A GREENHOUSE STUDY OF MINOR ELEMENTS AND ORGANIC MATTER DEFICIENCIES IN RELATION TO THE UNPRODUCTIVENESS OF THE A_2 AND B HORIZONS OF TWO MICHIGAN SOILS

THESIS FOR THE DEGREE OF M. OF S.

W. R. REYNOLDS

1939

A GREENHOUSE STUDY OF MINOR ELEMENTS AND ORGANIC MATTER DEFICIENCIES IN RELATION TO THE UNPRODUCTIVENESS OF THE A_2 AND B HORIZONS OF TWO MICHIGAN SOILS.

A GREENHOUSE STUDY OF MINOR ELEMENTS AND ORGANIC MATTER DEFICIENCIES IN RELATION TO THE UNPRODUCTIVENESS OF THE A_2 AND B HORIZONS OF TWO MICHIGAN SOILS.

BY

W. R. REYNOLDS

Submitted in partial fulfilment of the requirements
for the degree of Master of Science in the
Graduate School, Michigan State College.
Department of Soils
June, 1939

THESIS

ACKNOWLEDGMENT

The writer is grateful to Dr. R. L. Cook for guidance in the work reported in this paper and for his time spent offering his constructive criticism in its presentation. He also wishes to express his appreciation to Dr. Cook for the photography work presented in this manuscript.

TABLE OF CONTENTS

A GREENHOUSE STUDY OF MINOR ELEMENTS AND ORGANIC MATTER DEFICIENCIES IN RELATION TO THE UNPRODUCTIVENESS OF THE A_2 AND B HORIZONS OF TWO MICHIGAN SOILS.

"Subsoil farming" may be a new term in Agricultural literature, but actually many thousands of farmers have been farming subsoils in whole or in part for many years. Erosion has removed surface soils until today the subsoil is being cultivated on many acres of land. This is found to be especially true in the south and southeastern parts of the United States where large acreages of clean-tilled crops such as cotton and tobacco and comparatively small acreages of soil building, and soil-conserving crops such as clover and alfalfa are grown. The Southeast has a higher rainfall than the north, and since a larger percentage of it falls during the spring and early summer when the soil is being cultivated, it is easy to visualize that erosion is more serious in the south than in the north.

Many farmers have experienced a decline in soil fertility due to the removal of the surface soil. Through the proper methods of soil management it is possible to restore to some extent the fertility of these areas, and many farmers are already taking steps in this direction. The problem of the correct management of subsoils, where the top soil has been removed, should be carefully considered in the field of research today and in the future.

This paper is presented to discuss the unproductiveness of subsoils and the possibilities of minor element deficiencies in the A_2 and B horizons of two Michigan soils, namely, Miami loam and Hillsdale fine sandy loam. Any true soil is the product of the action of climate and living organisms upon the parent material. Soils are mixtures of fragmented and partly or wholly weathered rocks and minerals, organic matter, water and air, in greatly varying proportions, with more or less distinct layers or horizons developed under the influence of climate, topography, and living organisms. The soil formation is dependent upon intensity of the activity of the different soil forming processes. Due to the fact that these soil forming processes are more active in the upper horizon of the soil it seems logical to assume that the subsoils or the B horizon of these soils could possibly be deficient in minor elements or other plant nutrients. Based on the above assumptions an experiment was set up to study the possibility of deficiencies of boron, copper, magnesium and manganese, and organic matter in the sub-surface horizon of Hillsdale and Miami soils. It was believed that research of this nature might be valuable in the management of these soils where erosion has removed a part or all of the surface soil.

The Importance of Minor Elements

In the early history of Plant Physiology there were about 10 elements considered essential in plant growth. With the introduction of pure chemicals for greenhouse research and the use of concentrated fertilizer in field experiments it became evident that some of the "minor" or "trace" elements were essential for plant growth.

It has been shown by various investigators that many of these elements, needed only in traces, are plentiful in most soils and when supplied in larger quantities they become toxic to certain plants. This is true of the elements studied in this investigation; copper, boron, and manganese.

Previous to the period of research on the minor elements, agronomists began to notice that many crops were affected by what was known as deficiency diseases. Familiar examples of these are the sand drown of tobacco, the magnesium disease of potatoes, the chlorosis of tomatoes, and the heart rot of sugar beets.

The sand drown of tobacco is caused by a deficiency in magnesium. If the soil contains less than 0.2 per cent of magnesium oxide (MgO) the tobacco plant is liable to suffer.

Magnesium disease of potatoes is prevalent on the highly fertilized soils of Maine and the coastal plain, and is cured by the addition of magnesium in the fertilizer. Heart rot of sugar beets has been shown by several investigators to be due to a deficiency of soil boron.

Some of the minor elements have a very narrow range of concentration in which they can be used by the plant. Boron is one of these elements. Only a few parts per million is required for the normal development of plants but it has been shown that top rot of tobacco, cracked stem of celery, heart rot of sugar beets and similar diseases of other plants are due to a deficiency of boron. On the other hand, twenty or more parts per million of the element is fatal to many plants. An example of boron toxicity occurred during the World War when potash salts used in potato and tobacco fertilizers contained considerable borax. In some cases applicationsof 30 lbs. of borax per acre have resulted in greatly reduced yields, and applications in excess of 50 lbs. have killed the plants.

Copper apparently occurs in all soils, ranging from about one to over 50 parts per million in normal agricultural soils. It functions in plant nutrition. It has been recently found that dieback of citrus fruit can be remedied by the application of copper salts. In New York and Florida it has been found necessary to apply 25 to 50 pounds of copper sulphate per acre to soils high in organic matter before lettuce and other plants can be grown successfully. Plants grown without copper have a characteristic appearance. The upper leaves, unable to maintain their tugor, wilt badly. Growth is reduced in proportion to the degree of shortage.

Copper affects the flowering stage and stiffness of the stalk of plants.

Magnesium is a part of the chlorophyll molecule. On an average surface soils contain less than one per cent of magnesium, and in the case of coastal plain tobacco soils deficiencies occur where the soil contains less than 0.2 per cent of magnesium. Most plants develop a characteristic chlorosis when the magnesium supply is insufficient. The lower leaves are first affected.

The recognition that manganese is an essential element for normal plant development has been confirmed by numerous investigators in the past few years. The gray speck of oats has been attributed to a shortage of this element. Manganese shortage has also been demonstrated with the tobacco plant.

Organic Matter the Life of the Soils

It is generally recognized that a close correlation exists between organic matter content and soil productivity and for that reason soils should be managed in such a way as to provide for regular additions of organic materials.

The statement that organic matter supplies the "life" of the soil is very true. Organic matter is the fuel for bacterial fires in soils, which operate as a factor for producing plant nutrients. The matter is burned into carbon dioxide, ash, and other residues. This provides carbonic acid in the soil water, and the solvent effect of the acidified water on calcium, potassium, magnesium and phosphate minerals is many hundreds of times greater than that of rain water. At the same time nitrogen in the form of ammonia is converted into the nitrate form. Growing plants using the energy of the sun, synthesize carbon, nitrogen and all elements into complex compounds, and the energy stored up in these compounds is used more or less completely by the microganisms whose activity within the soil make nutrients more available for a new generation of plants. Organic matter is truly the life of the soil.

Subsoils used in this greenhouse experiment, contained only a trace of organic matter, and only a limited plant growth could be expected due to two or more reasons: first, the plant nutrients present might be present in sufficient amount but not available to plants, and second, the soils were poorly aerated due to a poor physical condition. In the surface horizon of the humid soils where most of the organic matter is concentrated, the bacteria and other soil organisms play an important part in breaking down the plant residues and making plant nutrients readily available to a new generation of plants.

Aeration is very necessary for most plants to grow and reproduce. The holes in the soil formed by the decayed plant roots, the action of rodents, worms, soil bacteria, and other soil organism on organic matter improves the structure of heavy silty and clay soils. Aeration is also increased and the environment for plant growth is greatly improved. Plant roots are able to spread and penetrate and make more efficient use of the available plant nutrients and moisture within the soil.

The high productivity of most virgin soils has always been associated with their high content of organic matter, and the decrease in the supply with cultivation has generally been paralled by a corresponding decrease in productivity.

The structure and other related physical properties of very sandy soils as well as heavy clay soils are improved by the addition of organic matter. In clay soils such as the B horizons of the soils used in this experiment, porosity should be increased and plasticity reduced by the addition of organic matter. The physical effect of organic matter on soil is very complex due to the complex nature of the two materials concerned. However, the effect is significant in connection with weight, cohesion, structure, porosity, color, temperature, and tilth.

Chemically soil organic matter functions in three important ways: (1) It supplies direct sources of nitrogen and other plant nutrients; (2) It aids in rendering available soil calcium, magnesium, iron and phosphorus; and (3) its humus colloidal substances function in base exchange and other soil reactions.

The soil horizon is made up of solids, liquids and gaseous materials. Proper proportions of each of these are necessary for a good medium for plant growth. The larger particles of soil act as the framework and the fine particles, chiefly colloidal material, act as a bank for plant nutrients. Soil solution consists of water containing varying quantities of dissolved mineral matter, carbon dioxide and oxygen. If the soil is compact it is difficult for plant roots to penetrate or secure an anchorage to obtain nutrients and water. However, if the soil is too porous it will not retain enough water to support good plant growth.

A Comparison of Field Experiments and Greenhouse Methods For Determining Fertilizer Needs of the Soil

Pot experiments, particularly with rapid growing crops, permit tests with a large number of soil treatments within limited space, and in relatively short time. The results are often directly applicable in practice, although allowance must be made for the fact that the conditions of the test are different from those in the field; the soil has been disturbed, and the more uniformly controlled temperature, moisture, and other factors modify the influences of the soil treatments themselves. In supplying information on the fundamental fertility characteristics of soils and particularly on the effects of specific substances on plant growth, pot experiments have the advantage of being less influenced by variable environmental factors than are field trials. The pot test with soil, sand, or solution cultures are most valuable in the study of certain specific factors such as the relative value of different forms of nitrogen or the toxicity of certain elements to plants.

Pot tests have long been used and excellent results have been secured, but considerable difficulty has arisen from their use. A heavy application of fertilizer, corresponding to one ton per acre, would require only about one-third of an ounce for the treatment of a 2 gallon pot containing about 20 pounds of soil. Uniform mixing is very necessary for accurate results. If some treatment requires only minute quantities of a constituent, such as used in this experiment, the materials may be dissolved in water and sprinkled over the mass of soil.

It is important that light, heat, and moisture conditions be kept as uniform as possible throughout the growing period of the plants. Pot tests in the greenhouse work are especially valuable in the determination of deficiences of certain minor elements, such as boron, copper, manganese, and others. Many greenhouse experiments have proven to be very valuable; the unproductiveness of soils in many cases has been demonstrated to be due to manganese deficiency or other minor element deficiences. Numerous illustrations can be chosen from the experiment station literature to show the value of the pot method of experimentation.

For direct evaluation of fertilizer requirements, taking into account all factors affecting crop production, field trials remain the ultimate criteria. Field experiments are, however, slow and expensive, particularly in regards to labor, area of land required, and the necessity for replication of treatment.

The major advantage of field trials is that different fertilizers and other cultural treatments are tested with various crops under essentially the same conditions as prevail in practice. The results reflect the affects of all climatic and other influences to which the crops and soil are subjected during the season. They are directly indicative of the results to be anticipated in practice under the same or similar conditions.

REVIEW OF LITERATURE

A search of the literature reveals very little information on the effects of the minor elements on the productivity of the subsoils of the humid region. However, the farmer and research man through experience have found that subsoils in general produce very poor crops unless they are given proper attention such as the application of barnyard manure and fertilizers. Agriculturists have done a considerable amount of work studying the unproductiveness of subsoils, but their possible deficiencies in minor elements were not considered in any of these studies in so far as the writer is aware.

Muckenhirn (16) reports the effect of boron, copper, and manganese on the growth of various plants. In quartz sand cultures lettuce was unable to make normal growth without boron. Application of copper and manganese to peat soil in pot cultures increased the growth of onions and sweet clover.

Willis and Piland (25) reported three cases of a definite response from boron treatment on alfalfa, and two with romaine. All three occurences were on highly limed soil.

Cook (8) reports boron deficiences for certain crops on a number of soil types. Alfalfa and alsike clover were grown on soil from fields where previous crops had shown signs of boron deficiency. Two pounds of $Na_2B_4O_7$ per acre on alfalfa resulted in an increase in yield of 4.3 per

per cent on Gilford soil while an increase in yield on Napanee soil amounted to 14.4 per cent. Boron treated soils growing alsike plants caused them to mature earlier than those not treated. Experiments with sweet clover produced results somewhat similar to those with alfalfa. Barley, beans and corn showed no indication of a need for boron. The effectiveness of boron as a control for heart rot of sugar beets was pointed out.

Colling (9) reached the following conclusions in studying the effects of boron on the growth of soybeans:

1. The presence of 250 Mgm. of Boron per liter of soil prevented germination, and only 10 Mgm. delayed germination.

2. Visible injury to leaves of the soybeans if as much as one pound of Borax or its equivalent was added per acre.

3. Boric acid, Potassium borate and Borax reduced the dry weight of the plants when applied in quantities equivalent to 7.5 pounds of borax per acre.

4. No marked stimulation of growth could be detected from soybeans growing in quartz sand.

5. Boron was found not to be necessary in the growth of soybeans during seedling stage of growth, when grown in nutrient solution. However, it was found necessary for the production of a mature soybean plant.

The following section of the review of literature will be based on the effects of organic matter on the physical properties of soil, and its effect on plant growth.

Smith, Brown, and Russell (21) found eight and sixteen tons per acre of manure on Clarion loam, applied once in a rotation of corn, oats, and red clover increased the infilteration capacity for a two-hour period from 1.7 for the untreated soil to 3.06 and 4.65 surface inches, respectively. This data emphasized the importance of organic matter in improving the physical condition of soil and reducing soil erosion.

Baver and Rhodes (4) found that soils high in organic matter contained 15 to 30 per cent more granules than a soil low in organic matter and that these granules were three times more stable when shaken in water.

Paschal, Burke, and Baver (20) obtained a positive and significant correlation between the degree of aggregation and the per cent of carbon in the different horizons of three soil series. The carbon content of these soils ranged from 1.18 to 3.43 per cent.

Baver (2), working with seventy-seven non-lateritic soils found a correlation between the quantity of aggregates and the per cent of organic matter.

Data by Jenny (11) indicate that cultivation for forty years reduced the amount of organic matter 38 per cent, which resulted in a 28 per cent decrease in sand-size granules when compared with virgin prairie soils.

Stauffer, (23) found that a good system of soil management which includes regular applications of barnyard manure increased the organic matter content, the moisture equivalent, the water-holding capacity, and also decreased the dispersion and erosion ratios.

Burr and Russell (5) found that an increase in organic matter increased the stability of the granules and increased soil porosity.

Browning (6) carried on considerable research work studying the changes in the erodibility of soils brought about by the application of organic matter. His data presented show a wide variation as to the effect of organic matter on the various soils studied. His conclusions were that the organic matter added had increased the large-sized aggregates, and the permeability had increased by the development of a more favorable structural condition. One month after organic matter was incorporated with the soil changes in the physical condition of certain soils were noted.

Baver (3) suggested that irreversible colloids are the best cements to develop a permanent aggregation of particles and that the calcium ion may cause floccules which may be bound together into stable aggregates by organic matter.

Rhodes (21) found that 80.4 per cent of the material in Grundy silt loams was in the form of stable aggregates, as compared with 44.4 per cent of fine material in Marion silt loam. The Grundy soil is high in total organic matter, and the Marion silt loam is low in this material.

Several early studies have been made of the "rawness" of subsoils, which are reviewed below.

Alway, McDole and Rost (1) made observations showing certain soils of eastern Nebraska to be very unproductive insofar as non-legumes are concerned, while inoculated legumes thrive on these soils almost as well as on the surface soil.

McCool, Veatch, and Spurway (13) reached the conclusion that the disagreement in the "rawness" of subsoil was due to the lack of uniformity in securing the soil samples.

Lipman (12) concludes from his observations in California that the subsoils of the arid regions are practically as raw toward non-legumes, as are the typical subsoils of humid regions.

Harmer (10) found that alfalfa grew as well on two Minnesota subsoils as on the surface soil. He also stated that other subsoils were far less productive than the surface soil. The unproductiveness of two of these same soils was studied by McMiller (15) and it was found that the "rawness" was overcome by an application of phosphate and potassum salts.

Millar (17) studied the available nutrients in subsoil and reached the conclusion that corn made very little growth on that portion of the profile of Coloma loamy sand and Leslie sandy loam below the surface or humus-bearing layer. The addition of available nitrogen increased the growth of corn. Millar (19) also made a study with alfalfa to determine if this deep rooted crop removed any appreciable amount of nutrients from the subsoil. Glass cylinders were used to prevent the roots from reaching the surface soil. Data were presented showing that this crop removes considerable nutrients from the lower horizons, and under extreme adverse conditions some of these plants lived three years, for three cuttings yearly.

Crist and Weaver (7) have shown that corn, oats, barley, potatoes, and two native grasses of the western plains are capable of absorbing soluble nitrates and phosphate from the lower horizons.

McCool and Millar (14) studied the solubility of nutrients in subsoils from many sections of the U.S. having widely different climatic characteristics, and arrived at the conclusion that very small amounts of mineral nutrients passed into solution from the lower soil horizons unless these horizons were composed of alkali salts.

Due to the fact that plants vary in their feeding power it seems advisable at this time to include several studies concerning this subject.

Truog (24) reports the views of many investigators on the utilization of phosphate by agricultural crops and the feeding power of plants. The feeding power of twelve common agricultural plants for raw rock phosphate was determined, and great differences in the feeding power were observed. He explained this difference in feeding power as follows:

"Plants containing a relatively high calcium oxide content have a relatively high feeding power for the phosphorus in raw rock phosphate form. For plants containing a relatively low calcium oxide content the converse is true." He also explained that there was a direct relation between the relative feeding power of plants and the amount of carbonic acid given off by the respective plant roots.

Truog (25) points out that the feeding power of plants is due to several factors, some of which are concerned with external equilibrium conditions around the feeding roots, and others with internal equilibrium conditions inside the plant where the elements are actually used. The amount of acid secreted as a cause of difference in feeding power of plants was discussed. He also reports that the acidity of the plant sap effects the feeding power of plants for potassium and the less acid the sap, the greater is the ability of the plant to utilize potassium. The more acid the plant sap the more easily can a plant compete with another acid system, as in acid soil.

Many factors effecting the feeding power of a plant were discussed, which demonstrate the fact that plants vary in their feeding powers.

Millar (18) experimented with oats and inoculated sweet clover on the different horizons of Fox sandy loam and Miami silt lowm showing that different crops may have quite markedly different feeding powers on the various soil horizons.

EXPERIMENTAL

Soil Descriptions, Location and Use

The Miami and Hillsdale soils belong to the Gray-brown Podzolic soils group. This group of soils of the eastern and midwestern part of the United States is developed under deciduous forest and in a humid temperate climate. Geographically, it lies between the Podzols on the north and the Red and Yellow Podzolic soils on the south and joinswith the Prairie soils on the west.

There are two important areas of the two soils used in this experiment. The first area has been called the "Miami"- Crosby - Brookston area" which forms the heart of a farming country of central Indiana and west central Ohio; and the second area has been the "Miami-Kewaunee area" which is located in southern Michigan, extending southwest and into northern Indiana, and an area in eastern Wisconsin extending southward into northern Illinois. The first area is often called the "Little Corn Belt" and its favorable climate and relief provide the physical basis for a prosperous and stable agriculture. However, the latter area is not so productive and in general it is a glaciated region that consists of roughly rolling or hilly moraines, undulating till plains, with marked depressions, nearly level outwash plains and old lake beds.

Miami loam is classed with the well drained groups of soils of this section ranging from undulating to rolling in relief. A very high percentage of this soil has been put into cultivation and its influence on the development of the prevailing agriculture is obvious.

The surface soil in the cultivated fields is grayish brown loose friable loam. Although the quantity of organic matter is small, much less than that of the poorly drained soils, it is probably slightly higher in this soil than in most of the other well drained soils. The organic material in the cultivated soil is finely divided and thoroughly incorporated. The total content is not sufficient to produce granulation of the soil, but the silt and sand is ample to insure excellent tilth, aeration, and rapid absorption of water.

The subsoil is largely silt and clay, with minor proportions of coarser material. The mass is distinctly yellowish-brown. In the lower part of the subsoil the yellowish-brown color is not nearly so prevalent or may disappear entirely. The subsoil is permeable to air and water under field conditions, and plant roots extend to considerable depth.

This soil is not as rich in many of the more important elements of plant nutrients as are the poorly drained soils, although its natural fertility is well above average of the region. The surface soil and upper subsoil layer has an acid reaction, but below 2 or 3 feet lime is sufficiently abundant.

Miami is closely associated with Hillsdale soil. The Hillsdale soil is characterized by undulating or rolling relief.

The surface soil of the Hillsdale plowed field is gray-brown, loose, friable fine sandy loam to loam. The organic content, although not high, is sufficient to give the surface soil a brown tint. The surface of this soil is somewhat looser and more open than the surface of the Miami soils.

The B horizon of the Hillsdale loam consists of a yellowish-brown friable sandy clay which, under moderate moisture conditions, breaks down into a structureless mass when crushed. On drying, this material does not assume the degree of hardness that characterizes the dry subsoil material of the Miami. The character of the subsoil should allow aeration and rather rapid movement of water. As compared with the Miami soils it reflects the effects of dry periods on crop yields to a greater extent.

The land use for the betterment of this area is for a permanent prosperous agriculture based on corn, small grain, hay and pasture, and the feeding of hogs, cattle, and few sheep, and the production of milk. The well drained soils such as the Miami and Hillsdale are only moderately fertile but generally responsive to good soil management and fertilization.

Experimental Procedure

Soil samples of the A_2 and B horizons of Hillsdale fine sandy loam and Miami loam were taken on the Michigan State College farm and from a near-by road cut. The A_0 and A_1 layers were removed from the profile before the samples were taken. Sixteen inches of the top of the B horizons of each soil were used for the samples. These soils were then passed through a 4 mm. screen and allowed to dry two weeks.

4000 grams of soil were packed into one gallon earthenware jars after nutrient solution had been mixed thoroughly with the soil. Water was added to bring the water content up to the point of optimum moisture.

Each treatment was repeated three times. Five hundred pounds of 4-16-8 fertilizer was applied per acre, or an application of .1886 grams of $(NH_4)_2 SO_4$, .2841 grams of $CaH_4(PO_4)_2 . H_2O$ and .1266 grams of KCl per jar, on all jars except checks. Minor elements were applied at the rate of .015 grams of $CuSO_4$, .024 grams of $Mn SO_4$, .10 grams of $Mg SO_4$, and .006 grams $Na_2B_4O_7$ per pot. These will be referred to as minor elements in this experiment, and the "minor element mixture" will be referred to as a mixture of .01 grams $Fe SO_4$, .01 grams $Al_2 (SO_4)_3$, .005 grams $Zn SO_4$, .001 grams NaI and .005 grams of NaCl. Reference is made to Table 1 for the different treatments.

Wheat was seeded on October 22, 1938 and harvested in the early stage of vernalization on January 6, 1939. During this growing period the moisture content was kept as near uniform as possible by weighing the jars weekly.

After the wheat was harvested each jar was cultivated and seeded to alfalfa on January 30, 1939. A good stand was secured in all jars and the water content was regulated by weighing the jars weekly.

The alfalfa crop seemed to indicate a complete failure on the B horizon of each soil type, which prevented the study of the effects from minor element treatment on these soils.

The experiment on the A_2 and B horizons of Miami soil was continued, but the remaining part of the experiment was discontinued. It seemed that this was an excellent chance to make a study of the differences in various plants as to their feeding power, or ability to grow in heavy sub-soils; and so these jars of Hillsdale A_2 and B horizon were seeded to soybeans on April 15, 1939. No further treatment was given this soil when soybeans were seeded.

Observations of the poor growth of alfalfa and wheat on the subsoils of the Miami and Hillsdale soils led to another experiment which involved a study of the same minor elements in combinations with organic matter. It seems possible that the poor growth of alfalfa and wheat on the B horizon of both

soils might have been due to the physical condition of the soil, rather than to plant food deficiencies. Briefly, the plan was to apply barley as a green manure crop to one series of pots and muck as another source of organic matter to the other series of pots, each receiving the same minor element treatment.

Samples of Miami and Hillsdale B horizons were taken in the same manner as described earlier in this paper and in the same locations. They were mixed, screened, and allowed to air-dry for two weeks.

Barley was grown in quartz sand for green manure crops with only N., P., and K. added as nutrients in order that the green manures would not contain any of the minor elements. Acid muck was used for another type of organic matter. The process of setting up these jars was as follows:

In this experiment 3500 grams of soil, 1000 grams of quartz sand and .35 grams of barley or 100 grams of muck were used as organic matter. The organic matter and soil were mixed together and water added to bring the percentage of water up to the point of optimum moisture. The quartz sand and organic matter were used to improve the physical condition of the subsoils. This was done to offer better conditions for plant growth.

A solution mixture of minor elements (composed of .015 grams of $CuSO_4$, .024 grams $MnSO_4$, .10 grams $MgSO_4$ and .006 grams of $Na_2B_4O_7$) was applied per jar to one-half of all jars receiving each type of organic matter. A fertilizer analyzing 4-16-8

was also applied at the rate of 500 lbs. per acre. The rate per jar was .1886 grams $(NH_4)_2SO_4$, .2841 grams $Ca\ H_2\ (PO_4)_2 \cdot H_2O$ and .1266 grams K Cl.

Soybeans were seeded in these jars April 16, 1939, and managed the same way as previously described.

Another experiment was set up to study the effects of different rates of application of Boron in the form of $Na_2B_4O_7$ on the growth of soybeans on Miami and Hillsdale B horizons. The two soils used were selected and samples taken from the same location as before; well mixed, screened, and air-dried for two weeks as in the other experiments.

All jars except the check which did not receive any treatment, received an application at the rate of 500 pounds of 4-16-8 fertilizer per acre, 1500 grams of quartz sand per jar and all minor elements used in the previous experiments, excepting Boron. $Na_2B_4O_7$ was added at the rate of 3.2, 6.4, 9.6, and 12.8 pounds per acre to each of the two soils. Each jar except check received a complete nutrient solution.

In this experiment all nutrients in solution were added to the 1500 grams of quartz sand before the sand was mixed with the soil. The reason for this procedure was to find out if there would be a difference in the growth of the soybeans as compared with the other experiments in which all nutrients were mixed with 500 c.c. of water and mixed with the soil by hand. It was believed that the physical condition of the soil was disturbed in the latter case, causing poor structure for plant growth.

OBSERVATIONS AND DISCUSSIONS

The experiment to study the affects of Cu., Mn., Mg., and B. on yields of wheat grown on the A_2 and B horizons of Hillsdale and Miami soils did not show any stimulation in growth from applications of any of the minor elements. From observations there seem to be no differences in growth except that the unfertilized jars yielded less than those fertilized. The increase in yield as a result of this treatment was greater on the B than on the A_2 horizons of each soil.

The yields of wheat presented in Table 1 do not show any beneficial effect from the application of Cu., Mn., Mg., or B. on either of the soil horizons.

The color of the wheat on the untreated B horizon of each soil appeared to be of a yellowish-green during the latter stage of growth. The color of the wheat on the untreated jars on the A_2 horizon of both soils was normal, but the plants were smaller in size than were the plants which received complete treatments.

The B horizon of the Hillsdale resulted in higher yields than did the corresponding Miami soil horizon. This may have been due to the better physical condition, since the Hillsdale soil contains more sand, or it may be that the particular sample was of higher than average fertility.

It is believed that watering the plants caused considerable dispersion of the larger soil aggregates in the B horizon of each soil, but to a greater extent with the Miami.

The data presented in Table 2 indicate that the jars which received the various combinations of Cu., Mg., Mg., and B. yielded slightly higher than those that received other minor elements. However, from observations it was not possible to detect growth differences. It was not possible to conclude just what combinations of these minor elements were best.

Due to the poor growth of alfalfa on the B horizon of the Hillsdale soil it was decided that this soil be cultivated and seeded to soybeans to study the differences in feeding power of various crops.

The alfalfa on A_2 and B horizons of the Miami soil was retained, and in the spring, with more sunlight the alfalfa on the A_2 horizon made a good growth, but the alfalfa on the B horizon made a poor growth.

It is difficult to explain the poor growth of alfalfa on the B horizon of this soil. The soil was not too acid for the alfalfa plant, and it was treated with 500 pounds of 4-16-8 fertilizer per acre. This would indicate that the poor growth was not due to plant food deficiencies, but some other cause. Observations of the hardness of the subsoils when dry indicated that the poor physical condition of the soil was possibly the major cause of the poor growth. This subsoil is generally low in nitrogen and phosphoric acid but the application of fertilizer should have corrected these deficiencies.

The poor growth of alfalfa of the B horizon prevented the study of the effects of minor elements on the yields.

Observations indicated that soybeans grew as well on the B horizon as on the A_2 horizon of the Hillsdale soil, while alfalfa made very poor growth on the B horizon of this soil. The comparison of the growth of the two crops on the different horizons is most outstanding in that it demonstrates the variations in the feeding power of different plants.

This crop was harvested May 22, 1939 and it is be-lived that the effect of the minor elements might have been greater had the plants been allowed to mature. Other investi-gators have found that young seedings of soybeans require very little boron, while the mature plant requires greater quanti-ties of this element for normal production. Colling (9) points this out in his work on effects of boron on growth of soybeans.

Reference is made to plate 3 which shows an increase in growth due to minor elements.

Table 3 also shows an average increase in yield of .2 grams over jars not receiving any minor elements, indicating that these minor elements are necessary for normal plant growth.

Plate 2 shows little, if any, beneficial effects of minor elements in combination with organic matter. It was observed that pots receiving the minor element mixture indica-ted a slight reddening and burning on the edge of the soybean leaves. The toxic symptoms were the same as shown in Plate 4 from the effect of boron, and it is believed that the 3.2

pounds of boron in the minor element mixture caused this condition.

The yields in Table 4 show a decrease in every case, except one, from the application of minor elements. However, these soybeans were harvested at the end of five weeks, and no conclusions can be drawn regarding this toxic effect on the young seedling.

The effects of organic matter on yields of soybeans was not marked, but there was an increase in yield due to the application of muck as a form of organic matter, but in this case there was also a decrease in yields when the minor element was applied.

In the experiment with different rates of application of boron on the B horizon of the Miami and Hillsdale soil marked differences were observed between the various treatments.

At the end of two weeks the soybeans receiving boron showed no stimulation in growth, rather there was an indication of toxicity as result of all treatments of boron. The seriousness of this toxic effect was in proportion to the rate of application of the boron. The leaves showed a reddening around the edges and a few specks in the center parts of the leaves. The symptoms gradually became more pronounced for a period of thirty days, after which plants receiving the smaller application of boron recovered and began to grow and produce healthy leaves. This recovery is shown when Plate 6 is compared with Plate 4.

Growth at the end of five weeks showed still greater variation and greater toxicity from the higher two rates of application of boron. Jars receiving 3.2 lbs. of borax indicated better growth throughout than plants in both soils receiving no borax. The effects appeared to be the same in each soil, with over 6.4 lbs. giving a decrease in growth. Shrinking and curling of the leaves, excessive amount of reddening and drying up, and the dropping off of bottom leaves were noted. Top leaves were yellow and shrunken to one-half the size of leaves on healthy plants. All indication pointed to the fact that 12.8 lbs. per acre would kill the plant in a few weeks. At this stage of growth it seemed that 3.2 lbs. per acre would increase the yield of soybeans but 6.4 lbs. per acre was toxic, although it increased the size of the plants. The check jars appeared to be lagging behind more than ever at this time. The specking and reddening on the edge of the leaves were only slightly visible on the plants receiving 3.2 lbs. of borax per acre.

The soybeans were harvested May 22nd, forty-eight days after they were planted. At this stage the plants seemed to be growing out of the injuries caused by the toxic effect of boron. The applications of 3.2 and 6.4 lbs. of borax per acre at this stage of growth indicated increases in yield. Table 5 shows this to be true in case of the 3.2 pounds treatment but not with the 6.4 pounds per acre treatment. This is due to the fact that the leaves on the bottom of plants receiving 6.4 pounds of borax dropped off. The weights were less for this reason.

Observations indicate the fact that 3.2 to 6.4 pounds of borax per acre would increase the dry weight of a mature soybean plant but it does not increase the growth of the young seedling.

Table 5 indicates an increase in yield of .4 grams on the Miami soil and a decrease of .1 gram on the Hillsdale soil from the application of 3.2 pounds of borax per acre. Six pounds and over of borax reduced the yields in case of both soils. It was also observed that 9.6 and 12.8 pounds of borax reduced the yields about one-half on each soil.

This study of the effects of different rates of applications of boron on soybeans agrees with Colling's (9) work. He found that very small amounts of boron were toxic to soybeans and that little boron was necessary for the growth of soybean seedings while the element is definitely essential for the production of a normal mature soybean plant.

SUMMARY

A greenhouse study of the effects of Cu., Mn., and B. on the yields of wheat, alfalfa and soybeans grown on the A_2 and B horizon of Hillsdale fine sandy loam and Miami loam was conducted. The effect of the combination of several minor elements with organic matter and the effect of different rates of applications of borax on the growth of soybeans grown on the B horizon of Hillsdale and Miami soil was also studied.

From these experiments the following conclusions were drawn:

(1) There was no increase in the yields of wheat on either of the soils as the result of applications of any of the minor elements studied.

(2) A combination of minor elements resulted in slight increases in the yields of alfalfa on the A_2 horizon of Miami soil. The alfalfa failed on the Hillsdale soil and was almost a failure on the B horizon of Miami soil.

(3) In one experiment a combination of Cu., Mn., Mg., and B. resulted in small increases in the yield of soybeans on the Hillsdale B horizon but had no effect on the A_2 horizon. In another experiment designed to study the effect of organic matter on the response to minor elements, no increases in yields were obtained as a result of minor element applications on either Miami or Hillsdale B horizons.

(4) In the early seedling stage of growth as little as 3.2 pounds of borax per acre was toxic to soybeans but at a later date (30 days after planting) it was evident that a stimulation in growth had resulted from respective applications of 3.2 and 6.4 pounds per acre. Applications greater than 6.4 pounds per acre were toxic throughout the growth period and resulted in greatly decreased yields.

Table 1. The Effect of Minor Elements on the Yield of Wheat Grown on A2 and B Horizons of Miami Loam and Hillsdale Fine Sandy Loam in Pot Cultures.

*Treatment	Jar No.	Yields of Wheat in Grams Based on Air-Dry Weights							
		Miami A2 Horizon	Av.	Miami B Horizon	Av.	Hillsdale A2 Horizon	Av.	Hillsdale B Horizon	Av.
Minor Element Mixture	1	3.5		1.8		3.3		2.5	
	2	2.6	3.0	2.1	2.1	3.2	3.1	2.9	2.5
	3	2.9		2.3		2.9		2.2	
**Complete Minor Element Mixture	4	2.9		2.4		3.0		2.8	
	5	2.1	2.5	2.4	2.4	3.4	3.3	3.1	2.9
	6	2.5		2.4		3.5		2.7	
Complete Minor Element Mixture Less Cu	7	2.6		2.1		3.1		3.1	
	8	2.5	2.6	2.0	2.2	3.2	3.1	2.7	2.9
	9	2.6		2.4		3.0		3.0	
Complete Minor Element Mixture Less Mn	10	2.6		2.0		3.3		3.8	
	11	2.9	2.7	2.0	2.1	3.5	3.3	3.0	3.3
	12	2.6		2.1		3.2		3.1	
Complete Minor Element Mixture Less Mg	13	2.6		2.0		3.0		2.9	
	14	2.6	2.6	2.5	2.3	3.0	3.0	2.9	2.8
	15	2.5		2.4		3.1		2.7	
Complete Minor Element Mixture Less B	16	2.6		2.6		3.1		2.7	
	17	2.5	2.6	2.2	2.3	3.1	3.2	3.5	3.1
	18	2.6		2.0		3.4		3.0	
No Treatment	19	2.0		.7		2.2		1.3	
	20	1.8	1.9	.9	.8	2.6	2.4	1.5	1.3
	21	1.8		.7		2.5		1.1	

*All except the untreated jars received 500 pounds 4-16-8 fertilizer and a minor element mixture of .01 gm. $FeSO_4$, .01 gm. $Al_2(SO_4)_3$, .005 gm. Zn SO_4, .001 gm. NaI and .005 gm. Nacl.

**Complete minor element mixture includes the minor element mixture described above plus Cu, Mn, Mg, and B. The rate of application was .015 gm. of $CuSO_4$, .024 gm. Mn SO_4, .10 gm. Mg SO_4, and .006 gm. Na_2 B_4 O_7 per jar.

Note: Yields are based on weight of 7 plants per jar.

Table 4. The Effect of Organic Matter in Combination with Minor Element Mixture on Yield of Soybeans Grown on B Horizons of Miami and Hillsdale Soil in Greenhouse Pot Culture.

*Treatment	Jar No.	Yields of Soybeans in Grams Based On Air-Dry Weights			
		Miami B Horizon	Av.	Hillsdale B Horizon	Av.
10 Tons of Chopped Barley Per Acre	1	2.0		2.0	
	2	2.0	1.7	2.0	2.0
	3	1.5		1.8	
	4	1.4		2.3	
**10 Tons of Chopped Barley Plus Minor Element Mixture	5	2.0		2.0	
	6	2.0	1.8	2.0	1.8
	7	1.5		1.6	
	8	1.5		1.5	
Check	9	2.0		2.0	
	10	2.5	2.3	2.0	1.8
	11	2.8		2.1	
	12	2.0		1.3	
Check Plus Minor Element Mixture	13	1.4		1.1	
	14	1.8	1.6	1.8	1.6
	15	1.5		2.0	
	16	1.5		1.6	
30 Tons Acid Muck Per Acre	17	2.3		1.9	
	18	2.5	2.5	1.9	2.3
	19	2.4		3.0	
	20	2.6		2.6	
30 Tons Acid Muck Per Acre and Minor Element Mixture	21	2.5		2.5	
	22	2.0	2.1	2.0	2.2
	23	2.0		2.0	
	24	2.0		2.5	

*All jars received 500 lbs. 4-16-8 fertilizer per acre and 1000 grams of quartz sand per jar.

**Barley used as green manure crop. Minor element mixture composed of .015 gm. of $CuSO_4$, .024 gm. Mn SO_4, .10 gm. $MgSO_4$, and .006 gm. of $Na_2B_4O_7$ per jar.

Note: Yields are based on weight of four soybean plants per jar.

Table 5. The Effect of Different Rates of Application of Boron on the Yield of Soybeans Grown on B Horizons of Miami Loam and Hillsdale Fine Sandy Loam in Pot Culture.

*Treatment	Jar No.	Yields of Soybeans in Grams Based On Air-Dry Weights			
		Miami B Horizon	Av.	Hillsdale B Horizon	Av.
	1	5.0		5.6	
No Boron	2	4.3	4.6	5.1	5.3
3.2 lbs. $Na_2B_4O_7$	3	5.5		5.0	
Per Acre	4	4.5	5.0	5.4	5.2
6.4 lbs. $Na_2B_4O_7$	5	4.0		5.0	
Per Acre	6	3.7	3.6	4.0	4.5
9.6 lbs. $Na_2B_4O_7$	7	3.0			
Per Acre	8	2.6	2.8		
	9			1.7	
12.8 lbs. $Na_2B_4O_7$	10			2.5	2.1
	11	3.0		3.1	
Check	12	3.6	3.3	3.5	3.3

*All jars except checks received 500 lbs. 4-16-8 fertilizer per acre. All jars received 1500 grams quartz sand, in which nutrients were mixed before sand was mixed with soil.

Note: Yields are based on weight of five soybean plants per jar.

Plate 1.

The effect of minor elements on the growth of alfalfa in the A_2 and B horizons of Miami loam.

A. Jar No. 1, 2, & 3, show very little differences in the growth of alfalfa due to the application of minor elements. No. 1 received N.P. & K.; No. 2, N.P. & K. plus Cu., Mn., Mg., and B.; No. 3, no treatment.

B. The yield of alfalfa on the B horizon of Miami loam. Jars No. 1, 2, & 3 received same treatments as stated above.

Plate 2.

The effects of minor elements in combination with organic matter on the growth of soybeans grown in the B horizon of Miami soil.

The three jars on the left (no. 1), no minor elements; and the three jars on the right (no. 2), received Cu., Mn., Mg., and B. as shown in Table 4. All the jars received barley as a green manure crop at the rate of 10 tons per acre.

Plate 3.

The effect of a minor element mixture of Cu., Mn., Mg., and B. on the growth of soybean seedlings.

The effect of minor element mixture on growth of soybean plant grown in Hillsdale B horizon. Three plants on left, no minor elements; three plants right, received a mixture of .005 gm. $CuSO_4$, .024 gm. $MnSO_4$, .024 gm. $MnSO_4$, .10 gm. $MgSO_4$, and .006 gm. $Na_2B_4O_7$ per jar.

Plate 4.

Marked toxic effect on the young soybean plants from the application of borax.

A. The effect of borax on the soybean plants grown on the B horizon of Hillsdale soil. No. 1, 12.8 lbs. of $Na_2B_4O_7$ per acre; No. 2, no borax.

B. The effect of borax on the young soybean plants grown on the B horizon of the Miami soil. No. 1, no borax; No. 2 12.8 lbs. of borax per acre; and No. 3, no treatment.

Plate 5.

A top view showing the effect of borax on soybean plants 48 days old.

The effect of borax on the growth of soybeans. Left, no borax; right, 12.8 lbs. of borax per acre.

Plate 6.

A side view showing the effect of 3.2 lbs. of borax on the growth of soybean plants after 48 days growing period.

A. The effect of 3.2 lbs. of borax on growth of soybean plants in Miami B horizon. No. 1, no borax; No. 2, [illegible]

B. The effect of 3.2 lbs. of borax on the growth of the soybean plant in Hillsdale B horizon. No. 1, no borax; No. 2, 3.2 lbs. borax per acre.

Plate 7.

The effect of borax on the growth of soybeans grown on the B horizons of Miami and Hillsdale soil.

A. The effects of different rates of application of **borax** on the growth of soybeans grown in **Miami** B **horizon.** No. 1, 12.8 lbs.; No. 2, 9.6 lbs.; No. 3, 6.4 lbs.; No. 4, 3.2 lbs.; of $Na_2B_4O_7$. No. 5, no borax; No. 6, no treatment.

B. **The effect of different rates of application of borax on the growth of soybeans grown in Hillsdale B horizon. All jars received the same treatments as stated above.**

LITERATURE CITED

1. Alway, F. J., G. R. McDole, and C. O. Post. The relative rawness of subsoil. Soil Sci. 3: 9-35. 1917.

2. Baver, L. D., Factors contributing to the genesis of soil microstructure. Amer. Soil Survey Assoc. Bull. 16: 55-56. 1935.

3. ____________ The relation of exchangeable cations to the physical properties of soils. Jour. Amer. Soc. Agron. 20: 921-941. 1928.

4. ____________ and H. F. Rhodes. Aggregate analysis as an aid in the study of soil structure relations. Jour. Amer. Soc. Agron. 24: 920. 1934.

5. Burr, W.W., and J. C. Russell. The importance of organic matter in soil structure and tilth. Abst. Proc. First Int. Cong. Soil Sci. 1: 67. 1927.

6. Browning, G. M. Changes in the erodibility of soils brought about by the application of organic matter. Soil Sci. of Amer. 9: 85-96. 1937.

7. Crist, J. W., & J. E. Weaver. Adsorption of nutrients from subsoil in relation to crop yield. Bot. Gaz. 77: 121-148. 1924.

8. Cook, R. L., Boron deficiency in Michigan soils. Soil Sci. Soc. 2: 375-382. 1937.

9. Colling, Gilbert H. The influence of Boron on the growth of the soybean plant. Soil Sci. 23: 83-93. 1926.

10. Harmer, P.M. The relative "rawness" of some humid subsoils. Soil Sci. 5: 393-401. 1918.

11. Jenny, Hans. Soil fertility losses under Missouri conditions. Mo. Agr. Exp. Sta. Bull. 324: 3-10. 1933.

12. Lipman, C. B. The "Rawness" of subsoils. Science 46: 288-290. 1917.

13. McCool, M.M. J. O. Veatch and C. H. Spurway. Soils profile studies in Michigan. Soil Sci. 16(2): 95-106. 1923.

14. ____________ and C. E. Millar. The formation of soluble substances in the soil taken from widely separated regions. Soil Sci. 10(3): 219-235. 1920.

15. McMiller, P. R. Some notes on the causes of the unproductivity of raw subsoils in the humid regions. Soil Sci. 7(3) 233-236. 1919.

16. Muchenhirn, R. J. Response of plants to Boron, Copper, and Manganese. Jour. Amer. Soc. Agron. 28: 824-842. 1936.

17. Millar, C. E. Availability of nutrients in subsoils. Soil Sci. 19: 275-287. 1925.

18. ______________ The feeding power of plants in the different horizons. Jour. Amer. Soc. Agron. 17(3): 150-157. 1925.

19. ______________ Studies of the removal of nutrients from subsoils by alfalfa. Soil Sci. 23: 261-267. 1927.

20. Paschal, A. H., R. T. A. Burke and L. D. Baver. Aggregate studies on muskingum, chester, landsdale silt loam. Amer. Soil Survey Assoc. Bull. 16: 44-46. 1935.

21. Rhoads, H. F. Aggregate analysis as an aid in soil structure studies. Amer. Soil Survey Assoc. Bull. 13: 165-169. 1932.

22. Smith, F. B., P. E. Brown, and J. A. Russell. The effects of organic matter on the infiltration capacity of Clarion loam. Jour. Amer. Soc. Agron. 29: 521-525. 1937.

23. Stauffer, R. S. Influence of soil management on some physical properties of soil. Jour. Amer. Soc. Agron. 28: 900-906. 1936.

24. Troug, E. The utilization of phosphates by agricultural crops, including a new theory regarding the feeding power of plants. Univ. of Wisconsin Research Bull. 41: 1916.

25. __________ The feeding power of plants. Science 56(1446): 294-298. 1922.

26. Willis, L. D., and J. R. Piland. Some recent observations of the minor elements in North Carolina agriculture. Soil Sci. 44: 251-264. 1937.