WHAT *is the importance of potassium to plants? What plants need it most? What are the effects of "potash hunger" on cotton, tobacco, potatoes, and other crops? How is the soil depleted of potash? Why does potash act differently in different soils? These and other questions are discussed in this article.*

Soil Potassium in Relation to Soil Fertility

By H. P. Cooper, Oswald Schreiner, *and* B. E. Brown [1]

POTASSIUM is very widely distributed in the earth's crust as a constituent of silicate minerals such as orthoclase and microcline, and certain forms of mica, chiefly muscovite. Under the influence of various weathering factors, principally temperature changes and the action of water, these and other potash-containing silicates are converted slowly to ordinary clay, termed kaolinite, and water-soluble potassium.

Oceanic waters contain only about 0.04 percent of potassium in contrast with about 2.45 percent in the earth's crust. Even with such wide distribution of potassium in the earth's crust and in the ocean, accumulation of soluble potassium compounds suitable for fertilizer purposes occur in large quantities in but few places, chiefly in Germany and France. In recent years underground deposits of commercial importance have been found in the United States, principally in the Southwest. In the European deposits the crude potassium salts occur as layers 80 to 100 feet thick, covering strata of common salt, which indicates that their origin was oceanic. The principal source in these highly developed potash mines are carnallite, consisting of potassium and magnesium chloride; and kainite, composed of magnesium sulphate and potassium chloride. Sylvite, chiefly potassium chloride, occurs principally in the Alsatian mines. Another source, although a comparatively minor one, is potassium nitrate found associated with sodium nitrate in Chile and Peru.

Inasmuch as soils are produced by the breaking down of rocks by the process of weathering, all soils contain potassium in the potash-bearing constituents, such as feldspar, occurring in these rocks. Investigators time and again have shown that practically all the potash

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minerals originally present in rocks are found as such in arable soils. As the potassium in such minerals becomes available or as potassium salt is added to the soil in the form of fertilizer, crop plants utilize its compounds as is evidenced by an analysis of their ash, in which the potassium is found principally as potassium carbonate, although occurring in the living plant in both organic and inorganic combinations. Since human beings and animals of all kinds obtain their food supply directly or indirectly from plants, it is not surprising that potassium is found in all animal tissues and secretions, such as muscles, blood, urine, albumen, eggs, milk, hair, etc. The dependence of all life upon potassium is, therefore, as self-evident as is the case with nitrogen or phosphorus.

QUANTITY OF POTASSIUM IN SOILS

Unlike nitrogen and phosphorus the quantity of potassium found in soils is comparatively high. A mineral soil with a nitrogen content of 0.2 percent—about 4,000 pounds of nitrogen in 6 or 7 inches of topsoil—is considered to be well supplied with this particular element, and the same applies to phosphorus. A soil with only 0.2 percent of total potassium would be rated very low in this element. There are some cultivable soils, such as sands and light sandy loams with pervious subsoils, and mucks and peats, which are generally not only very deficient in available potassium but quite low in total potassium. It is such soils that give the most striking response to applications of available potassium in fertilizers. The ordinary range of potassium, expressed as the oxide (K_2O), in the upper or plow surface of mineral soils will range from 0.15 percent in sands to 4 percent and over in clay soils. Taken as a whole, however, the general run of soils contain fairly large quantities of potash, averaging approximately 2 percent. This means about 40,000 pounds of potash in the plow layer whereas nitrogen will hardly exceed 4,000 pounds and phosphoric acid 3,000 pounds. It is important to consider, however, that even with such a large reserve of potash in soils it is generally present in relatively insoluble compounds. A chemical analysis of a few typical soils, ranging in texture from sand to clay, shown in table 1, will help to bring out the variation in potash in different soils and the relation of this constituent to depth of soil.

Table 1.—*Potash (K_2O) content in different soils at varying depths* [1]

Soil type	Location	Depth	Potash (K_2O) content	Soil type	Location	Depth	Potash (K_2O) content
		Inches	*Percent*			*Inches*	*Percent*
Lakewood sand	New Jersey	0-8	0.163	Canfield silt loam	New York	0-8	2.02
		8-24	.245			8-24	2.35
Sassafras sand	do	0-8	.233			24-36	2.71
		8-24	.287	Vergennes clay loam	do	0-8	2.57
Sassafras fine sandy loam	do	0-8	.737			8-24	2.94
		8-24	.833			24-36	3.23
Dunellen sandy loam	do	0-8	1.009	Vergennes clay	do	0-8	3.51
		8-24	1.25			8-24	3.91
Merrimac loam	do	0-8	1.46			24-36	3.96
		8-24	1.54				

[1] New Jersey analyses reported in (*37a*); New York soils in (*34a*).[2]
[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

POTASSIUM REMOVED BY CROPS

In practically every type of farming a fairly heavy drain on the supply of available potash takes place annually. This is well shown by plant analysis, which discloses that potassium is freely removed from the soil. It is essential therefore that the supply of available potassium be maintained at a proper level. This is particularly true of tuber crops and those producing starch or sugar. Some idea of how much potassium is utilized by different crop plants is shown in table 2 taken from Van Slyke (*441*).

Table 2.—*Approximate amount of potash* (K_2O) *in different crops*

Crop	Portion of crop	Yield per acre	K_2O removed
			Pounds
Corn	Grain	25 bushels	5.5
	Stalks	1,500 pounds	21.0
	Cobs	250 pounds	1.1
Total			27.6
Wheat	Grain	25 bushels	6.0
	Straw	2,500 pounds	15.0
Total			21.0
Rye	Grain	20 bushels	6.7
	Straw	2,000 pounds	17.0
Total			23.7
Oats	Grain	25 bushels	4.8
	Straw	1,250 pounds	15.6
Total			20.4
Alfalfa [1]		10 tons	100
Clover, red [1]		6 tons	60
Potatoes		150 bushels	45
Sweetpotatoes		200 bushels	55
Beets, common		12½ tons	125
Turnips, common		10 tons	90
Carrots		5 tons	53
Cotton	(Total crop)		32.2
Tobacco	Leaves	1,000 pounds	57.5
	Stalks		20.5
Total			78.0
Sugarcane	Stalks stripped	15 tons	18.3
	Leaves and tops	10 tons	18.0
Total			36.3

[1] Fresh cut.

That much potassium is taken out of the soil by crops is obvious from table 2 and that some crops take out more than others is equally clear. When crop after crop is produced on the same soil and sold away from the farm in the form of grain or livestock the supply of available potassium is gradually but nevertheless surely depleted. As a result of this loss in fertility crop yields are gradually reduced until a point is reached where soils once well supplied with available potash are being farmed at a minimum profit and frequently at an actual loss unless manures and potash-containing fertilizers are employed to compensate for the losses.

SOURCES OF FERTILIZER POTASH

The principal potash fertilizer materials used commercially are potassium chloride (muriate of potash), potassium sulphate (sulphate of potash), potassium nitrate, and manure salts. All of these are high-grade potash salts, the potassium nitrate containing nitrogen in addition to potash. Of these different salts the muriate, sulphate, and manure salts are the most extensively used. Many miscellaneous sources of potash are available also, but generally speaking their potash content is too low to warrant their commercial use. They do, however, possess considerable value when used locally and wherever the expense of transporting them is not excessive. A description of the various potash fertilizer materials will be found elsewhere in this Yearbook.[3]

The question is frequently raised as to the comparative value of the different commercial potassium salts in crop production. In general it might be said that there is very little difference in their effects except in very special cases, when the accompanying constituents or accidental impurities are usually the cause.

Results of experiments over a period of years (*295a, 360a, 360b*) on the principal soil types of the southeastern Cotton Belt with sources of potash in mixtures with phosphoric acid and nitrogen show that there is not a wide variation in their effects on cotton yields. On 12 soil types in the Coastal Plain, potassium chloride gave an average yield of 1,212 pounds of seed cotton per acre, potassium sulphate 1,231 pounds, and kainite 1,133 pounds. On five soil types in the Piedmont, potassium chloride gave an average yield of 938 pounds, potassium sulphate 937 pounds, and kainite, 892 pounds. On all of these soils potash gave an increased yield, and on some the crop failed or was greatly reduced in growth and yield unless potash was applied.

In experiments with sweetpotatoes on six soil types (*360d*) in the large sweetpotato-growing sections of the South, potassium sulphate as the source of potash in fertilizer mixtures with phosphoric acid and nitrogen gave an average yield of 148 bushels per acre, potassium chloride 142 bushels, and kainite 94 bushels. The low yield from kainite is attributed to injury from excessive salts carried in this low potash-containing material. Sweetpotatoes require a large amount of potash. Potash salts containing low percentages of potash are not suitable for use in sweetpotato fertilizers unless precautions are taken to apply the fertilizer so as not to injure the young plants. Best results were secured with 175 to 200 pounds of potash per acre.

In experiments with celery and lettuce in Florida (*360c*) on fine sand, potassium sulphate as the source of potash in mixed fertilizers gave a yield of 511 crates and potassium chloride 574 crates of celery per acre. Potassium sulphate gave a yield of 434 crates and potassium chloride 430 crates of lettuce per acre. Potash was effective in maintaining yields of these crops on the Florida soils. On other truck crops, including cabbages, peppers, tomatoes, and strawberries, potassium-magnesium sulphate gave somewhat larger yields than potassium sulphate or potassium chloride.

Experiments on soils in the potato belt of North Carolina (*295a,*

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[3] See Fertilizer Materials, p. 487.

467a) show only slight variations in yields from different potash sources. On Dunbar fine sandy loam potassium sulphate gave an average yield of 187 bushels per acre and potassium chloride 173 bushels. On Portsmouth sandy loam the two potash salts were equally effective in crop production. On Bladen fine sandy loam potassium sulphate gave an average yield over a 5-year period of 254 bushels per acre, potassium chloride 274 bushels, and potassium-magnesium sulphate 237 bushels. Potash increased the yields of potatoes on these soils; 80 to 100 pounds per acre gave the best results.

POTASSIUM CONSUMPTION IN THE UNITED STATES

The consumption of potassium varies widely in the different soil and crop regions. It has been estimated that in the United States as a whole about 410,000 tons of potash were consumed in 1937, more than one-half of which—218,500 tons—was used in the Southern States. The next largest consuming regions are the Middle Atlantic States with 62,700 tons and the Middle Western States with 59,400 tons. The New England group consumed 26,500 tons and the Western States 17,000 tons. These were chiefly used in complete fertilizers, the composition of which varied for different crops and soils, but with an average content of potash in the fertilizer formula of approximately 9 percent in the New England States, 6 percent in the Middle Atlantic and Western States, 5½ percent in the Middle Western States, and 4 percent in the Southern States. The estimated consumption of potash (as tons of K_2O) used in the various States in 1937 was as follows:

	Tons		Tons		Tons
North Carolina	44, 301	Louisiana	6, 941	Minnesota	838
Florida	35, 813	Tennessee	6, 462	Rhode Island	754
Georgia	33, 030	Kentucky	5, 301	Iowa	398
South Carolina	27, 644	Massachusetts	4, 369	Oklahoma	348
Alabama	27, 590	Texas	4, 335	Idaho	347
Pennsylvania	19, 705	West Virginia	3, 564	Kansas	336
Virginia	18, 335	Connecticut	3, 537	Arizona	293
Ohio	16, 634	Arkansas	3, 474	Montana	246
New York	16, 096	Missouri	3, 211	New Mexico	185
Indiana	15, 923	Illinois	3, 206	Utah	123
Maine	14, 216	Wisconsin	2, 758	Wyoming	92
Mississippi	13, 341	Delaware	2, 504	Colorado	57
California	11, 598	Washington	1, 862	Nevada	31
New Jersey	10, 951	New Hampshire	1, 319	Nebraska	16
Maryland	9, 639	Vermont	1, 271	North Dakota	14
Michigan	8, 131	Oregon	1, 045	South Dakota	4

NEED FOR AND EFFECTS OF POTASSIUM

Like nitrogen and phosphorus, potassium must be in an available form, or in other words soluble in the soil moisture, before plants can utilize it. Without sufficient available potassium in the soil crop plants suffer in reduced vigor, greater susceptibility to disease, impairment of growth processes—including assimilation of carbon dioxide—failure to develop normally and translocate starch within the plant, and in other ways equally adverse. On the other hand, the presence of an adequate supply of available potassium in the soil promotes the health and improves the quality of the plant, insures greater efficiency in photosynthesis, increases resistance to certain diseases,

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offsets the effect of an oversupply of nitrogen, and helps the plant to utilize soil moisture more advantageously, particularly during droughty spells. A plentiful supply of available potassium, moreover, insures the development of well-filled kernels in cereal grains and gives stiffness to the straw, encourages the growth of different leguminous crops, assists in the functioning of chlorophyll, and is particularly helpful in the production of starch- or sugar-forming crops.

Potassium might be considered to stand between nitrogen and phosphorus in its effects on plant growth. It tends to slow down the effects resulting from excessive nitrogen and to prevent the too rapid maturity often induced by too much available phosphorus. It is clearly evident, therefore, that the application of available potassium compounds to the soil or the employment of practices tending to make the unavailable potassium compounds of the soil available is particularly important to the maintenance of soil fertility and to the production of crops of high quality. In fertilizer mixtures potassium acts as a stabilizer to nitrogen and phosphorus.

A lack of available potassium in the soil is very likely to result in poor quality of the crop. Tubers from potash-starved potato plants have been found to be watery, contain less starch, and be of poor edible quality generally, particularly after several months' storage. A deficiency of available potash very often results in a measured bushel of wheat several pounds under weight owing to poor filling out of the kernels. This in turn affects the quality of the flour. Leaf quality of tobacco is markedly influenced by the kind and amount of potassium applied to the plants, which may attain full height but will have poor flavor and lack the free-burning quality essential to commercial requirements. Likewise it is generally recognized, as previously indicated, that available potash increases the resistance of many crops to disease. Certain diseases of the cotton plant vanished as soon as potash was obtainable and could again be used at normal rates following the shortage of the World War period.

About one-half the potash used on crops in the United States is applied to cotton. Without it, or with too small an amount, profitable cotton production is practically hopeless. This is particularly true of the general run of cotton soils in the Southeastern States. In the days when the cottonseed or later the meal was put back into the soil most of the potash extracted by the cotton crop was conserved. In more recent years cottonseed meal has been used as a valuable byproduct for stock feeding, a large share of it going abroad. This is simply a method of selling the potash of the soil, thereby making the cotton grower buy commercial potash to offset the loss.

In the case of potatoes, one of the most heavily fertilized crops in the United States, a ton or more of high-grade fertilizer to the acre is a common application in potato-producing sections along the Atlantic seaboard from Maine to Florida. Without potash in the fertilizer the well-recognized symptoms of potash hunger soon become evident and it is questionable whether much of the commercial crop could be produced without it. Tobacco, sugar beets, certain cereals, and truck crops in general, whether for canning or for consumption fresh, quickly reflect any potash shortage. While other farm crops get along on less potash than those enumerated, every crop without exception must have some available potash if it is to thrive and produce normally.

Amounts of Available Potassium Required for Various Crops

Plants differ markedly in their content of potassium. Plants grown together in soil cultures for 56 days by Newton (*279a*) showed the following potassium content: Wheat 4.16 percent, barley 4.04, sunflowers 3.47, and beans 1.19. Plants grown together in solution cultures for a similar length of time showed the following potassium content: Barley 6.92 percent, wheat 6.73, peas 5.25, sunflowers 5.01, beans 4.02, and corn 3.87. The percentages of potassium in barley and wheat grown in culture solution are relatively high, and are followed by those of peas and sunflowers, beans, and corn. In the cases of the four crops grown in loam soil, the same order of potassium content was obtained, except that wheat was slightly higher in potassium than barley, whereas when grown in the solution barley was slightly higher than wheat. However, wheat and barley contained considerably more potassium than was found in the other plants. The feeding power of various plants for potassium is probably related somewhat to their rate of growth. Plants that grow slowly can probably utilize the less soluble forms of potassium to a greater extent than those that grow rapidly, since they have a longer time in which to absorb the potassium.

For the production of satisfactory yields of alfalfa, corn, and cereals, about 160 pounds per acre of readily available potassium are needed according to Truog (*420a*). For potatoes, tobacco, garden, and other special crops, an even greater amount may be desirable. A crop feeds on both the readily and slowly available potassium. The readily available portion should be abundant enough to supply at least 75 percent of the needs of general farm crops and practically all the needs of special crops like potatoes and tobacco.

Crop plants have been grouped by Hartwell (*149a*) according to their response to applications of potash as follows: Low potash-response crops—oats, rye, wheat, millet, and carrots; medium potash-response crops—barley, rutabagas, parsnips, potatoes, and cabbage; high potash-response crops—tomatoes, mangels, buckwheat, corn, and onions. This classification, however, is based on the experiments at the Rhode Island Agricultural Experiment Station, and it is doubtful whether it is generally applicable to all soil regions.

Hester and Shelton (*162*) have shown that the efficiency of potassium utilization by vegetable crops varied with the different soil types. A given application of potassium was less effective on Bladen sandy loam than on either Norfolk fine sand or Portsmouth loamy fine sand. Bladen sandy loam showed the highest power for fixing potassium in a state unavailable to vegetable crops. The calculated percentages of removal of the added and replaceable potassium were 38.5 from the Bladen sandy loam, 82.8 from the Portsmouth loamy fine sand, and 84.8 from the Norfolk fine sand. Such results would definitely suggest that a higher available potassium level would be required for the Bladen than for the Portsmouth and Norfolk soils.

Bryan (*54a*) has also called attention to the wide variation in the availability of potassium in different soil types. He states that it is not necessary to have as high a level of potassium fertilization in the sandy soils of the Coastal Plain as in the soils of the Corn Belt. The potassium in sands is considered to be relatively highly available. It is possible to produce successful crops on these sandy loams at a lower potash level than would be possible in other regions where the soils are ordinarily inherently more productive. In general, it may be said that cotton growers in the Southeast have not raised the level of available potassium in their soils to the extent that is common in some of the central-western soils.

In the Southeastern States where the rainfall and temperature are relatively high, the soils have been thoroughly leached and are relatively low in available potassium. It has been pointed out that a large percentage of the total potash fertilizer used in the United States is applied to cotton and tobacco. Some of the other commonly grown field crops of this region, such as corn, small grains, and hay, produce satisfactory yields at a relatively low potassium level as compared with that required by tobacco and cotton. Where the latter crops are grown after legumes, corn, and small grains, potassium is very often the limiting factor in determining the yield. Since many of the soils in this region have a relatively low fixing power, considerable potassium may be lost in drainage if heavy applications of potassium salts are made. It is therefore often more practical and profitable to make applications immediately preceding all crops which give a marked response to potassium fertilization.

POTASH CYCLE

When a potash fertilizer salt is applied to the soil, part of the potassium is fixed in unavailable compounds. The extent of the fixation is almost always directly proportional to the content of colloidal matter in a soil, being greatest in clays and clay loams and least in light sands and sandy loams. The fixation or holding of potash by the soil is of great importance as it serves as a check against too rapid solution and leaching and makes for a more continuous supply of available potash.

Potash salts are more readily fixed than nitrogen salts but less readily fixed than the phosphates. While potash salts readily dissolve in the soil moisture they soon are taken out into less soluble forms as they unite with the colloidal complex and replace calcium or some other element associated with the finest soil particles. Potash so fixed may move slowly in the soil, the rate being dependent upon the amount and nature of the colloidal complex. In light sands and sandy loams the movement may in time carry the potash down to the ground water while in soils with high clay and silt content the movement is slow and frequently restricted to the upper 4 to 6 inches of soil.

The potash cycle is therefore a fairly simple one compared to that of nitrogen with its many transformations and its tie-up with organic matter. It is fixed by the soil; it is removed by crops and to some extent in drainage waters; it is returned to the land in crop residues or in the manure of farm animals, or it is exported in crops sold. While potassium occurs in nearly all animal tissues, there occurs no such accumulation as there is of phosphorus in bones or nitrogen in body proteins. The potassium remains essentially soluble and passes through the animal, being excreted chiefly in urine. The cycle is therefore essentially from fertilizer to soil moisture to plant, with the soil particles acting as a regulator of solubility; then from the plant to the animal; and through animal wastes back to the soil. The losses occur through leaching, sale of crops from the land, and wastage of manures, especially the liquid portions. Such losses must be supplied in added fertilizer to prevent potash deficiency and lowered soil fertility.