# Is Potassium Fertilizer Really Necessary?

**Dr. T. Scott Murrell, IPNI Scientist, November, 2013**

*Recently, the question has been raised of whether or not agriculture should be using potassium (K) fertilizers. Let's examine how soil fertility and plant nutrition scientists have determined if or when K should be applied.*

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It starts with the plant. Plants require 17 nutrients to develop properly. Potassium is one of these and is taken up in large quantities. It is therefore termed a "macronutrient." Plants get their K from the soil via their roots. Consequently, one of the most basic questions that soil fertility and plant nutrition scientists have addressed over the past several decades is, "How much of a plant's nutrient needs can be met by what's already in the soil?"

To determine if a soil already has enough K, scientists apply incremental amounts of K then measure the degree to which plants respond. A zero rate of K, termed a "check" provides a basis for comparison. Increases in growth and yield with K additions, when compared to the check, indicate that the soil supply alone is not sufficient to meet the plant's requirements.

An experimental design that is often used to measure response is the "omission plot." Omission plots are a set of treatments that examine how the lack of one nutrient affects yields and nutrient uptake when all other nutrients are at sufficient levels. As an example, a recent meta-analysis from China summarized results from a total of 522 omission plot experiments across three major wheat-growing regions (Liu et al., 2011). The average response to K additions (across sites varying widely in indigenous soil K levels) was 0.74 ± 0.23 Mg/ha or 11 ± 3.4 bu/A (error represents the 95% confidence interval).

Plant response has been and continues to be the basis for determining whether or not K is needed. One general type of approach, termed "plant-based" in this article, relies primarily on these types of plant measurements. The other approach, "soil-testing based" also relies on plant response but incorporates chemical soil tests. We discuss each of these approaches.

**Plant-Based Approaches**

To determine how much of the plant's nutrient needs can be met by the soil, plant-based approaches use measurements of K uptake. Using omission plots, the "indigenous supply" of K in the soil is found by measuring the total amount of K taken up by plants that are grown where no K has been applied but where all other nutrients are in sufficient quantities (Dobermann et al., 2003). Keeping all other nutrients sufficient ensures that other nutrients do not limit plant growth. If limitations from other nutrients did occur, plant growth and total nutrient uptake of K would be reduced and the indigenous supply of K in the soil would be underestimated.

But is the indigenous supply of K high enough? To answer this question, the indigenous soil K supply is compared to the amount of K taken up by plants receiving adequate K. If both quantities are the same, then plant-available K supplies in the soil are sufficient. If K uptake by fertilized plants exceeds the indigenous K supply, then the soil supply of K is not high enough.

The amount of K in the soil can often be quite large. Potassium is part of the atomic structure of several minerals in soils, like feldspars and micas. However, only a small portion of the total K in soils is available to plants during a cropping season. Plant uptake is perhaps the most direct measure of this plant-available supply.


*Potassium deficiency symptoms in soybean (top) and corn (bottom), IPNI Photos: T. Wyciskalla; C.R. Crozier.*

Because it is not feasible to put omission trials on every parcel of ground that is to be evaluated, scientists assemble data from various sites and years where such trials have been conducted and create models that help them estimate indigenous soil K supplies and total uptake requirements for areas where no data exist. Examples of such approaches are the Nutrient Decision Support System (NuDSS) for rice, developed by the International Rice Research Institute (Dobermann and White, 1999) and, more recently, Nutrient Expert (Pampolino, 2012). Both of these approaches rely upon a basic algorithm first outlined by Janssen et al. (1990), termed the "Qualitative Evaluation of the Fertility of Tropical Soils" or QUEFTS model. As these recommendations approaches are developed, they undergo a validation process where estimates are compared to measurements in order to test accuracy.

**Soil Testing-Based Approaches**

Soil testing is another approach to determining how much of the plant's nutrient needs can be met by the soil. It is also built around plant response, but the emphasis has most commonly been on yield response rather than on nutrient uptake.

Soil testing was developed to provide a method for predicting whether or not K is needed before a crop is grown (Bray, 1944). The strengths of this method are its speed and its ability to be used at higher spatial resolutions. Several soil tests can be taken in the footprint of just one omission plot experiment.

Soil testing usually uses chemical solutions to remove a portion of the K from soil particle surfaces that is considered to be plant-available. This K is held primarily by electrical charges on edges and surfaces of certain types of minerals. A portion of this K is removed from these sites by an extracting solution that initiates exchange reactions. These reactions "move" K from soil surfaces into solution where it can be measured by analytical equipment. Because of the way these extracting solutions work, the K that is measured is termed "exchangeable K." It is not a direct measure of the total amount of K available for plant uptake. Instead, it is simply an index that must be related to plant response to have any agronomic meaning. Creating this relationship is accomplished with a calibration study.

In a calibration study, a representative sample of the soil is taken from the experimental site, typically to a depth of 15 to 20 cm (6 to 8 in.). The soil is tested with the laboratory procedure and a result obtained. Then one of two experiments is conducted. The first option is an omission plot, like that described above, where crop yield without K (the check) is compared to crop yield fertilized with K. The second option is a K rate study, where incremental rates of K, including a check, are applied. The first approach measures yield response only. The second approach measures not only yield response but, when combined with statistical models, the quantity of K that was needed to just reach the highest yield attainable at that site. The yield of the crop grown without K is expressed as a percentage of the yield obtained with sufficient K. This percentage, called "relative yield" indicates whether or not the indigenous supply of K is adequate. A relative yield less than 100% signals deficiency. The soil test level measured at that site is then associated with the observed relative yield. This association indicates what percent of the attainable yield can be met by the supply of indigenous soil K indexed by the soil test (Dahnke and Olson, 1990).

Soil test calibration relies upon testing a range of indigenous soil K supplies. This approach is needed to test how sensitive a chemical test is to such changes. There are two basic approaches to obtaining a range of indigenous supplies. The first is to conduct trials across a large number of sites over time. A second approach is to conduct a rate study for many years on one site. The first approach provides calibration information that can be generalized across large areas and a range of conditions and management practices. The second approach provides calibration information for a single site across many years, providing site-specific information.

The most recent example of such a calibration comes from Iowa State University (Barbagelata and Mallarino, 2013) and is shown in **Figure 1**. Each point in the figure comes from one study conducted in one year, what scientists call a "site-year." The figure demonstrates that when many site-years of data are combined, a generalized relationship emerges: as the soil test level of K declines, crop yields decline when left unfertilized, indicated by lower relative yields. Such a relationship forms the basis of soil testing-based approaches that predict whether or not soil supplies of plant-available K are adequate at any given location.

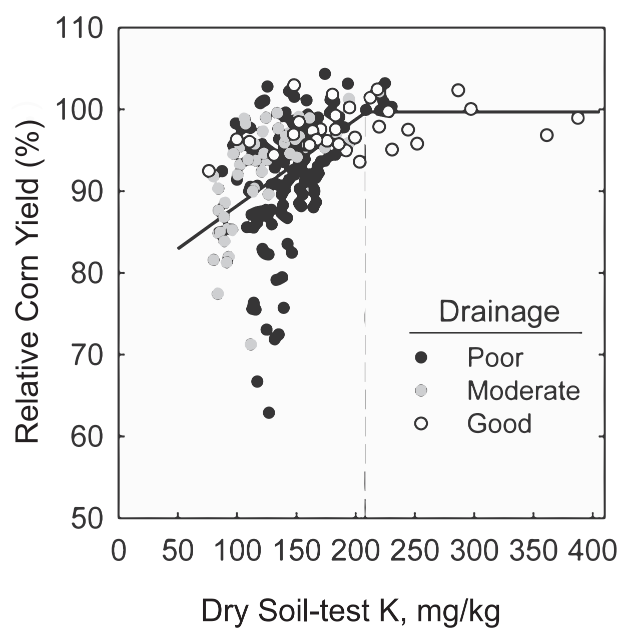


*Figure 1. An example of soil test calibration data (Barbagelata and Mallarino, 2013).*

**Table 1. Examples of K soil test calibration data from the peer-reviewed literature.**

| Crop | Location | Site-years | References |
|---|---|---|---|
| Alfalfa | Canada (British Columbia) | 16 | Zebarth et al., 1991 |
| Canola | Australia | 100 | Brennan and Bell, 2013 |
| Coastal bermudagrass | U.S. (Alabama) | 32 | Jordan et al., 1966 |
| Cotton | U.S. (North Carolina) | 3 | Cox and Barnes, 2002 |
| | U.S. (Virginia) | 4 | Mullins et al., 1999 |
| Lupin | Australia | 23 | Brennan and Bell, 2013 |
| Maize | Malawi | 27 | Chilimba et al., 1999 |
| | U.S. (Florida) | 2 | Obreza and Rhoads, 1988 |
| | U.S. (Illinois) | 23 | Bray, 1944 |
| | U.S. (Iowa) | 200 | Barbagelata and Mallarino, 2013 |
| | U.S. (North Carolina) | 6 | Cox and Barnes, 2002 |
| | U.S. (Pennsylvania) | 67 | Beegle and Oravec, 1990 |
| Maize, soybean, and wheat combined | Brazil (Rio Grande do Sul) | 48 | Schlindwein et al., 2011 |
| Maize, soybean, and sorghum combined | Brazil (Rio Grande do Sul) | 17 | Brunetto et al., 2005 |
| Pasture (legume-based) | New Zealand | 804 | Edmeades et al., 2010 |
| Peanut | U.S. (North Carolina) | 7 | Cox and Barnes, 2002 |
| Rice | Brazil (Tocantins) | 2 | Fageria et al., 2010 |
| | U.S. (Arkansas) | 32 | Slaton et al., 2009 |
| Soybean | U.S. (Arkansas) | 34 | Slaton et al., 2010 |
| | U.S. (Iowa) | 162 | Barbagelata and Mallarino, 2013 |
| | U.S. (Kentucky) | 4 | Grove et al., 1987 |
| Sunflower | Australia | 10 | Brennan and Bell, 2013 |
| Wheat | Australia | 211 | Brennan and Bell, 2013 |
| Total | | 1834 | |

**Table 1** provides examples of soil test calibration data in the peer-reviewed literature. The number of site-years making up any given calibration dataset in this table ranged from 2 to 200. Those studies with lower site years typically relied on rate studies that provided a range of plant-available K in the soil.

Not captured in this table are what some scientists consider to be the largest pool of calibration data: studies published in conference proceedings, experiment station reports, departmental reports, and data in individual filing cabinets and electronic spreadsheets in offices and laboratories around the world. Researchers, agencies, associations, and industries in Australia have recognized that data in these forms are valuable and in danger of becoming lost. The Better Fertilizer Decision for Crops National Database was developed to centralize individual site-year data that make up calibration relationships. Trained users, through an interactive web interface, are able to assemble various site-years of data into customized calibration sets based on various criteria (Watmuff et al., 2013).

Potassium recommendations made by universities and agencies around the world are based on studies like these that are reported in the peer reviewed literature and in local publications. They connect the science of soil fertility to potassium management decisions.

**Nutrient Budgets**

A key component of both plant-based and soil testing-based approaches is the nutrient budget. It is calculated by subtracting the amount of K removed from a parcel of land from the quantity of K applied. Positive budgets indicate K enrichment while negative ones signal K depletion. Most often, "partial budgets" are calculated. These simplified budgets compare: 1) nutrients removed with harvested portions of plants, termed "crop removal" and 2) K applied with commercial fertilizers, manure, and/or biosolids. These budgets are partial because they do not consider all inputs and outputs.

The degree to which partial budgets deviate from complete budgets depends on the system considered. Case studies conducted in flooded rice systems in the Mekong Delta of Vietnam (Hoa et al., 2006) found that just including fertilizer additions and crop removal in the nutrient budget produced significant budget calculation errors. Additional, major contributors to K balance in these systems were the addition of K in irrigation water, floodwater, and associated sediments. In contrast, a study in rainfed maize production in northeast China found that partial K budgets underestimated K additions by only 3.1 kg K/ha (3.7 lb $K_2O$/A) by failing to consider K in rainfall and in planted seeds (Ma et al., 2010).

Potassium budgets are of great interest to scientists around the world. They indicate whether agricultural practices are depleting, enriching, or maintaining indigenous K supplies. Where indigenous supplies of K are low, enrichment is appropriate. Depletion is appropriate where indigenous supplies are high, such as in more arid agricultural areas; however, there is a caveat to depletion. If it occurs long enough on soils with high amounts of K, the indigenous supply eventually becomes inadequate for crops.

At a workshop held in Uganda, stakeholders determined that negative nutrient budgets should be used as an indicator of land degradation (Bekunda and Manzi, 2003). The stakeholders were farmers, traders, decision and policy makers, staff of extension, researchers, and development organizations. Case studies demonstrated that, "…commercial farmers appear not to be re-investing some of the sale proceeds into replacing nutrients removed in harvests…."

Concern about long-term negative budgets have been expressed by others. Dobermann and White (1999) working in Asia remarked that,

*Because in most intensive rice systems fertilizer K and Si [silicon] use is small and much straw is removed from the field, the overall input-output balance of K and Si is almost everywhere highly negative. Surveys conducted in five countries suggest an average use of only 18 kg K/ha per crop. Average negative balances are probably in the range of -20 to -60 kg K/ha per crop and –150 to –350 kg Si/ha per crop. Potassium deficiency has* *become a constraint in soils that were previously not considered as K-limiting.*

Brennan and Bell (2013) working in Australia wrote: *The fact that K deficiency has developed in most crops in Australia as a result of K removal and possible leaching means that formulation of relationships between extractable STK [soil test K] concentrations and grain yield increases (responses) is a relatively recent phenomenon.*

A study from the U.S. state of South Dakota examined parameters that estimated the capacity of a soil system to maintain a certain level of K in the soil solution (Schindler, 2005). This is the K taken up by plant roots. The researchers surveyed eight sites across east-central South Dakota - areas with historically low K use but high indigenous K supplies. The researchers concluded that,

*The soils in east-central South Dakota are at or near a critical labile K level, and without proper K fertilization will be unable to sustain K levels necessary for proper plant growth and production.*

Other examples of K depletion and emerging constraints on crop yields come from New Zealand (Edmeades et al., 2010) and from India, Nepal, China, and Bangladesh (Ladha et al., 2002).

Thus, K applications must not only provide enough K to meet crop needs, they also need to sustain plant-available soil K supplies over the long term. Both plant-based recommendation examples cited earlier (Dobermann and White, 1999; Pampolino, 2012) contain a K budget component. There are many soil testing-based approaches that also explicitly factor K budgets into their algorithms (Fernández and Hoeft, 2013; Mallarino et al, 2013; Vitosh et al., 1995).

**Conclusion**

Potassium is required by plants. Not applying K on soils with low indigenous supplies limits yields and production and is considered a form of land degradation. On soils with high indigenous supplies, omitting K will not reduce yields or production; however, continued withdrawal of K through successive crop harvests will eventually deplete indigenous supplies to yield-limiting levels, as has been observed in several areas around the world.

Potassium fertilization is necessary. Both plant-based and soil testing-based approaches inform decisions about whether or not a K application is needed to provide plants with adequate nutrition and sustain soil productivity.

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