SOME EFFECTS OF POTASSIUM SALTS ON SOILS

A THESIS

PRESENTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF CORNELL UNIVERSITY FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

BY

RAYMOND STRATTON SMITH

SEPTEMBER, 1918

Reprinted from Memoir 35, June, 1920, of Cornell University Agricultural Experiment Station.

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CONTENTS

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R. S. Smith

The factors that determine the ability of a soil to support plant growth are known to be very complex, and any modification of this ability brought about by materials added to the soil is at least equally complex. It is now generally recognized that the secondary effects of fertilizing materials which are added to a soil may ultimately prove either beneficial or injurious when measured in terms of crop yields. The deleterious effects of ammonium sulfate have been particularly noted. The secondary effects of other fertilizer salts have been less thoroly studied because their action is thought to be less pronounced. However, attention has been called to various effects exerted by other materials, including the salts of potassium. The somewhat conflicting experimental data bearing on the effects of the chloride and the sulfate of potassium on the soil as a medium for plant growth led to the work reported in this paper.

The method of attacking the problem was, first, to determine the effect of various applications of potassium chloride and potassium sulfate on the growth of wheat, both in the variously treated soils and in water extracts of the soils; and secondly, to attempt to get at the causes of the effect of these salts on crop growth as noted in this work and as noted by other investigators.

HISTORICAL REVIEW

EFFECT OF POTASSIUM AND MANGANESE SALTS ON PLANT GROWTH

Potassium salts

The stimulative action on the growth of the higher plants exerted by the salts of potassium which are commonly used as fertilizing materials, is recognized. That this action is in part secondary seems evident from the fact that the specific effects noted vary with different soils and with the same soil variously treated.

Ordinarily, these salts would probably not be used in sufficient quantity to prove directly harmful to plant growth; but under certain intensive systems of farming, in which heavy applications of fertilizers are made, such a result might follow. Lyon, Fippin, and Buckman (1915) make the statement that "it [potassium] may be present in large quantities in the soil and yet exert no harmful effect on the crop." Whether this statement refers to soluble salts of potassium added to the soil, or to the slowly soluble compounds in the soil minerals, is not stated. There is a possibility, however, that even the ordinary applications of potassium salts may result in an increased loss from the soil of other bases, particularly calcium.

But little work has been done to determine at what concentration the salts of potassium become toxic to plant growth in soils. Headden (1915) found that yellow-berry in wheat is increased by the application of 150 pounds of potassium to the acre. He ascribes this condition to the excess of soluble potassium over soluble nitrogen. This effect of a comparatively small application of a potassium salt in aggravating an abnormal condition in the wheat crop is of interest in this connection in that it indicates a significant modification of the soil as a medium for plant growth.

Harris (1915), from an extensive investigation of the effect of alkali salts on the germination and growth of seedlings in three different soils, reports the concentrations of potassium chloride and potassium sulfate at which these salts become harmful to wheat seedlings. He found that heavier applications of these salts were required to cause injury to the seedlings than would ever be applied, even in the most intensive systems of farming.

McCool (1913) determined the effect of the chlorides of ammonium, magnesium, potassium, and calcium on the germination of pea seeds in soil. The salts were harmful in the order given. Potassium chloride caused slight injury when used at the rate of about 7456 pounds in 2,000,000 pounds of soil. The character of the soil is not stated by the writer.

Voelcker (1909), in conducting pot experiments with wheat at the Woburn experiment station, in which the chloride, the sulfate, the carbonate, and the nitrate of potassium were used in such amounts as to supply the soil in each case with 0.0075 per cent of the metal potassium — which is equivalent to 166 pounds of the chloride, 312 pounds of the sulfate, 248 pounds of the carbonate, and 369 pounds of the nitrate, per 2,000,000 pounds of soil — noted injury with the carbonate. It is difficult to understand how such small applications of any of these salts could cause injury to wheat.

Much work has been done on the toxicity of bases in solution cultures with various crop plants. This phase of the study is typified by the investigations of McCool (1913) on a large number of bases, including potassium. This type of investigation, however, has little direct significance in soil studies, because the conclusions drawn cannot be applied with a soil medium due to side reactions which are involved when so complex a medium is employed. McCool found that the chlorides of barium, manganese, ammonium, magnesium, sodium, potassium, and calcium were toxic to pea seedlings in the order named. It is of interest to note that manganese stands near the head of the list.

The degree of toxicity of all the salts is much less in soil than in nutrient solution. As has been noted, McCool found that potassium chloride caused slight injury to the germination of pea seeds in soil when applied at the rate of about 7456 pounds to 2,000,000 pounds of soil, and Harris reports much higher concentrations than this as being necessary to produce a toxic condition except in the case of coarse sand.

It thus appears that injury to plant growth has been found to result from the use of potassium salts in large quantities; that applications at the ordinary rate have been found to cause injury in but one case; and that small applications may possibly accentuate pathological conditions in the growing plant.

No reports of experiments on the growth of seedlings in soil extract made from soils to which only potash salts had been added, have been found in the literature.

Abbott, Conner, and Smalley (1913) report some soil-extract-culture experiments with corn, using soil high in soluble aluminium salts. This work is of interest in this connection in that it agrees with the conclusions of other investigators that the water extract from unproductive field soils is toxic to the root growth of seedlings.

Manganese salts

Manganese, as is noted later in this paper, is one of the bases replaced by potassium in some soils, and, since it has been shown by some investigators to have considerable influence on plant growth, a brief review of the literature regarding its action is here given.

As shown by Skinner and Sullivan (1914), manganese increases the oxidizing power of plant roots. This, however, was not accompanied by increased growth when the plants were grown in fertile soil. Infertile soils seemed to respond to manganese when it was used in small quantities, varying from 5 to 50 parts of manganese to 1,000,000 parts of soil.

Experiments by Skinner and Reid (1916) on silty clay loam of an acid nature at Arlington, Virginia, in which manganese sulfate was applied annually at the rate of 50 pounds to the acre previous to planting, show a decrease in the yield of wheat and cowpeas and inconsistent results with rye. When the lime requirement of the soil was just satisfied, the depression was decreased; and when an excess of lime was used, the crop yields were increased by manganese, except in the case of potatoes.

The results of other workers agree in the main in showing that the salts of manganese increase the yields of field crops when used in small quantities. In some instances a decrease results, and the work of Skinner and Reid seems to indicate that the reaction of the soil is an important factor.

Little work has been done to determine at what concentrations salts of manganese become toxic to plant growth in soils. McCool (1913), using a sandy loam soil, found that manganese chloride in solution was toxic to peas when added at the rate of 330 cubic centimeters of N/50 solution to 1000 grams of soil. This rate of application is equivalent to about 181 parts of the element manganese to 1,000,000 parts of soil. McCool found also that calcium overcame this injurious action, while Kelley (1908) reports that lime had no such effect.

The conclusion seems justified that if a neutral salt when added to the soil replaces even small amounts of manganese, the presence of this replaced base may affect crop growth adversely or occasionally beneficially, depending on other factors not well understood.

Other bases replaced by various fertilizer treatments are known to be toxic to plant growth, particularly iron and aluminium. But since neither of these elements was found to be present in the water extracts of the soils used in this work, no discussion of their action seems necessary.

EFFECT OF POTASSIUM AND MANGANESE SALTS ON NITRIFICATION IN SOILS

Potassium salts

Potassium salts have been found to produce specific effects on nitrification. Under certain conditions a stimulation has been noted, while under other conditions the reverse has been the case. The literature has been searched in an attempt to discover what effects potassium salts have on nitrification, and any specific effects that have been found to accompany certain conditions resulting from the application of potassium salts to soils. A close correlation between the nitrifying power of a soil and its crop-producing power may not exist, but the two are likely to be associated. A study of the nitrifying power of a soil should, then, furnish some indication of its crop-producing power and help to explain any departures from the normal in crop growth.

Dumont and Crochetelle (1893) report favorable effects of potassium salts on nitrification in soils rich in organic matter and limestone. They later (1894) report work with a sandy humous soil stated to be poor in lime. This soil as reported contained 17.5 per cent of humus and 0.285 per cent of limestone. Potassium carbonate and potassium sulfate, both with and without lime, were used in different amounts. Potassium carbonate was used in increasing amounts from 0.1 to 6 grams, to 100 grams of soil. Marked stimulation was found to accompany its use up to 4.5 grams, and then there was a steady decrease in the nitric nitrogen found. Potassium sulfate without lime had no consistent effect. The character of the results indicates that the differences found in the latter treatments were due to factors other than those under study. When 2.5 grams of limestone were applied in addition to the potassium sulfate, there was a constant increase in the amount of nitric nitrogen found with an increase in the amount of potassium sulfate used, the heaviest application being 5 grams to 100 grams of soil.

Lyon and Bizzell (1918) report the nitrogen recovered from the lysimeter tanks at Cornell University. Apparently potassium sulfate without lime depressed nitrification. Lime counteracted this effect, but even with lime the sulfate did not cause any appreciable stimulation of the process.

Greaves (1916), in laboratory experiments on the effect of potassium salts on the bacterial activities of sedimentary soils derived from limestone and quartzite, found that potassium chloride and potassium sulfate used at the rate of from 6.1 to 8602 parts per million depressed nitrification at all concentrations. Potassium nitrate and potassium carbonate, used at the same rates, stimulated nitrification at the lower concentrations but became toxic at the higher, the nitrate at 48.9 parts per million and the carbonate at 3910 parts per million. Greaves concluded that the extent of stimulation is governed largely by the cation, and that the toxicity of potassium salts is governed by the electro-negative ion combined with the potassium, since he found that the chlorides of sodium, magnesium, manganese, and iron, and the sulfates of calcium and manganese, increased bacterial activity, while the chlorides of potassium and calcium and the sulfates of sodium and potassium failed to cause any stimulation.

Pichard (1884) found that potassium sulfate caused strong nitrification of the organic nitrogen in a soil high in organic matter, but that its influence was not so marked as was that of calcium sulfate or sodium sulfate.

Allen and Bonazzi (1915) studied nitrification in soil samples from the plots at the Ohio experiment station. Ammonium sulfate in solution was used as the nitrifiable material at the rate of 21.2 milligrams of nitrogen per 100 grams of soil. The samples were incubated for ten days. The results with the samples from the potassium sulfate plots — which had received 80 pounds of the salt to the acre on corn, oats, and wheat of the five-years rotation — failed to show any increase in nitrification over the check; in fact, denitrification apparently took place in some cases.

Peck (1911) found that potassium sulfate used at the rate of 0.5 gram in 500 grams of sugar-cane soil decreased the bacterial activity, as measured by bacterial numbers and nitrogen fixation during one month of incubation.

Renault (1910) cites experiments by Dumont which show that slow ammonification and subsequent nitrification is always accompanied by a low percentage of potash.

It thus appears that potassium fertilizers, when applied at the usual rate under field conditions, commonly exert a depressing influence on nitrification. Under laboratory conditions both the chloride and the sulfate of potassium have generally been found to exert a depressing effect on nitrification, even when used in amounts as small as 12 pounds to 2,000,000 pounds of soil. Lime apparently counteracts the injurious effects of small applications of the sulfate and permits some stimulation of the process of nitrification.

Manganese salts

Salts of manganese are known to have marked influence on nitrification, and since manganese, as has already been stated, is one of the soil bases replaced by potassium, it is of importance in this connection to note what its effects have been found to be.

Kelley (1912), working with Hawaiian soils, found that those high in manganese had a stronger nitrifying power than those low in this element. However, the soils high in manganese were in a better physical condition, and their higher nitrifying power was attributed to this fact rather than to any difference in manganese content.

Montanari (1914) found that manganese dioxide and manganese carbonate apparently stimulated nitrification, while the sulfate exerted less stimulation or even depressed the process.

Leoncini (1914) found that manganese dioxide increased nitrification when used in amounts as high as 2.2 per cent, but that heavier applications apparently had no influence.

Brown and Minges (1916) determined the effect of various manganese compounds on nitrification and ammonification in Carrington clay loam. In the ammonification tests dried blood was used, and in the nitrification trials ammonium sulfate was used. Manganese chloride apparently had no effect on nitrification in amounts less than 0.5 per cent; but from that point on, increasingly heavy applications caused increased depression, until, with 5 per cent of the salt, nitrification was inhibited. With manganese sulfate there was decisive depression of nitrification when 0.5 per cent of the salt was used, but with increasingly heavy applications the results did not show an increasing depression. Manganese nitrate apparently depressed nitrification, the magnitude of depression increasing with the amount of the salt used. Manganous oxide in most cases depressed nitrification, altho definite conclusions regarding this point cannot be drawn from the data presented.

Greaves (1916) found the chloride, the sulfate, and the nitrate of manganese toxic to ammonification in soil at concentrations of 68.6, 137.3, and 274.6 parts of added manganese, respectively, to 1,000,000 parts of soil. The carbonate of manganese was without effect even at the highest concentration used, 6045.6 parts per million.

Olaru (1915) reports three experiments on nitrogen fixation in nutrient solutions with varying amounts of manganese. He found that stimulation of the process resulted from all the concentrations of manganese used, but that the proportion of 1 part of manganese to 200,000 parts of solution gave the greatest stimulation. Olaru suggests that increases in crop yields which have been found to follow the use of fertilizing materials are due, not only to the direct action of the materials on the plants, but also to their modification of the bacterial activities of the soil.

There appears to be much conflict in the data cited regarding the effect of manganese compounds on nitrification. In some cases very low concentrations of the various salts proved to be toxic, while in others relatively high concentrations were stimulative. Too little information is given regarding the nature of the soil used in the various experiments to permit any attempt to account for the discrepancies.

EFFECT OF REACTION OF THE SOIL ON NITRIFICATION

The reaction of the soil is generally considered to be an important factor in determining its capacity to support a vigorous nitrifying flora. Brown (1911:55) apparently takes an extreme position when he says: "The effect of lime on nitrification and the necessity for the presence of lime in the soil for the process to occur, have long been a matter of common knowledge."

The literature bearing on this problem is voluminous and no attempt is made here to summarize it. The stimulating action of lime on nitrification is generally conceded, but apparently the process may go on in soils very deficient in lime.

Fred and Graul (1916) state that "it seems that under laboratory conditions, the beneficial effect of calcium carbonate on plant growth must be accounted for by some processes other than the direct effect on nitrification." Temple (1914) and White (1914) report vigorous nitrification in strongly acid soils.

In the work herein reported, the heaviest treatments with the chloride and the sulfate of potassium caused a slight increase in the lime requirement of the soils, but in no case was the increase more than 300 pounds of calcium carbonate to 2,000,000 pounds of soil. This small difference in reaction is not considered significant so far as nitrification is concerned, particularly in view of the fact that nitrification has been shown to proceed in strongly acid soils. The increasing depression in nitrification which will be shown to have accompanied increasingly heavy applications of the potassium salts must be accounted for on some basis other than increased acidity.

INTERCHANGE OF BASES

As stated by Sullivan (1907), the fact that water is purified by filtration thru sand was known in the time of Aristotle. That common salt can be removed from water by filtering the water thru sand or soil has likewise been known for many years. Hilgard (1911 : 267) states that the latter is a clearly physical effect. When neutral salt solutions are filtered thru soil, the filtrate may be either acid or alkaline, depending on whether the cation or the anion of the salt has been removed the more strongly. This phenomenon has been attributed to selective ion adsorption. Truog (1916) and Sullivan (1907) think that it is better accounted for by an exchange of bases, in which the base of the soluble salt interchanges in part with the iron or the aluminium of the soil. The salts of the latter metals hydrolyze strongly in dilute solution and give an acid value.

The fact that soils enter into a chemical exchange with salt solutions was recognized at an early date by Thompson (1850), who found that an ammonium sulfate solution filtered thru soil gave up its ammonium in exchange for calcium. Way (1850, 1852, 1854), in a number of experiments, extended the observations of Thompson and found that the nitrates, the chlorides, and the sulfates of ammonium, potassium, sodium, and magnesium, when filtered thru soil, exchanged their bases for calcium from the soil. Way concluded that the active constituent of the soil entering into this interchange was a hydrated alumino-silicate of the clay fraction. It is now thought that any silicate is capable of entering into these reactions, according to Sullivan (1907).

Peters (1860) found that the absorption of the cation of a salt in neutral solution was of about the same magnitude regardless of the form of combination. Thus, he found that potassium was absorbed in about equal amount from equivalent solutions of its chloride, its sulfate, and its carbonate. In an extensive investigation Küllenberg (1867) confirmed Peters' conclusion. He found that the base entered into the reaction in about the same amount, whether it was combined with the sulfate, the nitrate, or the chloride.

The bases are mutually replacable, but are not replaced with equal facility. The stability of the silicate or the alumino-silicate is the controlling factor. Lemberg (1870, a and b, 1872, 1876), in a series of studies, found that the sodium in silicates is replaced more readily by potassium than is potassium by sodium, and that magnesium is replaced less readily from its silicate by calcium than is calcium by magnesium.

Van Bemmelen (1878) treated a soil with a solution of potassium chloride, and found that the potassium had been exchanged for sodium, calcium, and magnesium. Van Bemmelen states that the absorption of the entire salt takes place very slightly if at all.

The important point brought out by Van Bemmelen in this early work and reemphasized by him later (Van Bemmelen, 1900), is that colloidal silica and silicates do not abstract and concentrate the salts from neutral salt solutions when filtered thru soils. Any such apparent effect is due, he believes, to a redistribution of the salt in the solution between the water of the colloid and the water of the solution.

Joly (1902–04), Briggs and Lapham (1902), and Dittrich in 1903 (cited by Sullivan, 1907:26) also have presented data tending to show that the action of neutral salt solutions on soils consists in an equivalent exchange of bases.

Ruprecht and Morse (1917) report the presence of soluble salts of iron, aluminium, and manganese in soils repeatedly dressed with ammonium sulfate without the addition of lime.

It thus appears that neutral salts of potassium when added to the soil are strongly absorbed, thus resulting in the liberation of other bases which may have either beneficial or harmful effects on plant growth. These effects may be due to some direct effect of the replaced bases on the plant's activities, or they may be induced indirectly by the modification of some of the soil's properties.

CONCLUSIONS

It appears from this summary of the literature that the common fertilizer salts of potassium have usually been found to exert harmful effects on plant growth only when used in large quantities. These effects may be accounted for in part by basic exchange, in which case the composition of the soil would be an important factor. Significant modifications of the bacterial activities in the soil may be another factor. In the following pages are reported the results of experimental work which was designed to throw light on these problems.

EXPERIMENTAL WORK

SOILS USED

Three soils were used in the experiments here reported — Hagerstown silt loam, Dekalb silt loam, and Volusia silt loam.

Hagerstown silt loam is a residual soil derived from limestone. It is known as a productive soil, and has good surface drainage and good underdrainage. The sample was collected near State College, Pennsylvania, from an old field which had never been fertilized in so far as could be learned. In collecting the soil the immediate surface was scraped off and the soil was taken to a depth of eight inches.

Dekalb silt loam is a residual soil derived from sandstone and shale. Its productivity is considered as poor to medium. It is typically poorly underdrained. The sample was collected from an abandoned field near Snow Shoe, Pennsylvania, in the same manner as was the Hagerstown silt loam.

Volusia silt loam is a glacial soil composed of a small proportion of glacial material mixed with soil material derived from local sandstone and shale. There is such a wide variation in this soil that it cannot be characterized as a series. The sample was collected near Ithaca, New York, from an unproductive, poorly underdrained field, the same method being used as was used in collecting the other soils.

PREPARATION OF THE SOILS

The soil samples were brought to the laboratory and immediately screened thru a 4-millimeter screen. Small samples of the screened soils were taken for moisture and acidity determinations, and pots were filled with a known weight of the soil calculated to the water-free basis. After the pots were filled, the contents of each pot were emptied on an oilcloth, the required quantity of precipitated calcium carbonate and potassium salt was added and thoroly mixed with the soil, and the pot was refilled. In the case of the Volusia soil, the potassium salt was added in solution after the calcium carbonate had been mixed with the soil and the pot had been refilled. The pots were then brought to weight with distilled water. Sufficient calcium carbonate was added to the Hagerstown and Dekalb soils to just satisfy their lime requirement, which amounted to 2 tons of calcium carbonate to 2,000,000 pounds of soil in each case.

With the Volusia soil varying amounts of the carbonate were used, as follows: Series I — no lime, lime requirement 3393 pounds of calcium carbonate to 2,000,000 pounds of soil; Series II — lime requirement just satisfied; Series III — 2 tons of calcium carbonate to 2,000,000 pounds of soil in excess of the lime requirement.

PLAN OF THE EXPERIMENTAL WORK

On the Hagerstown and Dekalb soils no crop was grown the first year. Composite samples of each treatment, in triplicate, were taken for nitrate determinations, with a $\frac{3}{4}$-inch brass tube, the day after bringing the pots to weight and at regular intervals thereafter during the first year. The moisture content was maintained at approximately 24 per cent (water-free basis) by bringing the pots to weight weekly with distilled water.

TABLE 1. Treatments of Hagerstown and Dekalb Silt Loam Soils
(Lime requirement of soils just satisfied; moisture content maintained at 24 per cent)

Pot	Pounds of potassium salt to 2,000,000 pounds of soil	
	KCl	K_2SO_4
1 {a, b, c}	0	0
2 {a, b, c}	200	200
3 {a, b, c}	500	500
4 {a, b, c}	1,000	1,000
5 {a, b, c}	2,000	2,000
6 {a, b, c}	3,000	3,000

The following year the triplicates were thoroly mixed on oilcloth, duplicate pots were filled with each treatment, and wheat was planted and grown to maturity thru the winter and spring. At the time of making up the duplicate pots, samples were taken, air-dried, and stored to be used later in determining the effect of treatment on water-soluble bases and on the growth of wheat seedlings in the water extracts of the soils.

TABLE 2. TREATMENTS OF VOLUSIA SILT LOAM

(Moisture content maintained at 30 per cent)

Series 1 — No $CaCO_3$; lime requirement 3393 pounds $CaCO_3$ to 2,000,000 pounds of soil

Pot	Pounds of KCl to 2,000,000 pounds of soil	Number of pots	
		Cropped to wheat	No crop grown
1	0	4 1-gallon	1 3-gallon
2	200	4 1-gallon	1 3-gallon
3	500	4 1-gallon	1 3-gallon
4	1,000	4 1-gallon	1 3-gallon
5	2,000	4 1-gallon	1 3-gallon

Series II — Same plan as Series I, with lime requirement just satisfied

Series III — Same plan as Series I, with 4000 pounds of $CaCO_3$ to 2,000,000 pounds of soil in excess of lime requirement

In the case of the Volusia soil, quadruplicate 1-gallon pots were made up of each treatment, to be cropped to wheat, and one 3-gallon pot in each treatment was filled to be used later in the other studies. All of these pots were brought to weight weekly (30 per cent moisture content, water-free basis) with distilled water. All of the laboratory determinations, including soil extract cultures with wheat seedlings, were made on samples from the 3-gallon pots, which had been kept in the greenhouse under the same conditions as the cropped pots and maintained at an approximately constant moisture content for about seven months.

The outline given in tables 1 and 2 makes the plan of the work clear.

EXPERIMENTAL METHODS

Pot cultures

Two-gallon pots were used with the Hagerstown and Dekalb soils, each pot containing the equivalent of $9\frac{1}{4}$ pounds of water-free soil. One-gallon pots were used with the Volusia soil, each pot containing the equivalent of 6 pounds of water-free soil. Duplicate pots were used with the Hagerstown and Dekalb soils, and quadruplicate pots with the Volusia soil. The Hagerstown and Dekalb soils were maintained at a moisture content of 24 per cent, water-free basis, and the Volusia soil at 30 per cent. These moisture contents gave approximately two-thirds saturation.

Soil extract cultures

Soil extract.— The soil extract for the solution cultures and the analyses for water-soluble bases was prepared by adding five parts of water to one part of soil (after correcting for the water already in the soil), shaking for three hours, and immediately filtering thru Pasteur-Chamberland filters.

Analysis of extract.— The official methods of analysis of the United States Bureau of Chemistry[1] were used, with the following exceptions: Manganese was determined by the ammonium persulfate method as described by Hillebrand (1910). Calcium was precipitated according to the official method, and titrated with potassium permanganate after solution in dilute sulfuric acid.

Soil extract cultures.— The soil extract cultures were run in duplicate. Erlenmeyer flasks of 500 cubic centimeters capacity were used for culture vessels. Four wheat plants were grown in each flask by using a paraffined paper cover thru which four holes were punched to receive the rootlets. The plants were allowed to grow for four weeks. They were then removed, photographs were taken of the roots, and the dry weights were determined.

Nitrification

In the nitrification trials, tumblers were used for containers and 100 grams of soil was placed in each tumbler. Three nitrifiable materials — ammonium sulfate, ammonium hydroxide, and dried blood — were used.

[1]Official and provisional methods of analysis, Association of Official Agricultural Chemists. U. S. Bur. Chem., Bul. 107. 1912.

The ammonium sulfate and the ammonium hydroxide were applied in dilute solution, and the dried blood was well mixed with the soil on a piece of oilcloth. The cultures were incubated at room temperature and were brought to weight every six days with distilled water. Excessive evaporation was prevented by covering the tumblers with a layer of cotton placed between pieces of cheesecloth. The period of incubation, percentage of moisture maintained, and nitrifiable material used, are shown with each table in which the results are given.

Nitrates were determined by the phenoldisulphonic-acid method as described by Schreiner and Failyer (1906).

Soil acidity determination

The lime requirement of the soils was determined by a modified Veitch method (White, 1914).

EXPERIMENTAL RESULTS

Pot cultures

The crop on the Hagerstown and Dekalb soils was attacked by sparrows on the afternoon of the day before it had been intended to harvest the pots, and as a result only the yield of straw is given. In the case of the Volusia soil, the probable error of the average for the quadruplicate pots is so high as to render most of the possible comparisons of questionable value. The probable errors were computed by means of Peter's formula as given by Mellor (1909),

$$R = \pm\ 0.8453 \frac{\Sigma\ (+ v)}{n\sqrt{n - 1}}$$

in which Σ (+ v) denotes the sum of the deviations of each observation from the mean, disregarding their sign, and n denotes the number of observations made.

The results of the pot experiments are given in tables 3 and 4.

Potassium sulfate increased the yield of straw over the check in both the Hagerstown and the Dekalb soil. In the Hagerstown soil there was a continued increase in yield with an increase in the rate of application after 500 pounds was reached. In the case of the Dekalb soil the data are not conclusive, except that, as with the Hagerstown soil, there is no evidence of a toxic condition with any of the treatments.

TABLE 3. YIELD OF WHEAT STRAW IN POT CULTURES WITH HAGERSTOWN AND DEKALB SILT LOAMS

(Lime requirement of soils just satisfied)

Pot	Pounds of K_2SO_4 to 2,000,000 pounds of soil	Yield of straw in grams		Pounds of KCl to 2,000,000 pounds of soil	Yield of straw in grams	
		Duplicates	Average		Duplicates	Average
			Hagerstown silt loam			
1	0	4.36, 4.25	4.31	0	4.12, 4.18	4.15
2	200	5.56, 5.26	5.41	200	4.45, 4.37	4.41
3	500	5.02, 5.15	5.09	500	4.87, 4.07	4.47
4	1,000	6.70, 4.85	5.77	1,000	3.91, 3.95	3.93
5	2,000	6.50, 5.65	6.08	2,000	3.86, 4.02	3.94
6	3,000	6.69, 6.16	6.43	3,000	3.11, 3.41	3.26
			Dekalb silt loam			
1	0	1.85, 1.87	1.86	0	2.02, 1.87	1.95
2	200	1.82, 1.92	1.87	200	1.98, 1.83	1.91
3	500	1.83, 1.88	1.86	500	1.73, 1.85	1.79
4	1,000	1.59, 1.71	1.65	1,000	1.98, 1.90	1.94
5	2,000	2.08, 1.88	1.98	2,000	1.71, 1.65	1.68
6	3,000	2.01, 2.10	2.06	3,000	1.70, 1.66	1.68

Potassium chloride apparently became toxic at the 1000-pound treatment with the Hagerstown soil and at the 2000-pound treatment with the Dekalb soil. The data, however, are not conclusive, and warrant only tentative conclusions regarding the rate of application necessary to bring about a toxic condition in these soils.

TABLE 4. YIELD OF WHEAT STRAW AND GRAIN IN POT CULTURES WITH VOLUSIA SILT LOAM

Series	Pounds of KCl to 2,000,000 pounds of soil	Straw (average of quadruplicates, in grams)	Grain (average of quadruplicates, in grams)
I No lime; lime requirement 3393 pounds $CaCO_3$ to 2,000,000 pounds of soil	0 200 500 1,000 2,000	6.3 ± 0.41 6.5 ± 0.45 6.6 ± 0.40 6.7 ± 0.14 8.6 ± 0.44	3.03 ± 0.10 3.14 ± 0.18 3.17 ± 0.13 3.22 ± 0.13 3.85 ± 0.19
II Lime requirement just satisfied	0 200 500 1,000 2,000	8.8 ± 0.85 7.2 ± 0.37 6.6 ± 0.23 7.4 ± 0.13 7.9 ± 0.13	4.09 ± 0.62 3.46 ± 0.30 2.79 ± 0.13 3.12 ± 0.12 3.59 ± 0.05
III 4000 pounds $CaCO_3$ to 2,000,000 pounds of soil in excess of lime requirement	0 200 500 1,000 2,000	12.1 ± 0.76 13.4 ± 0.53 10.7 ± 0.22 15.5 ± 2.45 11.9 ± 0.33	6.06 ± 0.68 5.13 ± 0.66 2.80 ± 0.44 5.18 ± 0.64 4.14 ± 0.12

Soil extract cultures

Both the root and the top growth of the wheat seedlings were very uniform in the duplicate water extract cultures. The dry weights, however, while uniform between duplicates, did not give a good measure of the comparative root growth between cultures, and consequently are not reported.

The presence of some toxic substance or substances in certain of the cultures is indicated in figures 161 to 163. The sensitiveness of the roots of seedlings to toxic substances has been adequately demonstrated by Schreiner and his associates in the United States Bureau of Soils, and by Breazeale and LeClerc, of the Laboratory of Plant Physiology of the United States Department of Agriculture.

In the extract from the Hagerstown soil (fig. 161) the chloride is seen to have stimulated root growth thruout the series, the greatest degree of stimulation resulting from the 500-pound treatment. In the sulfate series there is seen a progressive stimulation of root growth up to the

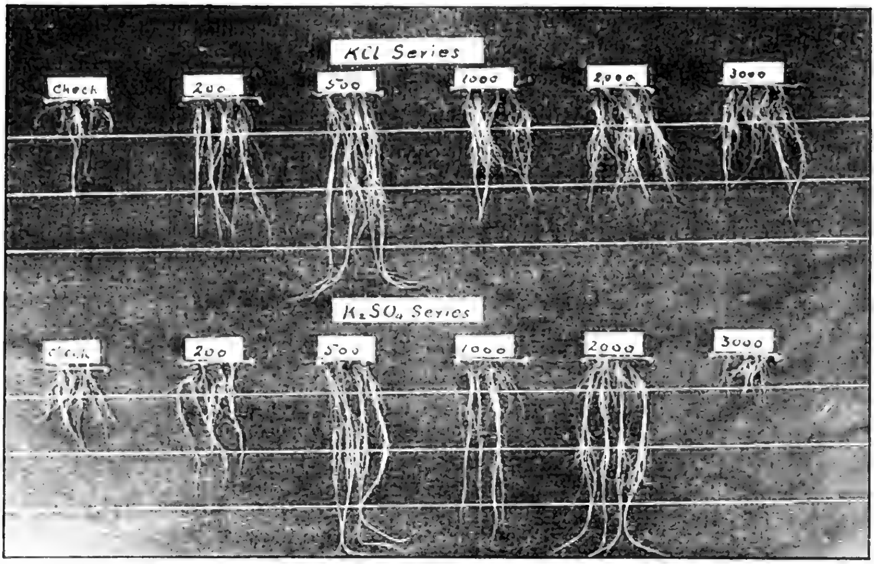

FIG. 161. ROOT GROWTH OF WHEAT SEEDLINGS IN WATER EXTRACTS FROM HAGERSTOWN SILT LOAM WHICH HAD RECEIVED VARYING AMOUNTS OF THE CHLORIDE AND THE SULFATE OF POTASSIUM

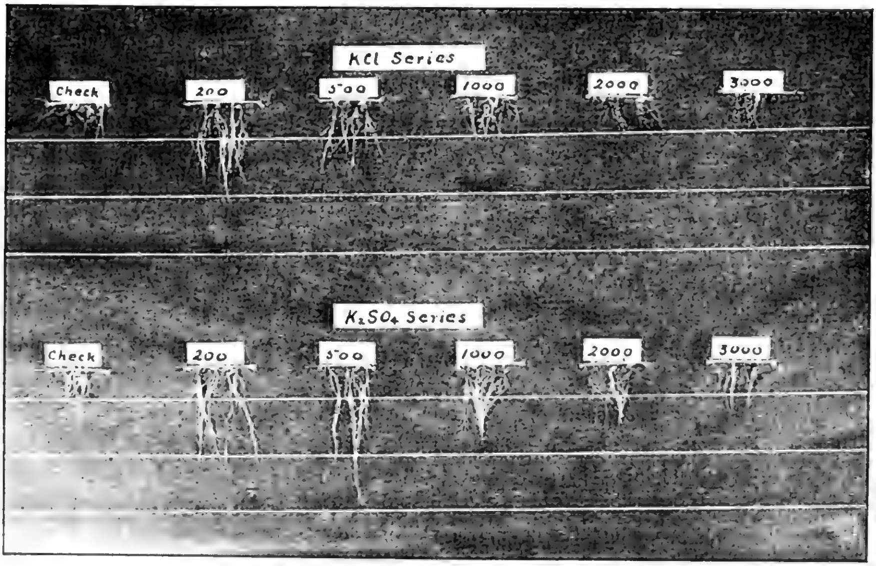

FIG. 162. ROOT GROWTH OF WHEAT SEEDLINGS IN WATER EXTRACTS FROM DEKALB SILT LOAM WHICH HAD RECEIVED VARYING AMOUNTS OF THE CHLORIDE AND THE SULFATE OF POTASSIUM

2000-pound treatment, and a marked toxicity with the 3000-pound treatment. These latter results agree in the main with the yield of straw in the pot cultures except in the case of the heaviest sulfate treatment. In this case the extract cultures showed strong toxicity, while no such condition was present in the pot cultures.

In the extract from the Dekalb soil (fig. 162) no distinct toxicity was shown in any of the cultures when compared to the checks. The checks, however, were apparently toxic. With the chloride the 200-pound treat-

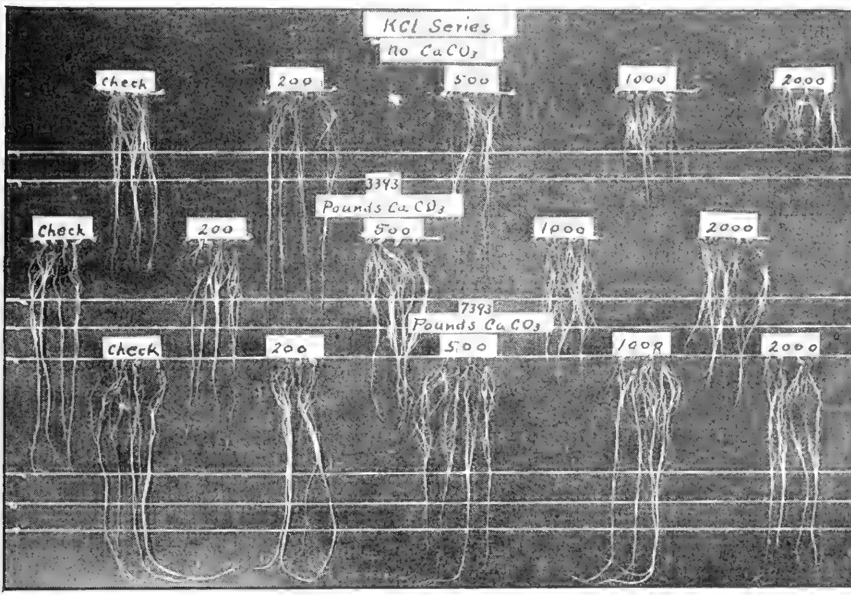

Fig. 163. ROOT GROWTH OF WHEAT SEEDLINGS IN WATER EXTRACTS FROM VOLUSIA SILT LOAM WHICH HAD RECEIVED VARYING AMOUNTS OF POTASSIUM CHLORIDE, BOTH WITH AND WITHOUT LIME

ment caused the greatest stimulation of root growth, while with the sulfate there was little difference between the degree of stimulation in the 200- and the 500-pound treatments. These results are not reflected in the yields from the pot cultures. The yields from the pots were very small and the final weights are probably not a good index of the relative vigor of growth.

In the Volusia extract cultures (fig. 163) the important point brought out is the neutralization of the toxic condition by the calcium carbonate.

A distinctly toxic condition was evident in the no-lime series with the heavier chloride treatments. This condition was less pronounced in the series receiving enough lime to just meet the lime requirement of the soil, and almost entirely disappeared when 4000 pounds of lime to 2,000,000 pounds of soil in excess of the lime requirement of the soil was used.

Nitrification

As a measure of the activity of the nitrifying organisms in the variously treated soils, determinations were made of the nitrates accumulated over long periods of time and of the nitrification of added materials. The accumulation of nitrates in the three soils used is shown in tables 5, 6, and 7, respectively. The figures represent the milligrams of nitrate nitrogen in 100 grams of soil as determined when the pots were set up and at stated intervals thereafter. The difference between the initial nitrate content and that after a given interval represents the actual

TABLE 5. Accumulation of Nitrates in Hagerstown Silt Loam as Determined at Intervals after the Experiment Was Set Up

(Moisture content, 24 per cent)

Pounds of potassium salt to 2,000,000 pounds of soil	Milligrams of nitrogen as nitrates in 100 grams of soil			
	At time of setting up experiment	After 33 days	After 61 days	After 86 days
(KCl)				
0	1.90	2.50	3.33	3.10
200	2.12	1.86	3.07	2.86
500	1.66	1.80	2.91	3.05
1,000	1.50	1.94	2.82	2.94
2,000	Trace	2.09	3.02	2.82
3,000	1.41	2.04	3.26	2.83
(K_2SO_4)				
0	1.53	2.06	3.88	3.87
200	1.96	2.53	3.22	3.60
500	1.68	2.83	3.65	3.35
1,000	1.69	2.61	3.89	4.06
2,000	2.15	2.53	3.81	4.40
3,000	1.46	2.54	3.97	4.48

accumulation, or, in some cases, loss. In the case of the Volusia soil, nitrate accumulation was determined but once, after a seven-months period.

TABLE 6. ACCUMULATION OF NITRATES IN DEKALB SILT LOAM AS DETERMINED AT INTERVALS AFTER THE EXPERIMENT WAS SET UP

(Moisture content, 24 per cent)

Pounds of potassium salt to 2,000,000 pounds of soil	Milligrams of nitrogen as nitrates in 100 grams of soil			
	At time of setting up experiment	After 33 days	After 61 days	After 86 days
(KCl)				
0	Trace	0.65	1.14	1.69
200	Trace	0.40	0.92	1.36
500	Trace	0.49	1.04	1.56
1,000	Trace	0.68	0.91	1.44
2,000	Trace	0.36	0.60	1.27
3,000	Trace	Trace	0.49	0.69
(K_2SO_4)				
0	Trace	0.71	1.44	1.25
200	Trace	0.70	1.31	1.97
500	Trace	0.67	1.65	2.27
1,000	Trace	0.89	1.86	2.71
2,000	Trace	0.81	2.13	2.16
3,000	Trace	0.63	1.87	2.08

It will be noted that in every case the potassium chloride decreased the accumulation of nitrates, and that the depression increased regularly with an increase in the amount of chloride applied except for one or two minor exceptions. In the Volusia soil the degree of depression with the heavy chloride treatments was less in the lime series than in the no-lime series, indicating the tendency of the lime to overcome the harmful effects of the potassium chloride.

Potassium sulfate seems to have exerted a stimulating effect on nitrate accumulation. In the Dekalb soil the greatest degree of stimulation occurs with the 1000-pound treatment, and then there is a gradual decline with the two heavier treatments.

TABLE 7. Accumulation of Nitrates in Volusia Silt Loam after Seven Months

(Moisture content, 30 per cent)

Series	Pounds of KCl to 2,000,000 pounds of soil	Milligrams of nitrogen as nitrates in 100 grams of soil	
		At time of setting up experiment	After seven months
I No lime; lime requirement 3393 pounds $CaCO_3$ to 2,000,000 pounds of soil	0	2.00	6.06
	200	2.00	5.55
	500	2.00	4.88
	1,000	2.00	3.77
	2,000	2.00	2.32
II Lime requirement just satisfied	0	2.00	7.50
	200	2.00	7.14
	500	2.00	5.97
	1,000	2.00	4.81
	2,000	2.00	4.08
III 4000 pounds $CaCO_3$ to 2,000,000 pounds of soil in excess of lime requirement	0	2.00	9.76
	200	2.00	9.09
	500	2.00	8.69
	1,000	2.00	7.01
	2,000	2.00	6.45

With the twenty-one-days incubation period (tables 8 to 10), all of the soils in which the lime requirement was just satisfied show the initial depression of nitrification with the 1000-pound treatment of the chloride. When ammonium hydroxide was the nitrifiable material added (table 10), altho the initial depression occurred at this point the nitrates found in the heaviest chloride treatment exceeded those in the check, indicating perhaps some action due to the basic nature of the hydroxide.

In the Hagerstown soil treated with potassium sulfate (table 8), nitrification was depressed slightly below that in the check with the heaviest sulfate treatment. This was not the case in the Dekalb soil (table 9), altho in the latter soil the 3000-pound treatment caused less stimulation of the process than did the 2000-pound treatment.

TABLE 8. NITRIFICATION IN HAGERSTOWN SILT LOAM WHEN AMMONIUM SULFATE IS USED

(Moisture content, 24 per cent; incubation period, 21 days)

Pounds of potassium salt to 2,000,000 pounds of soil	Nitrogen as nitrates in 100 grams of soil		Nitrogen in $(NH_4)_2SO_4$ nitrified	
	Check (milligrams)	21.2 milligrams N added (milligrams)	Milligrams	Per cent
(KCl)				
0	3.11	13.98	10.87	51.27
200	2.86	14.42	11.56	54.52
500	3.05	14.93	11.88	56.03
1,000	2.94	12.95	10.01	47.21
2,000	2.82	10.94	8.12	38.30
3,000	2.83	8.28	5.45	25.70
(K_2SO_4)				
0	3.87	17.18	13.31	62.31
200	3.60	16.80	13.20	62.26
500	3.35	17.52	14.17	66.83
1,000	4.06	19.03	14.97	70.61
2,000	4.40	21.60	17.20	81.13
3,000	4.48	17.64	13.16	62.07

TABLE 9. NITRIFICATION IN DEKALB SILT LOAM WHEN AMMONIUM SULFATE IS USED

(Moisture content, 24 per cent; incubation period, 21 days)

Pounds of potassium salt to 2,000,000 pounds of soil	Nitrogen as nitrates in 100 grams of soil		Nitrogen in $(NH_4)_2SO_4$ nitrified	
	Check (milligrams)	21.2 milligrams N added (milligrams)	Milligrams	Per cent
(KCl)				
0	1.69	3.75	1.76	8.30
200	1.36	3.49	2.13	10.04
500	1.56	4.28	2.72	12.83
1,000	1.44	3.61	2.17	10.23
2,000	1.27	2.21	0.94	4.43
3,000	0.67	1.21	0.52	2.45
(K_2SO_4)				
0	1.25	3.62	2.37	11.17
200	1.97	3.58	1.61	7.59
500	2.27	4.76	2.49	11.74
1,000	2.71	5.55	2.84	13.39
2,000	2.16	5.74	3.58	16.88
3,000	2.08	4.82	2.74	12.92

The beneficial action of lime is again brought out in table 10. Here it is shown that in the no-lime series depression in the nitrification of ammonium hydroxide accompanied the application of potassium chloride. When the lime requirement of the soil was just satisfied, the initial depression occurred with the 1000-pound treatment, and when lime was used in excess of the lime requirement the initial depression occurred with the 2000-pound treatment.

TABLE 10. Nitrification in Volusia Silt Loam When Ammonium Hydroxide Is Used

(Moisture content, 30 per cent; incubation period, 21 days)

Series	Pounds of KCl to 2,000,000 pounds of soil	Nitrogen as nitrates in 100 grams of soil		Nitrogen in NH_4OH nitrified	
		Check (milligrams)	21.2 milligrams N added (milligrams)	Milligrams	Per cent
I No lime; lime requirement 3393 pounds of $CaCO_3$ to 2,000,000 pounds of soil	0	6.65	8.19	1.94	4.73
	200	5.88	7.41	1.53	3.73
	500	4.88	6.25	1.37	3.34
	1,000	4.54	6.00	1.46	3.56
	2,000	2.70	3.50	0.80	1.95
II Lime requirement just satisfied	0	7.69	11.11	3.42	8.34
	200	5.58	10.96	5.38	13.12
	500	5.33	12.50	7.17	17.48
	1,000	5.12	10.77	5.65	13.78
	2,000	3.33	7.41	4.08	9.95
III 4000 pounds of $CaCO_3$ to 2,000,000 pounds of soil in excess of lime requirement	0	11.11	17.02	5.91	14.41
	200	11.11	20.00	8.89	21.68
	500	9.20	20.00	10.80	26.34
	1,000	8.00	19.52	11.52	28.10
	2,000	7.41	16.02	8.61	21.00

The results from the use of dried blood as the nitrifiable material are given in table 11. Here again the beneficial action of lime in counteracting the ill effects of potassium chloride is shown very strongly. It is possible that a longer incubation period would have allowed more nitrification in Series I. An acid condition is apparently very unfavorable to the nitrification of dried blood.

TABLE 11. NITRIFICATION IN VOLUSIA SILT LOAM WHEN DRIED BLOOD IS USED
(Moisture content, 30 per cent; incubation period, 14 days)

Series	Pounds of KCl to 2,000,000 pounds of soil	Nitrogen as nitrates in 100 grams of soil		Nitrogen in blood nitrified	
		Check (milligrams)	21.2 milligrams N added (milligrams)	Milligrams	Per cent
I No lime; lime requirement 3393 pounds of $CaCO_3$ to 2,000,000 pounds of soil	0	7.69	7.84	0.15	0.71
	200	7.76	7.14	0.00	0.00
	500	6.25	5.88	0.00	0.00
	1,000	4.54	4.66	0.12	0.57
	2,000	3.57	3.17	0.00	0.00
II Lime requirement just satisfied	0	8.60	10.96	2.36	11.23
	200	8.00	10.00	2.00	9.52
	500	7.41	8.69	1.28	6.09
	1,000	5.63	7.47	1.84	8.76
	2,000	4.60	5.06	0.46	2.19
III 4000 pounds of $CaCO_3$ to 2,000,000 pounds of soil in excess of lime requirement	0	11.59	21.54	9.95	47.38
	200	11.11	21.87	10.76	51.28
	500	9.63	20.58	10.95	52.14
	1,000	8.42	18.64	10.22	48.66
	2,000	7.76	16.08	8.32	39.51

Another series was run with Volusia soil, using ammonium hydroxide and incubating for fourteen days. The results of this series are not included herein, for they simply confirm the results of the twenty-one-days incubation period.

In the foregoing discussion of the nitrifying power of the variously treated soils, it has been assumed that the increase in nitrates during the incubation period was due entirely to the oxidation of the added materials. This assumption is clearly not entirely justified, and yet any other method of obtaining the desired information would probably be open to equally serious criticism.

Interchange of bases

The marked influence of potassium chloride on the nitrate bacteria raised the question as to whether the toxic effect might be due to replaced bases. With this possibility in view, the water extracts of the variously treated soils were tested for calcium, iron, aluminium, magnesium, and manganese, and when found to be present each of these elements was determined quantitatively.

No iron nor aluminium was found in any of the extracts, and no manganese nor magnesium was found in certain of them, as appears in tables 12 to 15. All determinations were made in duplicate, and checked very closely, so that only the averages are given.

TABLE 12. AMOUNTS OF CALCIUM IN VARIOUSLY TREATED SOILS

Pounds of potassium salt to 2,000,000 pounds of soil	Parts of calcium per million parts of soil extract				
	Hagerstown	Dekalb	Volusia		
	Lime requirement just satisfied	Lime requirement just satisfied	No lime; lime requirement 3393 lbs. $CaCO_3$	Lime requirement just satisfied	Lime 4000 lbs. in excess of requirement
(KCl)					
0	21.6	2.9	15.1	27.7	33.6
200	30.5	5.7	15.9	26.7	40.7
500	34.8	6.1	23.2	28.5	46.2
1,000	44.2	6.5	26.5	44.8	54.3
2,000	60.3	11.6	38.4	51.4	53.7
3,000	72.2	13.0	......	......	......
(K_2SO_4)					
0	21.1	2.1	......	......	......
200	24.1	3.8	......	......	......
500	25.2	3.8	......	......	......
1,000	29.5	4.5	......	......	......
2,000	36.7	5.5	......	......	......
3,000	45.1	6.0	......	......	......

As shown in table 12, with equal (but not equivalent) weights of the chloride and the sulfate of potassium the chloride replaced more calcium than did the sulfate. This result is to be expected, since equal weights of the two salts do not carry equal weights of the base.

As has been noted, Peters (1860) and Küllenberg (1867) both found that the base entered into the reaction independently of its form of combination. It does not follow from this, however, that equivalent weights of the bases in a soil would appear in the extracts from the same soil treated with various acids of the same base, because of the different solubilities of the products of the reactions. Calcium sulfate is less soluble than calcium chloride, and consequently less calcium would probably be found in the extract of a soil treated with the sulfate than in one treated with the chloride of potassium. This is apparently the condition that existed in these soils, for there is less calcium present in the extracts from the sulfate treatments than should be present theoretically if the relative solubilities are discarded and only the replacing power of the potassium actually added is considered.

No magnesium was found in any of the extracts from the Volusia soil. This series is reported by Robinson (1914) to be low in magnesium. In the Hagerstown and Dekalb soils (table 13), less magnesium than calcium was replaced by potassium. This result is in accord with results from previous work.

TABLE 13. AMOUNTS OF MAGNESIUM IN VARIOUSLY TREATED SOILS

Pounds of potassium salt to 2,000,000 pounds of soil	Parts of magnesium per million parts of soil extract	
	Hagerstown	Dekalb
	Lime requirement just satisfied	Lime requirement just satisfied
(KCl)		
0	15.6	2.9
200	18.0	3.5
500	19.4	3.7
1,000	21.2	3.7
2,000	24.8	5.0
3,000	26.2	5.7
(K_2SO_4)		
0	12.8	2.5
200	15.0	2.5
500	15.8	2.5
1,000	16.8	2.2
2,000	18.0	2.7
3,000	19.6	2.8

That appreciable amounts of manganese went into solution in the Hagerstown and Dekalb soils is indicated in table 14. As previously noted, manganese has been found to be strongly toxic both to plant growth and to nitrification. Skinner and Reid (1916), as already stated, found

TABLE 14. Amounts of Manganese in Variously Treated Soils

Pounds of potassium salt to 2,000,000 pounds of soil	Parts of manganese per million parts of soil extract				
	Hagerstown	Dekalb	Volusia		
	Lime requirement just satisfied	Lime requirement just satisfied	No lime; lime requirement 3393 lbs. $CaCO_3$	Lime requirement just satisfied	Lime 4000 lbs. in excess of requirement
(KCl)					
0	0.24	0.78	0.00	0.00	0.00
200	0.47	1.11	0.00	0.00	0.00
500	0.57	1.92	Trace	0.00	0.00
1,000	0.71	3.12	0.30	0.00	0.00
2,000	1.15	4.17	0.65	Trace	0.00
3,000	1.64	6.25	....	....	....
(K_2SO_4)					
0	0.93	0.50	....	....	....
200	0.99	0.53	....	....	....
500	1.44	0.83	....	....	....
1,000	2.03	1.08	....	....	....
2,000	2.35	1.78	....	....	....
3,000	2.80	2.50	....	....	....

that manganese chloride was distinctly harmful to crop growth in an acid soil when used at the rate of 50 pounds to the acre. This application would be equivalent to about 14 parts of manganese to 1,000,000 parts of soil if it is assumed that the salt became mixed with the surface soil only. The Dekalb soil showed approximately this concentration of manganese when its extract became toxic to wheat seedlings. To bring this out more clearly, the parts per million of manganese in dry soil are calculated in table 15.

The presence of manganese, however, cannot be considered as a complete explanation for the toxic condition found in the extract cultures and indicated in the pot cultures, and for the depression of nitrification particularly with the chloride treatments. The extract from the Volusia soil was toxic to wheat seedlings in certain treatments and no manganese was found in solution. Toxicity in solution cultures may arise from a

TABLE 15. AMOUNT OF MANGANESE IN DRY SOIL

Pounds of potassium salt to 2,000,000 pounds of soil	Parts per million of water-soluble manganese in dry soil	
	Hagerstown	Dekalb
	Lime requirement just satisfied	Lime requirement just satisfied
(KCl)		
0	1.20	3.90
200	2.35	5.55
500	2.85	9.60
1,000	3.55	15.60
2,000	5.75	20.85
3,000	8.20	31.25
(K_2SO_4)		
0	0.93	2.50
200	0.99	2.65
500	1.44	4.65
1,000	2.03	5.42
2,000	2.35	8.92
3,000	2.80	12.50

number of conditions, one of which is a lack of balance of nutrients. It is of interest, nevertheless, tho perhaps not of significance, to note that the soil having the highest content of water-soluble manganese showed the weakest nitrifying power and the smallest accumulation of nitrates, as well as the smallest growth of wheat in pot cultures and of wheat roots in extract cultures.

SUMMARY

Three silt loam soils were used in the experiments reported herein, each soil being representative of a large area in the United States. The productivity of the soils ranged from high to very low.

The soils were screened and the pots were filled with the treated soils as described. The official methods of analysis of the United States Bureau of Chemistry were used, with the exceptions noted.

Potassium sulfate increased the yield of straw in Hagerstown soil and showed no toxic effect in Dekalb soil. Potassium chloride apparently became toxic to wheat in Hagerstown soil with the 1000-pound application; in the Dekalb soil there was a slight decrease in yield with the 2000-pound treatment.

In the extracts from the Hagerstown soil, potassium chloride stimulated the root growth of wheat seedlings at all concentrations, the greatest stimulation occurring with the 500-pound treatment. With the sulfate there was a progressive stimulation to the 2000-pound treatment, and a marked toxicity with the 3000-pound treatment. In the extracts from the Dekalb soil the checks were toxic to the root growth of wheat seedlings. With the chloride the 200-pound treatment caused the greatest stimulation, and there was a decrease in stimulation and apparent toxicity with the heavier treatments. With the sulfate the 500-pound treatment caused the greatest stimulation, and there was a decrease in stimulation and apparent toxicity with the heavier treatments. In the extracts from the no-lime series of the Volusia soil, toxicity to root growth became evident with the 500-pound treatment. Lime overcame the toxicity even with the heaviest chloride treatment.

Potassium chloride decreased the accumulation of nitrates in all cases. Lime overcame this effect in part. Potassium sulfate apparently stimulated the accumulation of nitrates in Hagerstown and Dekalb soils.

The heavier potassium chloride treatments depressed nitrification of added materials. Potassium sulfate stimulated the process in all three soils with the exception of the heaviest treatment with Hagerstown soil. Lime had a tendency to correct the depression of the chloride in the Volusia soil, but did not entirely overcome it.

No iron nor aluminium was found in any of the water extracts, and no manganese was found in the extracts from the Volusia soil; hence the harmful action of the potassium salts cannot be attributed to replaced iron or aluminium, or to manganese in the case of Volusia soil. Both the chloride and the sulfate of potassium replaced calcium strongly. Less calcium appeared in the extract from the sulfate-treated series than would be expected, possibly because of the relative insolubility of calcium sulfate. Magnesium was replaced less strongly than was calcium. Manganese was replaced in very appreciable amounts in Hagerstown and Dekalb soil, particularly in the latter. The soil highest in water-soluble manganese showed the least nitrifying efficiency, the smallest growth of wheat in pot cultures, and the poorest growth of wheat rootlets in extract cultures.

The effects of potassium salts on plant growth are due to a complex interaction of factors, involving perhaps the direct action of the salts on plant growth and on bacterial activities, and also the action of bases replaced by the potassium, particularly manganese.

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