IDENTIFICATION OF REASONS FOR HIGH TEMPORAL SOIL-TEST POTASSIUM VARIATION

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Introduction

Extensive research has focused on potassium (K) fertilization and soil K testing during several decades in the Corn Belt. In Iowa, more than 200 conventional or on-farm strip trials were conducted since the middle 1990s until the early 2000s. Results of this research were used to update Iowa State University (ISU) K recommendations in 1999 and in 2002. In spite of increased knowledge about soil-test K calibration, K fertilizer placement methods, and needed K fertilizer rates, this 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. Figure 1 shows results of long-term Iowa research on STK changes over time as affected by K fertilization and years of cropping. Potassium is present in the soil in water-soluble, exchangeable (both readily available for crop), non-exchangeable (may become available over time), and mineral (unavailable for crop) forms. Estimates of soil exchangeable K with the ammonium-acetate or Mehlich-3 tests from air-dried or oven-dried soil samples are the most widely used STK method. These methods provide comparable K test results, and are suggested by the North-Central Regional Committee for Soil Testing and Plant Analysis (Warncke and Brown, 1998).In spite of extensive research, however, predicting plant-available soil K by soil or plant testing has proven to be a difficult task due to the complexity of dynamic equilibria between these soil K pools and many factors that influence plant K uptake. This article summarizes recent and ongoing research to study these problems and improve soil K testing and K management. This includes study of effects of sampling date, soil sampling drying, and K recycling with crop residues on STK and predictions of crop response to K fertilization.

Soil Sampling Date for Potassium

An on-farm research project was conducted since 2006 until 2009 to study soil sampling dates for K and the within-field variation of STK and yield response of corn and soybean to K fertilization. Soil samples were taken before applying K in the fall using a dense grid-point sampling approach (cells 0.2-0.5 acres in size). Samples were also taken in April from cells of the control strips before planting the crops, and again in early summer (early June). Soil samples were dried at 35-40 ºC and analyzed for K with the ammonium-acetate and Mehlich-3 K tests (results for the Mehlich-3 test are not shown). Grain yield was measured with yield monitors and GPS, and data was imported into GIS computer software for processing. Yield maps were subdivided into small cells defined by the soil sampling cells and strips to study yield response variation within the field.

The results showed large but inconsistent effects of the time of soil sampling on STK. 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, although there was large variability across fields. There was no consistency concerning sampling date effects on STK for other regions, and the variability across fields was very large in central Iowa and eastern Iowa. An interesting result for all regions with the exception of eastern Iowa was that the early June sampling date resulted in smaller variation across fields. Relationships between yield response and STK across sites (not shown) indicated no clear differences in critical STK levels or ranges for the three sampling dates, which agrees with inconsistent results shown in Fig. 2.

An arrangement of STK and crop response values into the Iowa interpretation classes (Fig. 3) showed, 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. An inconvenience of sampling in early June is that crops already are emerged, 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 for fertilization of the next crop, but an estimate of removal by the current crop is needed to deciding the fertilization rate. The results of this study do not necessarily indicate that sampling date is not part of the problem of high year-to-year STK variation, because the set of factors involved could not be the same in all fields and may not affect STK in the same way across regions.

Sample Drying Effect on Soil Test Potassium

Decades-old research has shown that wetting-drying and freezing-thawing cycles influence transformations of K between exchangeable and non-exchangeable soil K fractions in most soils. 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. The equilibrium between these soil K pools also is affected by K additions and plant K removal from the soil. Therefore, the time of sampling interacting with these factors in the field or during 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 from field-moist samples was better correlated with crop K uptake than K extracted from air-dried or oven-dried samples. A method for testing field-moist soil samples for P, K, and other nutrients based on a slurry was developed in the 1970s and was implemented in Iowa until 1988. The procedure was among methods recommended 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 the slurry K test were published by Mallarino et al. (1991a, 1991b).

No other public or private laboratory adopted the slurry test citing impractical procedures (soil moisture determination and slurry preparation), however, so the ISU Soil and Plant Analysis Laboratory discontinued its use in 1988. Therefore, based on comparisons of amounts of soil K extracted using dried (35 to 40 ºC) or moist samples, the soil-test interpretation categories for the slurry K test were increased by a factor of 1.25 for Iowa recommendations updated 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 recommendation update in 2002 (Sawyer et al., 2002).

An Iowa study conducted with corn and soybean from 2001 until 2006 (151 site-years of data) assessed the impact of sample drying on STK, studied correlations between K tests, and developed field calibrations for the based on dried samples and a test based on direct-sieving of field-moist samples (no slurry). As small set of samples representative of several soil series showed that the direct-sieving moist test was highly correlated with the slurry test (r = 0.99), but the slurry test on average measured 17% more K than the direct-sieving test. The most likely reason for this difference was an incomplete destruction of aggregates of fine-textured soils by the direct-sieving test. Observation of sediment after filtering sometimes indicated the presence of small soil pellets after shaking soil for the direct-sieving test but none for the slurry test. The results also showed that the slurry test provided a less variable K measurement than the quicker and simpler direct-sieving moist test in many samples.

Soil K extracted by the dry test was higher than for the moist test, and the difference decreased significantly with increasing STK, and the difference between dry and most tests increased significantly with increasing drying temperature and for different Iowa soil series (Mallarino et al., 2011). Other NCERA-13 committee research has shown that the effect of soil drying 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. 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. 4 and 5). 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 depth) for corn were 144 to 201 ppm for the dry test and 62 to 76 ppm for the moist test; while ranges for soybean were 121 to 214 and 52 to 90 ppm, respectively. According to the almost 1:1 correlation 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 ranges published for the slurry K test in the early 1990s (Mallarino et al., 1991b) and to the Optimum old interpretation class for the slurry test (68 to 100 ppm, called Medium before). Therefore, a K test based on field-moist samples predicts crop response to K fertilizer better than the test based on dried samples, and the magnitude of the improvement may justify more laborious laboratory procedures.

Data in Fig. 6 shows that use of the moist K test sometimes reduces temporal variability of STK by avoiding largely unpredictable interactions between the moisture content of the soil at the time of sampling and effects of drying the samples in the laboratory.

Equilibrium between Soil K Pools

We postulated that another process that may explain high temporal STK variation is an under-estimation of the short-term importance of the 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. We have used a modified version of the classic sodium tetraphenylboron extraction method developed in Iowa in the 1960s to assess the most reactive fraction of the non-exchangeable K. Cox et al. (1996) modified the classic method by using Cu^{2+} instead of Hg^{2+} and Cox et al. (1999) modified it further by decreasing the digestion time to facilitate its use. Figure 7 shows (as an example) results for two contrasting Iowa soils. In a northwest Iowa site, a high K application increased post-harvest STK compared with the control or a K lower rate because the K applied exceeded removal, but the non-exchangeable K remained approximately constant or decreased slightly compared with the control 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) have suggested that much of the increased non-exchangeable K is available for the next crop. Clearly, these processes could explain much of the high temporal STK variation (Fig. 1) and often unexpected short-term relationships between STK, yield response, and K removal (Mallarino et al., 2011).

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 at five dates from harvest until April of the next year (before planting the new crop).

In this article we summarize results for K, which are presented in more detail together with results for P in another article in this publication (Oltmans and Mallarino, 2011). Data in Fig. 8 show approximately similar plant tissue K loss trends for corn and soybean. A 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 very short period. This sharp decrease is explained by K leached to the ground from standing plants, and perhaps also by some unrecovered leaves that were laying on the ground often partially decomposed and contaminated with soil. Other results were another sharp K decrease in crop residue from grain harvest until late fall, little loss during winter (with snow covered and/or frozen ground), and another small decrease during early in spring. There was significant variation in the amounts and patterns of K lost from plant tissue and crop residues that were partly related to rainfall amounts, mainly in corn (Oltmans and Mallarino (2011).

Summary Conclusions

Results of recent and ongoing studies strongly suggest that effects of the sampling date, testing of dry soil samples, the equilibrium between different soil K pools, and K recycling in maturing plants greatly contribute to high temporal STK variation and often poor relationships between

STK, yield response, and K removal. Although some studies are not yet completed and it is unclear how all the new knowledge can be considered in recommendations, the preliminary results already are useful to crop advisors and farmers. The general knowledge and examples shared can help interpret better test values that sometimes seem illogical given a good sampling approach, testing by a certified laboratory, and 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 K fertilization rates when a STK 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.

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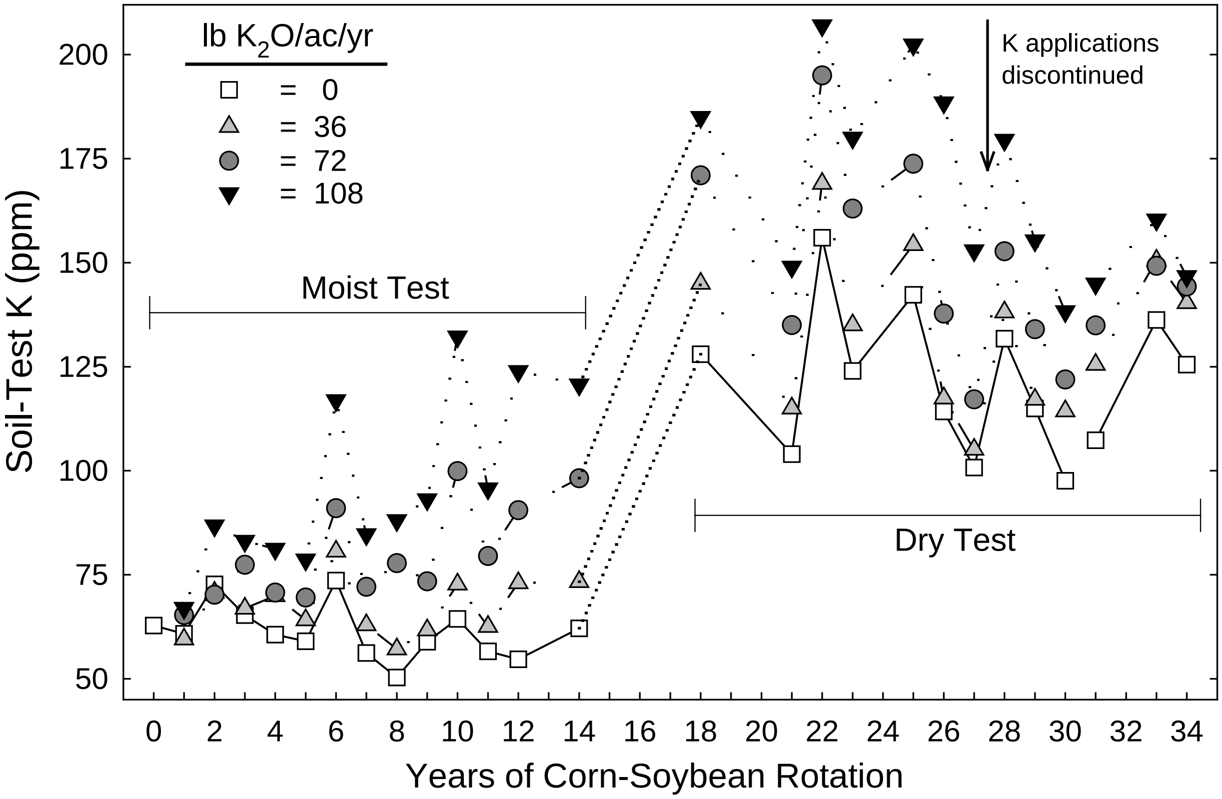

Fig. 1. Soil-test K values over time for an Iowa Webster soil as affected by four annual K application rates and K tests based on field-moist samples (through Year 14) or the commonly used test based on samples dried at 35 to 40 C (Years 18 through 34).

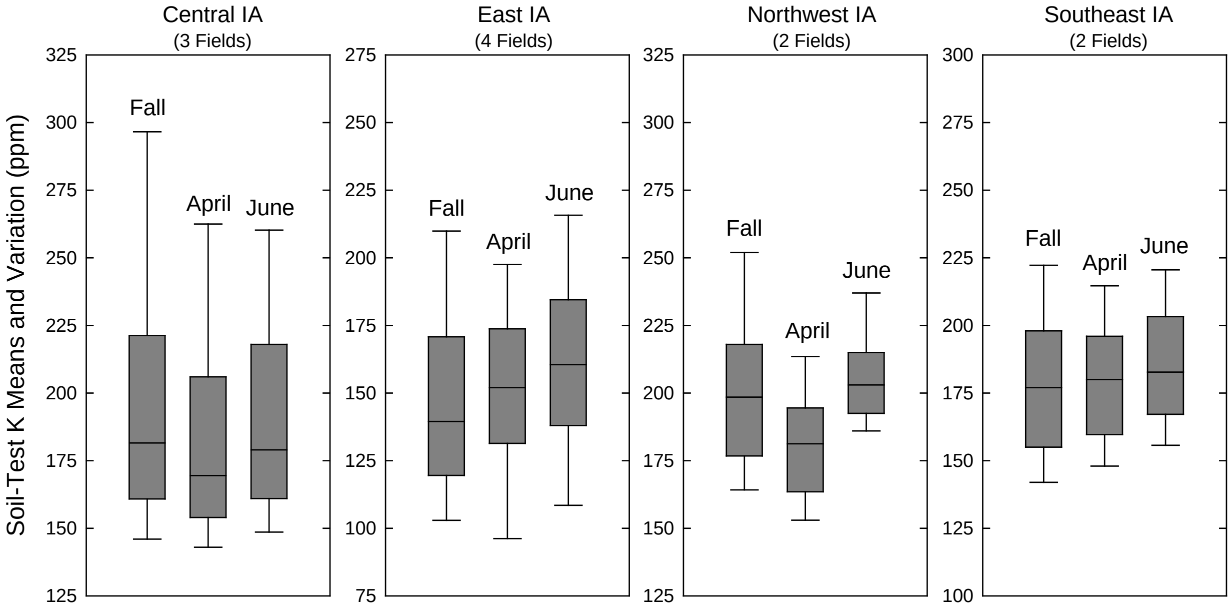

Fig. 2. Median and percentile distributions for soil-test K results for grid soil samples taken in the fall, April, and June from eleven Iowa fields. No fertilizer or manure was applied between the sampling dates.

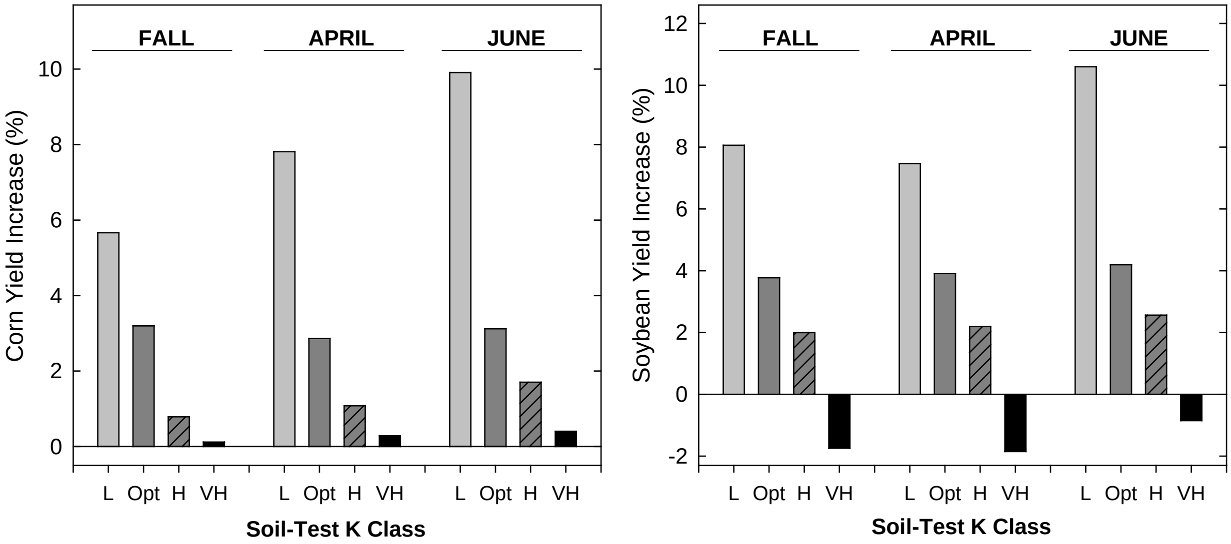

Fig. 3. Relationships between relative yield response and soil-test K from different sampling dates for Iowa on-farm replicated strip-trials managed with precision agriculture technologies (13 site-years for corn and 9 sites-years for soybean). GIS was used to consider responses for field areas testing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

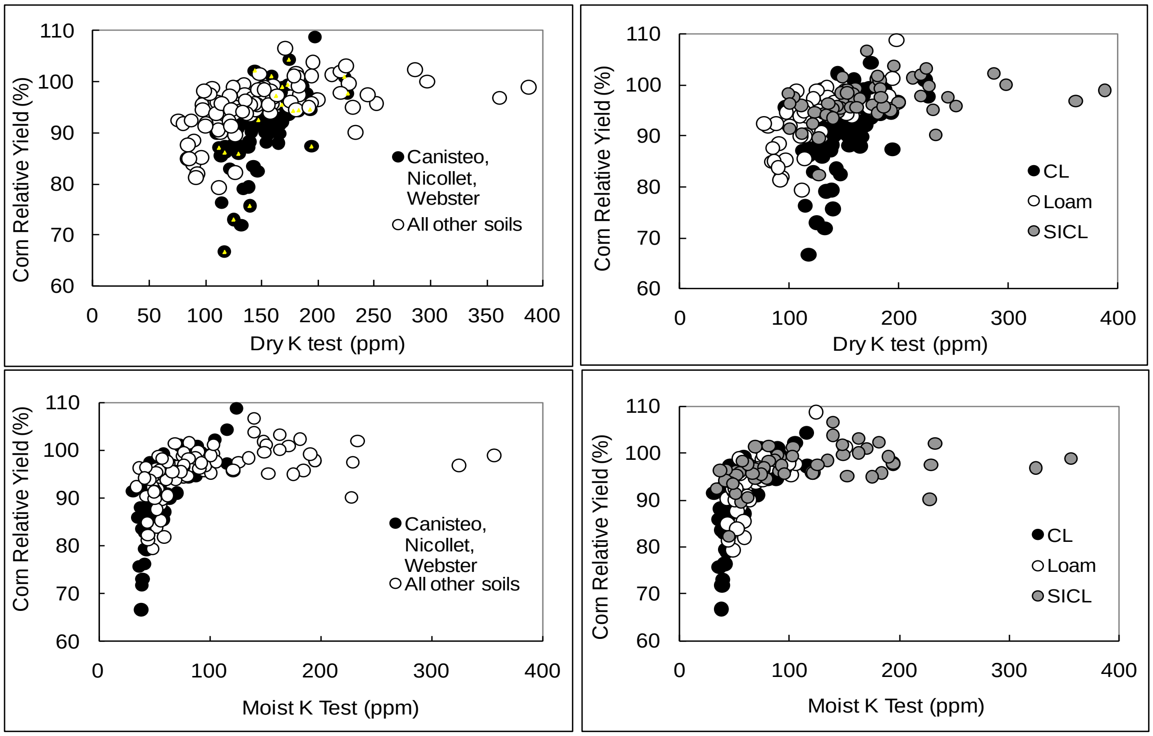

Fig. 4. Relationship between relative corn yield response to K fertilization and soil-test K based on dried (35-40 C) or field-moist samples.

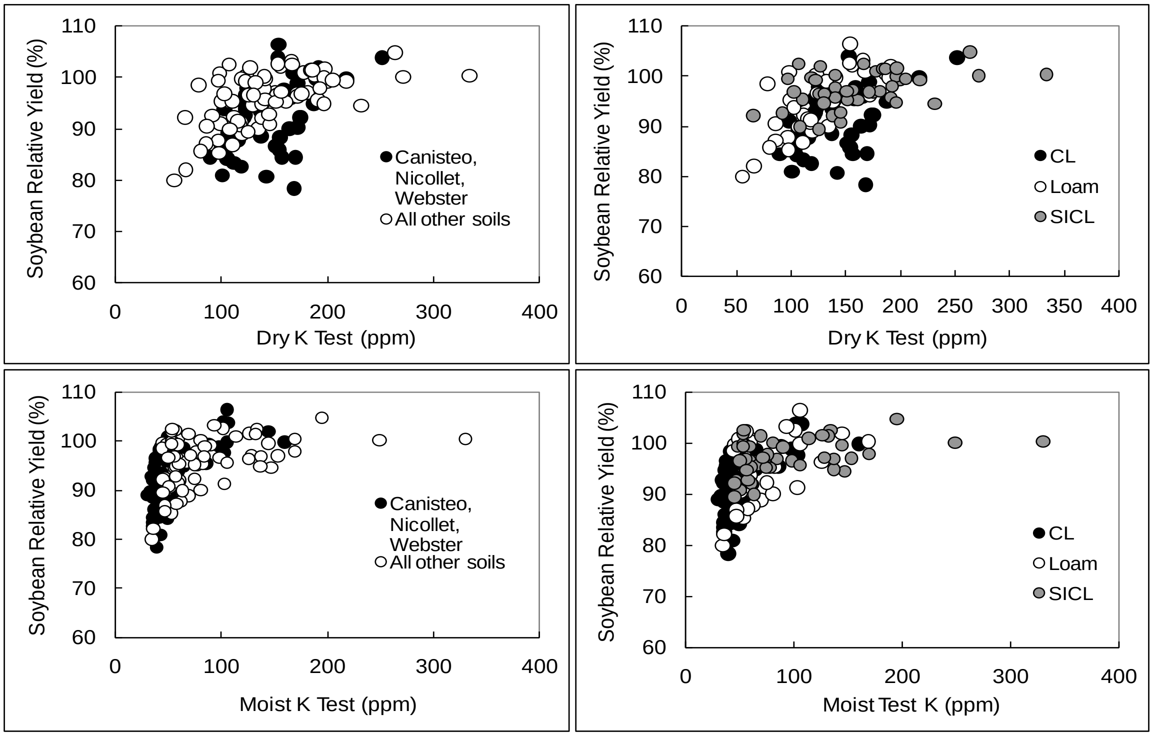

Fig. 5. Relationship between relative soybean yield response to K fertilization and soil-test K based on dried (35-40 C) or field-moist samples.

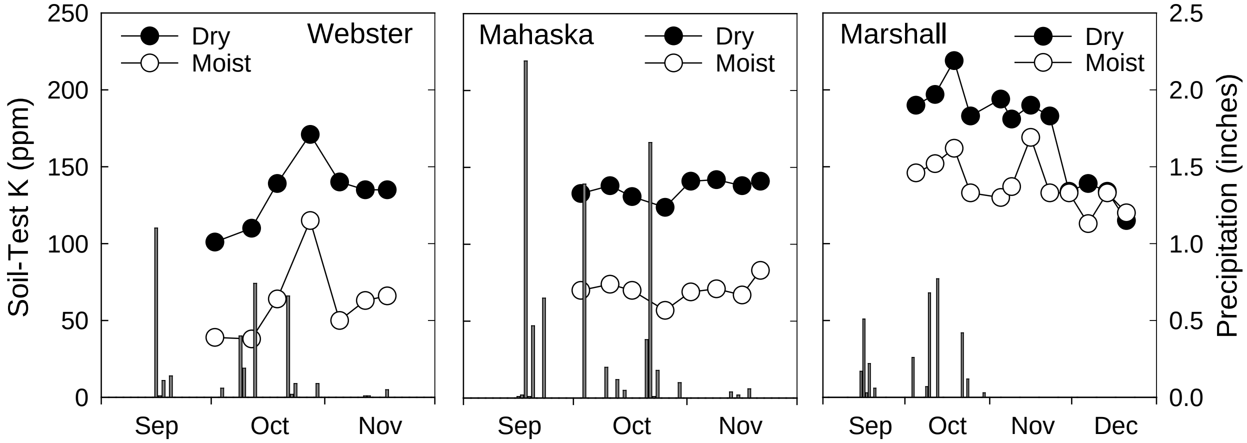

Fig. 6. Change of soil-test K from harvest to late fall for the Iowa soils Webster (north), Mahaska (southeast), and Marshall (southwest). Samples were analyzed using a test based on field-moist samples and the commonly used test based on dried samples (35-40 C).

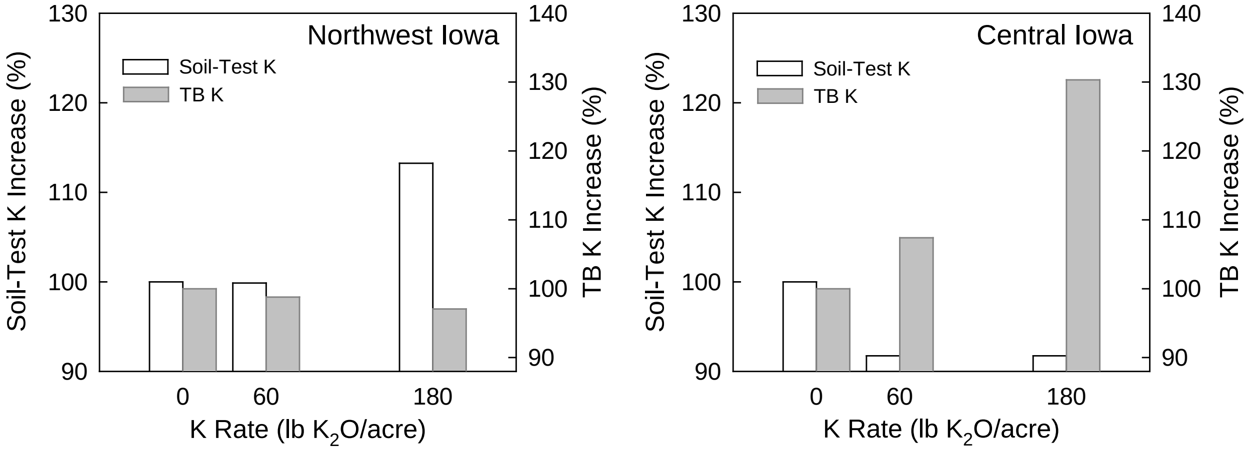

Fig. 7. Post-harvest soil-test K and non-exchangeable K [tetrapehnylboron (TB) test] when similar K fertilizer rates were applied for corn at two Iowa sites.

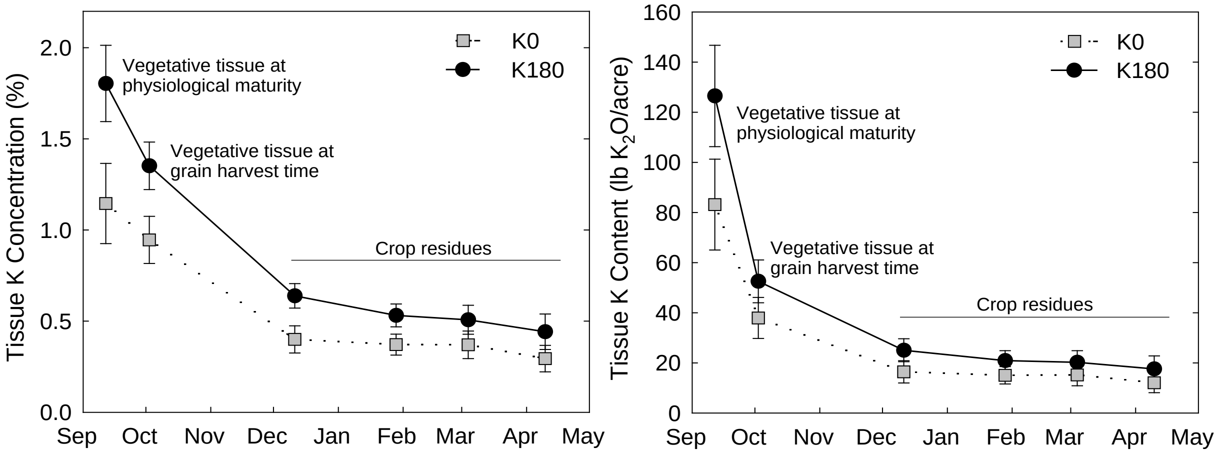

Fig. 8. Concentration and amount of potassium in soybean plant tissue (except grain) from physiological maturity until grain harvest and in residue until the following spring.

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