Soil Potassium and Fertility

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Plants need large amounts of potassium, one of the three major fertilizer elements. It is supplied to roots by natural sources in the soil and by fertilizers, manures, and mulches.

Our soils, except acid sandy soils and organic soils, such as peat and muck, usually have high contents of potassium—often 2 to 3 percent in the surface foot. The total potassium content of our soils generally increases from east to west; that is, in the direction of less severe soil weathering. The content tends to increase from south to north in the eastern half of the country.

Potassium (K) is a silvery-white, soft, highly reactive metal, much like sodium. In nature it does not occur in a free metallic state but is combined in many compounds and minerals. It is found in all living matter, and its salts are used as fertilizers. The term “potash” originally was used for K₂CO₃ (potassium carbonate), produced in the burning of plants, but commonly is applied also to KOH (caustic potash) and to potassium salts such as KCl (muriate of potash) and K₂SO₄ (sulfate of potash). In fertilizer and soil analyses, however, potash signifies the hypothetical potassium oxide, K₂O.

Soil potassium exists in a number of forms. One form is soluble in water. Some forms are insoluble even in strong acids. Others are of intermediate solubility. Most soil potassium is not available to plants even after years of cropping.

A large proportion of it is in primary high-potassium minerals in the silt and sand fractions. These minerals include two micas (muscovite and biotite) and two feldspars (orthoclase and microcline). The minerals in soils of arid regions are relatively unweathered and therefore are effective suppliers of potassium to plants. Biotite seems to decompose most readily. It can be an important source of potassium for crops in tropical soils when temperature and moisture are high.

Many soils also contain potassium-bearing, clay-size minerals, the hydrous micas or illites, which have less potassium and more water than the primary micas. Because of their smaller size, which gives them a greater exposed surface area, some forms of illite effectively supply potassium. The high potassium-supplying power of some soils in the Corn Belt is attributed to this source.

Such clay minerals as illite, montmorillonite, vermiculite, and kaolinite, and soil organic matter have cation-exchange capacity—that is, the ability to retain on their surfaces cations that can be replaced rapidly by other cations. Potassium ions often constitute from 1 to 3 percent of the exchangeable cations in the soil.

Exchangeable potassium is the important reservoir of readily available potassium. It may be derived from potassium-bearing minerals or from fertilizers, other soil additives, or crop residues. It generally represents only a small part of the total potassium. For example, in a soil containing 40 thousand pounds of potassium (to convert to potash, K₂O, multiply by 1.2) an acre at plow depth, the exchangeable potassium might be 400 pounds; that is, 1 percent of the total.

In turn, the soluble potassium that is free to move with the soil water amounts to a small fraction of the exchangeable quantity, about 1 to 5 percent. The soluble and exchangeable forms are in equilibrium with each other. A reduction of the soluble form by crop removal or leaching is followed instantly by a transfer from the ex-
changeable form so as to maintain the equilibrium relationship.

When a soluble potassium salt is added to the soil, a transfer occurs in the opposite direction, from solution to exchange surfaces, and the equilibrium is reestablished rapidly at a higher available potassium level. Because of this relationship, no distinction is made between soluble and exchangeable forms in the usual determination of exchangeable potassium by salt or acid extractions or other methods.

When a soluble potassium fertilizer, such as muriate of potash, is applied to some soils that contain expandable lattice clay minerals (like montmorillonite and vermiculite and some forms of illite) a substantial part of it may be converted into a form which is not readily available. Drying appears necessary for this fixation by montmorillonite, but not by illite. G. Brown, of the Rothamsted Experimental Station, in England, has named a potassium-fixing form of illite in Irish soils "degrading illite."

Fixation and release in these minerals are viewed as the comparatively slow entry and exit of potassium ions within the layers of cations located between silica layers of the lattice. When a large fraction of these cation sites is occupied by potassium ions, the lattice is contracted. The degree of subsequent availability of the fixed potassium depends on such factors as the kind of crop, type of mineral, moisture content, and the levels of exchangeable potassium, calcium, and hydrogen.

The illite of some river sediment soils in the Netherlands, named "ammersoite" by J. Temme and H. W. van der Marel, fixes fertilizer potassium so firmly that potatoes and clover cannot be grown successfully without extremely high potash applications, although sugar beets, oats, barley, and wheat yield satisfactorily.

Fixed potassium should not be considered as a total loss but as an addition to the reserve supply forms, which helps to reduce leaching and luxury consumption of soluble and exchangeable forms. Its availability generally is intermediate between that of exchangeable and natural nonexchangeable forms. In the case of illites, fixation may be regarded as the restoration of potassium previously lost from the crystal lattice by weathering, leaching, and cropping.

Another equilibrium exists between exchangeable and clay lattice forms, but this equilibrium is more sluggish than that between soluble and exchangeable forms. The overall equilibrium may be represented as follows: Soluble ⇌ Exchangeable ⇌ Lattice (fixed; illitic).

The time required for equilibrium to be established between each pair of forms increases from left to right. An increase of soluble potassium, as from a fertilizer application, results in a movement of some potassium to the right, and a decrease, as from cropping, in a movement to the left.

The release of the nonexchangeable forms to the more readily available exchangeable and soluble forms has been increased by cropping, freezing and thawing, liming, and drying. Drying fixes potassium in some soils if the readily available level is high but releases it if the level is low.

The exchangeable form is never depleted completely by cropping but it often reaches a minimum level characteristic of the soil and the cropping situation. In soils containing all the various forms, the exchangeable potassium value is usually lowest at harvest time and highest in the spring before planting.

Other cations can affect some of the forms of potassium.

When water is added to a soil, a small fraction of the exchangeable potassium changes to the soluble form because of replacement by calcium and magnesium ions originally in solution. During a drying period, some soluble potassium replaces an equivalent amount of calcium and magnesium in the exchangeable forms.

Both the fixation and the release of potassium in illite are favored by an
increase in the exchangeable calcium relative to exchangeable hydrogen, which is the basic process in liming. The increased calcium ions evidently expand some of the clay mineral lattice interlayers sufficiently to facilitate the entry or exit of potassium ions. Ammonium ions and hydrogen ions (actually hydronium ions, \( \text{H}_3\text{O}^+ \)) are of about the same size as potassium ions and therefore interfere and compete with potassium in fixation and release reactions involving the interlayers of expandable lattice minerals. Ammonium added to a soil containing vermiculite, montmorillonite, or degrading illite thus may become fixed and thereby decrease the fixation of subsequently added potassium. The converse would occur where the potassium was applied first.

**Losses of Soil Potassium** occur in cropping, leaching, and erosion. Soils that cannot supply significant amounts of natural and fixed non-exchangeable potassium (such as organic soils; acid, coarse-textured soils; and acid soils that do not contain illites) have no reservoir of reserve potassium to maintain the exchangeable form at a moderate or high level. Potassium removed from such soils by cropping must be replaced frequently by potassium in fertilizers. Exchangeable potassium is subject to leaching with water by exchange with hydrogen and other cations, and leaching losses in permeable soils in humid regions must be replaced. If clay is abundant in the subsoil, potassium leached from the surface soil may become concentrated there in exchangeable and fixed forms. Erosion of surface soil in extreme cases may cause an appreciable loss of available potassium by the removal of fertilizer particles and of soil particles and organic matter that have high exchangeable potassium content. Because the total content of potassium usually does not vary abruptly with depth, erosion does not alter appreciably the total potassium of the surface soil.

Crops remove large amounts of potassium from soil, as compared with other nutrients except nitrogen and calcium. The actual amounts are affected by the species, variety, and size of plant and by such factors as level of available potassium, supplies of other elements, soil moisture, soil aeration, and temperature. The potassium contents needed for average to good acre yields therefore should be regarded only as approximate needs.

The grain portion of barley, oats, and wheat crops contains about 10 pounds. The straw contains about 30 pounds. Corn grain contains 15 pounds and the stover about 50 pounds. The aboveground part of a cotton crop may have a content of 40 pounds, of which about one-third is in the lint and seed. Various grasses contain 25 to 50 pounds. Alfalfa and sweetclover contain 100 to 150 pounds, and other legumes 50 to 75 pounds. Potatoes contain 150 pounds, 100 pounds in the tubers and 50 pounds in the vines. A 15-ton crop of celery may contain 200 pounds of potassium.

When a high supply of readily available potassium is present and other growth conditions are favorable, the uptake by crops may far exceed average requirements. That may result from an increase in the size of the plants and from the luxury consumption of potassium.

Annual crops do not take up potassium at a constant rate but approximately according to the size of the plant at each stage.

In experiments with potatoes at the Virginia Truck Experiment Station, R. L. Carolus learned that during the 8th week of growth the crop absorbed about 1 pound of potassium an acre a day but absorbed 4 pounds a day between the 10th and 12th weeks. The potassium supply during the period of greatest growth should be enough to meet a high rate of demand.

Plant roots readily absorb soluble and exchangeable potassium, as must be obvious from the high potassium requirements of some annual crops.
Potassium apparently enters the root cells in combination with the organic compounds produced in metabolic processes within the plant. Once inside the roots, the potassium evidently reverts to an ionic form and can move rapidly through the plant. Although it is retained moderately tightly by living cells, it does not become permanently combined in organic molecules or structural components and is easily removed at the death of the cell.

During the time that seeds, fruits, and nuts develop, potassium moves to them from the leaves. Cereal plants normally appear even to lose a portion of their potassium to the soil as they approach maturity. Appreciable fractions of the potassium content of plants are lost sometimes by the leaching of potassium from the leaves by rain. This high mobility has hindered the determination of the essential functions of potassium in the growth of plants.

Potassium is necessary for several basic physiological functions—the formation of sugars and starch and their movement between different parts of the plant, the synthesis of proteins, normal cell division and growth, and the neutralization of organic acids. Potassium also assists different plants in a number of more specialized ways. It enhances the size, flavor, and color of some fruits and vegetables. It increases the resistance of some plants to particular diseases. Potassium improves the rigidity of straw and stalks, so there is less lodging. It increases the oil content of oil-bearing seeds. It helps overcome influences of adverse weather, such as low soil moisture and low temperature, and of poor physical soil conditions, such as compaction and inadequate aeration.

You may not be able to notice any deficiency effects in plants that have moderately inadequate levels of potassium because the usual symptom of this degree of deficiency is a general reduction in growth. That is not easy to detect unless you compare the size of the plants with that of others that are growing in a similar place and are getting enough potassium. Furthermore, this is a general deficiency symptom for many nutrients. Analyses and tests of the soil and plant may reveal a potassium deficiency.

The onset of characteristic visual symptoms, which signifies a more severe deficiency, means that production has already been seriously impaired. The application then of fertilizer potassium cannot overcome the damage already incurred, especially in annual quick-growing crops.

If legumes, such as clovers and alfalfa, and grasses are growing together, a shortage of potassium may lead to the reduction or disappearance of the legume without the occurrence of any severe deficiency symptoms. Grasses and weeds can thrive at levels of available soil potassium that are inadequate for forage legumes.

The general leaf pattern when potassium is low begins with a yellowing of the tips and edges. The yellow area then gets broader. The tissues at the edges and later the entire leaf die as the deficiency becomes more severe. These symptoms appear first in the older leaves and later in the younger leaves, because in line with the general tendency of potassium to concentrate in the rapidly growing tissues it moves from the older leaves (at their expense) to the younger leaves.

At first, in clover and alfalfa you usually see small, white spots around the edges of the leaf. As the deficiency worsens, the spots become more numerous, the edges and entire leaf turn yellow, the edges are scorched, and the older leaves drop.

In corn, the tips of the older leaves first become yellow. Streaks of yellow run lengthwise through the leaves. The edges become scorched. The stalks are weak and short. The ears are small, poorly filled, and chaffy at the tip.

A deficiency symptom in cotton, known as cotton rust, first appears as yellowish, mottled margins of the leaf and yellow spots between the veins. They finally merge to make a dry,
curled, reddish-brown leaf, which drops prematurely. Unopened and partly opened bolls containing cotton of poor quality result from this extreme deficiency of potassium.

The supply of potassium to plants often affects and is affected by the level of other nutrients.

In soils containing expandable lattice clay minerals, an increase in exchangeable calcium sometimes causes the fixation or release of nonexchangeable potassium, depending on whether the exchangeable potassium level is relatively high or low. Under the condition of very high soluble or exchangeable calcium and very low exchangeable potassium, the calcium may depress the immediate supply of potassium to plants. That appears typical also of some calcareous soils.

But normally within a wide range of saturation of the cation-exchange capacity with calcium, the calcium has only a minor effect on the uptake of exchangeable potassium. Actually an increase in the exchangeable potassium level may reduce the uptake of calcium or magnesium and cause the luxury consumption of potassium, even though the absolute potassium level is very low relative to the level of the other two cations, as is customary. Such an effect has been observed in alfalfa, clover, tomatoes, apples, and prunes.

The usual effects of nitrogen and phosphorus, the other two major fertilizer nutrients, are associated with nutrient balance in the plant. If the supply of nitrogen and phosphorus is high relative to that of potassium, growth may be rapid at first, but the potassium concentration in the plant may become reduced to a deficiency level. Thus, even though the total potassium uptake by the plant may be increased by the high nitrogen and phosphorus levels, additions of potassium to the soil would be necessary to maintain the nutrient balance required for rapid, continued growth. In situations of high available potassium level and low nitrogen or phosphorus supply, luxury consumption of potassium is to be expected.

Sodium is not considered to be an essential plant nutrient, but some plants (for example, beets, celery, turnips, and cabbage) require it for maximum production even in the presence of ample potassium.

Another group of plants, including barley, oats, wheat, cotton, tomatoes, asparagus, and alfalfa, respond to sodium when the potassium supply is inadequate.

A third large group of crops respond to sodium slightly or not at all at any potassium level. Among them are corn, rye, potatoes, lettuce, and soybeans. Sodium or potassium generally will depress the uptake of the other cation, but the results of this mutual relationship in any particular situation will depend on the levels of available sodium and potassium and the relative ease of absorption of the two cations by the plant.

The efficient management of soil with respect to potassium must be based on a number of soil-management factors: The kind of crop, the rotation system, the livestock-management system, the nature of the soil, the liming and fertilizer practices, and the weather.

Satisfying the potassium requirements of a cropping system should be based first on the natural potassium-supplying ability of the soil. In this regard soils range from organic and acid sandy soils (which cannot be depended on for any natural reserve supply) to clay soils that contain large amounts of relatively unweathered potassium minerals, which do not have to be supplemented by potash fertilizer.

Soils having little or no reserve potassium supply and low cation-exchange capacities require the frequent additions of small or moderate amounts of potassium. Large single applications to such soils may result in higher losses through leaching and unbalanced nu-
trient relations in the crop through luxury consumption. Leaching losses from rain can be serious in winter-fallowed soil of regions in which winters are warm. A winter cover crop reduces this loss. The continued removal of hay crops, however, severely depletes the soil potassium, and it must be increased by adding potash.

When rotations include row crops that respond markedly to potash (for example, cotton, tobacco, and potatoes), a potash application should be made to these crops at planting time. Excessive rains after planting may make additional applications necessary to replace leaching losses.

Legume crops that are removed from the land severely lower the available potassium level of soils. Liming of acid soils improves various growth conditions and thereby increases potassium requirements of legumes, but it also reduces the leaching of potassium. In a study at the North Carolina Agricultural Experiment Station, Adolph Mehlich found that even clay subsoils would not retain potassium effectively until they were limed.

If sodium is applied to the soil, either as sodium nitrate or as a treatment for a sodium-responsive crop, the extent of the substitution of this cation for potassium should be considered in estimating potash applications.

Loams and clays containing an abundance of illitic clay minerals or unweathered primary potassium minerals can be expected to supply from a moderate fraction to all of the potassium required for a cropping system. Younger soils in this group can be cropped for many years before fertilizer potash has to be included in the soil-management program. The exact length of time, of course, depends on the amount of potassium in crops removed from the land and on other losses from the soil.

In a soil-pasture-livestock management system on such soils, the potassium cycle would be as follows: Mineral, to exchangeable, to soluble, to plant, to animal, to manure, to soluble, to exchangeable, to mineral (fixed). After the forage plants have absorbed soluble soil potassium which has been replaced from the exchangeable form and released earlier from mineral lattice forms, the pastured animals consume it during their feeding. A large fraction of it is returned to the soil in the animal manure, some of which becomes, in turn, soluble, exchangeable, and finally fixed in mineral lattices. The main loss of potassium in this cycle arises from the removal of the animals and animal products from the land.

Byron T. Shaw, of the Department of Agriculture, has estimated that in such a system, 75 to 90 percent of the potassium removed from the soil would be returned to it. Other cropping and livestock systems will conserve a smaller fraction. If sheltered animals are fed hay from the same farm, losses of potassium may occur if the manure is improperly conserved before it is applied to the soil.

If the straw of small grain and corn crops is not removed from the land, only about one-fourth of the potassium in the crop is permanently lost from the soil. The harvested portions of potatoes, celery, other vegetable crops, and tobacco contain much higher fractions of the total crop potassium. Much of the potassium in leaves of deciduous fruit and nut trees that drop on the ground eventually will return to available soil forms. In places where the native potassium supply is inadequate to replace losses, fertilizer potash must be applied. In many soils, a fraction of it will be fixed, and the availability of the application to the current crop will be lowered accordingly. This fixed potassium will be slowly available in the future, however, and so improve the ability of the soil to supply potassium.

The determination of currently available potassium is made by a soil test or by a plant tissue test. Information about the reserve supply is obtained from other laboratory measurements and from the history and general knowledge of the particular soil.