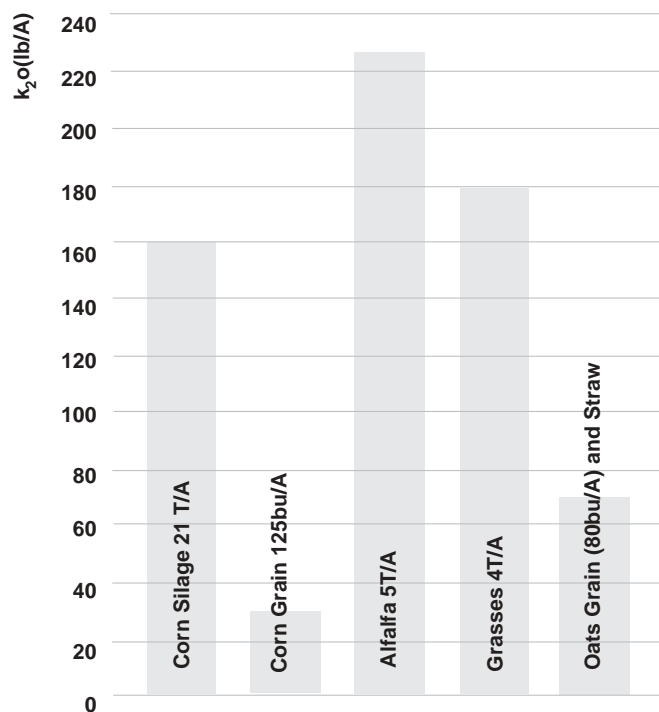




Managing potassium for crop production

A corn crop takes up nearly as much potassium (K) as it does nitrogen (N), yet management of each nutrient is entirely different. Because only the K in the harvested portion of a crop is removed from a field, managing K for corn silage is different than for grain. Whereas harvesting 125 bushels of corn grain per acre removes only 35 lbs of potash (K_2O), harvesting 21 tons of silage per acre carries away 160 lbs of K_2O ; and the voracious appetite of a 5-ton-per-acre alfalfa crop takes 230 lbs of K_2O per acre from a field (Figure 1). Yet, managing potassium for each of these crops is relatively simple because of the reaction of K with soil, a reaction completely unlike the behavior of N in soil. What happens in soil to provide the different needs of corn and alfalfa, and how do you manage fertility on farms where these crops and others are grown?

Figure 1. Approximate removal of K_2O in harvested portion of common Pennsylvania crops.

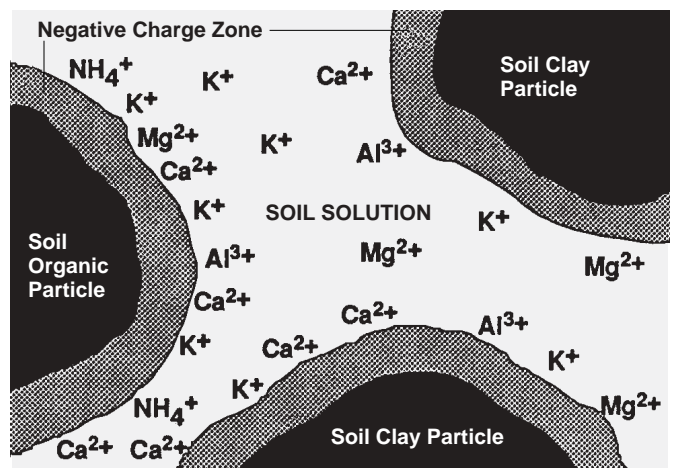


SOIL POTASSIUM

There are approximately 24,000 lbs of K per acre, so it is certainly not in short supply, even considering the amount alfalfa requires. So why add any? To begin with, K occurs in at least three main forms: soil solution, exchangeable, and mineral. Like other nutrients, K is taken up by plant roots only from the soil solution; and yet, K in solution represents a very small fraction of the total K in soil. The soil solution must be replenished with K from other sources in the soil to meet the need of a growing crop. That replenishment comes primarily from readily available, “exchangeable” K.

Exchangeable K, like other positive charged ions such as magnesium (Mg), calcium (Ca), and aluminum (Al), is loosely held in soil by an attraction to the negative charged surfaces of soil particles, somewhat like magnets on a refrigerator (Figure 2). The amount of negative charge in a soil is a characteristic of that soil and is called the soil’s cation exchange capacity (CEC). When K is added to soil it occupies negative charged sites on soil particles by “kicking off,” or exchanging with, other positive charged ions. This CEC holds K in ready reserve to supply the need of a small

Figure 2. Exchangeable and solution K in soil.



grain crop or the much greater need of an alfalfa crop. As plant uptake occurs, K is released from these sites to the soil solution in quantities dependent on both the amount of K present and the proportion of the CEC sites it occupies. The amount of exchangeable K is, therefore, related to the amount of K available to the crop, and it is the K measured by soil test at Penn State's Ag Analytical Services Laboratory.

The vast majority of K in soil is held more tightly, entrapped, or as part of the structure of soil minerals. These forms, called nonexchangeable K, are generally either unavailable or only slowly available. Mineral K is not, therefore, measured as part of the soil test procedure. Decomposing organic matter in soil contributes little K because K is a soluble nutrient that leaches quickly from fresh crop residue and manure. On the other hand, organic matter is important to K fertility because it provides many negative charged sites for holding exchangeable soil K (Figure 2).

CROP RESPONSE

The small amount of K removed by corn grain harvest is evidence that the grain of a crop is not the major site of K use or requirement. In fact, if that corn crop were harvested as silage, the amount of K removed would increase about fivefold. The action of K in a plant is not dramatic like that of N; rather, it plays a backstage role in nearly every facet of crop production. Photosynthesis, control of plant N, formation of new proteins and tissues, and strength of cell walls and stalk tissues are all influenced directly by K nutrition. With a K deficiency, seasonal duration of leaf photosynthesis is shortened, transport of nutrients and sugars within the stem is hamstrung, plant integrity is compromised, starch formation is hindered, and use of N is limited.

These conditions predispose plants to the effects of stress. Therefore, the real value of K to crop plants is most evident in times of stress. Adequate and balanced nutrition in all essential nutrients maintains a plant's vigor and reduces its vulnerability to stress. Potassium, however, has a standout role in a plant's defense, which is primarily preventative. Resistance of some varieties to stresses of disease, temperature, or moisture is related to a greater ability to take up soil K.

Disease requires at least two conditions to strike: an entrance and a favorable environment for development. Resistance to both the incidence and the severity of disease is conferred by K through alleviating these two conditions. In some plant species, wounds, which are potential entrance sites for infection, heal more rapidly when the plant is supplied with adequate K. Even if higher numbers of disease organisms are present, plants nourished with sufficient K are less affected because of greater plant integrity. But more than the incidence, the development of

disease in a plant is affected by its K levels. When K is deficient, production of proteins and tissues stops and production materials accumulate, thus providing an ideal environment for disease to develop.

Stalk strength of annuals is favored by good K nutrition. Lodging of corn or small grains is often related to low K levels through reduced stalk strength and higher incidence of stalk disease. Because lodging increases the time involved in harvesting and reduces the yield, thereby adding to the next year's volunteer crop problem, greater stalk strength often increases the harvested yield at a lower cost.

Resistance to low temperature stress can be important for crops seeded in fall or early spring, such as the small grains and perennial crops like alfalfa. As with resistance to disease development, K's effect on the levels of other plant constituents reduces a plant's vulnerability to frost injury and winterkill.

Worldwide, but even periodically in Pennsylvania, moisture stress is the factor most limiting to crop growth. When the soil is dry, the movement of nutrients, including K, to the plant root is reduced. This effect is more critical at low soil test K levels, but becomes less so as soil K level increases. Higher soil K level, therefore, relieves some of the nutrient stress associated with drought. More than just its greater availability, K alleviates the effects of both moisture deficit and excess on the crop and counteracts the yield reductions due to either. Evidence of this was shown for both corn and soybeans in Ohio, when a moisture stress year followed a good growing season during a K fertility study. Although the yield response to the optimum level of K was low during the good growing season, that same amount of K added during the following droughty year produced a much greater yield than the plots receiving no added K. Similarly, in Maryland, the response of alfalfa to added K in a droughty season was greater than expected relative to the soil test K levels. The reason may be that K maintains the valves controlling the release of water from the plant's leaves. If the valves are "loose fitting" during a dry year, the plant loses too much water, becoming further stressed. Under stress a crop is apparently more sensitive to K level, and the yield is more dependent on that level. Although this type of response to K level is not expected every year, the increased return in Ohio for corn during the droughty year was profitable even when averaged over both years.

POTASSIUM DEFICIENCY

Soil testing is the key to good K management. Fertility management in response to deficiency symptoms, especially with perennials, is a futile effort. Leaves already showing deficiency symptoms cannot be restored by adding K. But more important, the potential yield has already been reduced by the time the deficiency symptoms appear, and the plant has become more susceptible to the effects of other stresses.

However, K deficient crops are still grown in the Commonwealth, maybe because soil testing is not practiced or because crop removal of K, as figured into the recommendation, is underestimated when a farmer adds a crop or changes the form of harvest. Consider, for example, a recommendation that is made for 125 bushels of corn grain, but a change in the farmer's plans to include a winter cover crop of rye removed in spring as ryeilage and subsequent harvest of the corn crop as silage instead of grain. The estimated removal of K from the field in the harvest would increase from 35 lbs of K_2O per acre, on which the recommendation was based, to about 230 lbs (Figure 1). Although a corn crop's uptake of K is the same regardless of harvest form, residues from the grain harvest would return roughly 115 lbs of K_2O to the soil, but instead this is removed in silage. Additional K (about 80 lbs K_2O) is also taken up and removed in the rye crop. The subsequent crop may, therefore, experience K deficiency, if soil K reserves are depleted.

Figure 3. Characteristic symptoms of K deficiency in alfalfa and corn.



If insufficient K is available, characteristic symptoms of deficiency are likely to be evident during rapid crop growth. Symptoms will appear first on lower leaves because the nutrient is mobile within the plant and K from the older leaves is taken to supply the needs of newly developing tissues. Typically, symptoms first appear at the leaf tip and spread back along the edges. In alfalfa the symptoms begin along the leaf margins as small, whitish spots (Figure 3) that coalesce with intensified deficiency. In corn and the small grains, the symptoms start with yellowing of the leaf tips, and continue with a progression of yellow, light tan, and brown along the margins as the deficiency continues, until leaf death.

MANAGEMENT

The goal of Penn State recommendations for K is to gradually build the soil test level into the optimum range and maintain it there by replacing what the crop is expected to remove (Figure 4). This approach is based on the fact that, as with any nutrient, a profitable response to added K is most likely when soil test levels of K are low. Within the optimum range, nutrient availability will probably not limit growth. The response to added K can also be predicted somewhat by anticipating stresses to the crop. If the crop is planted in a poorly drained field, or conversely, a droughty field, moisture stress is likely, and so is a response to added K if soil levels are even borderline low. Early planting or no till planting carries the possibility of cool temperature stresses to the plant, and therefore, a higher priority for K.

Interpretation of a soil analysis depends on the relationship between the amount of K the soil test procedure extracts and the K that will be available to the crop. The procedure used at Penn State (Mehlich 3) extracts the solution and exchangeable K. For most soils, this adequately predicts K availability. But for some soils, the mineral K (which is not

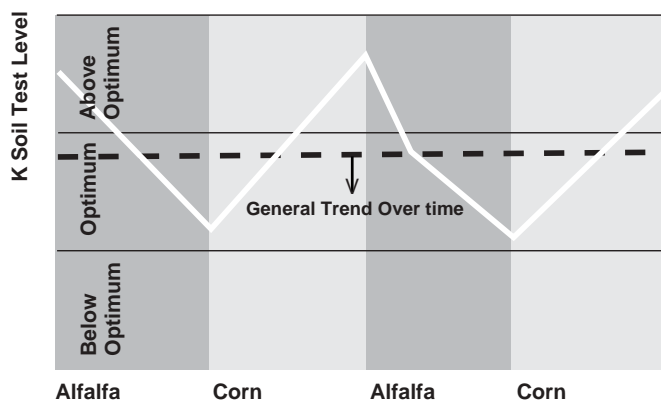
Figure 4. Sample calculations of K_2O recommendations for a soil of CEC=10 at three initial soil potash levels and for three crops.

		Below Optimum	Optimum	Above Optimum
Soil Nutrient Level:	Potassium 70 ppm			
Recommendation For:	Corn Silage, 21 T/A			
Plant Nutrient Needs:	Potash (K_2O) 180 lb/A			
Soil Nutrient Level:	Potassium 150 ppm			
Recommendation For:	Alfalfa, 5 T/A			
Plant Nutrient Needs:	Potash (K_2O) 65 lb/A			
Soil Nutrient Level:	Potassium 195 ppm			
Recommendation For:	Corn Grain, 125 bu/A			
Plant Nutrient Needs:	Potash (K_2O) 0 lb/A			

usually measured) supplies a significant amount of K to the crop, and thus the test based on the exchangeable and solution K does not fit the situation. This is most likely to occur with soils containing high amounts of the illite and vermiculite type clays. The clue may be that there is little change in soil test K when K removal is expected to be large, or conversely (because the reaction is reversible), little change in soil test K level when K is added. Although this situation occurs in relatively few Pennsylvania soils, it indicates that management of K fertility in this case, is still a matter of farm-level fine tuning. In evaluating the fertility program on the farm, observing the K soil test trend in a field over time gives a perspective that is really more important than the level at any one given time. Because maintaining the level within the optimum range over time is the goal, the effectiveness of recommendations, even Penn State's, can be evaluated and adjusted to achieve this goal individually for each field.

Managing K fertility for a corn grain/alfalfa hay rotation is a matter of extending your perspective from the K requirement of the present crop to the requirement of the next crop as well. Soil test levels are thus put into the context of the rotation. Potassium can be stockpiled during the corn years of a rotation in anticipation of the large requirement by alfalfa later in the rotation. Applying manure to supply N to corn will likely supply K in excess of what the corn crop generally removes. But because the concentration of K in the soil solution is low, and because it is held by the CEC, there is little potential for this nutrient to be lost through leaching, particularly in heavier soils of high CEC. The little leaching that does occur provides K for subsoil uptake by the deep-rooted alfalfa crop. In this case, soil test K levels may exceed the optimum during the corn years of the rotation, but for the rotation overall they should be around optimum on the average (Figure 5).

Figure 5. Potassium soil test levels for corn-alfalfa rotation during which manure was applied in corn years to build up K for hay crop requirements.



EXCESS K LEVELS

One problem in building soil K levels beyond the optimum range is that adding K is then a poor investment, or an investment with a delayed return. If manure is the source of the K, its best investment is in a field where all of the manure nutrients are in immediate demand. This, then, will provide a return on all the manure nutrients. Often, however, more manure is available on the farm than is necessary to supply the minimum nutrient level required in each field. In this case, the best use of manure is to apply it at a rate to supply its most vulnerable (to loss) nutrient, N, to meet crop requirement. Stockpiling of phosphorus (P) and K thus occurs, and a delayed return on the investment is better than no return at all. Stockpiling K is not likely to be economical if it is done with purchased nutrients, nor is it necessary because of the effectiveness of applying fertilizer K to a hay field.

Another danger of stockpiling by manure application is the potential nutrient pollution of surface water through erosion of the nutrient-rich soil. Potassium is not a problem pollutant, but when soil K levels are built up by applying manure, soil P levels are likely to be high, too. Soil conservation is, therefore, an important partner of good nutrient management.

Our knowledge about the negative effects of excess nutrients on crops is very limited, because research and recommendations have always dealt with the opposite problem. Depressed yields are a potential result of excess nutrient levels because uptake of other nutrients is often affected in such a case. At this time no one really knows the upper limit of soil test K above which negative effects are observed. The best course is to avoid excess soil nutrient levels to keep potential problems from becoming actual problems. Clearly, the only way of reducing soil K is to keep removing it, especially using crops with a high K requirement, without continued application.

High soil K levels also cause a depression of magnesium (Mg) uptake by cool season grasses. This can lead to grass tetany, a potentially fatal condition for ruminant animals. Its effects are related to N fertilization, low soil temperatures, and animal physiology. Grass, especially in fertilized pasture, accumulates K during the period of lush growth in May and early June, but Mg uptake is hindered by soil temperatures below 60 degrees F. Grazing cattle get a high K diet that increases their need for Mg, and a nutrient imbalance results in the animals. Guarding against grass tetany involves pasture and animal feed management. The potential for this condition is greatest in pastures composed totally of cool season grasses. Legumes accumulate Mg, even at soil temperatures below 60 degrees F. High K forages can also result in increased incidence of milk fever if these forages are fed to dry cows. For more information on avoiding grass tetany or milk fever, consult your veterinarian or county extension livestock agent.

POTASSIUM APPLICATION

Manure potassium

Manure is a K resource present on most Pennsylvania farms. The average K content of various animal manures is shown in Table 1. However, K concentration varies by water and bedding content. Manure nutrient analysis is the only sure way to manage amounts of applied manure nutrients. Potassium in animal manure is almost totally dissolved in the liquid fraction, so it is important to conserve this portion of the manure. As long as liquid is not lost, handling and surface or incorporated application do not affect K content or availability. If a soil sample is taken after manure application, then the available manure K will be reflected in the soil test level and recommendations. If, however, manure is applied after soil sampling, then manure K should be subtracted from the recommendations on the soil test report. Manure K is immediately available and may be considered a 1:1 substitute for K fertilizer.

Table 1. Average K₂O concentration in manure and variation in that concentration between farms.

Manure	Moisture (%)	K ₂ O (lbs/ton)	Variation (%)
Cattle	85	10	36
Pigs	91	11	53
Poultry	30	30	39

Fertilizer potassium

The most common fertilizer form is potassium chloride (KCl), called muriate of potash. It is a highly water soluble salt with a K₂O analysis of 60 to 62 percent. Processing differences result in two common chemical qualities, identifiable as red and white muriate of potash. Because the difference is of no consequence to the plant, deciding which to use should depend on the basis of cost per unit of K. The K analysis of a fertilizer material is given as the percentage of K₂O (potash) for the material. There is no actual K₂O in fertilizer, but this is the accepted and legal reporting form. Potassium recommendations are reported as lbs of K₂O per acre on Penn State's soil test report. The units of potash (K₂O) can be converted to potassium (K) by multiplying lbs of K₂O by 0.83. For the opposite conversion, multiply lbs of K by 1.2 to get lbs of K₂O.

Although KCl is the most common form of K in fertilizer, in special cases other forms are used. Chloride is generally believed to be beneficial for plants, except tobacco. Used with this crop, chloride adversely affects quality, and the sulfate form of K is preferred. Potassium sulfate, with a K₂O analysis of 50 percent, also supplies sulfur, but this is generally inconsequential since sulfur is rarely limiting for agronomic crops in Pennsylvania. Solution fertilizers may use KOH as the K source. While KOH has a high K₂O analysis, 70 percent, the K is no more available to the crop than if KCl were applied. Fertilizer solutions made with KCl may not be clear, but that is not a disadvantage from the plant's perspective.

As a salt, K has the potential to injure plant roots. Whether this becomes a problem depends on the rate of fertilizer (or manure, especially poultry manure) applied and its placement relative to plant roots. Rainfall dilutes and leaches the salts in soil, reducing the risk of injury. Because starter fertilizer is placed, by design, near seedling roots, this practice has the greatest potential for injury. You can avoid injury by reducing the rate or by placing the fertilizer farther from the seed. The Penn State recommendation is that total N plus K₂O should not exceed 70 lbs per acre when the fertilizer is placed 2 inches over and 2 inches down from the seed row, and less if placed closer. Except in low K soils, there has been little consistent benefit from banding K as a part of the starter application and, therefore, it may be best not to include K in starter fertilizer.

SUMMARY

In soil fertility we are concerned with crop response. We want to apply nutrients, K in this case, where we are most likely to get a profitable return. We have seen that crop response to K may be more indirect than direct. Effects will be an increased response to N and improved resistance to disease, drought, and cold temperatures, and may, therefore, depend on growing season conditions. In soil testing, we have a good, though not perfect, indicator of probable response to K. Soil testing needs a partner in management to make it effective: crop records. Then, by knowing the yield per field, growing conditions, problems, soil K level, and other factors, you can make decisions, based on good information, that will project into the coming years. This is important when you rotate crops in a field, especially when those crops, like corn and alfalfa, have very different K requirements. Managing nutrients makes better use of limited dollars. Manure needs to become a primary concern in nutrient management, because it is a readily available nutrient carrier on most Pennsylvania farms. And fertilizer K needs to be used wisely to ensure an adequate supply for your crops, but not oversupplied in “insurance applications.”

RECOMMENDATIONS

1. Test soil regularly, at least every three years or when changing crop. The Penn State soil test reports the amount of available K and the K_2O required, if any, to bring soil level up to optimum and offset crop K removal.
2. Evaluate the fertility program for each field by looking at the trend, over time, of the soil test levels in relation to the optimum range.
3. Plan ahead within a rotation to supply K for the crop with the larger requirement.
4. Reduce soil erosion with soil and water conservation practices, and don't stockpile nutrients in fields prone to erosion.
5. Adjust soil test recommendations using form ST 2 if crop or harvest form changes or see the Agricultural Analytical Services Lab web site at: www.aasl.psu.edu
6. Conserve the liquid portion of the manure with bedding or leakproof storage to conserve the manure K.
7. Have farm manure analyzed for its nutrient content. Apply manure uniformly and at a known rate as part of a planned nutrient management program.
8. Evaluate the need for K in a starter fertilizer relative to soil test levels. At optimum or higher K levels, a response to starter K is unlikely.
9. Keep rate of K used in starter low, or keep K away from the seed to avoid salt injury to seedlings.
10. Keep good crop records: include input amounts, measured yields, and production costs.

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Penn State College of Agricultural Sciences research, extension, and resident education programs are funded in part by Pennsylvania counties, the Commonwealth of Pennsylvania, and the U.S. Department of Agriculture.

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Issued in furtherance of Cooperative Extension Work, Acts of Congress May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture and the Pennsylvania Legislature. T. R. Alter, Director of Cooperative Extension, The Pennsylvania State University.

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CAT UC060 RV2.5M11/01ps3141