TESTING FIELD-MOIST SOIL FOR POTASSIUM AND OTHER NUTRIENTS -- WHAT'S IT ALL ABOUT?

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Introduction

Potassium (K) is present in the soil in water-soluble, exchangeable (both readily available for crops), non-exchangeable or fixed (may become available over time), and mineral (unavailable) forms. Estimates of soil exchangeable K with the ammonium-acetate and Mehlich-3 extractants from air-dried or oven-dried soil samples are the most widely used soil-test methods for K. These methods provide comparable K test results, and are suggested for the north-central region by the North-Central Regional Committee for Soil Testing and Plant Analysis (NCERA-13) (Warncke and Brown, 1998). In spite of extensive research, however, predicting plant-available K by soil testing has proven to be a difficult task because of complex and largely unpredictable equilibria between several soil K pools and interactions with many factors that influence crop-available K levels and plant K uptake.

Decades-old research has shown that wetting-drying cycles influence transformations of K between exchangeable and non-exchangeable soil K pools in most soils. Soils initially high in exchangeable K may fix K upon drying while those with very low exchangeable K levels tend to release K upon drying. The type of clay also influences sample drying effects on extractable K, and the equilibrium between soil K pools also is affected by K additions or K removal by crops. Some useful published articles, among many, include those by Luebs et al. (1956), Hanway and Scott (1959), Cook and Hutcheson (1960), Hanway et al. (1962), and Dowdy and Hutcheson (1963) and the review by Haby et al. (1990). Therefore, the time of sampling and the drying soil for laboratory analysis interacting with these factors partly account for high temporal variation of soil-test K (STK) and poor predictability of crop K sufficiency by soil testing. Research in the north-central region during the 1960s and 1970s mainly in the greenhouse, showed that soil K extracted from field-moist samples was better correlated with crop K uptake than K extracted from dried samples (Barber et al., 1961; Hanway et al., 1961; Hanway et al., 1962).

Therefore, procedures for extracting K with ammonium-acetate directly from moist samples or from a soil-water slurry were implemented by the Iowa State University (ISU) Soil and Plant Analysis Laboratory in the middle 1960s. Unpublished research comparing these two versions of the moist test gave similar results, but a slurry facilitated handling of fine-textured soil samples (J.J. Hanway and K. Eik, ISU). Detailed procedures for both versions of the test were included among sample handling procedures suggested for the north-central region by the NCERA-13 soil testing committee (Eik et al., 1980; Eik and Gelderman, 1988). The Iowa interpretations for the moist test varied over time, and were last published by Voss (1982). Field correlations for the moist K test based on data from long-term Iowa experiments with corn and soybean conducted from the 1970s to the late 1980s were published by Mallarino et al. (1991a, 1991b).

No other laboratory adopted the slurry test citing impractical handling procedures, however, so the ISU discontinued its use in 1989, and in 1998 the NCERA-13 committee dropped it from the its methods publication. Based on comparisons of amounts of soil K extracted using dried (35 to 40 ºC) or moist samples, the Iowa interpretations based on the moist K test were increased by a factor of 1.25 for recommendations updated in 1988, 1996, and 1999. Field calibration research for corn and soybean (Mallarino et al., 2002) revealed the inadequacy of this adjustment for the dry test because it over-estimated crop available K, and the new results were used to update interpretations in 2002 (Sawyer et al., 2002). However, the new data continued showing a poor prediction of K sufficiency by the commonly used test based on dried samples.

Objectives and Procedures

This article summarizes research to study effects soil sample drying on STK values and to compare field correlations of tests based on field-moist and dried soil samples for corn and soybean. A field study was conducted from 2001 to 2006, which measuring crop-available soil K with the ammonium-acetate and Mehlich-3 extractants on dried and moist samples. New laboratory research was conducted in 2011 to compare dry and moist tests for phosphorus (P), calcium (Ca) and magnesium (Mg) and the repeatability of dry and moist test results.

Field response K trials with corn and soybean were conducted across 20 Iowa counties. The study included 32 Iowa soil series, some of which are also present in areas of neighboring states. There were 162 trials, 63 of which were single-year trials and 99 were were evaluated 2 to 6 years by re-applying treatments each year for corn-soybean rotations. Therefore, there were 200 corn site-years and 162 soybean site-years. Crops and soils were managed with chisel-plow/disk tillage for 120 trials and no-till for 42 trials. Each trial included two to five K fertilizer rates (granulated KCl 0-62-0) applied in the fall before soils froze, and before chisel plowing at sites managed with tillage. The fertilizer was broadcast, except in 30 trials that evaluated broadcast and planter-band K placement methods. Means across placement methods were used for the field correlations since they seldom differed. Previous Iowa research has shown small or no difference between broadcast and planter-band K application methods for corn or soybean.

Soil samples (6-inch depth) were stored at 5 ºC from 2 to 10 weeks in plastic-lined soil sample bags, sieved through a 5-mm screen, thoroughly mixed, and divided in two sub-samples. One subsample was prepared for K analysis with the oven-dried sample handling procedure (35 to 40 ºC) suggested for the North Central region (Warncke and Brown, 1998). The other subsample was not dried, and was used for a field-moist K analysis by the direct sieving method described in detail by Eik and Gelderman (1988) and by R. Gelderman and A.P. Mallarino in an updated chapter version (in press). Soil moisture was determined immediately after sieving soil by drying a small subsample to constant weight at 40 ºC, and ranged from 6 to 31% (mean was 20%). The extraction and K measurement for the ammonium-acetate and Mehlich-3 methods were similar to those used for the dried samples. The grain yield data was expressed as relative responses to K fertilization by dividing the mean yield of non-fertilized soil (across replications) by the mean of the highest K rate and multiplying the result by 100. The STK critical concentrations were calculated with the statistical Cate-Nelson (CN) method (Cate and Nelson, 1971) and the linear-plateau (LP) and quadratic-plateau (QP) segmented polynomial models. This article includes results for the ammonium-acetate extractant.

In spring 2011, soil samples collected from many Iowa fields were analyzed by P, K, Ca, and Mg from moist and dried samples. The sample handling for the dry tests was similar to that described for the earlier study. For the moist test, however, this time we used the slurry version described in the NCERA-13 methods publications referred to above. Briefly, moist soil was sieved through a 1/4-inch screen and an amount of soil equivalent to 100 g of oven-dry soil was mixed with 200 mL water and stirred to prepare an homogenous slurry. A 6 mL subsample was extracted with the same procedures used for the dry and direct-sieving moist tests, except that the molarity and amount of the extracting solutions were modified to maintain the dry soil/solution ratio and molarity recommended for the dry tests. The P in extracts was measured colorimetrically, whereas K, Ca, and Mg were measured by inductively-coupled plasma (ICP).

Highlights of Results

Comparison of Dry and Moist Tests for Potassium

Potassium extracted from dried (35 to 40 C°) soil samples was higher than for the moist samples for samples collected and analyzed in the 2000s and also for samples collected and analyzed in 2011. The difference between dry and moist K decreased with increasing STK levels in both sets of samples. Results for the ammonium-acetate and Mehlich-3 K tests showed similar differences between dry and moist tests (not shown). Figure 1 shows results for the large study conducted in the 2000s. Potassium test results for the ammonium-acetate extractant averaged 145 ppm and ranged from 56 to 388 ppm for the dry method. Results for the moist test (using the direct sieving version) using the ammonium-acetate extractant averaged 76 ppm and ranged from 30 to 356 ppm. Therefore, the average for the dry K was 1.92 times higher than for the moist test. The difference and ratio between dry and moist K values decreased with increasing STK levels, although the relationship was very weak for the difference but strong for the ratio (r^2 0.15 and 0.77, respectively). The amounts of K extracted tended to be the same for values greater than about 200 ppm by the moist test.

Figure 2 shows K test results using the ammonium-acetate extractant for soil samples collected in 2011. Potassium for the dry test averaged 161 ppm and ranged from 73 to 373 ppm. Results for the moist test (now using the slurry version) averaged 112 ppm and ranged from 25 to 567 ppm. Therefore, on average the dry K was 1.44 times higher than for the moist test. The difference and ratio between dry and moist K values decreased with increasing STK levels, but the relationship was weaker for the difference than for the ratio (r^2 0.72 and 0.90, respectively). The highest STK levels observed for this sample set were higher than for the sample set from the 2000s. Figures 1 and 2 show that trends of differences or ratios between dry and moist tests were approximately similar for both sets until about 350 ppm moist test, but that at higher STK levels (available only in the recent set) K extracted from dried samples was less than for moist samples. This inverse relationship between the difference of dry and moist K methods from very low to extremely high STK values also was observed in studies conducted during the 1960s.

Therefore, the amounts of K extracted from dried and moist samples indicate that no simple factor can be used to relate dry and moist K test results. Also, laboratory studies with soils of several states of the North-Central Region showed that the difference sometimes differed across states. For example, differences tended to be larger for the western states of the region than for the eastern states (Barber et al., 1961; Hanway et al., 1961; Hanway et al., 1962).

The ratio dry/moist K results of both sets of samples increased linearly (not shown) with soil clay, organic matter, cation exchange capacity (CEC), and (Ca+Mg)/K ratio but the strengyth of the relationships was poor (r^2 < 0.35). The ratio dry/moist K increased with increasing sample moisture content for both sets, but the relationship was very poor (r^2 < 0.10). This research and other NCERA-13 committee research (not shown) have demonstrated that the effect of soil drying increases with increasing temperature but can vary greatly across soil series.

Comparison of Dry and Moist Tests for Phosphorus, Calcium, and Magnesium

Unpublished results of laboratory research during the 1960s (J.J. Hanway and K. Eik, ISU) showed no significant differences for soil P measured by the Bray-1 method from dried or field-moist samples, as long as the ratio of the extracting solutions to equivalent dried soil was the same. Data from samples collected in 2011 shown in Fig. 3 confirm this result for the Bray-1 method, and show a similar result for the Mehlich-3. Small deviations from an intercept of zero and a slope of 1 were not statistically significant or agronomically important given the usual variability due to soil sampling or analytical error.

Figure 4 shows relationships between Ca and Mg measured with the Mehlich-3 extractant from dried and moist samples. For these two nutrients there was more variability than for P, but the slope of the relationships were close to one. The estimates of the intercepts for both Ca and Mg are not reliable for this data set because, as it is typical for Iowa soils where corn and soybean production predominate, there were no low values. Differences between dried and moist samples using the ammonium-acetate extractant were approximately similar (not shown).

Many wonder about the repeatability of the moist test, mainly of the slurry version, assuming higher nutrient extraction variability than for the commonly used dry test. Unpublished Iowa research during the 1960s showed this was not the case as long as the slurry preparation and subsampling for analysis follow normal laboratory quality control procedures (J.J. Hanway and K. Eik, ISU). We confirmed these results by comparing duplicate analysis for P and K using the scooping version of the dry test (used by almost all laboratories for routine analyses) and the slurry version of the moist test. Data in Figs. 5 and 6 show very similar repeatability for dry or moist P and K tests, respectively. In fact, the average difference between duplicates for both nutrients was slightly higher for the dry test than for the moist test. Approximately similar repeatability for dry and slurry tests also was found by a private laboratory which, moreover, used weighing instead of scooping for the dry test (not shown).

Correlation between Soil-Test K and Crop Response to Fertilization

Figure 7 shows relationships between relative corn and soybean yield response to K fertilizer and dry K test results using the ammonium-acetate extractant for the field response trials conducted from 2001 until 2006. The graphs show the response curve for the LP model and its estimated critical concentration (CC). The R^2 values for CN, LP, and QP models across both crops for the dry test ranged from 0.24 to 0.27. The CC ranges defined by the CN, LP, and QP models for the dry test were 144, 208, and 301 ppm for corn, respectively; and 136, 186, and 283 ppm for soybean. This research confirms previous research for P and K in that CCs identified by the LP model are intermediate between those by CN and QP models (Mallarino and Blackmer, 1992 and 1994). The CC ranges defined by the three models are higher and wider than the optimum Iowa interpretation category (131-170 ppm for most soils of the state) and for which only maintenance fertilization is recommended (Sawyer et al., 2002). Applying the current boundaries of the optimum category to results for the dry test in Fig. 7 encompasses mean relative yields of 93% for corn and 95% for soybean. The CC range defined by the CN and LP models encompassed a mean relative yield of 96% for both crops, and the CC range defined by LP and QP models encompassed a mean relative yield of 100% for corn and 99% for soybean.

The drainage of the 32 soil series ranged from very poorly drained to excessively well drained according to the USDA soil drainage classification. The graphs for both crops show that according to the dry test crops grown on the best drained soils needed less STK than crops grown on soils with poor drainage, and that crops grown on soils with moderate drainage were distributed between these two extremes. The sometimes different predominant STK values for the different groups of soils and the number of site-years for each group do not allow for determining reasonable separate relationships or CCs for the different drainage groups. A of soil samples based on clay, CEC, K saturation, cation ratios and other properties (not shown) did not indicate a so clear grouping as that shown by soil drainage. Several, but not all, of the soils with poor drainage also had deep profiles and higher CEC, extractable Ca, and organic matter compared with the other soils (not shown).

Data for the moist K test in Fig. 8 show contrasting relationships between crop yield response and STK. The tighter relationships for the moist test indicate a better capacity to identify different soil K sufficiency for corn and soybean than the dry test, and better prediction of yield response to K fertilization. Moreover, with few exceptions the data points representing contrasting soil drainage now blend into the same general trend without the obvious differences between drainage groups shown for the dry test. Although there was still significant unexplained variation, the moist test r^2 values for the three models were much higher than for the dry test, and ranged from 0.39 to 0.58 across across crops. The CC range for the moist test defined by CN, LP, and QP models were 51, 65, and 82 ppm for corn, respectively; and 49, 64, and 84 ppm for soybean. The CC range for the moist test defined by the CN and LP models encompassed a mean relative yield of 93% for both crops, and the CC range defined by the LP and QP models encompassed a mean relative yield of 97% for both crops. Results for the Mehlich-3 K test (not shown) showed comparable relationships between crop yield response and STK measured from dried or moist samples and also comparable CCs.

Critical concentrations identified for the moist test compare well with CCs identified by Iowa field research with the moist conducted in the 1970s and 1980s, and also with interpretations for corn and soybean used in Iowa until 1988. Trials summarized by Mallarino et al. (1991b) included a wide range of moist test K values and showed significant relationships between relative yield response and STK for both crops, although CCs were not shown. We fitted CN, LP, and QP models to those data (not shown). Critical concentrations for corn were 55, 70, and 85 ppm, respectively; and for soybean were 54, 70, and 93 ppm. Therefore, the CC ranges identified by the three models were about the same for both data sets. This coincidence is remarkable since Mallarino et al. (1991b) used data collected from 1976 through 1988 when crop yields were lower and hybrids or varieties were different, and the soil series included in the studies sometimes differed.

The Iowa interpretation category for the moist K test until 1988 for which maintenance fertilization is recommended (which was named medium at the time) was 68 to 100 ppm for both corn and soybean. Therefore, the lower boundary is approximately similar to CCs identified by the LP model for the Mallarino et al. (1991b) data set and for the data set summarized in this article, but the upper boundary is 7 to 15 ppm higher than CCs identified by the QP model for either data set. Comparison of the distribution of data points in Fig. 8 with distributions in figures published by Mallarino et al. (1991b) (not shown) indicated very similar distributions from low to high STK values. Therefore, if criteria for establishing the moist test interpretation categories were the same as in the 1980s, similar interpretations could be used today. The categories very low, low, optimum, high, and very high for the moist test were defined as 0-36, 37-67, 68-100, 101-149, and > 150 ppm, respectively (Voss, 1982).

Conclusions

Results of the summarized studies strongly suggest that testing of K on dried soil samples contributes to poor relationships between STK and crop yield response to K fertilization. Results for testing field-moist samples for K showed that implementation of this test should be seriously considered by soil testing laboratories, at least in Iowa for which good field correlations exist. Based on the new field research results, and because at least two private laboratories already are using the moist test for P, K, and other nutrients, the NCERA-13 committee has re-introduced the moist sample handling procedure to the Sample Preparation chapter of the publication with recommended soil testing procedures for the North-Central region (in press). Also, the ISU soil and plant analysis laboratory is considering adoption of the moist test for K beginning next year. The ISU interpretations and K recommendations for the moist test will be developed in the near future, as results of additional field research that began in 2011 become available and can be merged with results summarized in this article. Interpretations for the moist test for P using Bray, Olsen, and Mehlich-3 methods (using colorimetric or ICP procedures) should be similar to those for the dry tests, since data already showed similar test results. Interpretations for the moist test for K likely will be approximately similar to those suggested by ISU in the 1980s.

References Cited

Barber, S.A., R.H. Bray, A.C. Caldwell, R.L. Fox, M. Fried, J.J. Hanway, D. Hovland, J.W. Ketcheson, W.M. Laughton, K. Lawton, R.C. Lipps, R.A. Olson, J.T. Pesek, K. Pretty, M. Reed, F.W. Smith, and E.M. Stickney. 1961. North Central Regional potassium studies: II. Greenhouse experiments with millet. North Central Regional Publication No. 123. Indiana Agr. Exp. Stn. Res. Bul. RB 717.

Cate, R.B., Jr., and L.A. Nelson. 1971. A simple statistical procedure for partitioning soil test correlation data into two classes. Soil Sci. Soc. Am. Proc. 35:658-660.

Cook, M.G. and T.B. Hutcheson. 1960. Soil potassium reaction as related to clay mineralogy of selected Kentucky soils. Soil Sci. Soc. Am. Proc. 24:252-256.

Dowdy, R.J., and T.B. Hutcheson, Jr. 1963. Effects of exchangeable potassium level and drying on release and fixation of potassium by soils as related to clay mineralogy. Soil Sci. Soc.

Amer. Proc. 27:31-34.
Eik, K., E.L.Hood, and J.J. Hanway. 1980. Chapter 1. Soil sample preparation. *In* Recommended chemical soil test procedures for the North Central region. North Central Regional Publ. No. 221 (Rev.). North Dakota Agric. Exp. Stn. Bull. 499. Fargo, ND.
Eik, K., and R.H. Gelderman. 1988. Chapter 1. Soil sample preparation. *In* Recommended chemical soil test procedures for the North Central region. North Central Regional Publ. No. 221 (Rev.). North Dakota Agric. Exp. Stn. Bull. 499 (rev.). Fargo, ND.
Haby, V.A., M.P. Russelle, and E.O. Skogley. 1990. p 181-227. Testing soils for potassium, calcium, and magnesium. *In* R.L. Westerman (editor) Soil testing and plant analysis (3rd ed.). SSSA Book Series No. 3. SSSA, Madison, WI.
Hanway, J.J., S.A. Barber, R.H. Bray, A.C. Caldwell, L.E. Engelbert, R.L. Fox, M. Fried, D. Hovland, J.W. Ketcheson, W.M. Laughlin, K. Lawton, R.C. Lipps, R.A. Olson, J.T. Pesek, K. Pretty, F.W. Smith, and E.M. Stickney. 1961. North Central Regional potassium studies: I. Field studies with alfalfa. North Central Regional Publication No.124. Iowa Agr. Home Econ. Exp. Stn. Res. Bul. 494.
Hanway J.J. and A.D. Scott. 1959. Soil potassium-moisture relations: III. Determining the increase in exchangeable soil potassium on drying soils. Soil Sci. Soc. Amer. Proc. 23:22-24.
Hanway, J.J., S.A. Barber, R.H. Bray, A.C. Caldwell, M. Fried, L.T. Kurtz, K. Lawton, J.T. Pesek, K. Pretty, M. Reed, and F.W. Smith. 1962. North Central Regional potassium studies: III. Field studies with corn. North Central Regional Publication No. 135. Iowa Agr. Home Econ. Exp. Stn. Res. Bul. 503.
Luebs, R.E., G. Stanford, and A.D. Scott. 1956. Relation of available potassium to soil moisture. Soil Sci. Soc. Amer. Proc. 20:45-50.
Mallarino, A.P., and A.M. Blackmer. 1992. Comparison of methods for determining critical concentrations of soil test phosphorus for corn. Agron. J. 84:850-856.
Mallarino, A.P., and A.M. Blackmer. 1994. Profit-maximizing critical values of soil-test potassium for corn. J. Prod. Agric. 7:261-268.
Mallarino, A.P., J.R. Webb, and A.M. Blackmer. 1991a. Corn and soybean yields during 11 years of phosphorus and potassium fertilization on a high-testing soil. J. Prod. Agric. 4:312-317.
Mallarino, A.P., J.R. Webb, and A.M. Blackmer. 1991b. Soil test values and grain yields during 14 years of potassium fertilization of corn and soybean. J. Prod. Agric. 4:560-566.
Mallarino, A.P., D.J. Wittry, and P.A. Barbagelata. 2002. Iowa soil-test field calibration research update: Potassium and the Mehlich-3 ICP phosphorus test. p. 29-39. *In* North-Central Extension-Industry Soil Fertility Conf. Proceedings. Vol. 17. Des Moines, IA.
Voss, R.D. 1982. General guide for fertilizer recommendations in Iowa. Publ. AG-65. Iowa State Univ. Coop. Extension Service. Ames, IA.
Warncke, D. and J.R. Brown. 1998. Potassium and other basic cations. p. 31-33. *In* J.L. Brown (ed.) Recommended chemical soil test procedures for the North Central region. North Central Regional Publ. No. 221 (Rev.). Missouri Exp. Stn. Publ. SB 1001. Univ. of Missouri. Columbia.
Sawyer, J.E., A.P. Mallarino, R. Killorn, and S.K. Barnhart. 2002. General guide for crop nutrient recommendations in Iowa. Publ. PM 1688 (Rev.). Iowa State Univ. Ext., Ames.

Figures

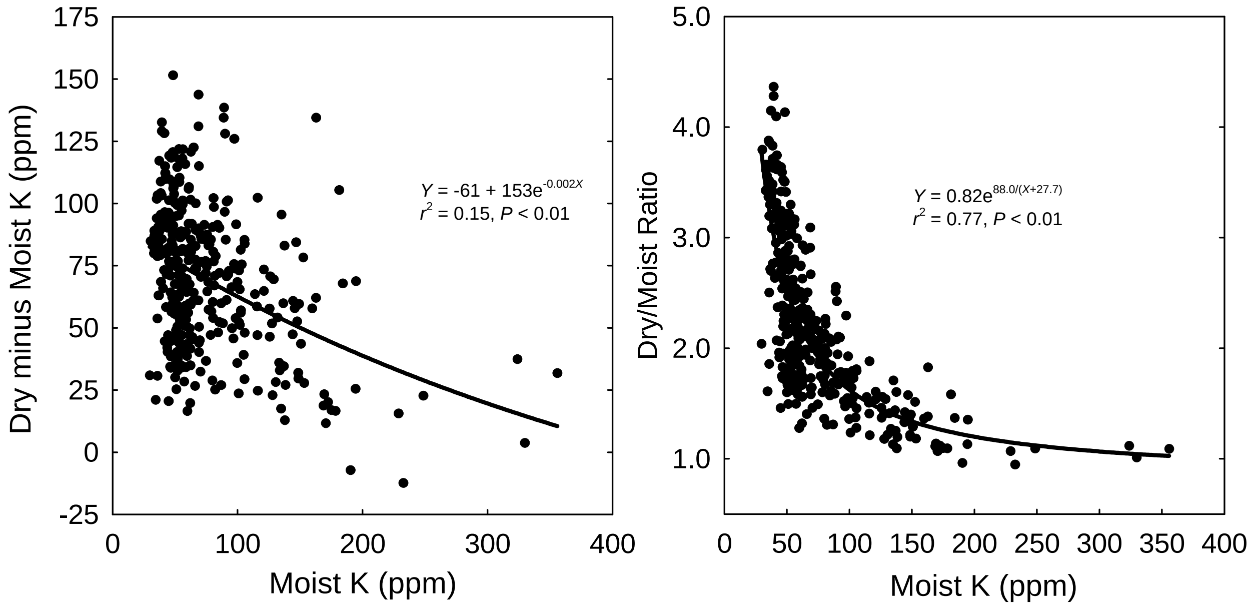


Fig. 1. Relationship between the difference or the ratio of K extracted from dried or field-moist soil samples collected and analyzed from 2001 through 2006.

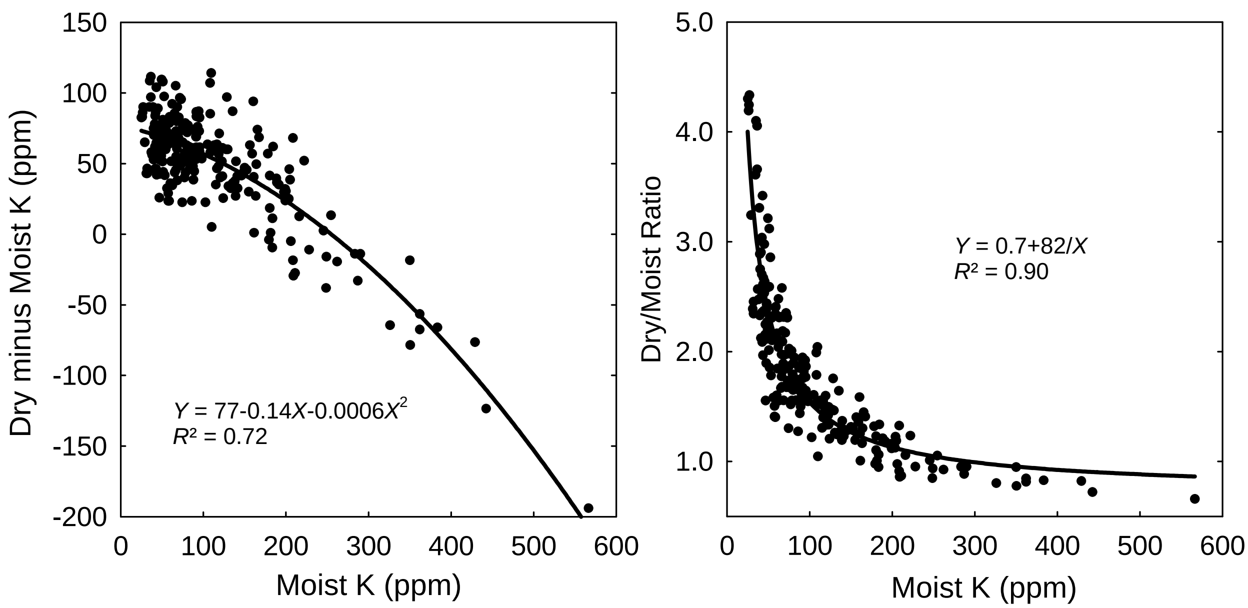


Fig. 2. Relationship between the difference or the ratio of K extracted from dried or field-moist soil samples collected and analyzed in 2011.

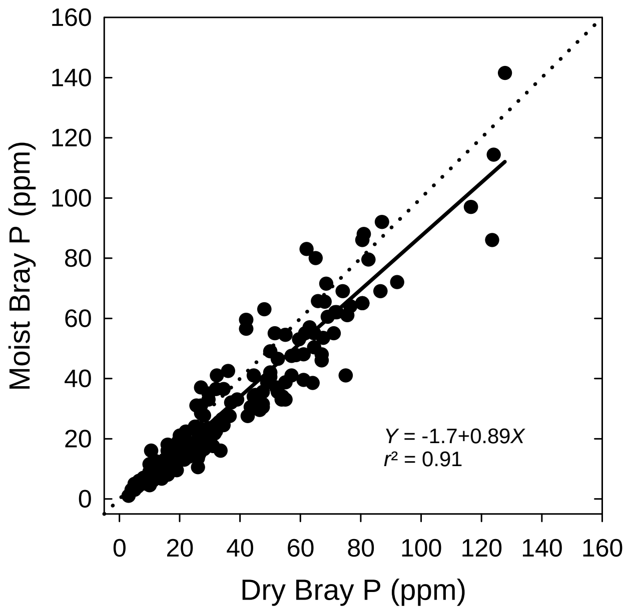


Fig. 3. Relationship between P measured on moist or dried samples using the Bray-1 and Mehlich-3 methods (extracted P was measured colorimetrically for both methods).

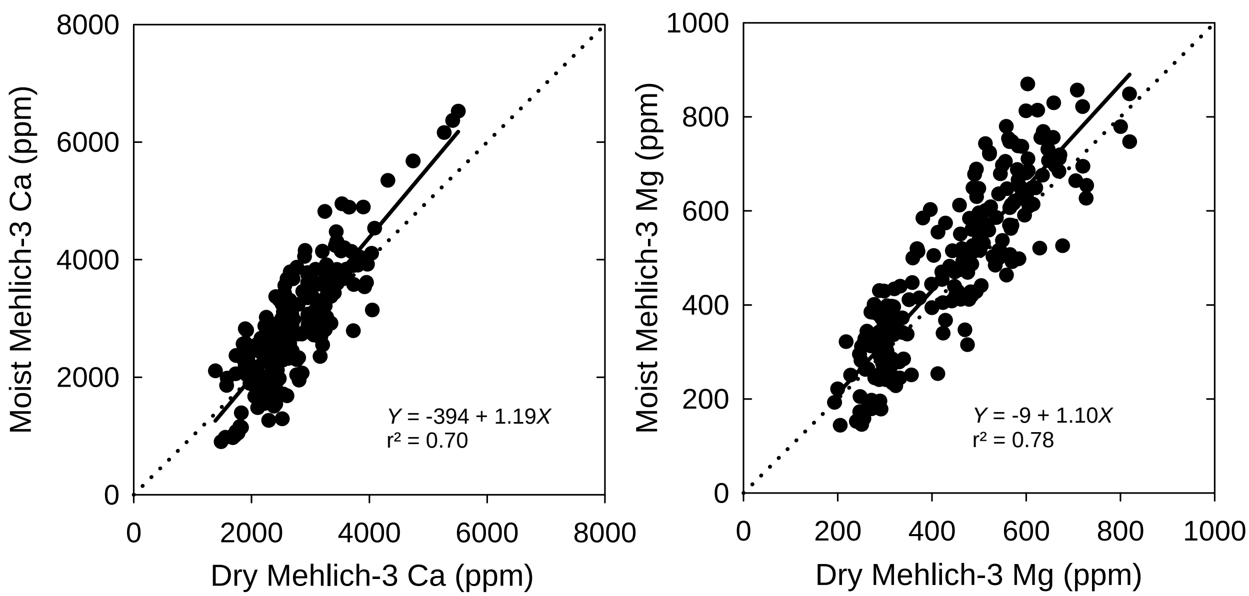


Fig. 4. Relationship between Ca and Mg measured on moist or dried samples using the Mehlich-3 method (the extracted Ca and Mg were measured by ICP).

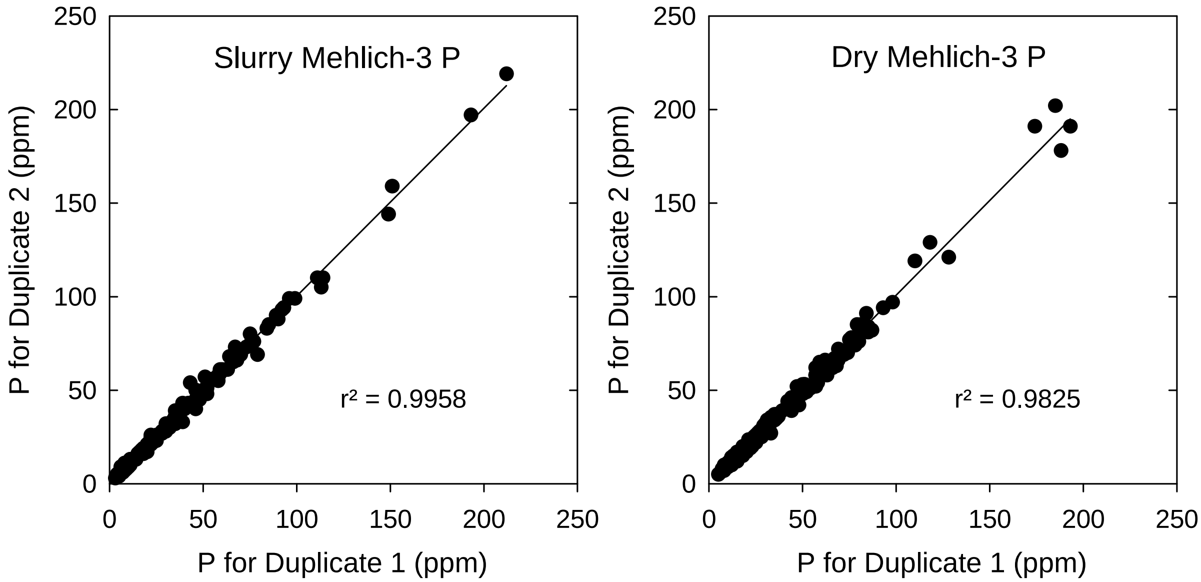


Fig. 5. Variability between duplicate P extractions with the Mehlich-3 extractant for dried samples and moist soil samples using the slurry version of the moist test.

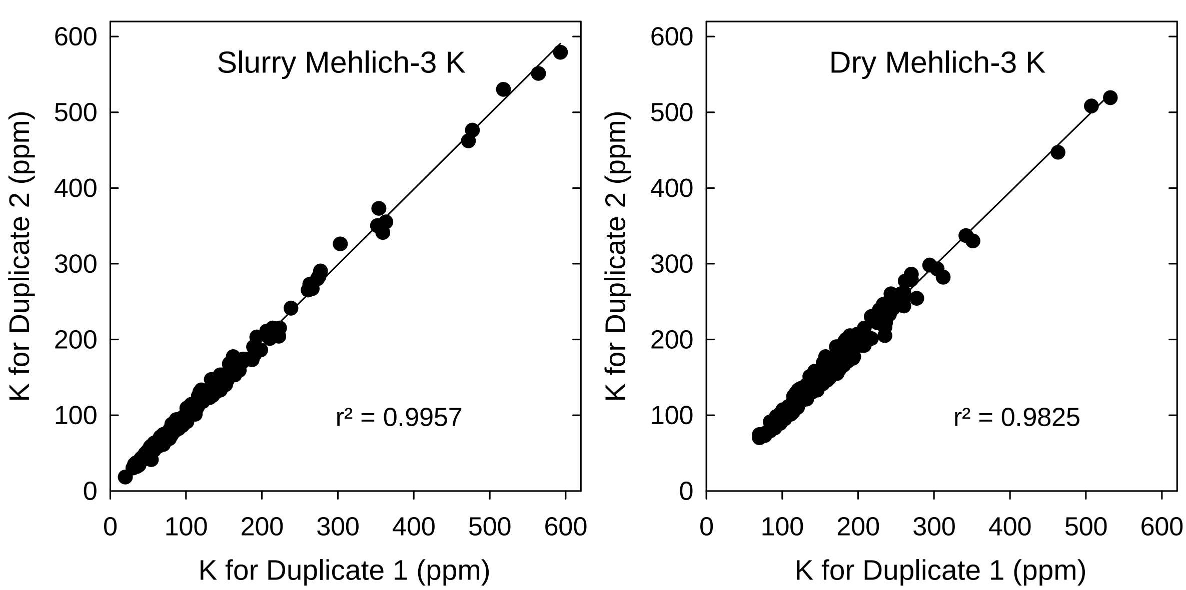
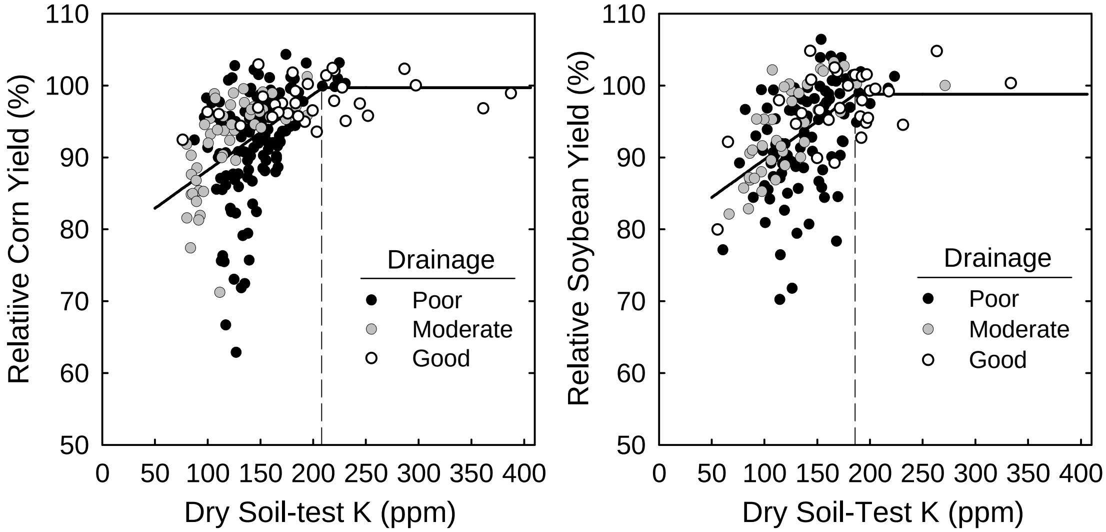


Fig. 6. Variability between duplicate K extractions with the Mehlich-3 extractant for dried samples and moist soil samples using the slurry version of the moist test.



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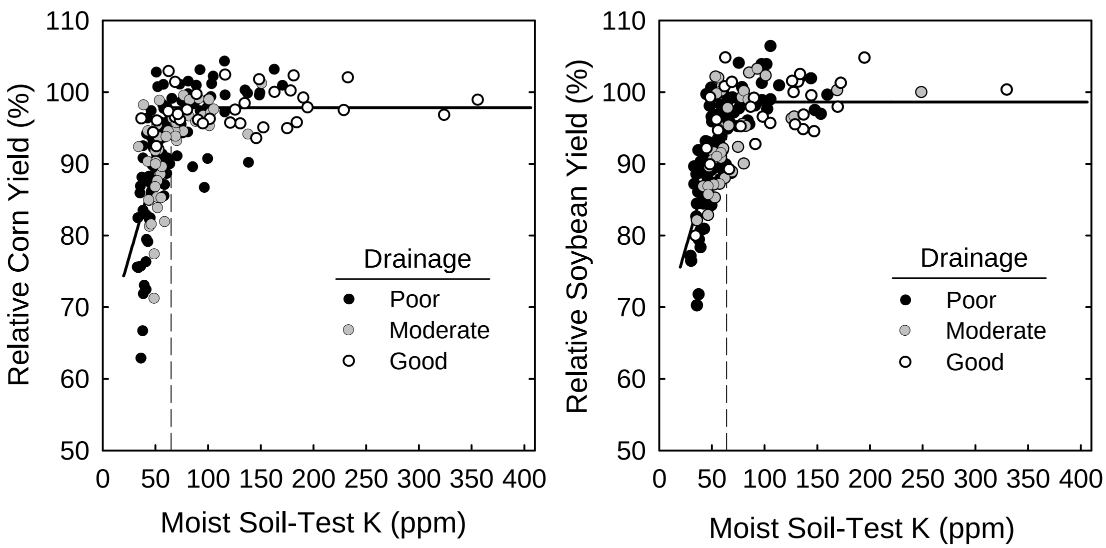

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NORTH CENTRAL
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Volume 28

November 14-15, 2012
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Published by:

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