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SOME OBSERVATIONS UPON THE EFFECT OF BORAX IN FERTILIZERS.

CONTENTS

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BULLETIN 288

SOME OBSERVATIONS UPON THE EFFECT OF BORAX IN FERTILIZERS.

W. J. Morse.

SUMMARY

Unexpected and material losses in the form of partial or almost total crop failure occurred in 1919 on a large number of Maine potato fields where the customary relatively large applications of commercial fertilizer were made. Injury to the parts of the plants below ground was apparent early in the season. In severe cases many plants failed to reach the surface of the ground and those that grew had a characteristic appearance differing from types of injury or disease previously observed.

Field studies, covering a wide variety of conditions, showed that these losses were, for the most part, confined to the fields where fertilizers manufactured by certain individual companies were applied. Moreover the trouble appeared to be associated with the potash used in the manufacture of these fertilizers, for it did not occur where the no-potash fertilizers put out by the same concerns were used.

The Station chemist found boron present in appreciable amounts in these fertilizers wherever samples could be obtained of those used on the fields where the type of injury in question appeared. No definite cases of similar injury were observed where it could be shown that borax-free fertilizers carrying approximately similar amounts of nitrogen, phosphoric acid and potash were applied.

Limited experiments have been made with pot cultures in the greenhouse in which fertilizers containing borax were applied to potatoes, beans, oats, wheat and buckwheat.

With potatoes samples of 6 different lots of fertilizer sold in Maine in 1919 were used. At the rate of application the amount of anhydrous borax used varied from nothing to 38.6 pounds per acre, the most extensive trials being at the rate of 17.6 pounds per acre.

The results of the greenhouse experiments to a large extent confirm the field observations. Potato plants in pots containing no commercial fertilizer and those in pots to which a borax-free fertilizer was added were free from injury. No plants which received fertilizer containing borax escaped injury in some form or other. In general the amount of injury varied with the amount of fertilizer used, but the results were not uniform in this respect.

Except where the largest amount of borax was applied, the type of injury in the greenhouse differed in some important respects from that observed in the field. Killing of the tips and margins of the leaves was characteristic of the greenhouse potato plants. At the rate of 17.6 pounds of anhydrous borax per acre the most severe leaf injury was obtained where the fertilizer was mixed with the upper 6 inches of soil in the pot or with the 3 inches of soil below the seed-piece and the plants heavily watered. The larger applications of boron caused greater root injury, more stunting of the plants and less tip and marginal injury to the leaves.

An application of fertilizer in the drill equivalent to 4.4 pounds anhydrous borax per acre caused severe injury to beans, while broadcasting the same fertilizer, applying the equivalent of 8.8 pounds anhydrous borax per acre caused no apparent injury to oats, wheat and buckwheat.

INTRODUCTION.

The soils of New England are particularly free from substances which are deleterious to plant growth. Hence the apparent presence of some poisonous salt in the fertilizer used by many potato growers in Maine in the season of 1919 presented an entirely new problem to the farmers and the fertilizer trade and to the students of plant diseases as well.

Certain difficulties had been experienced in the use of chemical commercial fertilizers coincident with the partial and later the total disappearance on the market of European potash as the result of the war. Partly because experiments conducted by this Station and partly because the experience of certain practical growers had shown that on the Caribou loam, the most extensive and best type of potato soil in the State, the potash content of the fertilizers could be reduced materially without greatly lessening the potato crop, but more on account of the fact that

potash was high in price and was for the most part unobtainable, a large amount of no-potash fertilizers were used for the first time in 1916. Most frequently these contained 5 per cent of ammonia and 10 per cent of available phosphoric acid and were known as 5-10-0 goods.

A "new potato disease" made its appearance in July of that season. The foliage of the affected plants, instead of being a normal, healthy dark green, showed first a peculiar bronzing and yellowing. As the disease progressed the plants had, on casual inspection, much the appearance of potatoes just previous to ripening. In the final stages the leaflets hung limp and the entire plant wilted. Usually discolored areas appeared on various parts of the stems. A very characteristic feature of the trouble was the formation of a dry, discolored, spongy area which involved the whole stem just at the surface of the ground. Following this discoloration of the basal portions of the stem the tissues would dry out, the stem would become hollow at that point and the plant would fall over. Cross sections of the stem sometimes showed a discoloration of the water or food conducting vessels.

When the trouble first appeared in 1916 there was some reason to suspect that it was of a parasitic nature. The various lesions scattered over the stems were of a light brown or reddish brown color and later usually showed a lighter colored center. A number of different fungi were found to be associated with the lesions, but most frequently the lighter colored portion would be studded over with the fruiting bodies of a fungus of the genus Phoma. Repeated attempts to reproduce the disease in healthy plants by inoculation with cultures of this and other fungi isolated from spots on potato stems obtained from different parts of the State resulted in failure. This seemed to disprove the theory of a parasitic cause of the disease.

It was soon discovered that this so-called "new disease" occurred only where the 5-10-0 fertilizers were used and there, in destructive amounts, it was largely confined to the poorer types of soil. Even small amounts of potash in commercial fertilizers or the application of relatively small amounts of stable manure in addition to the 5-10-0 fertilizer would correct the difficulty. Later experience fully confirmed the conclusions

reached in 1916 that the fundamental cause of this trouble was lack of potash in the fertilizer.*

These experiences led Maine potato growers to demand that the manufacturers supply them with fertilizers containing potash. The manufacturers met this demand as far as possible, using various American sources of this material, but it was not till 1919 that relatively large amounts of such fertilizers were sold which contained potash in amounts at all comparable to that used before the war. The so-called Searles Lake deposits in California being the largest and most promising source of American potash were naturally used in many cases. These deposits are not pure potash salts but contain mixtures of other materials, including compounds of boron. Certain samples of this potash, used in the manufacture of fertilizer that came to the attention of the Station in 1919 contained the equivalent of from 5 to 10 per cent of sodium biborate or borax.

No attempt will be made to discuss in this publication the general problem of the effect of boron or its compound borax upon plant growth or to review previous literature upon this subject. It may be said, however, that it is only within a very short time that it has even been suspected that the small amounts of borax that have been found in the fertilizers under consideration would prove so toxic to farm crops as now appears to be the case.

Neither is an attempt made to discourage the use of American potash, provided it can be produced cheaply enough so that American farmers can afford to use it and provided it can be sufficiently freed from deleterious impurities so that it can be used with safety. The experiences of the past few years simply serve to emphasize the importance and even the necessity for all concerned to unite in supporting, in every way possible,

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*For some reason, possibly due to more general use of stable manure, this trouble did not attract much attention in southern New England till later. In 1918 it was sufficiently common in southern Connecticut and on Long Island and surrounding territory to cause much comment and alarm. Here again there was a strong tendency to look upon it as a parasitic disease with Phoma as the causal fungus. On the other hand Dr. Geo. P. Clinton, after a thorough canvass of the situation seems to have reached, in part, similar conclusions as to the fundamental cause, as were obtained in Maine. (See Potato Magazine Vol. 1, No. 12, June, 1919. Prematuring and Wilting of Potatoes, G. P. Clinton.)

any movement which has for its object making American agricultural and manufacturing interests partially or wholly independent of foreign sources of potash. In this connection it may be said that the company principally interested in marketing potash from the Searles Lake deposits states that with improved methods of refining they are now putting out a potash in which the amount of borax is reduced to less than one per cent.

SOME PRACTICES FOLLOWED BY MAINE POTATO GROWERS.

Methods of growing the potato crop vary considerably in different parts of the country. It may, therefore, assist the general reader if a brief statement is made relative to certain of the practices followed in Aroostook county where most of the observations were made upon the effect of borax in fertilizers. While there are numerous variations, potatoes usually follow clover in a 3-year rotation, in which oats constitute the third crop. While some stock is kept, the great majority of potatoes are grown upon chemical fertilizers supplemented by humus obtained from clover sod alone or from this and "second-crop" clover plowed under the fall before.

In the last 20 or more years the amount of commercial fertilizer used has gradually and quite materially increased until now an application of 2000 pounds per acre is not an uncommon practice and some growers use more than this. With few exceptions this fertilizer is all applied in the drill at planting time. Some planters distribute it above the seed-piece and some below. Those planters in most general use do not deposit the fertilizers in direct contact with the seed-piece, but close to it and not mixed very much with the soil.

Formerly, when potash was relatively low in price, it was not uncommon to apply fertilizers containing as high as 10 per cent of this ingredient. A 4-6-10 was one of the mixtures popular with Maine potato growers in 1914 and for some years previous. The samples collected by the Bureau of Inspections of the State Department of Agriculture and analyzed by the Station chemists show that the amount of potash in the special potato fertilizers had dropped to 4 per cent or lower in 1915. In 1916 only a few samples of 4-per cent goods were found. For the most part the fertilizers found that year contained one

or two per cent of potash and many none at all. Conditions improved somewhat in 1917, there being more evidence of 3 and 4-per cent goods. A still greater proportion of the 1918 samples were of the 4-per cent potash grade, while in 1919 some 6-per cent goods were found. With the reduction in the amount of potash used in potato fertilizers sold in Maine during the last 5 years there has been a tendency to increase the amount of phosphoric acid, not because experience had indicated any need for this, but apparently because it was the cheapest and most plentiful fertilizing material that the manufacturers could obtain.

It is interesting to note that, in spite of these wide variations in the composition of the fertilizers used, no general complaints have been made by the potato growers, previous to 1919, of ill effects from their use, except where 5-10-0 or similar mixtures were used, although in 1918 there was some undercurrent of feeling that the results obtained from goods carrying American potash were not quite up to expectations. While it is an open question whether such excessive applications of potash as are made when 2,000 pounds of fertilizer per acre are used, containing 10 per cent of this material is necessary or wise, the results obtained from the practice previous to 1914 were such as to convince many practical potato growers that it was good business. The only bearing that the question has on the matter under consideration is that it serves to emphasize the fact that even excessive applications of the type of potash used prior to 1914 resulted in no dissatisfaction on the part of the users.

FIELD OBSERVATIONS ON INJURED POTATO FIELDS IN 1919.

Early in July 1919 rumors began to reach the Station that some fields of potatoes in Aroostook County were not showing normal germination and growth. Definite complaints began to be received about the middle of July by both the State Department of Agriculture and the Experiment Station. The Director of the Station, and the Chiefs of the Bureaus of Inspections and Seed Improvement of the State Department at once decided to make a joint, personal investigation of the situation. As a member of this party the writer spent 10 days in the field studying conditions at that time. During the remainder

of the growing season considerable attention was given to similar field studies in various sections of the State.*

It soon developed that the trouble was confined largely to the fertilizers manufactured by certain individual companies and, as far as the writer observed, to the brands put out by these companies which contained 4 or 6 per cent of potash. Wherever samples could be obtained of the goods used, the analyses made by the Station chemist showed the presence of borax in appreciable amounts. It later developed that borax might be present in a fertilizer from other sources, from mixtures of nitrate of potash and soda for instance, but in the field observations under consideration the trouble seemed always associated with the potash used. For example, some fields were seen where a part was planted with a fertilizer containing potash, and another part planted with a no-potash fertilizer put out by the same concern. The plants where the last named material was used appeared strong and vigorous when examined the latter part of July, while those where the potash goods were used showed various degrees of what will be described as borax injury.

Nature and Amount of Injury Occurring on Potato Fields and Its Relation to the Fertilizer Used.

Although the type of injury may differ, as will be pointed out later, the presence of even small amounts of borax in a fertilizer when such fertilizer is applied at the rate of a ton per acre has a very marked effect on the potato plant, both in the field and in the greenhouse. In the field the casual observer first notes, in severe cases, a stunted appearance of the plants, with an abnormal number of "skips" or failures to germinate. Such a field is shown in the foreground of Fig. 14. Note the vigorous growth and even stand of the plants in the background. This portion of the field was planted three weeks after the first.

*The writer was especially fortunate in being able to inspect a large number of these fields in company with Dr. George H. Pethybridge, Economic Botanist to the Department of Agriculture and Technical Instruction for Ireland, Dr. A. D. Cotton, Mycologist to the Ministry of Agriculture and Fisheries, London, and Mr. E. J. Wortley, Director of Agriculture, Bermuda, all of these gentlemen being potato-disease specialists of international reputation.

A 4-8-6 fertilizer was applied in the same manner in each case, but different lots obtained from different manufacturers were used.* Equally striking differences were observed from the use of these two fertilizers on the same field, using the same seed planted the same day. All injury disappeared at the exact point where one fertilizer ran out and the other was placed in the planter.

On severely injured fields, like that mentioned above, a close inspection revealed the fact that there were few normal plants. At the time when the plants on uninjured, near-by or adjoining fields were for the most part strong and vigorous and nearly covered the ground, those where the injury occurred presented a very striking contrast. An occasional plant might be found which approached normal appearance, but for the most part those that came were weak and sickly looking, many being only two or three inches high. An intertesting fact was noted that many of these stunted plants blossomed at the same time as healthy plants of the same age.

The foliage of the injured plants, where borax was present in the fertilizer, had a characteristic appearance. There was considerable yellowing of the leaves, more particularly of the margins. This was most prominent on the more dwarfed and more severely injured plants. The yellowing was of a bright golden color, and not the pale, sickly yellowing usually present in plants that are normally or prematurely ripening. In the milder cases the abnormal color was restricted to the extreme edges of the leaves. In fact, as field observations progressed, the appearance of this very narrow band of yellow at the mar-

*Unfortunately samples of these two lots of fertilizer could not be obtained for analysis. The only evidence that the differences shown on the adjoining portions of this field was due to the presence of boron in one of the fertilizers used is that wherever it was possible to obtain samples of the same brand of fertilizer where it had been used on fields that showed similar injury, these samples contained borax in more than appreciable amounts. On the other hand no samples of the other brand were found which contained any borax. Only one complaint was received where any of the goods manufactured by this concern were used. Here no sample could be obtained. The writer examined the field in question and, while it was seen too late in the season to form an accurate opinion, was not convinced that the owner's contention that he had a case of borax injury was correct.

gins of the leaves, particularly the lower ones, came to be looked upon as an important diagnostic character in cases of suspected borax injury, where the effects were not sufficient to produce serious stunting and failures to germinate. In severe cases the leaves themselves were frequently narrowed and in certain instances the smaller leaves at the top were noted as folded upward on the mid-rib.

FIG. 14. Two different brands of 4-8-6 fertilizer were used on this field. The portion shown in the background was planted 3 weeks later than that where the weak, scattered plants occur. See foot-note on p. 96.

On many borax injured fields, for the most part planted during the last two weeks in May, a marked change began to take place about the first of August. The plants which survived started to grow and, as a result, many of the more marked symptoms of the trouble as already described either disappeared or became masked by the growth of the plant. This apparent recovery is explained on p. 100. The only borax injured potato field that the writer was able to visit at regular intervals throughout the season, indicated that this improvement in the condition of the plants came too late to materially aid in producing a crop. This seemed to be the general opinion of owners of fields which showed similar conditions.

The parts below ground showed other striking evidences of injury. The nature of this injury varied somewhat with the type of planter used, that is, whether the planter deposited the fertilizer above or below the seed piece. It also varied with the amount of borax-containing potash which was applied. For example, the injury where a 4-8-6 fertilizer was used was more severe, as a rule, than where the same amount of 4-8-4 goods from the same manufacturer was applied.

As might be expected some of the worst cases of injury observed were those where the fertilizer was deposited above the seed piece and the stem of the plant had to grow up through it. On one such field in particular there was a large amount of browning of the stems in the region of the fertilizer. Many cases were found where the stem was entirely cut off and in some instances it had sent out new branches from below, which in turn might or might not be cut off. Injury to the stems below ground also frequently occurred where the fertilizer was deposited below the seed piece but this was more often close to the base or point of attachment of the stem.

The lesions somewhat resembled those caused by Rhizoctonia, but were invariably much lighter brown in color and were more likely to entirely encircle the stem. Rhizoctonia may or may not be present as a complicating factor, but there is plenty of evidence in the line of field observations which indicate that neither it nor any other parasitic fungus is a material factor in the production of stem lesions which are attributed to the presence of borax in the fertilizer used. For example, the owner of the field shown in Figure 15 used a fertilizer containing borax up to the point where the stake is placed in the row. At this point he changed to another brand of fertilizer of the same formula but which contained no borax, and immediately continued planting. The plants on the left showed all the typical symptoms of severe borax injury described above and numbers of them selected at random showed the stem browning and injury in practically every case. On the other hand the plants of the portion of the field at the right of the stake, where the other fertilizer was used, were normal in appearance, nearly covered the ground at the time the record was made, and showed no evidence of injury to the parts below ground.

FIG. 15. A fertilizer containing borax was applied to the left-hand portion of this field. The stake in the row at the center marks the point where the owner changed to a fertilizer of the same formula, but containing no borax.

FIG. 16. A 3-6-6 fertilizer, with a smaller amount of 5-10-0 applied later, was used on the two and a fraction rows beginning with the point marked with the hat and ending at the point where the stake is placed. The potatoes on either side were fertilized with 5-10-0 alone. See p. 102.

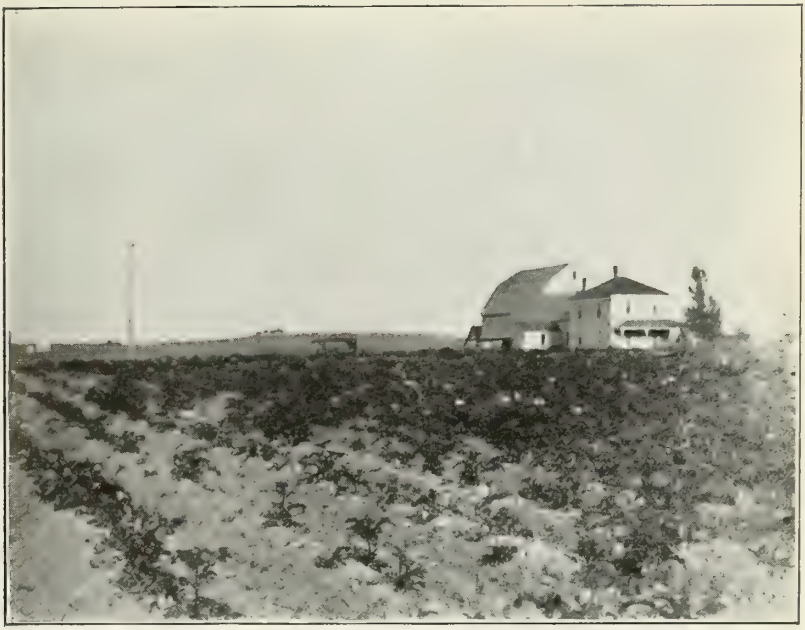

FIG. 17. The plants on the left received a small amount of fertilizer containing borax. Those on the right received no fertilizer. See p. 103.

FIG. 18. This illustrates the appearance of many of the badly injured fields during the latter part of July.

FIG. 19. Bad cases of borax injury in the field. This represents the entire growth made by the plants in three months. Note that the root system is almost entirely destroyed. Compare with Fig. 21.

Browning and killing of the roots was a very prominent sign of the trouble, being more pronounced in the case of the badly dwarfed plants. This condition is well illustrated by Figure 19 from a photograph made on August 13. It will be noted that in spite of the fact that the seed pieces had been planted nearly 3 months the plants had made practically no growth above the surface of the ground. The roots had been killed off at the base and there were no roots present at the nodes of the stem, where it was covered with soil, as would normally be the case. Of the roots at the base of the stem, whether the fertilizer was applied above or below the seed peice, frequently nothing remained but a tuft of dried, brown stubs.

Seed-pieces in direct contact with the fertilizer often showed a burning and erosion of the cut surfaces. In general, however, the presence of borax seemed to have a preservative

effect on the seed-piece, since there was a marked absence of decay in the latter where fertilizers were used which contained it in considerable quantities.

Plants which survived till the middle of the summer usually began to put forth roots from the stem close to the surface of the ground or in the region most remote from the point of application of the fertilizer.* These plants, if they had not been too severely injured, then began to grow fairly rapidly as the result of the partial establishment of a new root system in the hilled-up soil, out of contact with the fertilizer. As has already been stated the yellowing and other evidences of injury disappeared more or less completely with the new growth. This belated or secondary growth of the injured plants tended also to obscure the number of missing hills and thus improved the appearance of the affected fields generally. Such of these fields as it was possible to observe from time to time during the season proved very deceptive to those who were not familiar with their history. The yields of tubers were far from what might be expected from the appearance of the partially recovered plants. One field in particular, which the writer had under observation during the latter part of the growing season, showed marked improvement during August and September, but the owner obtained only about one-third of a normal yield. The fertilizer used carried 0.88 per cent anhydrous borax and at the rate used was equivalent to an application of 17.6 pounds of anhydrous borax per acre.

The above description of the injury to potatoes in the field and attributed to the presence of borax in the fertilizer used, applies more particularly to the severe cases. All gradations between this and fairly normal plants might be found on the same field. A few mild cases of injury were seen where it was rather difficult to decide whether or not the trouble was due to the presence of borax in the fertilizer. Some of these were

*For the benefit of those who are not familiar with the cultural practices followed with potatoes in Maine it may be said that it is customary to cover the plants with a horse hoe as soon as they begin to break ground. This is repeated when the plants begin to appear a second time. Hence a considerabe ridge or hill is already formed from the surface soil, well above the seed-piece and fertilizer, before the plants finally come up.

seen so late in the season that most of the prominent symptoms had disappeared. None of these were classed as borax injury unless fairly conclusive evidence such as the characteristic stem and root burning could be obtained. In this connection it may be said that in every one of such mild or doubtful cases where field observations gave presumtive evidence of borax injury and samples of the fertilizer could be obtained the samples were found by the chemists to carry borax in appreciable amounts.

No attempt has been made by the present writer to secure data as to the yields on any considerable number of fields where borax injury occurred, but numerous cases have been reported where the yields were not over half or one-third of a normal crop and some of the more severely injured fields would hardly produce a sufficient crop to pay the cost of harvesting.

The early part of the growing season of 1919 in Aroostook county was quite dry. In a few instances much less injury was observed on the lower and less thoroughly drained portions of the fields. In one case the owner planted part of a field a few days before a heavy shower and finished the remainder of it after the rain. Much less injury occurred on that part of the field planted after the rain. Since borax is readily soluble, these observations suggested that it was carried away by the soil water and that in seasons of ordinary rainfall in June much less injury from borax might be expected. Other observations indicated that more thorough mixing of the fertilizer with the soil than is commonly practiced would prevent or materially reduce the amount of injury. In the greenhouse experiments described later an attempt was made to test these theories and it will be seen that they were not wholly confirmed.

In studying conditions in the field it soon developed that there was sufficient evidence of a general nature to convince the average person that the trouble under consideration was associated with the fertilizer applied, moreover, that it was in some way connected with the potash used in the fertilizer in most instances. On the other hand many individual cases of themselves, when considered alone, fell far short of actual proof of this, or of proof approximating that which can be obtained through experimental evidence. However, a few fields of potatoes were found which provided conditions approaching

those which might be selected under actual experiment. Two of these will be described by way of illustration.

Mr. A. on one side of a field of several acres applied a 3-6-6 fertilizer at the rate of 1700 pounds per acre, all in the drill at planting time. Next to this, a section of the field was planted with 1300 pounds of the 3-6-6 goods per acre in the drill, with 500 pounds of a 5-10-0 fertilizer applied later on top of the row. Next came 4 rows with 1700 pounds per acre of 5-10-0 applied in the drill at planting time. Then following were two and a fraction rows with 1300 pounds per acre of 3-6-6 in the drill at planting time and with 500 pounds of 5-10-0 on top of the row, the same as the second section of the field described. The remainder of the field was planted with 5-10-0 goods at the rate of 1700 pounds per acre in the drill at planting time.

When examined first on July 21 the plants where the 5-10-0 fertilizer was used alone were, on the average, strong and vigorous. Where the 3-6-6 fertilizer was used alone or in combination with the 5-10-0 goods there appeared, in addition to numerous "skips" or failures to produce plants, the characteristic stunting of the plants, with yellowing of the leaves, more especially at the margins, and varying amounts of injury to the parts below ground. The injury was more pronounced where the 1700 pounds per acre of the 3-6-6 fertilizer was applied in the drill at planting time than where only 1300 pounds of this fertilizer was used at that time and 500 pounds of 5-10-0 was applied later.

Figure 16 is from a photograph of the two and a fraction rows which received 1300 pounds per acre of the 3-6-6 in the drill and 500 pounds of the 5-10-0 later. On either side are rows of plants which had 5-10-0 alone at the rate of 1700 pounds per acre in the drill. The barrel stave in one row indicates where one fertilizer gave out and the other began.

Mr. B. had a field of 44 acres of potatoes, on which he applied a 4-8-4 fertilizer in the drill. He began to plant using this at the rate of 2400 pounds per acre. Later he cut the amount down to 2000 pounds per acre. Then seeing that he had an insufficient amount of fertilizer to finish the piece, and being unable to secure an additional supply, he reduced the amount from time to time till he reached the minimum that the planter

would apply. Finally he ran out of fertilizer and finished the piece without any.

It was impossible to locate with any degree of accuracy where all of these changes in the amounts of the fertilizer application were made on this field, but one had no difficulty in locating the exact point where he began to plant with no fertilizer at all. The plants where no fertilizer was used were more vigorous and uniform than those on any other portion of the field. The contrast between the appearance of the plants where no fertilizer whatever was used and those next to them that received only a small amount of fertilizer is shown in Fig. 17.

Fig. 18 is a fairly representative illustration of the conditions observed on this field and numerous others during the latter part of July, 1919.

Where the larger amounts of fertilizer were used there were many missing hills. The plants averaged small and weak with yellowing of the margins of the lower leaves. The smaller leaves at the tops of the more stunted plants were folded together. Not much stem injury was noted at the time of observation, but frequently the stems were found to be those which had branched up from below where the original stems had been killed below ground and had entirely disappeared.

The injury appeared in different degrees on all parts of the field to which the fertilizer was applied, but with each decrease in the amount of application it was evident that there was a corresponding decrease in the amount of injury produced. In a few instances the differences between adjoining sections of the field were sufficiently marked to indicate the probable point where the changes were made on the planter to reduce the amount of fertilizer application.

Greenhouse Experiments with Fertilizers Containing Borax.

The close relation between the presence of borax in the fertilizers used and the injury which occurred on many potato fields, as shown by the observations made during the summer of 1919, led to the planning of certain greenhouse experiments with fertilizers, with and without borax, using potatoes, beans,

oats, wheat and buckwheat. The results reported here are those obtained from what from the first have been regarded as preliminary studies, but it is believed that they are of sufficient significance to be of value as a matter of record at this time.

These preliminary experiments possess certain limitations, some of which will be mentioned. While, as will be seen, the results with potatoes and beans were quite striking and uniform, a larger number of pots for each individual treatment would have been better. The relatively small number of pots used was partly due to the limitations imposed by lack of greenhouse space, but more particularly in the case of potatoes it was due to the fact that at the time the work was begun, October 3, it was difficult to secure a sufficient amount of satisfactory seed potatoes in condition for immediate germination. While the results show that fertilizers containing borax produced varying amounts of injury to potatoes and that such injury did not occur on plants in pots containing borax-free fertilizer or in pots containing no fertilizer, they do not show conclusively that borax is the sole and only factor involved. They furnish very strong presumptive evidence that this is the case. There are also certain objections that might be raised to the method used in applying water to the pots.

Plans were made whereby it was intended to repeat and amplify these experiments to meet the objections enumerated, as far as the limitations of greenhouse space would permit. It was then found that the Directors of the other Agricultural Experiment Stations in New England, New York and New Jersey were interested in joining in conducting a cooperative greenhouse experiment on a relatively large scale in which the effects of the presence of different amounts of borax in fertilizers when used on potatoes, corn and beans would be determined. Arrangements were perfected whereby this work was begun about February 1, the final plans being prepared by the Director of the Maine Station and the writer. To Mr. J. R. Neller of the New Jersey Station, an expert in pot culture, was assigned the responsibility of carrying out the details of these cooperative experiments, which are now in progress in the Vermont Station greenhouses.

As soon as the plans mentioned above were perfected, work along similar lines was discontinued at Orono. The following

concerns only the results previously obtained in the preliminary experiments at this Station, or between October 1, 1919, and about January 15, 1920.

WORK WITH POTATOES.

Soil. The soil used for potatoes was a medium heavy loam which had been under cultivation for many years, being used each year for garden purposes. In recent times it has had an application of barnyard manure on alternate years and commercial fertilizer applied yearly. It was taken directly from the garden and placed in pots in the greenhouse.

Kinds of fertilizers used and amounts applied. Six different brands of fertilizers, made by five different concerns and sold in Maine in 1919, were used. In every instance the applications of all fertilizers to pots containing potatoes were made at planting time and as nearly as possible at the rate of 2,000 pounds per acre. The usual fertilizer analysis of each lot had been made by the Station chemists, including a quantitative determination for borax. These results and certain other data, including the number of pounds of anhydrous borax used when the several fertilizers are applied at the rate of 2,000 pounds per acre, are shown in tabular form.

Table Showing Composition of Fertilizers Used.

Station No.	Composition	Per cent of anhydrous borax	Pounds of anhydrous borax per acre	Number of pots used
5549	4-8-6*	0.88	17.6	20
5389	4-8-6	0.35	7.0	4
5518	3-6-6	0.93	18.6	4
5536	3-6-6	1.44	28.8	4
5513	4-8-6	1.93	38.6	4
5409	4-8-6	0.00	00.0	4
Checks, no fertilizer	——	——	——	4

*The figures in this column represent approximately the per cents of ammonia, available phosphoric acid and potash respectively.

Variation in methods of application of fertilizer. As will be seen by the number of pots given in the right-hand column of the table, the most extensive trials were made with

fertilizer No. 5549 which, when applied at the rate of 2,000 pounds per acre, was equivalent to an application of 17.6 pounds of anhydrous borax per acre. With this fertilizer the 20 pots were divided into 5 different lots of 4 pots each, according to the method of application. In the first lot the fertilizer was thoroughly mixed with the upper 6 inches of soil in each pot. In the second it was distributed in a strip about 3 inches wide across the pot (in a manner similar to the way it is deposited in the row in the field by the planter) just below the seed-piece, but not in direct contact with it. In the third the fertilizer was distributed in a manner similar to the second, but just above the seed-piece. In the fourth lot it was thoroughly mixed with the 3 inches of soil just below the seed-piece, while in the fifth it was thoroughly mixed with the 3 inches of soil above the seed-piece.

With each of the remaining 5 fertilizers, namely, Nos. 5389, 5518, 5536, 5513 and 5409, only 4 pots were used, representing two pots each of the second and third methods of application described for No. 5549. Four other pots were planted with potatoes without adding any fertilizer. These and those in which fertilizer No. 5409 was used, which contained no borax, were introduced as checks.

Seed tubers used. There were available a small amount of tubers which had been produced in pots in the greenhouse, harvested in the early summer and stored in a cool basement. These were firm and vigorous and some were just beginning to sprout at the time of planting. A half of a tuber was placed in each pot, care being taken to distribute the halves so that no two would have the same fertilizer treatment.

Depth of planting. In all cases the distance was 3 inches from the top of the seed-piece to the top of the soil after planting. Wherever the fertilizer was distributed in drills above or below the seed-piece without mixing with the soil, a thin layer of soil was placed between it and the seed-piece.

Watering. All of the pots which were 10-inch and of the ordinary unglazed type, were placed on benches with saucers underneath. One-half of all of the pots, representing the different methods of application of the various fertilizers, were kept heavily watered, while the other half had a scanty water supply or were kept as dry as possible and still have them moist enough for growth. As a rule this required about 300 and 150

cc. of water respectively per pot daily. All of the water was applied in the saucers, thus making the water current always upward through the soil in the pot.

Temperature. The temperature control was set at about 70 degrees F. during the day and from 50 degrees to 55 degrees F. during the night. During the night of December 15 on account of the failure of the University heating plant to furnish sufficient steam the temperature fell to the danger limit and some of the plants nearer the walls of the house were frozen. This seriously interfered with certain features of the work and made it impossible to make some desired photographic records, but it did not materially affect the final results and conclusions.

Records. While changes in the appearance of individual plants were noted as soon as they appeared, detailed records of the growth and appearance of each plant were made weekly. At the close of the experiment all plants were removed from the pots and the root systems separated from the soil as carefully as possible and examined for injury.

RESULTS OBTAINED FROM GREENHOUSE EXPERIMENTS WITH POTATOES.

Except for some mosaic the unfertilized check plants remained perfectly healthy till they were removed from the pots 3 months after planting. The plants in the pots containing the borax-free fertilizer No. 5409 were entirely free from any evidence of fertilizer injury or disease. This entire lot was included in the few plants which were badly injured by frost. However, all of the other plants which developed borax injury had shown it, in marked degree, some time previously. Of the 4 pots fertilized with No. 5409 one was about 9 inches high and the other 3 about 15 inches high when killed by frost on December 15. Unfortunately no photographs had been taken to show their appearance at that date. All that can be said is that at this time the health and vigor of these 4 plants showed a marked contrast to the other 40 in the experiment, including the unfertilized checks.

No plants which received fertilizer containing borax escaped injury in some form or other. In general the amount of injury varied with the amount of borax present in the fertilizer

FIG. 20. These two plants were photographed about two weeks after appearing above ground. The fertilizer used in pot 32 carried a relatively high percentage of borax, while that applied to pot 44 contained no borax. See p. 109.

FIG. 21. This represents the total growth made in the greenhouse in three months by one of the plants fertilized with No. 5513, equivalent to 38.6 pounds of anhydrous borax per acre. Compare with Fig. 19.

used, but the results were not entirely uniform in this respect. As might be expected the most severe injury occurred with fertilizer 5513 where the amount of anhydrous borax applied was equivalent to 38.6 pounds per acre. The 4 plants in this series were much stunted and yellowed, although those having the fertilizer applied above the seed-piece finally made a partial recovery and attained a height of 7 and 12 inches respectively in 3 months time. The early condition of the last mentioned or larger plant is shown in Fig. 20, pot 32. At that time it was weak and yellowed. The plant in pot 44 was grown on fertilizer No. 5409 which contained no borax. The two plants germinated within two days of each other and were about two weeks above ground when the photograph was made. The two plants where fertilizer 5513 was placed below the seed-piece made very little growth. At the end of 3 months one consisted of simply a rosette of small leaves just at the surface of the soil. See Fig. 21. The other was only 3 inches high.

The amount of injury obtained with fertilizer No. 5389 where the application of anhydrous borax was equivalent to 7 pounds per acre was somewhat surprising. Not only was there some stunting and yellowing of the plants where the fertilizer was applied below the seed-piece, but a considerable amount of the type of injury next to be described was present on all of them.

THE MOST COMMON TYPE OF INJURY TO POTATOES IN THE GREENHOUSE.

While some of the plants in the greenhouse, more particularly in the case of heavy applications of borax, showed the yellowing and a stunted, shrubby appearance similar to that characteristic of plants in the field where borax was present in the fertilizer used, this was not general. Yellowing was more or less in evidence in a number of cases when the plants were young but this usually disappeared as they became older. Quite a different type of injury occurred, without exception but in varying degree, upon all plants which were grown in pots containing a fertilizer which carried borax.

This type of injury was characterized by death and drying out of the tips and margins of the leaflets. The injury first

appeared on the basal leaves and afterwards on the upper ones, and almost without exception was noted on the tips of the leaflets first and then on the margins. While the whole margin might be affected, the trouble was more severe and appeared first on the half of the leaflet nearest the tip. In like manner the terminal and first two lateral leaflets were attacked first and were more severely affected. Fig. *22* shows a plant all of the leaves of which are affected in this way. The injury was first observed between two and three weeks after the plant came up and the photograph was made six weeks after that. At that time the two lower leaves had fallen and two more were about ready to fall.

FIG. *22*. Type of injury most common in the greenhouse. The tips and margins of practically all of the leaves are affected. See also Fig. *26*, p. 117.

The age of the leaf seemed to be a determining factor. A lower leaf might be badly affected while the leaves from a young

shoot formed in its axil would appear entirely healthy at the same time. However these leaves from the younger shoots nearer the base later showed the same marginal injury.

The dead tissues suggested more of an olive tinge than a browning. A comparison with standard color charts failed to match any shade or tint of brown except possibly in the case of the first appearance of the injury on the tip of a leaflet. The color was difficult to match and about the best description that can be given is that it resembled most closely what might be expected where a potato leaf had been killed rapidly and quickly dried with little yellowing.

The appearance of the affected leaves seemed to indicate simply a progressive death and drying out of the tissues. While there was a fairly sharp line of demarkation between the diseased and healthy portions of the leaves, the latter near this line usually showed more or less fading out of the normal green color to a lighter green or even a yellowish tinge. In advanced stages the leaf-blades themselves would become yellow, soon followed by the dropping of the leaf. Some of the more severely injured plants lost all of their leaves before they were dug up early in January.

In some instances there was a suggestion of what has been called "tip-burn" of the potato. However, there is no reason for confusing this tip and marginal injury on greenhouse plants, resulting from borax applied to the soil with the fertilizer, with the usual forms of the tip-burn in the field. It occurred under relatively humid conditions, at a time of the year when sunlight was at its lowest intensity, and in greater degree on the plants supplied with an abundance of moisture. The plants were entirely free from insects of all kinds.

Several facts, taken together, strongly suggest that this tip and marginal injury is the direct result of the accumulation of compounds of boron in the tissues affected. Droplets of liquid were constantly observed upon the tips and margins of the leaflets of potato plants grown in the greenhouse particularly at the times when no other explanation could be given for their presence, except that they exuded from the leaves themselves. Moreover faint traces of a whitish deposit were repeatedly seen on these leaves in the same locations after the droplets had evaporated. This condition was found to be common and was

in no way restricted to plants grown in pots containing borax or to plants included in the experiments under consideration.

The size and rapidity of growth of many of the plants which showed this type of injury in marked degree, particularly those which were heavily watered, indicated considerable root growth and this was confirmed by later examination. Likewise plants which suffered severe root injury and stunting as the result of heavy applications of borax showed relatively smaller amounts of the tip and marginal injury. Therefore it seemed reasonable to suppose that compounds of boron were being taken up by the roots, were being carried along with dilute solutions of food materials and deposited in the leaves. Since there is constant evaporation of water from the leaves and a fairly constant current of water from the roots upward through the stems and continuing through the leaves to the margins of the latter, it would seem that any materials or salts brought along in solution in this transpiration current, which were not used by the leaves in the manufacture of food materials for tissue building or for storage, would tend to concentrate most at or near the margins and that this concentration would be greater in the older leaves. A sufficient concentration of any poisonous material would result in the death of the tissues at that point.

To test the above assumption with reference to boron in the plants in question some of the dead margins of the injured leaves were removed with scissors. At the same time an approximately equal amount of the margins of healthy leaves was obtained from plants which were grown upon fertilizer No. 5409 which contained no boron. These were tested qualitatively by the Station chemist on December 3, or two months after the tubers were planted. The sample from the injured leaves gave a positive test for boron while that from the healthy leaves gave a negative test.

RELATION OF THE TIP AND MARGINAL INJURY OF THE LEAVES TO THE METHOD OF APPLICATION OF THE FERTILIZER AND WATERING.

Based upon the larger series of pots with fertilizer 5549 where the applications of anhydrous borax were equivalent to 17.6 pounds per acre, fertilizer applied below the seed-piece,

whether mixed or unmixed with the soil, caused greater tip and marginal injury than where it was applied above the seed-piece. Mixing fertilizer with the soil resulted in greater leaf injury, unless it was mixed with the soil above the seed-piece. Abundant watering increased the amount of leaf injury. Stated in another way, the most severe leaf injury was obtained where the fertilizer was mixed with the upper 6 inches of soil or with the 3 inches of soil below the seed-piece and the plants heavily watered.

It will be remembered that with the remaining 5 lots, the fertilizer was applied only in the drill, both above and below the seed-piece. Half of the pots in each lot were abundantly watered and the other half scantily watered. As has been stated very healthy, vigorous plants were obtained with No. 5409 which contained no borax. The other 4 lots which represented varying applications of borax gave results in general agreement, as far as they went, with those given above for No. 5549. The most severe injury of both types resulted from the application of the fertilizer below the seed-piece, and abundant watering—as a rule—produced more tip and marginal injury.

On account of the relatively small rainfall in Aroostook county in June, 1919, the water supply for the plants, previous to the appearance of the injury in the field, where most of the more serious cases were seen, was largely from below upward. A desire to duplicate field conditions as nearly as possible was what led the writer, in planning the greenhouse experiments, to decide to make all applications of water to the pots from below. The results obtained indicate quite clearly that the method of watering adopted, materially influenced the relative amounts of leaf injury which resulted from the variation in the methods of fertilizer application. Continued watering from above has still greater objections as it would have a tendency to carry the borax away from the plants. Alternate watering from above and below, such as was decided upon in the case of the cooperative experiments now in progress, undoubtedly is the nearest approach to field conditions that can be obtained in the greenhouse. It is granted that, in the confined conditions imposed by the pot, there is less opportunity for the plant to escape from the poisonous action of the borax, but in spite of this fact and the objection to the method of watering mentioned above it is

believed that these greenhouse experiments may serve as a fairly accurate index of the relative amounts of the various forms of injury which may be expected from the application of like amounts of borax to potatoes in the field.

ROOT INJURY IN POTS.

The potato plants were all removed from the pots early in January and an examination was made of the root systems. While care was exercised to remove them in as nearly a natural condition as possible it was extremely difficult to separate them from the soil without breaking off many of the finer rootlets. Hence the illustrations show the relative and not the absolute conditions.

The plants which were grown upon fertilizer No. 5409, free from borax, had long fibrous roots running to the bottom and penetrating to all parts of the pots. Fig. 23 shows the root system of one of these plants.

FIG. 23. Root system where borax-free fertilizer, No. 5409, was used in pots in the greenhouse.

As might be expected the most severe root injury occurred where the fertilizer was applied in drills, unmixed with the soil. This was more pronounced in the presence of the larger amounts of borax and showed a distinct correlation with stunting and yellowing of the plants, or with the prevailing type of injury which was observed in the field during the previous summer. Fig. 21 shows a plant having a very severe type of injury where practically the whole root system had been destroyed. It also illustrates the entire growth made by this plant during a period of 3 months. This was obtained with fertilizer 5513, or where an application of 38.6 pounds of anhydrous borax was made per acre.

Where the fertilizer was applied above the seed-piece the injury was least near the base of the plant. Where it was applied below the seed-piece it was least near the surface of the soil. Rather marked cases of these forms of root injury are shown in Figs. 24 and 25. It will be noted that while a part

Fig. 24. Root injury to plant in greenhouse where fertilizer containing borax was placed in the pot above the seed-piece unmixed with the soil.

FIG. 25. Root injury in greenhouse where the same fertilizer as was used on the plant, the root system of which is shown in Fig. 24, was placed in the pot below the seed-piece unmixed with the soil.

of the roots which have grown out near the surface of the soil from the stem shown in Fig. 25 have been killed, 3 long, fibrous ones remain. In such cases the roots ran along near the surface till the wall of the pot was reached. Then they passed downward through that portion of the soil in the pot that was more remote from the fertilizer. This condition, of course, only obtained where the fertilizer was applied in the drill below the seed-piece. It was exactly in accord with what was observed repeatedly under like conditions in the field.

It may be of interest to briefly sketch the history of the plant shown in Fig. 25. The seed-piece was planted October 3, using fertilizer 5513. The plant broke ground on November 18, but it was less than one inch high on December 1. (Plants grown on 5409, carrying the same amounts of ammonia, phosphoric acid and potash, were from 8 to 14 inches high at this time). By December 15 it was about 1½ inches high, and was 3 inches high on January 1. At that time it had the curled,

stunted and yellowed appearance similar to that of badly injured plants in the field. Undoubtedly, if allowed to grow, it would have shown the partial recovery that was observed with those plants in the field which produced roots that started near the surface of the ground and penetrated the soil remote from the fertilizer.

Root injury was less severe where fertilizer was mixed with the soil above and below the seed-piece than where it was placed in drills above and below. Little or no root injury could be found where the fertilizer was mixed with the upper six inches of soil in the pots. However, as has already been stated, it was where the fertilizer was mixed with the soil that most of the tip and marginal injury of the leaves was obtained. The root system of one of the plants where the fertilizer was mixed with the upper six inches of soil is shown in Fig. 26. The ap-

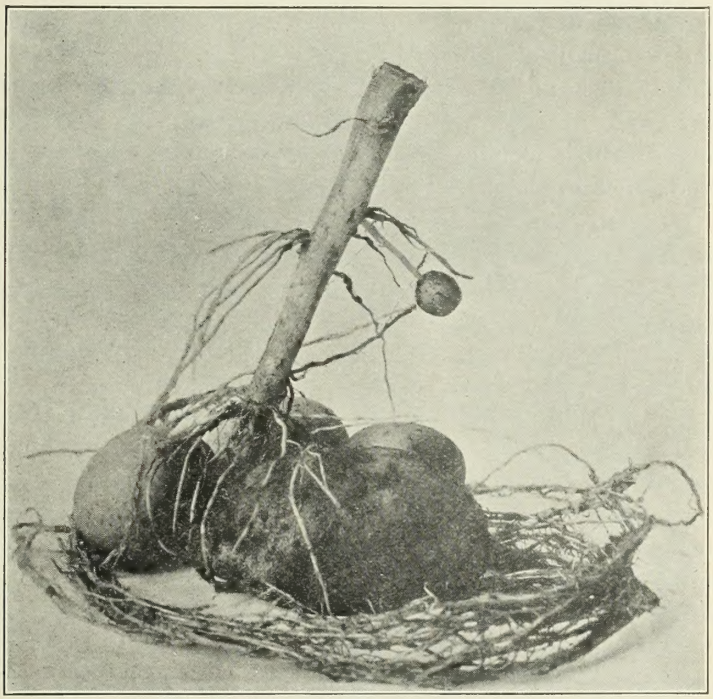

FIG. 26. Root system of plant shown in Fig. 22. The fertilizer, No. 5549, was mixed with the upper six inches of soil in the pot. The root injury was slight but the leaf injury was marked.

pearance of the plant itself on January 1 is shown in Fig. 22. The record states that at that time the margins of all leaves were badly affected, the two lowest leaves had fallen and the next two were about ready to fall.

It should be remembered that tests with fertilizer mixed with the soil were confined to No. 5549, or with applications of 17.6 pounds of anhydrous borax per acre. Undoubtedly greater root injury from mixing fertilizer with the soil would have been obtained if the samples carrying higher percentages of boron had been used in this way.

WORK WITH OTHER CROPS.

The work of testing the effects produced upon crops other than potatoes by fertilizers containing borax was only incidental, was planned simply as preliminary tests, and was conducted upon too small a scale to be of much value. The results obtained with beans in comparison with those obtained with other crops were of such a striking character that it is desirable to record them in detail. No. 5549 was the only fertilizer used, and regular greenhouse potting soil was employed.

Beans. Three different varieties of beans were used. The seed of two of them was produced in 1918 and the other in 1919. Three eight-inch pots were used for each variety. Fertilizer 5549 was applied to two of these and nothing added to the third pot which served as a check in each instance. The potting soil contained an abundance of natural fertilizer.

The fertilizer was applied at the rate of 500 pounds per acre in the drill, making an application of anhydrous borax equivalent to only 4.4 pounds per acre. This fertilizer was distributed in a strip 3 inches wide across the soil in a nearly filled pot, and covered with a thin layer of soil. In each pot 6 seeds were evenly spaced in two lines directly over the strip of fertilizer, and then covered with an inch of soil.

All of the beans in the check pots germinated and produced normal, vigorous plants, although those from the variety grown in 1919 came more slowly. The behavior of the beans in the pots containing fertilizer contrasted very strikingly with that of those in the check pots. This was shown by a much delayed

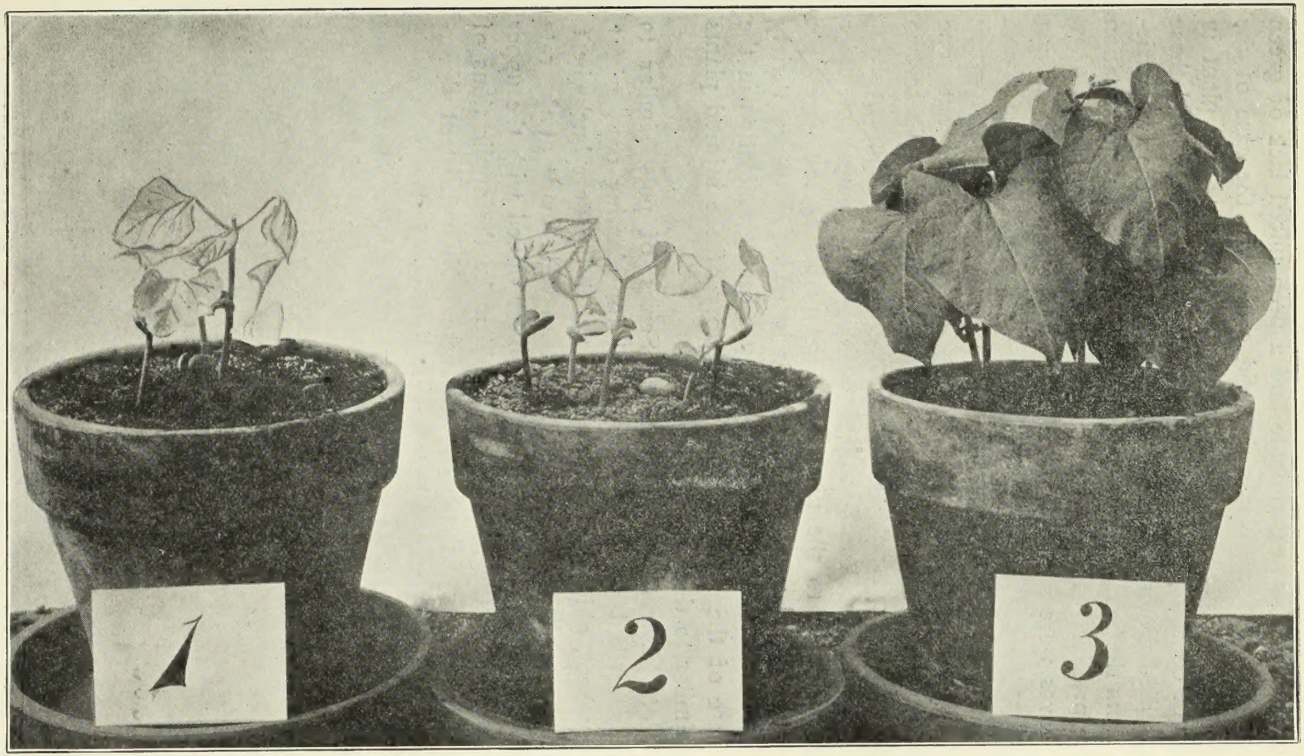

Fig. 27. Beans growing in greenhouse potting soil. To pots 1 and 2 fertilizer No. 5549 was applied at the rate of 500 pounds per acre, equivalent to 4.4 pounds anhydrous borax. No commercial fertilizer was added to pot 3.

or partial failure to germinate and a pronounced lack of green in the leaves of all plants that did grow. In the case of the variety where the seed was grown in 1919, only one plant in each pot containing fertilizer appeared above ground and these plants died almost immediately. In the case of the two varieties from the 1918 seed one finally gave 100 per cent germination in the presence of the fertilizer but the plants grew very slowly, the leaves were stiff and of a pale, waxy color, entirely lacking in chlorophyll. Their appearance as compared with the check, pot 3, is well shown in Fig. 27. This is from a photograph taken about 6 weeks after planting. Eventually all but one plant in each of pots 1 and 2 of this series died. These two plants slowly, but not wholly, developed a normal green color and remained weak and stunted, although they were kept under observation up to the time when the plants in the check pot were practically mature. The series in which the third variety of beans was used showed only 50 per cent germination in the presence of the fertilizer and the history of the injured plants was similar to that given above.

Oats, wheat and buckwheat. Series of pots similar to those described for beans were used for planting oats, wheat, India wheat, old-fashioned buckwheat and Japanese buckwheat. Here the applications of fertilizer 5549 were made at the rate of 1000 pounds per acre, broadcasted, or mixed with the upper inch of soil in the pots. This would make the applications of anhydrous borax 8.8 pounds per acre. No consistent differences could be noted either in germination of the seeds or in the health of the plants growing in the pots which did or did not contain the borax.