Site-Specific Nutrient Management

For Nutrient Management Planning To Improve Crop Production, Environmental Quality, and Economic Return

Potassium: Chapter 4 of 10

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Chapter 4:
Potassium Management

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Introduction

Potassium (K) is abundant in most soils, but the vast majority is unavailable to plants. Plants require K for photosynthesis; synthesis of ATP (an energy exchange compound), many carbohydrates, and proteins; translocation of sugars, and nitrogen (N) fixation in legumes. Adequate K supply strengthens plant stalks and stems, thus helping reduce lodging, and also increases resistance to several diseases through a variety of mechanisms. Typical K-deficiency symptoms develop first in the older leaves and may consist of yellow or white spots on the leaf edges (as in alfalfa, for example), chlorosis and necrosis of the leaf edges (as in corn and soybean), or chlorosis of leaf tips (as in wheat).

When compared with other macronutrients, K total plant uptake is generally second only to N, and in some crops such as sugar beets and potatoes K uptake exceeds N uptake. Annual K removal from fields depends greatly on the plant part harvested, crop, and yield level; and ranges from 50 to 500 lb K_2O/acre. Table 1 shows an example of guidelines concerning K concentration per unit of yield for several crops. Commercial K fertilizer analysis has historically been expressed as the oxide form (K_2O) rather than the elemental form (K). Therefore K uptake and removal values are usually expressed as K_2O per unit of yield. Using the ratio of their molecular weights, the amount of K_2O can be converted to K by dividing by 1.2. To estimate K_2O uptake, multiply the yield by the amount in the table per unit of crop yield harvested.

In contrast to phosphorus (P), the K concentration and removal with grain harvest of cereals is a much smaller proportion of the total plant uptake. Most grain crops reach the maximum K uptake before physiological maturity, and the total K contained in aboveground plant parts can even decrease by grain maturity. Figure 1 shows, as an example, the total K uptake by wheat and its distribution among plant parts during the growing season. Therefore, if most of the plant material is removed at harvest (such as for corn silage or biomass for bioenergy), K removal can result in a severe depletion of soil available K. Also, because the absorbed K ions are not incorporated into plant organic compounds and are soluble in water, leakage of K from vegetative plant tissue or crop residues is an efficient recycling mechanism to the soil.

Table 1. Potassium amounts in harvested portions for selected agricultural crops.

Crop	Unit of Yield	Pounds K_2O per unit of yield
Corn	bu	0.3
Corn silage	bu grain equivalent	1.3
Soybean	bu	1.5
Oat and Straw	bu	1.0
Wheat	bu	0.3
Sunflower	100lb	0.7
Alfalfa	ton	40
Tall fescue	ton	66

Source: Iowa State University Extension publication PM 1688.

Plant uptake can also influence the recycling of available K from deep in the soil. Deep-rooted plants can act as nutrient pumps by transferring K from the subsoil to the surface layers. This process makes previously inaccessible K available for shallow rooted crops.

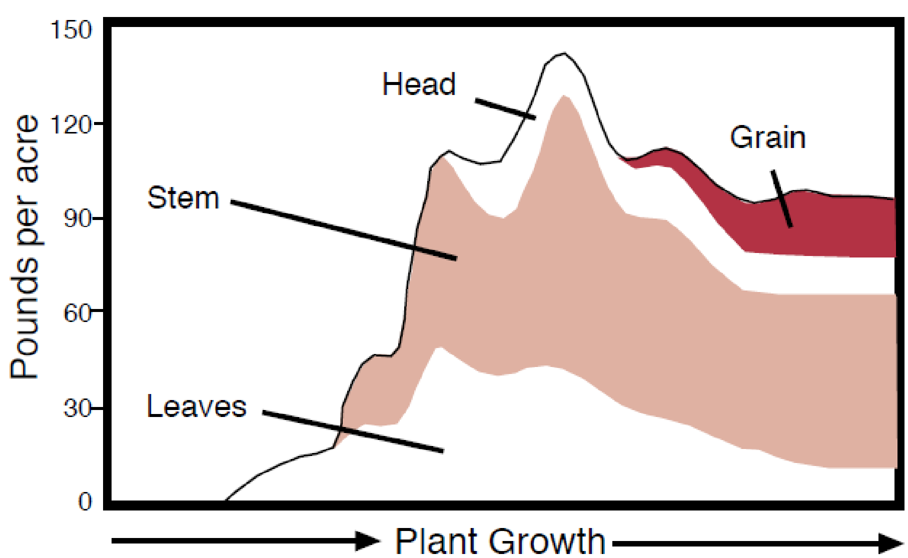

Figure 1. Potassium accumulation during growing season for hard red spring wheat. Adapted from Jabosen et al. (1992). Montana AgResearch 9:23-26.

Potassium application and management does not result in water quality concerns as with N and P. An understanding of K reactions in soils, cycling, and availability for crop is important to improve K use efficiency, to meet crop K needs in a profitable way, and to help with K management decisions.

Potassium Processes in the Soil-Plant System

Forms of Soil Potassium

The vast majority of soil K is contained in unweathered primary minerals such as feldspars and micas (muscovite, biotite, and others). The top layer of most soils contains thousands of ppm of mineral K, but the K in the crystal structure of these minerals is released very slowly over dozens or hundreds of years and has no relevance for crop nutrition. Other soil K pools include dissolved K^+ ions (solution K), exchangeable K, and slowly exchangeable K (often referred to as nonexchangable K in textbooks). Readily plant-available K includes the solution and exchangeable K fractions, and there is a fast equilibrium between these two fractions in response to K additions and plant uptake or leaching. The exchangeable K fraction contains hydrated K^+ ions weakly sorbed to the negatively charged surfaces of mineral soil particles and organic matter, and can rapidly replenish the solution K pool as K is taken up by plants. Plants can only directly use K from the soil solution, yet solution K concentrations range from only 1 to 10 ppm except shortly after fertilization, and the exchangeable K fraction in U.S. soils may range from about 20 to 1,000 ppm. The slowly exchangeable K is held within clay layers by stronger bonds and is not readily exchangeable or available to plants in the short term (days or weeks). In soils of the U.S., the amount of K held in this fraction varies greatly, and may range from about 100 up to 2,000 ppm.

Potassium Exchange and Reactions in Soils

When solution K is depleted due to plant uptake or leaching, K desorbs from the soil particles and enters the solution. When the amount of solution K is increased by fertilization or K leaching from crop residues, added K will also be held on the soil exchange capacity (CEC) sites. Fine-textured soils with high CEC generally have large exchangeable K concentrations and a strong capacity to maintain a sufficient K supply to the soil solution and for plant uptake throughout the growing season. Low CEC soils often lack the capacity to sorb sufficient K reserves to satisfy crop requirements over a growing season.

Exchange reactions involving the slowly exchangeable K fraction are important in the long term (weeks to years), and can dominate processes affecting the long-term crop availability of K mainly in soils with predominant mica (illite) or vermiculite clay types. A portion of the K in this fraction may become plant available during the growing season and over the years; conversely, some added K may become strongly retained and nonexchangeable. Both processes are highly influenced by the opening (peeling apart) and closing of sheet-like clay crystal structures near fracture borders in response to drying-wetting, freezing-thawing, changes in soil aeration, or long-term weathering (Figure 2).

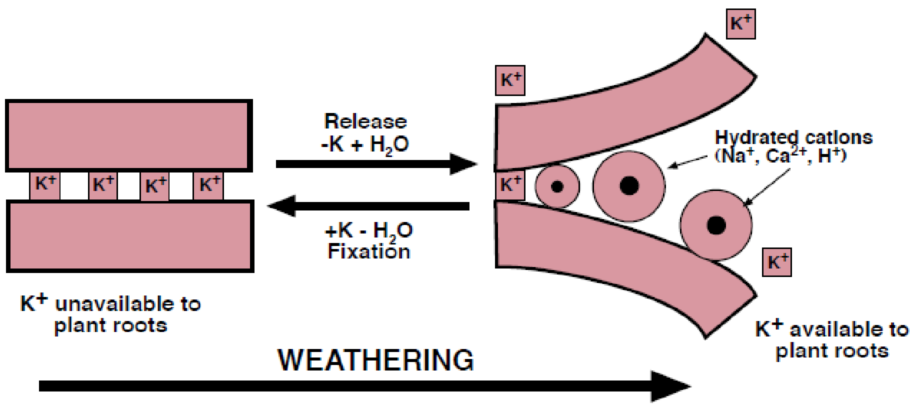

Figure 2. The opening and closing of layered clay minerals releases K into solution and also can retain K in a form that may be unavailable to plants. Adapted from McLean (1978), Potassium in Soils and Crops.

Potassium retention and release by clay, and its availability to plants can be affected by soil pH. As the pH increases (i.e., with increased lime application, for example) in very acid soils having exchangeable aluminum (Al), which are common in the southern and southeast regions of the U.S., the soil capacity to retain K (and added calcium) in an exchangeable form increases mainly because the liming transforms exchangeable Al into insoluble forms. In acid soils without exchangeable Al, the effect of a pH increase is less clear concerning availability to plants. As the pH increases due to liming, the soil CEC is increased and H^+ ions are removed from cation exchange sites, and more exchange sites are available for holding K^+ and calcium ions (Ca^{2+}) in an exchangeable form. However, high amounts of Ca^{2+} can reduce crop uptake of K, and the pH increase can cause the collapse of expanded clay layers and trapping of K ions in the non-exchangeable form.

Soils with high K-fixing capacity typically show a smaller soil-test K (STK) response to fertilizer application than other soils because a portion of the supplied K can quickly bind to clays in a nonexchangeable form. A soil with high K-retention capacity will generally be capable of sustaining available K levels to a crop over many years of production, thereby buffering the crop removal of K. This property has been called the ‘K supplying power’ of a soil. A sandy soil and a clay loam soil may have the same initial exchangeable K levels, but their response to crop uptake and removal of K will be different because sands have low CEC and, therefore, a lower K supplying power than clay loams (Figure 3).

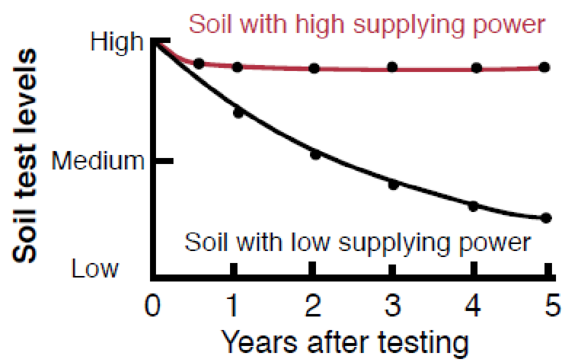

Figure 3. Soils with the same initial K level may have very different abilities to supply K to crops over time. Adapted from Hoeft et al. (2000), Modern Corn and Soybean Production.

Potassium: A Relatively Immobile Nutrient

As a result of K exchange reactions and retention in soils, K moves only short distances through soil and only slightly more than P. The amount of K that reaches the root surface with water mass flow is not sufficient to supply plant needs, and K ion diffusion through the soil solution is the main mechanism of plant K uptake. This characteristic has several important consequences. Factors that limit the rate of K diffusion and both the rate of root growth and the size of the root system can limit K uptake. These include cold temperature and low moisture (which limit diffusion and root growth), soil physical properties that inhibit root growth, and diseases or pests that impair root function. Therefore, induced K deficiency may occur even with presumably adequate soil-test K levels. In these situations, placement that puts applied K near young plant roots may increase plant growth and yield compared with broadcast application.

The amount of K loss with leaching through the soil profile is much less than K loss with erosion and surface runoff in most soils and landscapes. In coarse-textured soils or in moderately textured soils with sustained high K applications, K can move through the profile and increase subsoil K concentrations or leach to groundwater or surface waters through subsurface tile drainage. Therefore, although K does constitute a water quality problem, minimizing soil erosion and excess application to coarse textured soils will help maximize K utilization by crops.

Potassium Soil Testing

The primary goal of soil testing for K is to estimate the supply of K available to a crop. Solution and exchangeable K are the most important forms for plant growth, but the estimate of exchangeable K is far more important than the solution K fraction. The STK methods used in the U.S. measure solution K and most of the exchangeable K. The most widely used methods extract K with the ammonium acetate and the Mehlich-3 methods, but a few states use the Bray-P1, Morgan, or Mehlich-1. In contrast to P, the measurement of extracted K can be done by various laboratory procedures that give the same result Only the top six to eight inches of soil is generally tested for K because the surface soil is the most significant source of K for most plants, although in a few states a shallower sampling depth is recommended for pastures and no-till. The relationship between STK and relative yield response in the U.S. has been a subject of significant research (Figure 4). Soil test levels are categorized into low, medium (or optimum), or high, and sometimes also into 'very low' and 'very high' (or excessive) categories. At STK levels below the 'critical level or range' (usually medium or optimum) the probability that a yield increase will result from fertilizer addition is high. Above the critical level, small or no yield responses to K fertilization would generally be expected.

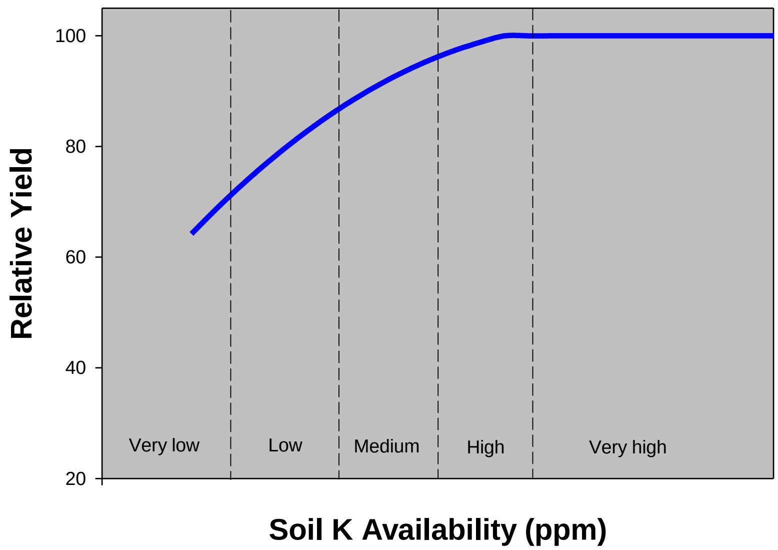

Figure 4. Relationship between soil-test K level and crop yield.

The STK and exchangeable K levels can change significantly during the year due to effects of crop uptake, soil moisture and rainfall, and different rates of recycling of K in crop residues. This happens also for other nutrients, but is especially the case for K. As an example, Figure 5 shows how STK changes due to crop uptake and also soil moisture. Figure 6 shows how the rapid recycling of K from crop residues, which is faster and of greater magnitude than with P. Soil STK levels are usually highest and more stable a few weeks or months after crop harvest and with normal moisture, and before plant uptake becomes substantial. Over the growing season, K is removed from solution and exchange sites by plants, so STK will be lowest from mid-season to crop physiological maturity. Therefore, the time of year that soils are sampled is critical for effective K management and must be consistent over time in order to monitor the K fertility of a site over time. Different states may have different sampling date recommendations as soils, climate, and crops vary greatly across the U.S.

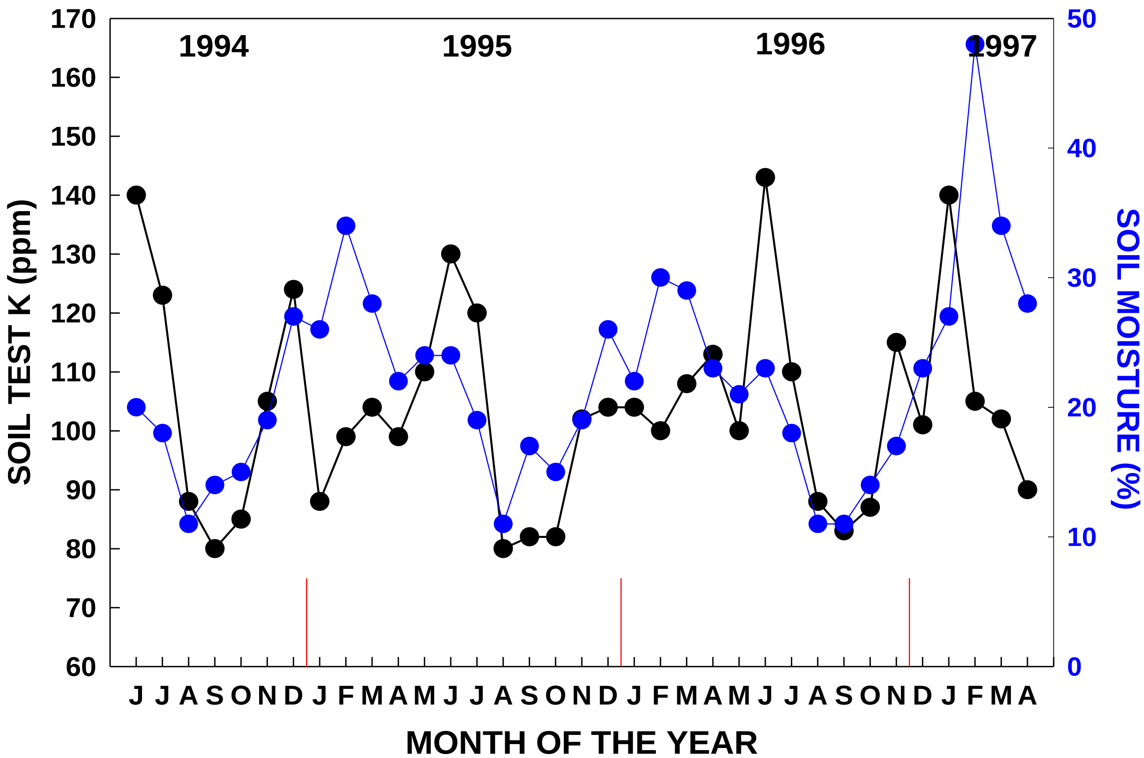

Figure 5. Relationship between soil moisture and soil-test K levels in an Illinois soil (Dixon Springs Agricultural Center). Soil-test K data adapted from S.A. Ebelhar and E.C. Varsa. 1999. Tillage and potassium placement effects on potassium use efficiency in a corn-soybean rotation. Illinois Fertilizer Conference Proceedings. January 25-27, 1999. University of Illinois, Urbana-Champaign. Moisture data adapted from T. R. Peck (University of Illinois, unpublished).

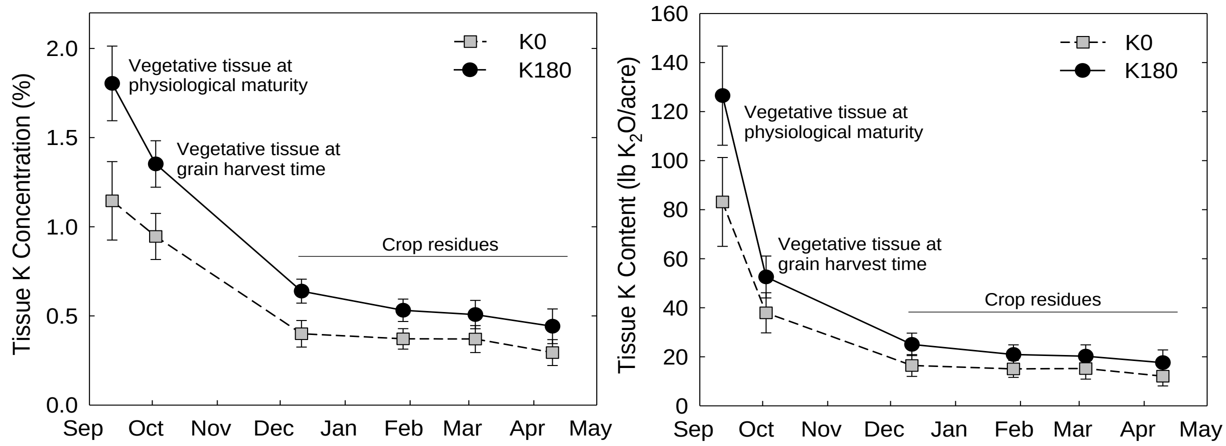

Figure 6. Concentration and amount of potassium in soybean plant tissue (except grain) from physiological maturity until grain harvest and in residue until the following spring for two K application rates. Adapted from R.R. Oltmans and A.P. Mallarino (2011). Identification of reasons for high temporal soil-test potassium variation. p. 65-73 In North-Central Extension-Industry Soil Fertility Conf. Proceedings. Nov. 16-17. Vol. 27. Des Moines, IA.

Potassium Fertilizer Recommendation Concepts

The interpretation of soil-test results in terms of sufficiency for crops and the amount of nutrient to apply are determined from many field trials on different soils over many years. Interpretations of STK results concerning fertilization rates vary greatly across regions due to different crops, soils, or economic issues related to crop response to nutrient application. Also, interpretations differ due to different concepts and assumptions concerning nutrient management in relation to the crop production system. The concepts of sufficiency level and buildup/maintenance for P, K, and other immobile nutrients have been widely discussed in soil fertility circles.

According to a strict sufficiency level concept, the soil nutrient availability should be determined by soil testing and the nutrient application rate for a given STK level should be the one that results in maximum yield or maximum economic yield. This approach emphasizes short-term profitability from fertilization, high return per pound of fertilizer applied, and reduced risk of fertilizer over-application by accepting a moderate risk of yield loss. It requires frequent use of soil-testing and a research data base that accurately predicts the nutrient need for different soil-test values. A strict build-up and maintenance concept emphasizes increasing soil-test levels to a desirable level in a short period of time by applying rates higher than those needed to achieve maximum yield or maximum economic yield. This approach reduces the risk of yield loss due to insufficient nutrient levels and emphasizes long-term productivity and profitability from fertilization. It may not require frequent soil testing or accurate soil-test calibration, but requires knowledge of fertilizer rates needed to maintain soil-test values over time, which usually is based on measured or estimated K removal with crop harvest. A short-term yield response or profit to maintenance fertilization usually is not expected.

The soil test interpretation and fertilizer recommendation systems used across the U.S. seldom strictly follow these two concepts. For example, recommendations by the University of Illinois are closer to the buildup/maintenance concept, those in Minnesota are closer to the sufficiency level concept, and those in Kansas provide recommendations for both concepts. The main reason that allows the use of the buildup and maintenance approach for K is that many soils retain applied K but do not "fix" it in forms unavailable for crops, and this allows for both buildup and drawdown as management options within the cropping system. For example, Figure 7 provides an example of long-term relationships between K removed with harvest and STK for several typical Iowa soils managed with corn-soybean rotation. Data in this figure shows high temporal variability of STK (much more than for P), but shows a linear relationship between K removal and STK over the long term.

The keys for developing sound STK interpretation and K application guidelines includes appropriate information for crop response to fertilization, calibration of soil-test methods, and profitability of fertilization for different soil-test interpretation categories; long-term STK trends as affected by fertilization, yield levels (because of removal), and K concentration of harvested plant parts. Additional consideration of management philosophies, land tenure, and attitudes toward risk (related to yield loss or gain, short-term or long-term profitability, and environmental impacts) can influence utilized STK interpretations and K fertilization practices suitable to a large variety of soils, production conditions, and producers. Applying K fertilizer at rates higher than crop requirements or to soil testing higher than recommended is unwise from economic and resource conservation perspectives. There is no agronomic or economic justification for building STK levels higher than sufficient for crop needs.

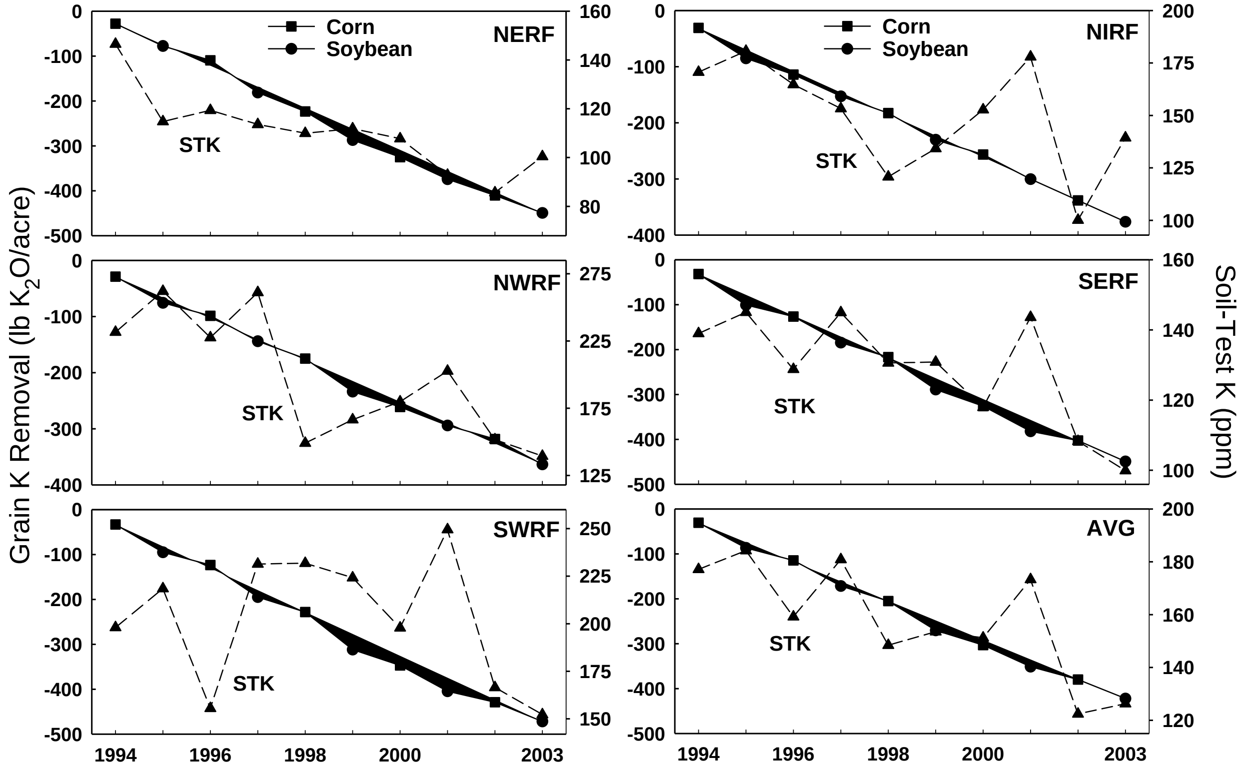

Figure 7. Soil-test K and cumulative K removal long-term trends for five Iowa sites and the average. From Mallarino et al. (2011). Factors determining high temporal soil-test potassium variation and soil sampling and testing alternatives. In Proceedings, North Central Region Soil and Plant Analyst Workshop. Feb. 23-24, 2011. Bettendorf, IA. Available at http://ncera-13.missouri.edu/publications.htm.

Fertilizer and Manure Potassium Management

Potassium Sources

Potassium fertilizer is available commercially mainly as potassium chloride (KCl, 0-0-60), potassium sulfate (K_2SO_4, 0-0-50), and potassium nitrate (KNO_3, 13-0-44). The potassium is all water soluble for these sources. These sources (especially potassium nitrate) have the potential for inhibiting plant growth due to salt effects (the plant cannot get enough water from the soil) if applied in excess and close proximity or with the seed. Potassium chloride accounts for over 95% of all K fertilizer sold in the U.S. because it is mined from raw KCl deposits, and minimal processing and transportation make this the most economic K source. Potassium sulfate is primarily used where Cl toxicity or sulfur (S) deficiency is a problem. Potassium nitrate also is a source of N, but is expensive and is widely used only for foliar sprays of K application to fruits and vegetables.

Potassium in organic sources, manures and sewage sludge, occurs predominantly as soluble inorganic K^+ and is readily available for crop uptake. In animal manures, the K concentration ranges between 0.2 and 2% of dry matter, so large application rates are required to meet crop needs.

Placement Method and Timing

There are many ways of applying K to crops and most considerations, except potential salt effects, are similar to those for P fertilizers. Band applications concentrate nutrients at or near the root zone, which is important for young plants with limited root systems, particularly in cold and/or compacted soils. The "starter" effect from K is much less than for N and P, however, and too much K fertilizer close to the seed can reduce seed germination and injure roots due to high salt concentrations. Band K should be placed beside and below the seed level to reduce potential damage or by using very low rates if it is applied to the seed furrow. Band K applications can be more effective than broadcast application in soils with a strong capacity to retain added K in forms of low plant availability. This may be the case in soils with very high clay content or soils with significant levels of vermiculate in the clay fraction. Otherwise, and in most regions, broadcasting K fertilizer before planting is a convenient and low-cost way for applying high amounts of K fertilizer. Research with corn, mainly in Iowa and Minnesota, has shown that deep banding of K can be more effective than other placement methods, especially for ridge-till and sometimes for no-tillage and strip-tillage. The research demonstrated that the cause of increased efficiency of this method does not necessarily relate only to STK stratification typical for these systems, and that is explained by water availability deeper in the soil profile when the top few inches of soil are dry.

With the exception of regions that have soils with very high K retention capacity, the timing of K application before planting has little or no impact on K use efficiency by crops. This fact justifies, for example, widespread K application in the fall for summer crops in the Corn Belt and the Great Plains, and also application every other year for some rotations. In soils that retain or transform a significant proportion of applied K into forms of low crop availability, however, application long in advance of crop growth may reduce K use efficiency and often there are large differences between placement methods (less efficiency with broadcast and incorporated application, for example).

Variable Rate Potassium Application

Dense soil sampling in many fields has shown very large within-field spatial variability of STK, crop yield levels, and crop response to K fertilization. Figure 8 shows an example of the variation in corn yield response to K fertilization for field areas 10 to 25 acres in size that had different STK values. Precision agriculture technologies available to producers or custom fertilizer applicators facilitate application of fertilizer and manure at rates adequate for different parts of a field based on STK and estimated K removal. Grid or zone soil sampling methods, combined with variable rate application of fertilizer or manure K, may not always increase crop yield or increase profits compared with traditional uniform rate application, because the average fertilization effect on yield and amount of K applied depends on the overall level and distribution of STK values. Also, soil testing seldom is performed on an annual basis, there is always a certain degree of sampling error (especially in fields with high small-scale variability), and research has shown that short-term relationships between K removal and STK are very variable. Therefore, even with annual soil sampling and variable-rate application, use of this technology faces challenges for K management. However, variable-rate application of K fertilizer minimizes or avoids K application to high-testing areas within fields, reduces STK variability, and as a consequence, improves K use efficiency. Variable rate application of K fertilizer is now common in the Great Plains and Corn Belt.

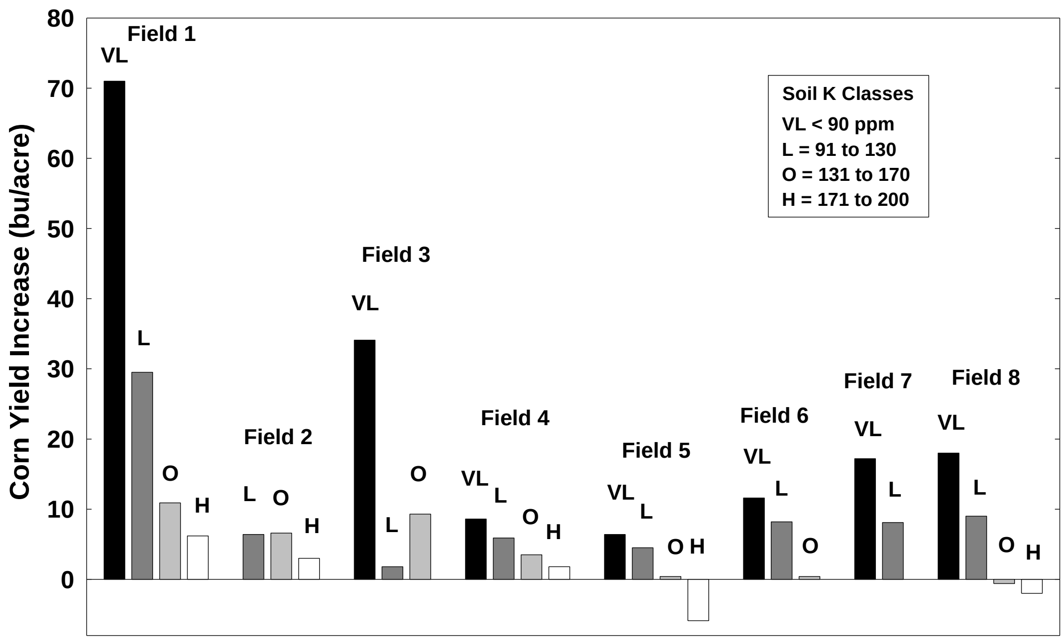

Figure 8. Within-field soil-test K variability and yield response variability from eight representative strip trials conducted in Iowa (field identifiers are arbitrary codes). From A.P. Mallarino and D.J. Wittry (2006). Variable-rate application for phosphorus and potassium: impacts on yield and nutrient management. p.219-224. In The Integrated Crop Management Conf. Proceedings. Nov. 29-30, 2006. Iowa State Univ. Extension. Available at http://www.agronext.iastate.edu/soilfertility/info/mallarino_Variable-PK%202.pdf

Summary

Effective K management requires not only a thorough understanding of K reactions in the soil, but also an awareness of how climate, aeration, and moisture can affect the capacity of a plant to access the large reserves of soil K. Potassium exists in large, albeit finite amounts in soils, but the readily available forms can be depleted during short period of high crop demand or over long-term crop production.

Proper management of K is essential to maximize the profitability of crop production as well as maximize the efficiency of a non-renewable resource. Potassium management, as well as P management, is somewhat simpler than for N in humid regions due to relatively easier to predict chemical transformations and no gaseous phase or volatilization problems. Also, although there is more temporal variability of STK and uncertainty with soil testing than for P, soil sampling and testing for K is still a useful diagnostic tool. The goal of sound K management in most regions of the U.S. should be to keep the STK level at optimal ranges for maximum economic crop yield and utilize application methods that optimize K use efficiency and profitability. Substantial within-field variability of STK and K removal with harvest in most agricultural areas justifies the use of appropriate soil sampling methods and variable-rate application technology to increase K use efficiency.

Best Management Practices for K Fertilization:

Any list of best K management practices will need to be tailored to a specific region because of large variation in crops, soils, and production systems; and likely will be incomplete in regard to addressing all potential issues. However, the following list includes the most important concepts underlying K management strategies.

1. Sample soil as frequently and densely as possible, and use appropriately calibrated soil-test methods based on research for each state or region.
2. Consider yield levels and crop removal between and within fields to help maintain optimum soil-test K levels in conjunction with soil testing.
3. Fertilize K deficient soils using economically sound agronomic guidelines. In general, soils testing ‘high’ or “very high” will not respond economically to additional K and should not receive fertilizer except for a small amount of starter fertilizer in certain specific conditions.

4. Divide large, non-uniform fields into smaller fertility management units based upon yield potential, soil tests, and relevant soil properties.

5. Account for crop available K applied with manures and other organic sources when deciding on K application requirements.

6. Refer to local research and guidelines concerning K placement methods to optimize K use efficiency and the profitability of nutrient application.

Case Study

Several K management strategies and philosophies are used by producers across the U.S. One example representative for all geographic areas, crops, and current management systems is not possible. Therefore, the following situation and suggested options for improved management apply to a specific farm in the U.S. Corn Belt. However, many issues and possible practices the producer could consider to improve crop K use efficiency and economic return from K application apply to other regions.

Example scenario

- An 800-acre dairy farm in northeastern Iowa.

- Soils are well drained, moderately permeable, are of loam, silt loam, or silty clay loam texture, and slopes range from 2 to 12 percent.

- The farm has fields with continuous corn and others in a rotation consisting of three years of alfalfa, two year of corn, and then soybean one year. About one-half of the corn is used for silage that is fed to dairy cattle.

- The producer uses chisel plow in approximately one-half of the fields and no-till in the other half.

- Some corn fields receive high rates of dairy manure, including for corn after the last alfalfa production year. Large quantities of manure are produced in the overall farm operation, which is applied without using manure nutrient analyses or soil testing.

• For many years the farmer has assumed that sufficient amounts of nutrients are applied with the dairy manure, including K, so only occasional fertilizer application is used. This fertilizer is mainly N for the continuous corn and some broadcasts K fertilizer (as potassium chloride) to some fields with alfalfa.

• The dairy manure is broadcast and incorporated by chisel plowing and disking in fields managed with tillage (all with continuous corn), but is not incorporated or injected in fields managed with no-tillage.

• In recent years, especially after harvesting some high yielding corn silage, the farmer has noticed older corn leaves on the lower part of plants with yellow or brown edges in spots, and also wonders about apparently increasing within-field variation of yields of both corn and alfalfa.

The farmer's recent observations are consistent with likely K deficiency given the crop and nutrient practices that he has been using. This scenario could be a frequent situation in geographic areas with crops that remove large amounts of K when manure and soil analysis are not used as it should, and the manure is not managed appropriately. With the high nutrient removal with alfalfa and corn silage harvest, it is likely that the amount of K applied is not adequate to maintain soil test K at optimum levels. This, together with uneven or not careful manure application, will lead to extreme variation in soil tests across and within fields, and limited crop yields at least in some areas.

Following are some new management options to consider:

• It is very important from the agronomic and economic point of view to monitor soil nutrient levels routinely. This is crucial in order to adjust nutrient application rates to meet crop requirements, maximize profitability, and avoid potentially high risk of water quality impairment due to excess N and P loss from fields. In this specific case, it is very likely that the spotty K deficiency symptoms in corn, and large within-field crop yield variability, is due to continued uneven application of dairy manure without consideration of K being applied and varying yields. For example, corn silage harvest removes almost four times more K than grain only harvest. Harvest of a high yielding alfalfa crop can result in even more K removal than a high yielding corn silage crop. While soybean is a minor crop in the rotations, soybean grain harvest will remove more K than corn grain harvest. Therefore, the producer should adopt a soil sampling strategy for monitoring soil test levels, K in particular, and within-field soil test variability. An ideal sampling strategy would be a 2.5 acre grid sampling on all fields, or a less dense zone sampling approach that considers at least soil map units and topography. Some measurement of within-field yield variation would be very useful, although this is easy and of relatively low cost only for grain yield with yield monitors and GPS. The soil sampling frequency should reflect the crop rotation. For example, sampling before each new alfalfa seeding and before the first-year corn after alfalfa, and every two to three years in the continuous corn. The soil test information would allow the farmer to know what fields and field areas require supplemental K fertilizer application, and if excess manure P is being applied to some fields or field areas.

- The farmer should have a regular manure sampling and analysis program so the amount of nutrients applied can be appropriately determined. In fact, regular soil and manure analyses are beginning to be required by many NRCS programs and state agencies in charge of preserving environmental quality.

Once a K soil test map of the farm is carefully studied, the next step would be to target dairy manure or K fertilizer application in field areas with lower K levels and avoid/reduce applications in areas with high K levels and/or excessive soil-test P levels (if they exist). Consideration should be made for the needed N, P, and K. For example, if soil test P is very high, and K soil test is low, then fertilizer K should be applied instead of manure. If the field is rotating from alfalfa to first year corn, then manure application should be avoided, or only a low rate should be applied, since first-year corn after alfalfa crop requires little or no additional N. Application of manure or fertilizer can be accomplished by using conventional manure/fertilizer application practices, or variable rate application equipment depending on the degree and scale of P and K spatial variability and the availability of variable-rate technology equipment.

- The dairy manure should be injected when it is applied to fields managed with no-tillage. This will increase manure N use efficiency (by reducing ammonia volatilization) and will reduce the risk of P loss with surface runoff. Known crop availability of N, P, and K in dairy manure, and the diversity of cropping and harvest systems being used in this dairy farm (and in most farms that include animal production), present a serious challenge concerning maximum use of the manure resource while attending to crop nutrient needs and risk of water quality impairment due to excess N and P application.

- In order to properly maintain adequate K supply for all crops and minimize the risk of excessive N and P loss, the farmer has to appropriately consider manure and inorganic fertilizer application rates, avoid application of N at rates much higher than needed by each corn crop, and use an environmental P risk assessment tool (such as the P Index). Use of the P Index helps to determine what fields or field areas testing high in P can have application of manure to supply N and K, and will not result in excessive risk of P loss and water quality impairment.