

Potash in Massachusetts Soils
Its availability for crops.

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By F. W. Morse

The proper use of commercial fertilizers is a factor in farm management based on related information from many sources. This bulletin brings together results from soil surveys, soil analyses, and general investigational work in Massachusetts with the aim of promoting the more efficient use of potassium as a plant-food element.

MASSACHUSETTS STATE COLLEGE
AMHERST, MASS.

POTASH IN MASSACHUSETTS SOILS: ITS AVAILABILITY FOR CROPS

By F. W. Morse, Research Professor of Chemistry

The Soil Survey Shows the Soils to be Derived from Potash Minerals

The soils of Massachusetts have been surveyed and classified by the Bureau of Soils of the United States Department of Agriculture; and the results have been published from time to time, as one area after another was covered. The survey of Plymouth County was made by W. B. McLendon and G. B. Jones, and was the first to be published. The other counties were all surveyed by W. J. Latimer, who was assisted by men supplied by the State Department of Agriculture. The publications of Mr. Latimer's survey began with Norfolk, Bristol, and Barnstable Counties, issued in one bulletin, and ended with Franklin County. His continuous service gave consistency to the classification of soils into series.

The system of classification is described in Soil Survey of Norfolk, Bristol, and Barnstable Counties (p. 1058):

Soils can be divided into three main groups. Those of the uplands, where the material has been accumulated by the action of ice, and consists of a heterogeneous mixture of rock flour, sand, gravel, and stones, form one group. Another group includes the old stratified deposits usually lying at lower levels in the form of plains and in areas of more irregular topography. A third group comprises the areas of recent alluvium along the streams, where the process of accumulation is still going on.

In each of these major groups are minor groups, or what are called series. A series includes soils with a common origin, which are similar in color of surface, color and texture of subsoil, absence or presence of lime carbonate, and the depth to the substratum and its character. Each series is further subdivided into soil types which differ only in texture and are classified as loam, sandy loam, loamy sand, and many other types.

Since Massachusetts was completely subjected to the action of ice in the glacial period, its soils have been formed from the drift left by it. In the Soil Survey of Essex County (p. 12) Latimer says:

In most places the glacial material from which the soils are derived, . . . is made up of material of the same mineralogical composition as the underlying rock. However, the ice movement from northwest to southeast across the area did, to some extent, drag material from its source onto the rocks to the south and southeast, but much of the material shows evidence that it has not been transported very far.

Since the glacial drift links the soil on its surface with the rocks beneath it, the minerals composing the soil must be similar to those in the rocks, although modified by weathering and plant growth.

Granite and gneiss are the rocks most widely distributed throughout the State. Both are made up of quartz, feldspar, and mica. Gneiss is finer grained than granite and splits readily into thin blocks. Mica schist is also a widely distributed rock. It contains more mica than granite and gneiss and splits into thinner sheets than gneiss. Slate and phyllite resemble schist in cleavage but are not as soft and are less common. Sandstone is common in the Connecticut Valley, and a coarser rock called pudding-stone is noticeable in Norfolk and Bristol Counties. They are classed together as conglomerate and contain a larger proportion of quartz than is found in granites and schists.

Limestone is a negligible rock east of the Connecticut River, although a small deposit in Bolton, on the eastern edge of Worcester County, supplied the needs of surrounding towns a century ago. The limestone formation of the Green Mountains extends into Berkshire and Franklin Counties and influences some of the soil within their bounds. The absence of limestone results in supplies of soft water for home and public use throughout most of the State. Reports of the State Board of Health show that streams supplying the Wachusett Reservoir carry water with a hardness of only 1, while mountain streams supplying Pittsfield bear water with a hardness of 5.3. But in those parts of Berkshire County where limestone is absent, the natural waters are as soft as those in the eastern counties.

In the Soil Survey of Worcester County, Latimer points out that weathering of the glacial drift seldom goes deeper than 4 feet and in most cases does not go beyond 30 to 36 inches. An accumulation of organic matter and a brown color are about the only changes from the underlying drift to the overlying soil (p. 1549). Corroborative of these observations by Latimer are the results of a survey of the area now submerged in the Wachusett Reservoir. This survey was made by the State Board of Health to determine the probable depth to which the soil must be removed from the bed of the reservoir, in order to prevent excessive organic matter in the water. Organic carbon was determined in numerous samples and at a depth of 36 inches was found to have shrunk to little more than traces in most cases and not more than .25 percent in any.

Granite and gneiss influence the largest area of soils of the State: 2,400,000 acres are included in the different series derived from such glacial material. The largest of these is called the Gloucester Series, and is found on the uplands. The drift from which it has been weathered was deposited directly by the ice as it ground its way across the land, and is a mass of earth ranging from clay to angular pieces of granite.

In the Soil Survey of Franklin County (p. 15), Latimer says:

The soils of the eastern uplands, like most of the soils of eastern New England, are not inherently poor as is usually considered. Although they are not so fertile as the soils of the western plains or prairie regions of the United States, they are more fertile than most of the soils of the Atlantic Coastal Plain or Piedmont Region and compare favorably in fertility with the non-lime soils of the North Atlantic States.

The next series of granitic soils in extent is the Merrimac Series, which is derived from the glacial material deposited by the waters formed from the melting ice. The underlying drift is usually stratified and ranges from clay to rounded boulders worn by the water. These soils are found on the plains and terraces and gravelly knolls. In the Soil Survey of Hampden and Hampshire Counties (p. 18), Latimer says:

The soils developed on the terraces are similar to the soils of southern New England in the same situations, and they approach in development and character the soils of the Atlantic Coastal Plain of Long Island and New Jersey However, they are less fertile than the hill or bottom-land soils, as they are weathered from lighter textured material than the hill soils and are leached to a greater extent than the upland or bottom-land soils.

Soils influenced by mica schist are also widely distributed and are divided into numerous series because the different schistose rocks vary in proportions of mica and in color. The most striking schist soils are those of the Brookfield Series in the central part of Worcester County. The Brimfield schist, which contains considerable iron, dominates the glacial drift and imparts a distinctive ellow color to these soils.

Soils derived from coarse conglomerate or pudding-stone are found principally in Norfolk and Bristol Counties where they are classed in the Coloma Series. Sandstone soils are limited to the Connecticut Valley, where Chicopee Soils on the plains and Cheshire Soils on the uplands include most of the acreage on such glacial drift.

Limestone influences about 240,000 acres of soil, of which 45,000 acres are in Franklin County and the major amount in Berkshire County. The Dover Series is derived from limestone drift. Several other series are formed from gneissic or schistose drift in which more or less limestone was intermingled by glacial action.

The chemical composition of the weathered soil is similar to that of the underlying drift, which in turn must be related to the rocks from which the drift was formed. These crystalline minerals, quartz, feldspar, and mica, make up much of the granite, gneiss, schist, slate, and sandstone of the glacial debris. Orthoclase feldspar and muscovite mica are both potash minerals. Dana states that the former contains 16 percent and the latter 9 percent of potash. Quartz does not contain potash.

While each crystalline mineral has its characteristic composition, rocks like granite from different localities differ in the proportion of each kind of crystals and may vary in the percentages of potash to be found. Feldspar is the dominant mineral in granite, while mica is most prominent in gneiss, schist and slate. Leith and Mead, in "Metamorphic Geology," state that granite contains an average of 4.1 percent of potash. The micaceous rocks average less. Quartz prevails in sandstones, but the coarse pebbles are usually of granitic character and sandstones are not barren of potash. Limestone is usually associated with other rocks like schist or gneiss. Although it does not contain potash, the weathering of limestone in glacial drift dissolves the limestone faster than it does the harder rocks which contain potash.

Effects of Potash in Fertilizer Experiments

Fertilizer experiments at the Massachusetts Agricultural College were begun soon after it was founded. From these experiments together with observations of farm practice, Stockbridge in 1876 published several formulas for fertilizers based on the chemical composition of the crops and their probable yields per acre. For example, a crop of 50 bushels per acre of corn might contain 64 pounds of nitrogen, 31 pounds of phosphoric acid, and 77 pounds of potash. To replace this fertility, the corn formula called for 320 pounds sulfate of ammonia, 248 pounds superphosphate, and 154 pounds muriate of potash.

Stockbridge's formulas were vigorously criticized by Director Johnson of the Connecticut Agricultural Experiment Station as uneconomical and therefore not practical. The large proportion of nitrogen was found to be uneconomical and was lessened without any reduction in effects. Goessmann's experiments, begun in 1883, finally settled in 1889 to the following quantities per acre: 45 pounds of nitrogen, 80 pounds of available phosphoric acid and 125 pounds of potash. By this time it had become generally known that nitrogen from the air was being fixed by bacteria which grew on roots of leguminous plants.

Soon after the establishment of the Office of Experiment Stations under the Hatch Act in 1888, its director, Dr. W. O. Atwater, suggested to the agricultural experiment stations of the separate states that fertilizer experiments should be conducted on different farms in order to show farmers what their soils most needed of the various kinds of fertilizers. He called a conference of experiment station representatives to formulate a plan of uniform fertilizer experiments,

at which it was settled that the fertilizers to be employed should consist of 160 pounds nitrate of soda (16 percent nitrogen), 320 pounds dissolved boneblack (16 percent soluble phosphoric acid), and 160 pounds muriate of potash (50 percent actual potash) per acre. When all three substances were applied together, the soil would receive per acre 25.6 pounds nitrogen, valued at \$4.35; 51.2 pounds soluble phosphoric acid, valued at \$4.10; and 80 pounds potash, valued at \$3.60. The outstanding features of this combination of fertilizer chemicals were the simple units of 1 and 2 pounds per square rod, and the nearly equal distribution of cost between the three kinds of fertilizers used.

The plan of cooperative fertilizer experiments was adopted by this station and was executed by Dr. Wm. P. Brooks. Cooperation of farmers was secured in thirteen different towns, distributed from Cape Cod to the Berkshire Hills. Most of the experiments were conducted in 1889, 1890, and 1891; three were continued until the seventh annual crop was secured. Nearly all the fields selected for the experiment were fairly level and free from stones, and had been several years in grass, either as hayfield or pasture, without manure or fertilizer of any kind.

All the experiments used corn for the first crop. On some farms, new fields were used in the succeeding years, but in most cases the same fields served year after year. Potatoes or oats were used for succeeding crops on a few farms. Most of the experiments showed that the fields required all three forms of fertilizer for the highest yields. One hill farm in Shelburne did not require potash, and one near the river in Montague needed only nitrogen at that time. A comparison of localities and description of soils with the soil surveys shows that these cooperative experiments were almost always on the soils of the plain and terrace group. The Shelburne soil was in the upland group, and the Montague soil may have belonged to the alluvial or river-bottom group. All fertilizer experiments at this experiment station have been on soils of the plain and terrace group.

The results of these numerous fertilizer experiments with a variety of crops, together with the relatively low cost of potash fertilizers, led to recommendations for liberal applications of potash to most crops on all soils in this State.

At the New Hampshire Agricultural Experiment Station, however, fertilizer experiments on its soils and observation of farm practices in its vicinity showed that the liberal use of potash was unnecessary on such soils. In general, they were a clay loam overlying a dense unweathered clay, or granite rock. Angular boulders of granite were scattered through the soil and showed that the material had been deposited from the melting glaciers as they approached the ocean, and not from streams of water. In fertilizer experiments with grass and clover, potash gave no increases in yields, while nitrogen alone produced marked gains. Analyses of the crops showed that the percentages of potash in the crops were fully maintained by the soil. Such results indicated that liberal applications of potash might be uneconomical because a part of the crop's needs could be obtained from the soil without its impoverishment.

Review of Soil Analyses

In the Annual Report of the Massachusetts Agricultural Experiment Station issued in 1911, there are descriptions and chemical analyses of thirteen soils which represent distinctive geological formations in different sections of the State (pp. 339-341).

In 1914 Director Wm. P. Brooks had these typical localities again sampled, together with some additional areas. The purpose of this later study was to

determine whether the subsoils were richer in potash than the surface soils. Localities were chosen because of typical underlying rock or glacial drift. The areas selected for the sampling were in uncultivated pastures or woodland. Samples were secured of the surface soil 6 to 8 inches in depth and each foot of subsoil to the sixth foot in depth. The field work was done by Robert L. Coffin. The chemical analyses were made of the fine soil which passed through a sieve with holes 1 millimeter in diameter and were limited to the loss on heating the soil to red heat and to the potash soluble in hydrochloric acid solution of specific gravity 1.12. All the chemical analyses were made by Walter S. Frost. The results have remained unpublished until now.

Since these soil samples were secured, the soil surveys have been published and by the soil maps the soil series for each of the localities has been identified and included in the table with the analytical data. The three major groups of soils are each represented by these samples: Glacial drift, water-borne drift, and recent alluvial soils. The analytical data in the table are not carried beyond the 4th foot in depth.

TABLE 1.--POTASH IN MASSACHUSETTS SOILS

Soil Group	Soil Series	Locality	Percentage of Potash				
			Surface Soil 6-8 in.	Subsoil			
				1 ft.	2 ft.	3 ft.	4 ft.
Glacial Drift							
Granite.....	Gloucester	Dedham	.20	.14	.20	.35	...
Gneiss.....	Gloucester	Wendell	.15	.15	.17	.14	.27
Mica Schist.....	Hollis	Deerfield	.29	.43	.53	.52	.53
Pyrites Schist.....	Brookfield	Templeton	.10	.10	.06	.07	.23
Sandstone.....	Cheshire	Agawam	.14	.11	.15	.15	.14
Limestone.....	Dover	Pittsfield	.18	.13	.07	.09	.20
Water-borne Drift							
Plain.....	Merrimac	Concord	.18	.12	.15	.16	.17
Plain.....	Merrimac	Marshfield	.08	.07	.09	.05	.06
Terrace.....	Hadley	Hadley	.29	.24	.24	.22	.14
Plain.....	Chicopee	Agawam	.19	.20	.14	.19	.20
Lowland.....	Scarboro	State College	.43	.33	.28	.24	.27
Recent Alluvial Soils							
Fresh-water Meadow.....		East Sudbury	.21	.27	.55	.64	...
Diked Tidal-marsh.....		Marshfield	.72	.77	.86	.69	...
Cranberry Bog Peat.....		North Carver	.08	.10	.11

Aside from the marsh soils, the only soil showing marked increases in potash in the 1st and 2nd feet of subsoil is the Hollis soil from Deerfield. This soil series is derived from a slaty schist high in mica, which is the principal potash mineral in such rocks. The variation in potash may be due to leaching, but is more probably due to different proportions of mica when the several levels were deposited.

In the Survey of Worcester County Soils (pp. 1544-1547), Latimer discussed the formation of soils from glacial drift, bringing out these salient points. Soil-

forming processes have not yet effected any profound changes in the soil material. One of these processes removes clay from the surface layer, carries it downward, and deposits it in the layer beneath. The surface layer becomes coarser in texture, while the underlying layer becomes finer. Six Worcester County soils of different series showed no marked increase in clay at depths between 6 inches and 2 feet. They are young soils because the changes which have taken place in the glacial material are comparatively slight.

Soils are never wholly dissolved in the solution of hydrochloric acid used in these analyses. The proportion that is dissolved depends principally upon the fineness of the soil particles. Clay will dissolve more freely than the finest sand. In glacial soils, the clay was formed by the grinding action of the moving ice, which reduced the softer minerals to rock flour. Feldspar, which contains potash, is softer than quartz, which does not contain any. The finer the soil, the more potash it may yield to any solution and clay may appear to be richer than sand.

Numerous samples of soils from different levels were procured from the vicinity of the College and analyzed by Frost, who also subjected them to a mechanical analysis by separation into several graded sizes of soil particles. In the next table are given the results of the mechanical analyses as well as the percentage of potash in those samples.

TABLE 2.—POTASH AND TEXTURE OF SOILS AT MASSACHUSETTS STATE COLLEGE

Locality	Soil Level	Potash Percent	Texture (Percent)			
			Clay	Silt	Very Fine Sand	Fine Sand
Campus Trench (North of cross-walk).....	Surface	.24	1.8	56.3	26.3	6.8
	1st foot	.38	9.6	38.1	32.2	11.0
	2nd foot	.99	26.5	30.1	10.6	21.9
	3rd foot	1.22	22.1	36.3	21.5	7.4
	4th foot	1.18	35.8	24.4	20.8	10.4
Campus Trench (Southwest of Draper Hall).....	Surface	.66	7.7	23.5	24.1	7.3
	1st foot	.50	1.7	36.9	34.8	8.4
	2nd foot	.24	.6	19.9	47.7	13.2
	3rd foot	.88	7.3	33.5	12.4	7.2
	4th foot	1.29	19.7	36.3	18.5	3.2
Farm Pasture (Untilled many years).....	Surface	.28	2.5	31.4	51.1	6.9
	1st foot	.18	.9	53.5	38.2	4.1
	2nd foot	.18	.9	46.8	42.5	6.8
	3rd foot	.13	.8	25.8	30.6	36.5
	4th foot	.20	.9	26.9	41.7	26.1
Farm Meadow (West of hay barns).....	Surface	.23	2.8	34.0	50.4	6.0
	1st foot	.27	1.5	17.1	48.1	24.3
	2nd foot	1.17	8.6	22.1	18.0	22.6
	3rd foot	1.73	20.0	11.8	21.7	5.5
Experiment Station (Forage crop plots).....	Surface	.14	.2	7.3	62.1	24.5
	1st foot	.11	.1	5.1	39.7	43.8
	2nd foot	.13	.3	7.1	46.5	27.6
	3rd foot	.06	.04	.1	.3	3.4
	4th foot	.09	.09	.3	.4	7.9

The soils represented by these samples show wide variations in texture when they are separated into the different grades of soil grains. High potash in the whole soil accompanies the larger proportions of clay, whether it be surface soil or the lowest levels. All of these soils were deposited from water coming from the melting glaciers. Excavations reveal very irregular distribution of clay, sand, and gravel; but the deposits represent long periods of alternate summers and winters, with the accompanying thawing and freezing, floods, and ice. The extremes in texture and potash are shown by the Campus Trench near Draper Hall and the Forage Crop Plots, yet they are less than 30 rods apart and practically in the same field.

The loss in weight which occurs when a dry soil is heated to red heat is commonly calculated to be organic matter; but this is not accurate because the clay does not part with all its water in the drying oven but does lose it at the higher heat. Lime carbonate also loses weight on heating to redness and is changed to quicklime. Frost's results on the soils in this investigation are of interest because in all cases except clay and limestone soils the loss at red heat was less than 1 percent in the samples from the 3rd and 4th foot, while in the surface soil it ran as high as 12 percent. Such results agree with those reported for organic carbon at the Wachusett Reservoir and confirm Latimer's statement about the depth of weathering of glacial drift from which the soils are formed.

During the existence of the experiment station many samples of soil have been analyzed, which have been sent from all parts of the State. In the Annual Report of January 1911 there were published detailed results on 148 samples. From these pages it was found that the potash dissolved in strong acid fell below .25 percent in 88 samples; was between .25 and .45 percent in 39 samples; and amounted to .45 percent and upward to 1.02 percent in 21 samples. Little can be learned from these results beyond the facts that many of the low results were from sandy and sandy loam soils, while several of the highest results were obtained from garden soils. Hilgard, in his book "Soils," makes the statement from long experience that soils with less than .25 percent of acid-soluble potash will need potash fertilizers, while those with .45 percent or more seldom show any benefit from such fertilizer. One fourth of the samples were between these two extreme groups and should require some thoughtful observation of results of fertilizers.

At the International Congress of Soil Science at Washington, D. C., in 1927, the consensus of opinion held the strong hydrochloric acid solution of soils to be an excellent index of the extent to which the soil minerals had been changed by weathering. The relation of the soil minerals to the underlying drift and rocks is better shown, however, by determining the total percentages by other methods such as fusion with some chemical.

In the soil surveys of Massachusetts only two chemical analyses of typical soils have been reported. These soils were Gloucester stony fine sandy loam and Becket loam, the complete analyses of which were published in the Soil Survey of Franklin County (p. 35). Both of these soils are derived from granite, gneiss, and related rocks. The deep subsoil of Becket series is compact and fine, while Gloucester soils are underlain by looser and coarser material. In these analyses the soils were not dissolved in acid but changed to soluble compounds by fusion with alkalis in order to recover all the plant food. The data for total potash are given here.

	<i>Depth Inches</i>	<i>Total Potash Percent</i>
Gloucester stony fine sandy loam....	0—3	2.50
	3—5	2.33
	5—15	2.60
	15—24	2.64
	24—36	2.29
Becket loam.....	0—6	2.06
	6—11	2.89
	11—13	3.41
	13—24	3.45
	24—36	3.79

Bizzell has published complete analyses of a large number of New York soils in Bulletin 513 of the Cornell University Agricultural Experiment Station. Among them are several series common to Massachusetts: viz., Coloma, Dover, Dutchess, Gloucester, and Merrimac. All the determinations were for total and not acid-soluble constituents. Below are given summarized results for the five different series, limited to the potassium in the surface soil to a depth of 8 inches. Since the percentages are of potassium, the figures are somewhat smaller than if calculated for potash, which is potassium oxide.

TABLE 3.--TOTAL POTASSIUM IN SOME NEW YORK SOILS
(BIZZELL)

	<i>Number of Samples</i>	<i>Percentage of Total Potassium</i>		
		<i>Maximum</i>	<i>Minimum</i>	<i>Average</i>
Coloma fine sandy loam..	3	1.84	1.73	1.81
Dover loam.....	2	2.86	2.86	2.86
Dutchess silt loam.....	3	1.82	1.07	1.48
Gloucester loam.....	4	2.64	1.68	2.17
Merrimac sandy loam....	2	2.69	2.36	2.53

Morse and Curry published numerous determinations of total potash in clay loam and clay soils in the Report of the New Hampshire Agricultural Experiment Station for 1906-1908 (p. 265). In twelve lowland soils, total potash ranged from 2.21 to 3.96 percent; in ten upland soils, the range was from 2.05 to 2.75 percent.

Bizzell noted that clay loams and clays were much higher in potassium than the soils of lighter character. Sands were especially low in that substance.

Failyer, Smith, and Wade of the U. S. Bureau of Soils made a study of the plant-food constituents contained in the different sizes of soil particles separated into sands, silt, and clay. The study covered many representatives of numerous soil series and its results were published in Bulletin 54 of the Bureau. Of their examination of glacial soils, they say (p. 24), "In general, the finer separates of the soils of this group contain the greater percentages of the several elements determined . . . The glacial soils consist largely of crushed rocks. Much of the material composing them has not been profoundly weathered." Of the potash content, they say (p. 30), "the clays of the glacial soils contain about twice the percentage that the sands do." In the summary (p. 35) it is stated that as a general rule the smaller particles of soils are richer in potassium, calcium, magnesium, and phosphorus than the coarser particles. In glacial soils, the coarser particles are relatively high in percentage of potash, lime, and magnesia. The larger mechanical

components contain these elements in forms which by protracted weathering will become more soluble, and they will ultimately be concentrated in the finer components. A comparison of soils with crystalline rocks indicates that, in the process of weathering, the lime and potash seem to decrease in percentage, although minerals containing them are always present.

Potash in Sand, Silt and Clay of Two Fields

In Bulletin 232 of this experiment station, Haskell showed that crops on Field G were much less influenced by potash fertilizers than crops on the North Soil Test.

The soils of the two fields were compared in pot experiments without additional potash but with varied supplies of water. The experiments have been reported in the *Journal of Agricultural Research*, Vol. 35 (1927). Japanese millet took up nearly twice as much potash from Field G soil as it could obtain from the soil of the North Soil Test, and on both soils it took up more potash with a liberal water supply than it did with a scanty supply.

The soils of Field G and the North Soil Test were next compared by both mechanical and chemical analysis. Samples were obtained from five plots on Field G and from eight plots on the North Soil Test, none of which had received any potash fertilizer. Each sample was a composite of several borings to the depth of 8 inches. A weighed portion of the dry sample was first sifted to remove the coarse sand. The fine soil was next separated into two groups of particles by repeated subsidence in water. In one group were the sand grains and in the other the silt and clay together with floating organic particles. For chemical analysis the sands of the plots of each field were blended into a composite sample for that field, and similarly with the silt clay particles. A portion of the sand sample was next pulverized to a fine powder in an agate mortar. Total potash was determined by fusion with calcium carbonate and ammonium chloride.

TABLE 4.—PERCENTAGES OF SAND, SILT-CLAY, AND POTASH IN THE SOIL OF TWO EXPERIMENT STATION FIELDS

Field G			North Soil Test		
Plot	Sand	Silt-Clay	Plot	Sand	Silt-Clay
1.....	77.6	18.4	3E.....	86.3	11.1
9.....	74.1	21.9	3W.....	88.5	9.5
17.....	79.3	17.7	4E.....	84.2	12.7
25.....	77.4	20.0	4W.....	81.7	16.8
33.....	73.4	22.9	6E.....	88.2	8.6
			6W.....	85.3	11.7
			8E.....	91.5	4.6
			8W.....	87.0	9.9
Average...	76.4	20.2	Average...	86.6	10.6
Potash....	1.90	2.57	Potash....	1.97	2.41

It may be noted that the soil of every plot on Field G contained more silt and clay than any plot on the North Soil Test, and the average for Field G soil shows twice as much silt and clay as in the other field. The percentages of potash in the two soils indicate them to be essentially alike in mineral composition. The silt and clay are definitely richer in potash than the sands, but in the soil as a whole the bulk of its potash is in the sands.

Excavations have shown that the two fields probably possess distinctly different underlying drift. The Forage Plots included in Frost's work are immediately adjacent to the North Soil Test and were positively coarser in their lower levels. On the other hand, a deep trench recently dug across the end of the original Field G showed heavy clay in those levels. Field G contained more potash in fine particles to be acted on by water, and also an underlying unweathered drift of great capacity to retain water. Hence a liberal supply of soil-potash was available.

Potash in Sand, Silt and Clay of Different Soil Series

Samples of soil representing different soil series have been analyzed with the object of comparing the percentages of total potash in the two groups of soil particles, sands and silt-clay. Some of the samples were from series of wide distribution. Others were from series with distinctive rocks predominating in the drift from which the soils were weathered. The samples were taken at locations which appeared to be distinctive of the particular series, shown by rock fragments, color of soil, and other characteristics. They were essentially random samples of Massachusetts soils, because there are numerous variables influencing the chemical composition of any particular soil series.

Glacial action has been stated by Latimer as reducing rocks to sand and rock flour. The softer minerals like feldspar would be more finely ground than the harder quartz. Therefore, the rock flour might contain more feldspar and the sand more quartz. Mica, which splits into thin, paper-like sheets, would slip and slide and instead of being pulverized to flour might remain as fine scales in the sands. Mica crystals contain 9 percent of potash, while potash feldspar contains 16 percent. Rock flour has been subjected to the dissolving effect of water throughout its formation and subsequent weathering, which must modify the percentage of potash originally present in the feldspar much more than the percentage of that element in the mica scales.

Among the different soils in the table, Brookfield, Cheshire, Dover, Gloucester, and Merrimac soils have been mentioned as influenced respectively by schist, sandstone, limestone, and granite in the glacial drift from which they have been weathered. The Gloucester and Merrimac soils are both granitic but differ in the form of the drift: the Gloucester drift was deposited directly from the ice as it melted, while the Merrimac drift was washed away in the streams of water from the melting ice and deposited at some distance. Becket soils were weathered from drift containing more gneiss than granite, which produced a finer grained, more compact drift than that underlying Gloucester soils. Becket soils are common on the hills west of the Connecticut River. Charlton soils form an important series in Worcester County and were weathered from drift containing both schist and granite, which is compact and retentive of moisture. Holyoke soils are limited to the vicinity of the Holyoke Mountain Range, and are of interest because the distinctive rock which characterizes them is trap rock or diabase, and diabase contains little if any potash. Lenox soils are underlain by drift in which limestone and schist are mingled together. The sample was taken in the vicinity of a mica schist outcrop and its coarse sand contained numerous grains of limestone, which were identified by the action of weak acid on them.

Three samples of soils were taken near outcrops of ledges where the soil was not more than a foot in depth above the underlying rock. It is uncertain how much of the soil was weathered from the rock and how much from thin glacial drift. Diorite rocks are not mentioned by Latimer in connection with any series of soils. They are mentioned by Emerson in "Geology of Massachusetts" as

fairly common in the ridges east of the Connecticut Valley. Diorite is of interest because, instead of potash feldspar, it contains lime and soda feldspar; therefore soils weathered from diorite may be poorer in potash than those derived from granite. Phyllite resembles slate in its composition, but does not cleave in thin sheets. It is distinctive in the Bernardston soils and is related in its properties to the slate of Hollis and Dutchess soils. Mica schist represents the dominant rocks underlying the glacial drift from which Berkshire soils have been weathered, and is unlike in color the iron-stained schist of the Brookfield Series.

TABLE 5.--PERCENTAGES OF SAND, SILT-CLAY, AND POTASH IN SOME MASSACHUSETTS SOIL SERIES

Soil Series	Locality	Sand	Silt-Clay	Potash	
				In Sand	In Silt-Clay
Surface Soils					
Becket.....	Windsor	75.4	12.2	2.87	2.31
Brookfield.....	North Brookfield	80.2	7.5	1.91	1.45
Charlton.....	Paxton	73.7	12.7	2.12	2.12
Cheshire.....	Amherst	75.2	15.1	1.40	2.17
Dover.....	Great Barrington	68.9	17.9	2.44	2.34
Gloucester.....	Hardwick	76.1	9.9	1.50	1.53
Holyoke.....	Mt. Tom	70.4	11.9	1.46	1.72
Lenox.....	Lenox	73.0	19.0	3.19	3.43
Merrimac.....	Amherst	76.4	20.2	1.90	2.57
Merrimac.....	Berlin	71.3	8.7	1.06	1.69
Average of Surface Soils.....		74.6	13.5	2.07	2.13
Soils near Ledges					
Diorite.....	Greenwich	74.2	13.9	1.27	1.53
Mica Schist.....	North Adams	77.2	16.4	3.91	3.18
Phyllite.....	Clinton	65.9	11.6	2.19	2.64
Subsoils					
Gloucester.....	Hardwick	74.3	12.0	1.57	1.66
Brookfield.....	North Brookfield	80.5	6.1	1.45	1.85

The mica schist soil showed more potash in the sand than in the silt-clay, which may be due to the accumulation of fine mica scales in the sand. The soil from the diorite outcrop was lowest in potash, indicating it to be weathered from the underlying rock. It is possible that the Gloucester soil from Hardwick was influenced by diorite because the glacial movement may have dragged material from the diorite localities onto the Hardwick ridge. A painstaking mineralogical analysis would be necessary to determine the facts.

The Holyoke soil indicates the mixing effect of glacial action because it contains a reasonable amount of potash, although diabase, its dominant rock, contains as a rule none. Becket and Brookfield soils have micaceous characteristics and have higher potash in the sands. The two Merrimac soils represent distinctly different formations of water-borne drift. The Amherst soil is an outwash formation, and is not stratified but is irregular in its make-up of clay, sand, and gravel. The Berlin soil represents the typical Merrimac stratification and was underlain by coarse gravel, which permitted rapid percolation and drainage. The lower potash in the clay may be due to leaching. It may be noted that the percentages in the sands are closely alike in the two samples.

A majority of the samples have higher potash in the silt-clay particles. However, the averages for the ten surface soils show potash practically equal for the two groups of soil grains. Since sands constitute approximately 75 percent of the soils, however, it follows that the bulk of soil-potash is contained in them; and, as Failyer has remarked, it is a large reserve to be gradually weathered into availability for plants.

Soil Potash Soluble in Water

Potash in commercial fertilizers is required by law to be soluble in water. The amount of water-soluble potash in soils has received comparatively little study.

Morse and Curry found that, in the soils around the New Hampshire Agricultural Experiment Station, water-soluble potassium ranged from 6 to 18 parts per million parts of soil in upland soils, and from 6 to 35 parts in lowland soils. Fraps has reported water-soluble potassium in over 200 Texas soils, of which more than half contained between 6 and 36 parts per million parts of soil. The remainder of the soils extended the range as high as 168 parts. Shedd in *Soil Science* has described eleven Kentucky soils of silty and silty loam types. In eight of them, water-soluble potassium ranged between 14 and 30 parts per million parts of soil; one sample contained 97 parts. King, in Bulletin 26 of the Bureau of Soils, U. S. Department of Agriculture, has reported an exhaustive study of eight distinct soils in as many different parts of the nation. The water-soluble potassium naturally present in them ranged from 9 to 25 parts per million parts of soil.

From these different reports it may be calculated that in many soils there may be between 10 and 65 pounds of actual potash per acre in the surface 6 inches that is immediately soluble in water. Furthermore, there is evidence that as plants absorb the soluble potash, more of it passes into the soil solution from the soil grains.

King treated his soils eleven successive times with water, with a thorough drying of the sample between the treatments, and succeeded in recovering from 128 to 273 parts of potassium per million parts of the soils. Fraps conducted pot experiments with all of his soils in which he grew two successive crops without adding fertilizer. The crops were analyzed. The first crop contained more than three times as much potassium as was found in the water solution. Both crops together contained about six times the amount.

At this experiment station, in the different fertilizer experiments, plots without potash have borne crops that contained from 20 to 90 pounds of potash per acre. If these quantities were distributed in the surface 6 inches, there would be approximately 13 to 60 parts of potash per million parts of soil, which dissolved in the soil solution before being absorbed by the plants.

Morse and Curry reported sixteen soils in which water-soluble potassium was determined. The grass crops growing on these soils were also analyzed for potash. The soils were divided into two groups of eight soils each.

	<i>Water-soluble</i>	
	<i>Potassium in Soils</i>	<i>Potash in Crops</i>
	<i>Percent</i>	<i>Percent</i>
Group A.....	6.0 to 13.8	.79 to 1.46
Group B.....	15.8 to 35.1	.84 to 1.65

The crops from the soils with the higher water-soluble potassium had absorbed the larger percentages of potash.

The amount of water transpired by crops, together with the percentages of potash contained in them, may be used to show the solubility of potash in the soil.

Lyon and Bizzell, in Memoir 12 of Cornell University Agricultural Experiment Station, have reported data from which has been calculated the possible concentration of potash in the water when taken into the plant. Especially striking were their results for the seasons of 1913 and 1914, in two soil tanks, with hay from mixed grasses. The yields of hay and the potash contained in the crops were reported in pounds per acre. The transpiration ratio is the amount of water apparently taken up by the plant in producing a pound of hay. From this ratio was calculated the probable total water taken up by the crop and its concentration in potash. In 1914 the abundant rainfall allowed a liberal supply of water to the growing grass which enabled it to use potash more efficiently than in 1913 and in a more dilute solution. Similar results were obtained with timothy grass in four other soil tanks.

TABLE 6.--POTASH IN TRANSPIRED WATER OF HAY CROP, AT ITHACA, N. Y.

	1913	1914
Hay, pounds per acre.....	4,519	6,063
Potassium in crop, pounds.....	41.4	34.6
Transpiration ratio.....	266:1	408:1
Total water, pounds.....	1,202,000	2,473,000
Potassium in water, parts per million..	34	14
Rainfall, April 1 to August 21, inches	10.15	20.72

Briggs and Shantz of the Bureau of Plant Industry made a comprehensive study of the water used by many different kinds of plants. They reported that the corn plant transpired 415 pounds of water as the maximum and 342 pounds as the minimum for each pound of dry matter built up in the plant. The plants were grown in soil contained in large pots, and water was supplied as liberally as needed by the crops, which varied with the season.

At this experiment station, numerous analyses of crops have shown approximately 1 percent of potash in the dry matter of corn crops. This amount of potash would be equivalent to 24 parts per million parts of water with the maximum transpiration and 29 parts with the minimum transpiration.

Availability of Soil Potash for Crops

Fertilizer experiments in the field, together with chemical analyses of crops in the laboratory, supply data from which may be estimated the availability of the potash naturally present in the soil.

Morse and Curry found that hay crops on heavy clay loams took from the soil from 60 to 90 pounds of potash per acre, when nitrogen and rainfall were in ample supply. Field G of this experiment station supplied hay crops with from 74 to 95 pounds of potash per acre. On the coarser sandy loams of North Soil Test and South Soil Test, hay crops were much influenced by variations in rainfall. In the favorable seasons, they were able to secure from 40 to 50 pounds of potash per acre.

Corn on Field G took up 45 to 65 pounds of potash per acre, but on the coarser soils it seldom got more than 25 pounds except when it followed hay crops, the turf of which yielded about twice as much potash. Our fertilizer experiments have shown that the coarser soils were somewhat exhausted of soluble potash after the turf was wholly used.

The investigations by Briggs and Shantz showed that clover transpired about twice as much water as corn in proportion to its weight, which would make it possible to get more potash into its tissues. Grasses were between corn and clover in the amount of water transpired.

Economical Use of Potash Fertilizers

The field and laboratory data often show that more potash is applied in fertilizers than the crops will take up.

Two soil tanks at the New York State Agricultural Experiment Station received, over a period of sixteen years, muriate of potash that was equivalent to 1184 pounds of potassium per acre. The crops took up the equivalent of 894.9 pounds of potassium and the drainage water carried away 77.5 pounds of potassium per acre. There remained in the soil 212 pounds of potassium, which was more than 17 percent of the amount applied.

Fixation of potassium in the soil by transformation of soluble potash salts into less soluble soil compounds has been much studied by investigators of soils. The opinion was general at the First International Congress of Soil Science that potassium thus fixed in the soil was later available for crops.

When soluble potash is abundant in the soil, crops may take up more than appears to be needed for growth. In our pot experiments it was found that soybeans grown in soil with residual potash weighted 393 grams and contained 4.8 grams of potash. On the same soil with a liberal addition of sulfate of potash, the pots produced 390 grams of crop which contained 8.5 grams of potash. Similar results were obtained with Japanese millet in other pots filled with the same soil. An excessive supply of fertilizer potash is not economical when taken up by the crop. The only short cycle of recovery of the potash in the crop, other than plowing the crop under, is to feed the crop to animals and return the potash in farm manure. Losses occur in such a cycle, some of which cannot be avoided.

Lyon and Bizzell in Memoir 134 of the Cornell University Agricultural Experiment Station described experiments with soil tanks in which, during fifteen years, 536 pounds of potash per acre had been applied in farm manure. During this period the drainage water had carried away 975 pounds of potash per acre. The decomposing manure apparently decomposed some of the mineral potash, as Vandercavey has shown with decomposing straw in investigations reported by him in *Soil Science*.

The application in fertilizer of all the potash that a crop can take up may be an extravagance. It is using the deposits of potash salts, which exist in limited areas, for wide distribution with the possibility of their ultimate exhaustion. The naturally available soil potash may require reenforcement, but its reasonable use may be considered as income from a substantial principal.

The fundamental differences between the soils which have appeared to need potash and the soils which have not needed it are differences in soil texture and in water supply. Light soils with their larger proportion of sand grains yield their potash sparingly to the soil water, which is also scanty unless rains are frequent. Heavy soils, with much more of clay and silt, hold more water in which the potash dissolves more freely from the fine soil particles.

Efficient use of fertilizer potash requires consideration of the soil texture and the water supply. Abundance of water will enable a crop to make use of soil potash. Scanty water supply should be supplemented with easily dissolved potash fertilizers.

Summary

The soils of Massachusetts have been completely surveyed by the U. S. Bureau of Soils, aided by the State Department of Agriculture. The soils are derived from glacial drift, which consists principally of material from potash-bearing rocks.

Fertilizer experiments have been limited almost wholly to soils of plain and terrace formation, which were more leached than upland soils or those of alluvial origin. The lighter soils required potash. Heavy clay soils did not respond to potash fertilizers.

Many analyses have been made at the experiment station of soil samples from all parts of the State. Potash has been determined in an acid solution. So far as can be ascertained, the percentages of potash have been influenced principally by the texture of the soil. The finer the soil, the more potash has been dissolved by the acid.

The soils of two fields used for fertilizer experiments have been sampled plot by plot where no potash fertilizer had been used. The samples were separated into sands and silt-clay. The sands contained a lower percentage of total potash by fusion than the silt-clay but held the major portion of the soil-potash. One soil contained twice as much silt-clay as the other, which indicated a larger amount of available potash.

Characteristic samples of important soil series were separated into sands and silt-clay. Total potash by fusion was determined in them. The average percentage of potash in sands was 2.07 and in silt-clay 2.13. The lowest percentage of potash was 1.27 in the sands overlying a diorite ledge.

A review of investigations of the water-soluble potash in soils showed that the soil particles yield an important part of the potash required by crops. Efficient use of potash fertilizer should include the available soil potash as part of the supply for the crop.

Clay presents more surface to the soil-solution than sand and also holds more water. Therefore, clay soils supply more available potash than sandy soils of similar origin.