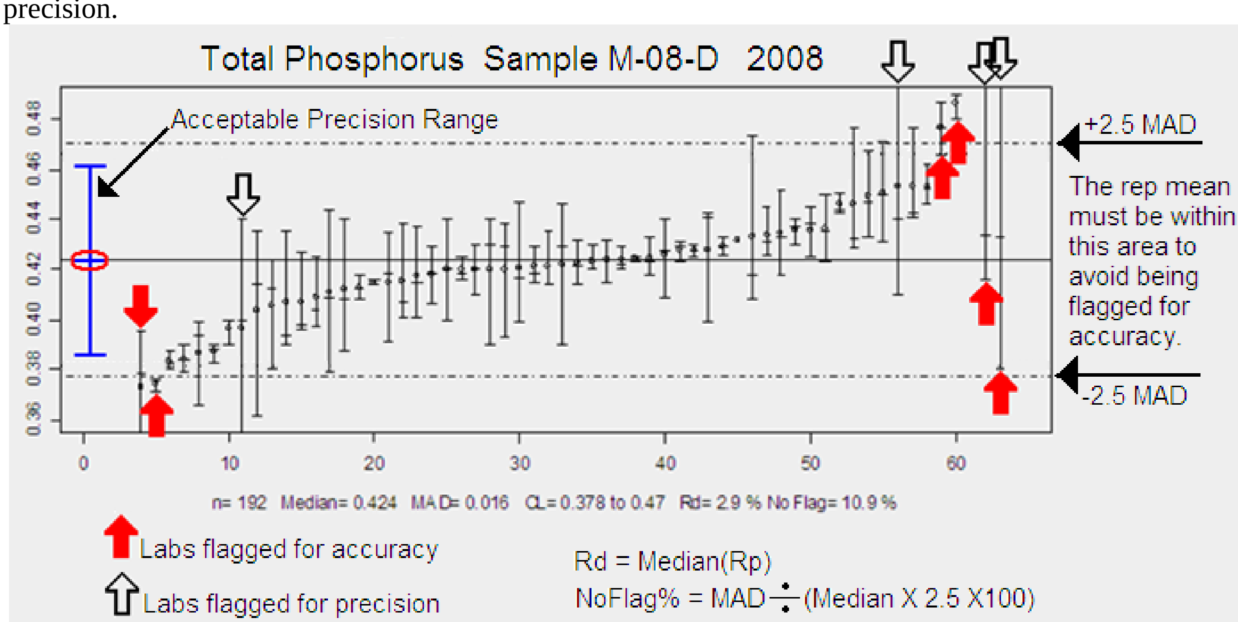
[1] *Recommended Methods of Manure Analysis*; Editor, John Peters, University of Wisconsin-Madison; http://learningstore.uwex.edu/assets/pdfs/A3769.pdf; 57 pages.

The MAP Program reports accuracy as NoFlag%. This is the maximum percent a laboratory's result for a specific sample and test can deviate from the median value without being flagged for accuracy. NoFlag% is calculated from the MAD and the median as follows:

$$\text{NoFlag\%} = \text{MAD} \div \text{median} \times 2.5 \times 100.$$

Figure 1 is an example of a graph for total phosphorus results submitted in 2008 for the three replicates of sample D. Each vertical line represents the results from individual labs with the replicate results represented by a hash mark and the mean of the three replicates represented by a dot. The dot-dash line is at ±2.5 MAD units from the median. Labs with replicate mean results outside of this line were flagged for accuracy (solid arrows). The Rd value for this sample is 2.9%, and labs were flagged for precision if their Rp value exceeded three times the Rd (8.7%). The thick line on the graph's left margin represents the acceptable precision range for this sample.

Figure 9: A typical graph of each lab's replicate results with a dot-dash line at ±2.5 MAD units from the median. Solid arrows denote labs flagged for accuracy, and outline arrows denote labs flagged for precision.



What range of laboratory variability did the MAP labs display from 2003 through 2010? Table 1 gives the range and median NoFlag% values and median Rd values. The table is sorted by NoFlag% with tests having the lowest variability for accuracy listed first.

Table 8: Summary of variation for all MAP Program tests from 2003 through 2010. Not all tests were available for the full program, and "n" represents the number of manure samples analyzed for each test.

Increasing Variability

Analysis	n	Minimum NoFlag%	Median NoFlag%	Maximum NoFlag%	Minimum Rd	Median Rd	Maximum Rd
Moisture Content	15	0.9	1.9	13.0	0.2	0.3	3.2
Total Solids	60	1.4	5.4	32.5	0.3	1.1	5.5
pH	24	2.9	6.4	12.7	0.5	0.6	0.9
TKN	60	6.4	12.1	64.7	1.1	2.2	6.2
Potassium	60	10.0	15.3	21.9	1.6	2.4	4.3
Magnesium	18	11.0	16.7	42.9	2.1	3.4	7.6
Phosphorus	60	9.4	18.6	45.5	1.7	3.2	6.6
N-Combustion	60	5.0	18.9	106.7	0.9	2.9	8.1
Sodium	18	14.3	20.0	27.8	1.9	3.3	5.6
Zinc	60	13.3	20.6	82.3	1.7	3.8	9.5
Calcium	18	12.1	21.1	46.7	2.4	4.8	7.6
Sulfur	51	12.5	23.9	50.0	1.8	3.3	6.8
Copper	60	12.3	26.4	100.9	1.7	4.0	10.9
NH4-N	77*	8.2	35.3	166.2	1.3	3.1	11.1
Electrical Conductivity	78*	9.5	48.0	117.6	1.0	2.5	15.0
Chloride	7	20.7	56.3	114.3	1.4	2.8	4.5
Water Extractable Phosphorus	33	29.1	59.7	156.3	1.4	4.4	7.2
NO3-N	18	67.0	190.5	249.9	3.9	9.8	25.8

*For electrical conductivity and ammonium nitrogen, the number of manure samples is greater than 60. Labs used several different methods for these tests, and some laboratories used more than one method.

Conclusion: Even with carefully split manure samples, expect some nutrient content variability when different laboratories analyze manure, or even if the same laboratory analyzes manure on different days. There are a number of reasons for this variability, and variability is expected in all measurements. Table 1 summarizes the variability found for all 60 manure samples analyzed by labs participating in the MAP Program. The table helps explain why a person may send, "… the same manure sample to several different labs and receive very different results from each lab."