SOME EFFECTS OF NUTRIENTS ON GROWTH AND MINERAL COMPOSITION OF ALFALFA AND TOMATOES ON FOUR MICHIGAN SANDY SOILS

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Leslie Warren Tobin

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SOME EFFECTS OF NUTRIENTS ON GROWTH AND MINERAL COMPOSITION OF ALFALFA AND TOMATOES ON FOUR MICHIGAN SANDY SOILS

by
Leslie Warren Tobin

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan
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1951

THESIS

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ABSTRACT

This experiment was a continuation of an earlier investigation to study the effect of fertilizers and minor elements on the establishment and growth of alfalfa on four problem sandy soils of Michigan.

The design consisted of a control and 15 fertilizer treatments including minor elements all replicated three times using the four problem soils. Yield data from two cuttings were collected and reported upon from the earlier investigation. Tomato plants were grown as an intermediate crop to deplete the soil, and another alfalfa planting was made and two cuttings harvested from this experiment. Calcium sulfate was added in this experiment to one replicate in each treatment to determine the effect of calcium without changing the pH. The alfalfa plants from the two cuttings harvested from the previous experiment were analyzed for phosphorus, potassium,calcium and magnesium and the tomato plants were analyzed for phosphorus and potassium only.

The data of the two cuttings of alfalfa from the earlier investigation that were reported in this paper indicated that both phosphorus and potassium was necessary for best growth. Minor elements were probably responsible for increased plant growth in some cases, but no one element or even group of elements consistently improved yields. The plant analyses of the alfalfa harvested from the first investigation showed no significant results except that potassium appeared to be absorbed in proportion to its concentration in the soil.

The tomato plants were most affected by a lack of potassium on two of the soils whereas there was little difference in growth where either phosphorus or potassium alone was applied on the other two soils. There was little response from minor elements compared with those plants fertilized with both phosphorus and potassium. The tomato plant analyses showed no significant results.

In this investigation, the lack of potassium was more detrimental than the lack of phosphorus upon the growth of alfalfa. Nitrogen and extra potassium generally caused some plant response compared with those that received both phosphorus and potassium in equal ratio. Minor elements may have been responsible for some increased growth but the larger yields were not consistent in any treatment. No one element or combination of minor elements appeared to be responsible for the response.

The results of this investigation were inconclusive as no consistent results were obtained. There is a possibility that the problem is partially one of environment such as moisture as reflected by profile characteristics of the soils. Further investigation with field experiments in the problem areas may be necessary before the problem may be solved.

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INTRODUCTION

Alfalfa has been recognized as an important hay and pasture crop in Michigan for many years. Veatch (19) has estimated that there are about 9,152,000 acres of first class alfalfa land in Michigan, and about 13,393,000 acres that can produce the crop under careful management. An additional 13,242,000 acres may be considered as unfit for the crop due to a number of factors.

Recently some of the lighter textured soils in several parts of the state that were thought to be adapted to alfalfa have not grown and maintained adequate stands even under normal fertilization and proper cultural practices. It was the opinion of soil scientists at Michigan State College that the problem might be a nutrient deficiency, perhaps of some minor element. Plans were made to conduct a greenhouse experiment under controlled conditions using the problem soils.

The investigation was originated by Roy D. Bronson (6) in partial fulfillment of the requirements for the Master of Science degree. Soil was obtained from the four problem areas, and an experiment was designed to include a control and 15 fertilizer treatments replicated three times on all four soil types.

Bronson observed the growing crops throughout a period of about seven months when three alfalfa crops were harvested, yield data collected, deficiency symptoms noted and tissue tests made. Insufficient time prevented him from harvesting more crops, but two additional cuttings were made by others at the Station. An examination of the data at that time suggested the advisability of continuing the experiment another year. By coincidence, the continuation of the study worked conveniently into the author's schedule for graduate study.

Because calcium was the only element that had not been included in the original pattern, the author decided to redesign the experiment to include that nutrient. The author was aware that the data would be incomplete for statistical analyses. However, the plan was justified in that no significant conclusions had been obtained from the previous investigation.

This paper is thus a continuation of the investigation originally conducted by Bronson (6) for the purpose of securing data in regard to the establishment and maintenance of alfalfa stands on certain light textured, sandy soils in Michigan. In addition to collecting yield data and making observations for nutrient deficiencies, the author conducted analyses of plant tissue for the purpose of determining whether the nutrient concentrations of the plants were near the critical levels, and to note any correlations between nutrient concentration in the plant and fertilizer treatments.

REVIEW OF LITERATURE

It would be impossible to cover even generally the literature pertaining to alfalfa nutrition. In his review Bronson mentioned most of the major and minor elements necessary for alfalfa growth.

To avoid any duplication, it is the author's intentions to approach the subject from the angle of nutrient relationships, and present a few of the theories relative to that subject.

As early as 1869 Hellriegel discussed the amount of potassium in oat straw as related to the supply in the soil.

In 1880 Heinrich analyzed roots of oat plants, and attempted to use plant composition as an index of soil requirement.

Recently the use of plant analysis as a diagnosis for nutritional problems of plants has gained prominance among many agriculturalists.

It is impossible to estimate the supply of a given nutrient in the soil from its content in the plant unless all other growth factors are controlled. Assuming controlled conditions, if plant analysis is to be used as a criterion of soil conditions, the stage at which the crops are sampled is important. Generally, nutrient absorption is more rapid during the early stages of growth and slower during later stages than is the average growth rate. Furthermore, changes occur in composition as the plant passes from vegetative to reproductive stages.

The fact that plants absorb more nutrients if they are supplied in excess is well established. Likewise, most investigators are in agreement that there exists a mutual mechanical replacement of the basic elements in plants. Hence, a plant deficient in one element will absorb more of another element than is actually required.

If this substitution results in the sum total of the cation equivalents adsorbed being the same, the phenomenon of cation constancy is said to be operating. Apparently some plants exhibit this characteristic while others do not.

It is believed that calcium, magnesium and potassium all have specific functions in plants and, in addition, other general functions in which one may be substituted for another. In a discussion of this topic, Bear and Prince (3) state that, "Substitution of one cation for the other can be affected without detriment to the yield until a point is reached at which the content of the other is reduced below the critical value necessary for the specific functions it performs." They add that potassium is more readily absorbed by plants in excess of the amount needed to perform its specific functions than are any of the other cations. It is their opinion that if the supply of all cations is sufficient, there can be a wide range in ratios in the remaining quantities that are absorbed by the plant. Their experiments in growing alfalfa on 20 different New Jersey soils indicate that cation constancy does occur in alfalfa under controlled conditions. From repeated harvesting of eight successive crops of alfalfa, they noted that calcium and magnesium contents increased with successive cuttings whereas the content of potassium decreased. However, the sums of the equivalents of calcium, magnesium and potassium tended toward a constant.

Lucas and Scarseth (10) have observed cation constancy in some crops but not in others. Increasing the level of potassium in the soil for any given per cent saturation of calcium caused a lowering of the calcium and magnesium contents of some plants growing under controlled conditions. However, they are of the opinion that constancy may readily occur under field conditions.

The conclusions of Wallace, Toth and Bear (20) on analyses of alfalfa plants in respect to cation equivalent constancy were:

1. The total cation values of the whole plants tend to be fairly constant.
2. Leaves have a high constancy with terminal leaves highest in constancy.
3. The total cation values of stems are less than leaves.
4. The total cation values of stems tend to increase with increasing amounts of potassium in the nutrient media.

In contrast, Mehlich and Reed (12) found a greater uptake of calcium, magnesium and potassium in cotton plants at higher degrees of calcium saturation even though reciprocal relationships occurred. In addition, the magnesium and calcium contents in the plants decreased with increasing levels of potassium.

Most investigators are of the opinion that lime is usually the first limiting element in alfalfa growth. The fact that pH is utilized as the basis for lime requirement does not insure ample amounts of calcium as a plant nutrient. Calcium saturation may not be sufficient on the exchange complex or the calcium may not be available. From investigations with Connecticut soils by Owens and Brown (13), soil reactions of pH 6.3 to 6.6 have appeared to be associated with an ample supply of replaceable calcium. This is probably true in Michigan under most conditions.

Potassium, as well as lime, is often lacking, especially after several crops of hay have been removed. This deficiency is explained by the fact that the plants exhibit "luxury consumption" and, thus, most of the available potassium is utilized immediately. Hence, for all practical purposes, potassium should be supplied in increments.

Data from Peech and Bradfield (14) indicate that the uptake of potassium by plants is not affected appreciably by calcium whereas potassium (the most readily absorbed cation) may suppress the uptake of both calcium and magnesium.

Plant analyses of alfalfa grown by Bear and Wallace (5) showed an inverse relationship between calcium and potassium. They found that as more calcium was absorbed, less potassium was absorbed and vice versa.

Hunter, Toth and Bear (9) have concluded that alfalfa can adjust itself to a wide variation in soil calcium-potassium ratios making normal growth between 1:1 and 100:1 ratios. From their data it would appear that a 4:1 ratio would probably be most nearly optimum.

The relationship of magnesium with calcium and potassium is not fully understood. From his investigations Zimmerman (22) found that when the level of potassium was high in the soil, a magnesium deficiency tended to develop in the plant. Further evidence indicated that as the concentration of potassium decreased in the soil, the magnesium content increased in the plant even though the soil was deficient in magnesium. Thus, magnesium is apparently needed to balance calcium and to overcome high potassium concentrations.

Hunter, Toth and Bear (9) have obtained evidence that the calcium-magnesium ratios in the plant were roughly proportional to the ratio in the soil. In addition, the magnesium-potassium ratio in plants showed a wide variation being similar to calcium-potassium ratios.

According to Lucas and Scarseth (10), the potassium content in plants is affected by the ratios of exchangeable calcium and magnesium in the soil. For this reason, a measure of potassium cannot be evaluated adequately unless both the calcium and magnesium contents of the soil are known. Experiments conducted by them showed a potassium deficiency in the plant when a wide $\frac{Ca+Mg}{K}$ ratio (over four) existed in the soil. They believe, therefore, that a ratio of 3.5 or less is necessary to avoid potassium deficiency in alfalfa.

Analyses of alfalfa plants grown on New Jersey soils by Bear, Prince and Malcolm (4) revealed that as the per cent of potassium increased in the alfalfa plant, the percentage of calcium and magnesium declined. From a practical standpoint then, calcium and magnesium should be available in abundant quantities for alfalfa as they are less expensive than potassium.

The theory that lime aids in making phosphorus available is accepted by most authorities. Experiments by Lucas, Scarseth and Sieling (11) on silt loam soils indicate that even though the phosphorus utilization was better when lime was added to hay crops, the potassium became insufficient for larger crops later on and potassium became the limiting factor.

Most investigators are in agreement that a positive correlation exists between phosphorus and magnesium contents in plants. It is believed that magnesium may function as a carrier of phosphorus. Truog and others (17) have noted that the phosphorus content of pea seeds increased with increasing supplies of available magnesium.

The fact that critical limits occur in plant nutrition is well established, and apparently the limits differ with plants. Hunter, Toth and Bear (9) have reported that alfalfa yields declined when the calcium content increased over 2% and when the potassium content fell below 1%.

It is the opinion of Bear, Prince and Malcolm (4) that the potassium content of the plant can vary between 1.15% and 3.3% of the dry matter without materially affecting the nutrition of the plant.

Bear and Wallace (5) conducted analyses of alfalfa tissue grown on New Jersey soils and found the critical limits to be: potassium 1.4%, magnesium 0.24% and phosphorus 0.27%. From analyses of alfalfa grown on Michigan soils, they found the critical limits were: potassium 0.62%, calcium 2.2%, magnesium 0.54% and phosphorus 0.15%.

EXPERIMENTAL PROCEDURE

Bronson (6) has already described the four soils under study which included Grayling, Emmet, Allendale loamy sand and Allendale sandy loam. All of the soils were low in organic matter, generally low in fertility, and had failed to produce good alfalfa stands in the field.

Previous to the time that the author assumed charge of the experiment, the alfalfa plants were allowed to dry up after the last harvest had been removed on June 15, 1949. These plants were removed from the pots and the soil screened through a four mesh screen and returned to the containers.

As mentioned earlier, the original plan was to repeat the alfalfa experiment. In order to deplete the soil, a tomato crop was grown before the second crop of alfalfa was planted. Tomatoes were chosen because they grow rapidly and do well in warm weather. In addition, the plants show nutrient deficiencies more plainly than do many crops.

On August 10 a tomato plant about five inches high of the Indiana-Baltimore variety was transplanted into each of the 192 pots. Observations were made throughout the growing season until September 25 when the plants were harvested, dried and each one weighed.

The original experiment included three replicates of 16 treatments on each of the four soil types. There were no calcium treatments originally, and therefore, the experiment was revised to include an application of this element in each treatment. This calcium application was made in the form of calcium sulfate at the rate of 1,000 pounds per acre in the upper one third of the soil in each pot. The remainder of the fertilizer treatments were the same as originally outlined by Bronson(6) as follows:

1. Control, no treatment.
2. 0-20-0, 1,000 lbs. per acre.
3. 0-20-20, 1,000 lbs. per acre.

4. 0-0-20, 1,000 lbs. per acre.
5. 5-20-20, 1,000 lbs. per acre.
6. 0-20-40, 1,000 lbs. per acre.
7. 0-20-20, 1,000 lbs. per acre + Mg, Mn, Fe, B, Cu.
8. 0-20-20, 1,000 lbs. per acre + Mn, Fe, B, Cu.
9. 0-20-20, 1,000 lbs. per acre + Mg, Fe, B, Cu.
10. 0-20-20, 1,000 lbs. per acre + Mg, Mn, B, Cu.
11. 0-20-20, 1,000 lbs. per acre + Mg, Mn, Fe, Cu.
12. 0-20-20, 1,000 lbs. per acre + Mg, Mn, Fe, B.
13. 0-20-20, 1,000 lbs. per acre + Mg.
14. 0-20-20, 1,000 lbs. per acre + Mn, Fe.
15. 0-20-20, 1,000 lbs. per acre + B.
16. 0-20-20, 1,000 lbs. per acre + Cu.

Minor elements were supplied at the following rates in pounds per acre of salts: Mg - 200 lbs. of magnesium sulfate, Mn - 100 lbs. of manganous sulfate, Fe - 100 lbs. of ferrous sulfate, B - 10 lbs. of sodium tetraborate and Cu - 10 lbs. of cupric sulfate.

About 40-50 alfalfa seeds of the Hardigan variety were planted in each pot on November third. Some of the seedlings were so badly infected with a damping-off organism that several of the pots had to be replanted. The pots were finally thinned to 12 plants each. Because of the short days, the plants grew slowly during November and December. About the first of the year, the plants were placed under a bank of fluorescent lights, and the photoperiod increased to about 15 hours a day.

By March first blooms began to appear. The damping-off disease had left some of the plants weak and undersized. The plants were harvested but discarded in order to allow a more uniform second growth. The second crop was harvested about a month later at one fourth bloom. The top growth was dried in an oven at 180° F for three days and each sample weighed. The third cutting was harvested about five weeks after the second.

The remainder of the greenhouse study was followed identically to Bronson's procedure in respect to planting, watering, fertilizer treatments and harvesting.

OBSERVATIONS DURING GROWTH OF FIRST ALFALFA PLANTING

Bronson (6) was not present at the time when the fourth and fifth cuttings of his experiment were harvested and, therefore, no observations were recorded. A brief resume' of his findings in regards to the first three cuttings will therefore be presented.

Little difference in plant growth was noticed between the various treatments early in the experiment. After the first cutting, the check plants and those that had received only phosphorus or potassium singly appeared to be retarded. Potassium and boron deficiency symptoms were apparent on some of the plants in certain treatments.

On the Grayling and Emmet loamy sands, the check plants and those that had received only phosphorus or potassium alone were stunted and sparse of vegetation. Copper appeared to give some plant response on the Grayling soil, but no differences were obvious as a result of other minor elements.

The plant growth on the Allendale soils was comparable to the two previously mentioned soils. Thus, when either phosphorus or potassium was lacking in the treatment, growth was curtailed. The differences were less noticeable on the plants grown on the Allendale sandy loam than on any of the other soils. Also, it was noticed that the plants grown on this soil responded to copper. No conspicuous differences in plant growth were observed as a result of one or any combination of minor elements except as mentioned in the case of copper.

RESULTS AND DISCUSSION OF ALFALFA YIELDS FROM FIRST PLANTING

The visual differences in plant growth discussed previously in regards to the first three cuttings were reflected in later yields as may be seen in Tables 1 and 2.

The data from the fourth cutting reveals a significant plant response as compared with the check in treatments 3, 4, 5 and 6 where 0-20-20, 0-0-20, 5-20-20 and 0-20-40 respectively had been applied. This increased yield occurred on the Emmet, Grayling and Allendale loamy sand soils. Potassium alone (treatment 4) did not cause a significantly increased alfalfa yield on the Allendale sandy loam, but this treatment resulted in a slightly larger yield on all four soils than did treatment 2 which provided only phosphorus. Only one treatment which included minor elements in addition to 0-20-20 caused yields significantly different from those which resulted from the 0-20-20 treatment. This occurred on the Allendale sandy loam where boron alone had been applied (treatment 15). Conversely, the yields from this treatment were significantly lower than from some of the other treatments on the Emmet and Allendale loamy sand soils.

Thus it appears that the addition of minor elements caused no profound changes in plant yields on the four soils under study, at least in the fourth cutting.

The results of the fifth cutting did not correspond very closely with those of the fourth. The addition of 0-20-20, 5-20-20 and 0-20-40 resulted in significantly increased yields on all four soil types. A significant response occurred in the plants fertilized with phosphorus alone on the Emmet soil and with potassium alone on the Allendale loamy sand. Outside of these two exceptions, the effect of either phosphorus or potassium alone was not significant.

Nitrogen may have been responsible for a significantly higher alfalfa yield in treatment 5 on the Allendale sandy loam as compared with the 0-20-20 treatment. The extra potassium added in treatment 6 significantly increased yields on the Emmet, Grayling and Allendale sandy loam soils.

Some of the treatments which included minor elements produced larger yields than did the straight 0-20-20. This effect was most noticeable in treatments 7, 8, 12 and 13 on the Emmet and Grayling soils. No one element or any group of elements appeared to be responsible for this result. There is a possibility than boron may have had a beneficial effect on the Grayling soil in that the yields obtained in treatments 9, 10 and 15 were significantly larger than where the plants received only 0-20-20. On the other soil types, however, such was not the case. The yields from both cuttings in treatment 15 that was fertilized with 0-20-20 and boron were significantly less than from the same cuttings in several of the other treatments where minor elements had been added. In two cases, the Emmet in the fourth cutting and the Allendale loamy sand in the fifth cutting, the yields were significantly smaller than those from the 0-20-20 fertilized pots.

Table 1. The effect of fertilizer, including minor elements, on the growth of alfalfa on four problem soils. First planting. Fourth cutting#. Average dry weight in grams of three replicates.

Soil treatment&	Emmet loamy sand	Grayling loamy sand	Allendale loamy sand	Allendale sandy loam
1. Check	5.6	3.2	5.3	6.6
2. 0-20-0	6.4	3.5	5.5	7.1
3. 0-20-20	8.0 *	7.9 *	7.4 *	8.9 *
4. 0-0-20	6.6 *	6.4 *	8.0 *	7.5
5. 5-20-20	8.5 *	8.2 *	8.0 *	9.7 *
6. 0-20-40	8.5 *	8.1 *	8.1 *	9.8 *
7. 0-20-20 ≠ Mg, Mn, Fe, B, Cu	8.2 *	7.7 *	7.5 *	9.9 *
8. 0-20-20 ≠ Mn, Fe, B, Cu	8.6 *	7.8 *	7.4 *	9.3 *
9. 0-20-20 ≠ Mg, Fe, B, Cu	7.8 *	8.5 *	7.8 *	8.6 *
10. 0-20-20 ≠ Mg, Mn, B, Cu	7.7 *	8.3 *	8.6 *	9.2 *
11. 0-20-20 ≠ Mg, Mn, Fe, Cu	8.4 *	8.4 *	8.1 *	9.2 *
12. 0-20-20 ≠ Mg, Mn, Fe, B	6.9 *@-	7.9 *	7.6 *	8.6 *
13. 0-20-20 ≠ Mg	7.3 *	8.6 *	7.6 *	9.7 *
14. 0-20-20 ≠ Mn, Fe	6.8 *@-	8.1 *	7.5 *	9.3 *
15. 0-20-20 ≠ B	6.3 @-	8.5 *	6.7 *	10.3 *@
16. 0-20-20 ≠ Cu	5.9 @-	8.5 *	7.5 *	9.6 *

\# The first three cuttings were harvested and reported upon by Roy D. Bronson in a Master's thesis (6).

& Fertilizer rates given on pages 10 and 11.

* Significant at the 5% level.

@ Significant at the 5% level in respect to the 0-20-20 treat.

Table 2. The effect of fertilizer, including minor elements, on the growth of alfalfa on four problem soils. First planting. Fifth cutting. Average dry weight in grams of three replicates.

Soil treatment[&]	Emmet loamy sand	Grayling loamy sand	Allendale loamy sand	Allendale sandy loam
1. Check	6.5	6.1	5.6	8.5
2. 0-20-0	7.7 *	6.4	6.4	7.9
3. 0-20-20	7.7 *	7.4 *	9.6 *	10.1 *
4. 0-0-20	7.2	6.3	7.9 *	9.0
5. 5-20-20	8.7 *	8.1 *	8.9 *	11.7 *@
6. 0-20-40	9.2 *@	10.0 *@	9.9 *	11.5 *@
7. 0-20-20 + Mg, Mn, Fe, B, Cu	9.1 *@	9.6 *@	9.7 *	10.5 *
8. 0-20-20 + Mn, Fe, B, Cu	9.2 *@	9.1 *@	10.2 *	10.8 *
9. 0-20-20 + Mg, Fe, B, Cu	8.7 *	8.4 *@	9.8 *	10.6 *
10. 0-20-20 + Mg, Mn, B, Cu	8.6 *	8.6 *@	10.2 *	11.1 *
11. 0-20-20 + Mg, Mn, Fe, Cu	8.7 *	7.9 *	10.1 *	10.6 *
12. 0-20-20 + Mg, Mn, Fe, B	9.6 *@	8.5 *@	10.7 *	10.2 *
13. 0-20-20 + Mg	9.7 *@	9.2 *@	10.3 *	11.4 *@
14. 0-20-20 + Mn, Fe	8.1 *	7.7 *	10.1 *	10.7 *
15. 0-20-20 + B	7.5	8.5 *@	7.9 *@	10.1 *
16. 0-20-20 + Cu	7.7 *	8.0 *	8.5 *	10.3 *

& Fertilizer rates given on pages 10 and 11.

* Significant at the 5% level.

@ Significant at the 5% level in respect to 0-20-20 treat.

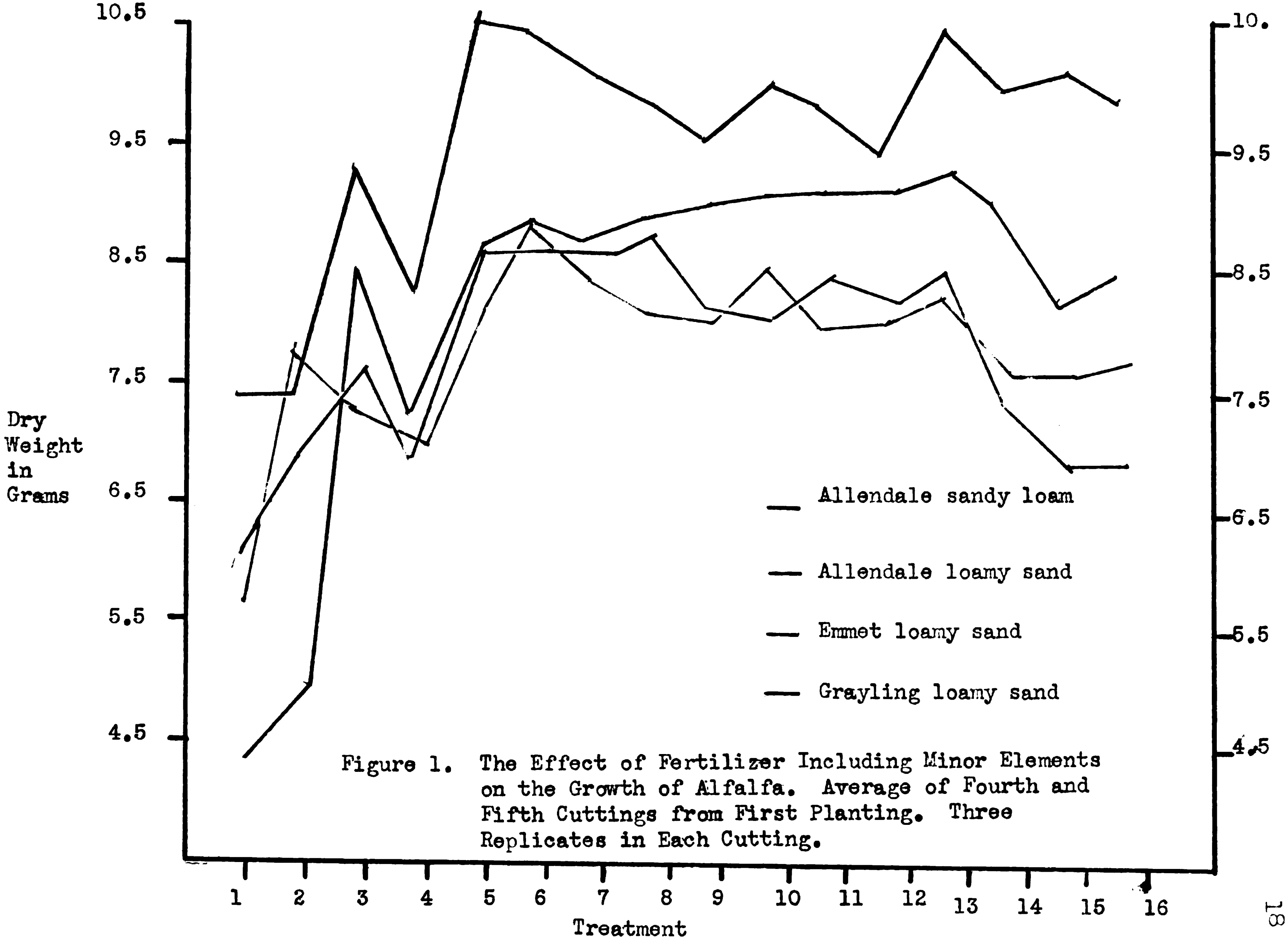

Figure 1. The Effect of Fertilizer Including Minor Elements on the Growth of Alfalfa. Average of Fourth and Fifth Cuttings from First Planting. Three Replicates in Each Cutting.

The last two cuttings from the first alfalfa planting were combined for each treatment and analyzed for phosphorus, potassium, calcium and magnesium. The tomato plants that were grown as an intermediate crop were analyzed for phosphorus and potassium only.

Both the tomato and alfalfa samples were dried in an oven and ground in a Wiley mill to pass a 1 mm mesh screen. The samples were dried in an oven at 90-100° C. Two gram samples were weighed and the material transferred to silica crucibles. Six ml of dilute sulfuric acid (1 + 2) were added and mixed so that all the material was moist. The tissue was charred on a hot plate and transferred to a muffle furnace with a temperature of 500-550° C until a light gray ash was obtained.

The ash was moistened with 10 ml of dilute hydrochloric acid (1 + 1) and 10 ml of distilled water was added. The solution was warmed on a hot plate until all of the soluble salts were in solution. The solution was filtered and the insoluble residue washed with 20 ml of hot dilute hydrochloric acid (1 + 19). The filtrate was collected in a 200 ml volumetric flask and made to volume with distilled water.

A portion of the solution was used for the determination of potassium using the flame photometer method as described by Attoe and Truog (2) and Ellis and Marshall (8). Aliquots of the solution were used for the determination of phosphorus colormetrically using the Fisk-Subbarrow reducing agent.

Calcium was determined from a 50 ml aliquot by precipitation as calcium oxalate and titration with standard potassium permanganate. Magnesium was determined from the filtrate of the calcium oxalate solution by precipitation as magnesium ammonium phosphate. The procedures for both the calcium and magnesium determinations were according to the Association of Official Agricultural Chemists (1).

RESULTS AND DISCUSSION OF ALFALFA PLANT ANALYSES

In all four soils, the check plants were as high in phosphorus as were some of the other plants which had received phosphorus. However, plants which had been fertilized only with phosphorus were higher in phosphorus content than were those fertilized with 0-20-20. Where potassium was added without phosphorus, the tissue was found to be low in phosphorus. There was some variation in percentages of phosphorus among the plants in the various remaining treatments, but there appeared to be no one treatment in which the differences were consistent for the various soils.

Greater differences in percentages of potassium as a result of treatment were noted on all four soils. The check plants and 0-20-0 treated plants contained about equal percentages of potassium. The plants that had received 0-20-20 were considerably higher than were either the check plants or those that had received only phosphorus. A wide variation of potassium content occurred among the plants on all four soils that had been fertilized with 0-20-20. The addition of nitrogen did not appreciably affect the percentage of potassium in the plants. However, the potassium content was considerably higher in the plants which had received 0-20-40 than in those which had grown where a lower potassium ratio fertilizer was applied. The remaining treatments did not appreciably change potassium percentages.

The calcium content of the alfalfa varied only slightly among the treatments. Generally, the check plants and the 0-20-0 treated plants contained a higher percentage of calcium than did those in the other treatments. A tendency for lower calcium percentages where potassium was applied is in accordance with the theory of constancy in the equivalent cation concentration of plants. However, this does not hold to any appreciable extent in the comparison between the analytical results obtained on the plants from the 0-20-40 treatment as compared to those from that which included only 0-20-20. The percentage increase of potassium in the 0-20-40 treated plants was not accompanied by a similar decrease in calcium percentage as compared with the content of these nutrients found in the plants fertilized with 0-20-20. The calcium content of the plants in the remaining treatments did not seem to be affected appreciably by any of the minor elements.

Wide variations occurred in magnesium content among the

Table 3. Plant analyses of alfalfa tissue as affected by fertilizer including minor elements. First planting. Fourth and fifth cuttings combined for each treatment. Percentage of element in plant. #

Soil treatment	Element	Emmet loamy sand	Grayling loamy sand	Allendale loamy sand	Allendale sandy loam
1. Check	P	0.20	0.26	0.25	0.27
	K	0.85	0.76	0.75	0.80
	Ca	2.18	2.38	1.96	1.70
	Mg	0.65	0.35	1.04	0.61
2. 0-20-0	P	0.30	0.30	0.36	0.35
	K	0.86	0.80	0.76	0.80
	Ca	1.90	2.22	1.42	1.70
	Mg	0.52	0.35	1.00	0.39
3. 0-20-20	P	0.28	0.25	0.32	0.31
	K	1.33	1.30	1.23	1.06
	Ca	1.78	1.72	1.36	1.52
	Mg	0.52	0.30	1.22	0.30
4. 0-0-20	P	0.21	0.19	0.24	0.15
	K	1.45	1.82	1.34	1.10
	Ca	2.04	1.56	1.42	1.32
	Mg	0.34	0.30	0.56	0.22
5. 5-20-20	P	0.26	0.22	0.31	0.30
	K	1.23	1.28	1.23	1.20
	Ca	1.64	1.88	1.24	1.44
	Mg	0.43	0.34	0.56	0.22
6. 0-20-40	P	0.25	0.19	0.33	0.29
	K	1.85	1.62	1.82	1.65
	Ca	1.34	1.62	1.42	1.36
	Mg	0.35	0.34	0.52	0.43
7. 0-20-20 + Mg, Mn, Fe, B, Cu	P	0.21	0.22	0.31	0.19
	K	1.18	1.09	1.10	1.10
	Ca	1.70	1.88	1.40	1.50
	Mg	0.52	0.30	0.61	0.39
8. 0-20-20 + Mn, Fe, B, Cu	P	0.24	0.22	0.31	0.27
	K	1.10	1.15	1.15	0.92
	Ca	1.74	1.90	1.40	1.32
	Mg	0.35	0.34	0.56	0.22

Table 3. Continued from page 22.

Soil treatment	Element	Emmet loamy sand	Grayling loamy sand	Allendale loamy sand	Allendale sandy loam
9. 0-20-20 + Mg, Fe, B, Cu	P	0.24	0.20	0.31	0.17
	K	1.14	1.03	1.13	1.05
	Ca	1.70	1.82	1.40	1.56
	Mg	0.56	0.52	0.65	0.13
10. 0-20-20 + Mg, Mn, B, Cu	P	0.26	0.25	0.31	0.19
	K	1.23	1.03	1.10	1.01
	Ca	1.64	1.82	1.44	1.48
	Mg	0.43	0.48	0.65	0.43
11. 0-20-20 + Mg, Mn, Fe, Cu	P	0.24	0.23	0.30	0.27
	K	1.20	1.01	1.10	0.98
	Ca	1.70	1.76	1.50	1.42
	Mg	0.43	0.30	0.61	0.22
12. 0-20-20 + Mg, Mn, Fe, B	P	0.24	0.23	0.29	0.27
	K	1.07	0.97	1.10	1.10
	Ca	1.64	1.76	1.50	1.58
	Mg	0.65	0.48	0.69	0.39
13. 0-20-20 + Mg	P	0.29	0.20	0.31	0.28
	K	1.30	0.97	1.10	1.03
	Ca	1.76	1.78	1.30	1.56
	Mg	0.56	0.43	0.65	0.39
14. 0-20-20 + Mn, Fe	P	0.27	0.23	0.29	0.31
	K	1.33	1.08	1.09	1.04
	Ca	1.94	1.94	1.42	1.44
	Mg	0.39	0.35	0.69	0.17
15. 0-20-20 + B	P	0.29	0.23	0.34	0.31
	K	1.52	1.10	1.33	1.04
	Ca	1.78	1.96	1.44	1.42
	Mg	0.30	0.22	0.61	0.35
16. 0-20-20 + Cu	P	0.29	0.24	0.31	0.29
	K	1.30	1.13	1.23	0.98
	Ca	1.88	1.90	1.48	1.48
	Mg	0.43	0.26	0.61	0.30

The plant tissue from the fourth and fifth cuttings was ground together and thoroughly mixed before analyzing.

& Fertilizer rates given on pages 10 and 11.

treatments on the four soils. It is the author's opinion that these differences were influenced not from treatment effect but from possible errors that may have occurred because of the difficult method used.

The analyses indicate that phosphorus and potassium contents were well above the critical limit suggested by Bear and Wallace (5). However, the calcium content for most of the plants was below the 2.2% critical limit and the magnesium content in many of the plants was below the critical limit of 0.54%.

OBSERVATIONS DURING GROWTH OF TOMATOES

1. Emmet and Grayling loamy sand soils

Throughout the growing period, it was obvious that the check plants and those that had not received complete fertilization were inferior in every way. The plants were small and lacked vegetation and a healthy green color. Phosphorus alone caused considerably more response than did potassium alone on the Grayling soil (see Plate 2). Little difference could be noticed between these same treatments on the Emmet soil (see Plate 1).

The plants that had received 0-20-20, 5-20-20 and 0-20-40 attained larger growth and were greener in color on both soils than those which had been left unfertilized or which had received only a single element.

The additional potassium that was contained in the

0-20-40 fertilizer resulted in plants which were similar in growth and color to those grown where minor elements were included in the fertilizer.

No obvious visual differences appeared among the plants which had received all or any combination of several of the minor elements.

2. Allendale sandy loam and Allendale loamy sand soils

Plant growth on these two soils appeared to follow almost the same pattern as occurred in the plants on the previously mentioned soils. The check plants and the 0-0-20 treated plants made considerably less growth than did the other plants on the Allendale sandy loam. Phosphorus alone caused a greater response than did potassium as is revealed in Plate 4. No differences were apparent between the plants that had received only phosphorus and those that had been fertilized with 5-20-20 and 0-20-40.

The phosphorus effect was not as great on the Allendale loamy sand as it was on the sandy loam (see Plate 3). Growth where this treatment was made was similar to that exhibited by the 0-0-20 and 5-20-20 treated plants. No conspicuous differences were noted in plant growth as a result of any of the variable minor element treatments on either soil type.

Plate 1. Tomato plant growth on Emmet loamy sand at time of harvest.

Plate 2. Tomato plant growth on Grayling loamy sand at time of harvest.

1. Check
2. 0-20-0
3. 0-20-20
4. 0-0-20
5. 5-20-20
6. 0-20-20 + Mg, Mn, Fe, B, Cu

Plate 3. Tomato plant growth on Allendale loamy sand at time of harvest.

Plate 4. Tomato plant growth on Allendale sandy loam at time of harvest.

1. Check
2. 0-20-0
3. 0-20-20
4. 0-0-20
5. 5-20-20
6. 0-20-20 ≠ Mg, Mn, Fe, B, Cu

RESULTS AND DISCUSSION OF TOMATO PLANT YIELDS

A comparison of tomato plant yields in the first six treatments with the control showed that significantly higher yields occurred in treatments that had contained 0-20-0, 0-20-20, 5-20-20 and 0-20-40 on all four soil types. In no case did potassium alone cause a significant plant response. The remainder of the treatments resulted in yields that were significantly greater than those from the control plants. No significantly higher yields were obtained from the addition of minor elements compared with the plants that had received 0-20-20 on the Emmet and the Allendale sandy loam soils. The fact that larger tomato plant yields were obtained in three treatments (10, 13 and 14) containing minor elements on the Grayling soil cannot be explained as no one minor element or any group of minor elements appeared to cause the significant difference. By the same token, there seems to be no explanation why the yields in three treatments (8, 11 and 12) on the Allendale loamy sand and four treatments (7, 8, 11 and 14) on the Allendale sandy loam should be significantly less than those that had occurred where the fertilizer was 0-20-20. Thus, the indications are that minor elements were not very influential in affecting tomato plant growth.

Table 4. The effect of fertilizer, including minor elements, on the growth of tomato plants on four problem soils. Average dry weight in grams of three replicates.

Soil treatment	Emmet loamy sand	Gray-ling loamy sand	Allen-dale loamy sand	Allen-dale sandy loam
1. Check	1.4	1.5	7.7	6.5
2. 0-20-0	5.9 *	4.8 *	13.0 *	11.6 *
3. 0-20-20	8.5 *	6.0 *	14.6 *	14.0 *
4. 0-0-20	3.7	2.2	8.4	5.5
5. 5-20-20	9.2 *	7.7 *	12.1 *	13.0 *
6. 0-20-40	9.6 *	7.9 *	13.2 *©-	12.5 *
7. 0-20-20 + Mg, Mn, Fe, B, Cu	8.0 *	7.8 *	14.7 *	10.5 *©-
8. 0-20-20 + Mn, Fe, B, Cu	8.0 *	7.7 *	11.5 *©-	11.4 *©-
9. 0-20-20 + Mg, Fe, B, Cu	7.5 *	8.1 *	14.5 *	13.8 *
10. 0-20-20 + Mg, Mn, B, Cu	8.4 *	8.9 *©	14.6 *	14.4 *
11. 0-20-20 + Mg, Mn, Fe, Cu	7.9 *	8.0 *	9.7 *©-	10.6 *©-
12. 0-20-20 + Mg, Mn, Fe, B	7.6 *	7.0 *	11.7 *©-	11.9 *
13. 0-20-20 + Mg	7.7 *	8.8 *©	14.8 *	12.7 *
14. 0-20-20 + Mn, Fe	8.3 *	8.7 *©	14.0 *	10.7 *©-
15. 0-20-20 + B	8.8 *	7.4 *	14.2 *	11.7 *
16. 0-20-20 + Cu	8.4 *	7.8 *	16.8 *©	13.5 *

* Significant at the 5% level.

© Significant at the 5% level in respect to 0-20-20 treat.

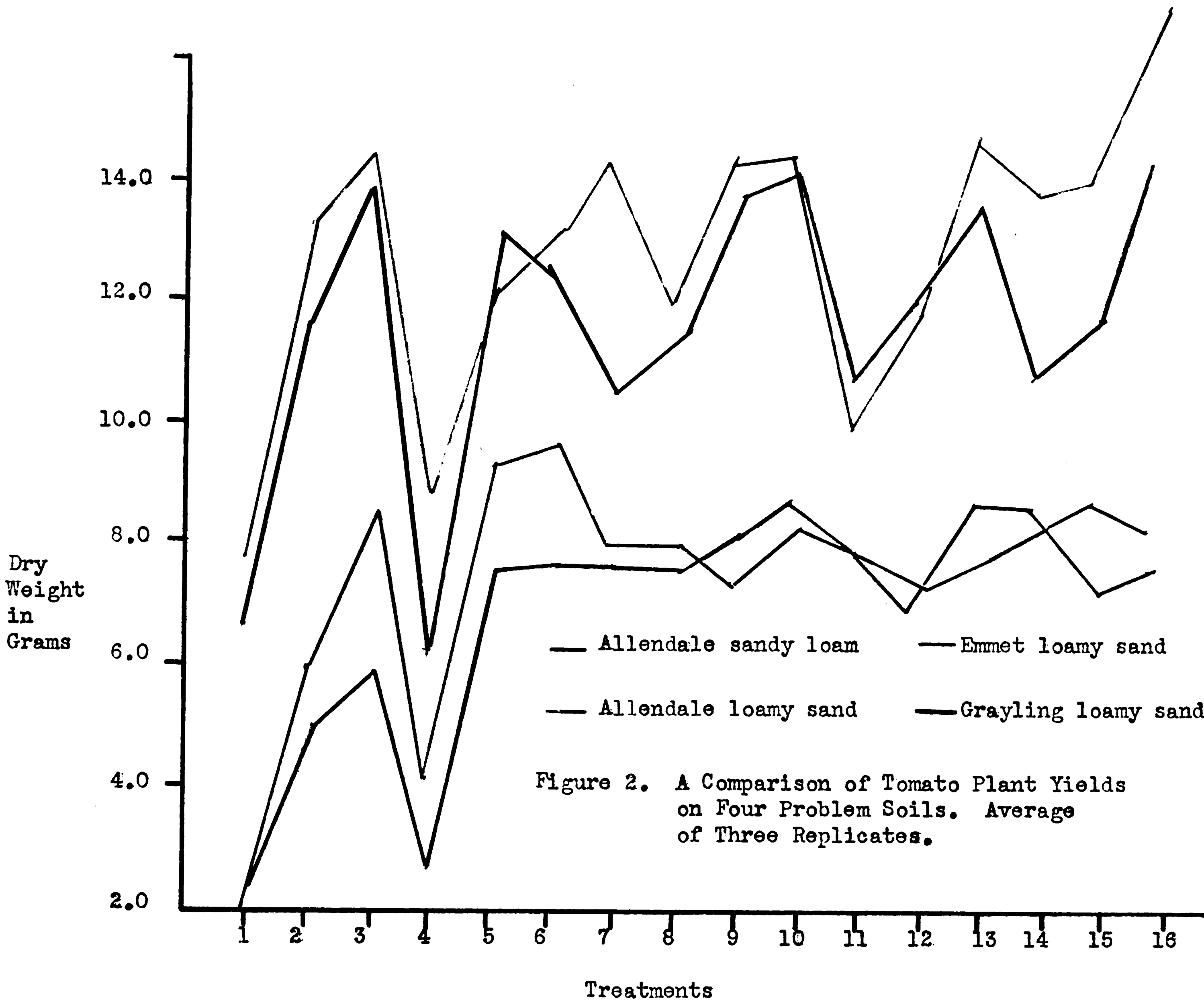

Figure 2. A Comparison of Tomato Plant Yields on Four Problem Soils. Average of Three Replicates.

RESULTS AND DISCUSSION OF TOMATO PLANT ANALYSES

The analyses showed that the phosphorus content of the plants varied between treatments on all four soils. However, no consistant differences occurred that could be traced to any one fertilizer treatment. The phosphorus content was in some instances high in one treatment on one soil and low in the same treatment on another soil. There appeared to be no difference in phosphorus content where phosphorus had been added or where it was absent. There was a tendency for the phosphorus content of the plants to be slightly lower in most treatments on the Allendale sandy loam than on the other soils.

The potassium content of the plants varied more between the treatments than did the phosphorus content. The plants that had been fertilized with 0-20-0 were slightly lower in percentage of potassium than those from most of the other treatments. Conversely, the potassium content was usually high where 0-0-20 and 0-20-40 had been supplied. The remaining treatments caused no appreciable change in the potassium content. The results of the analyses may be seen in Table 5.

Table 5. Plant analyses of tomato plant tissue as affected by fertilizer treatments including minor elements. Average of three replicates. Percentage of element in plant.

Soil treatment	Element	Emmet loamy sand	Grayling loamy sand	Allendale loamy sand	Allendale sandy loam
1. Check	P	0.23	0.25	0.21	0.21
	K	1.32	1.86	1.30	1.50
2. 0-20-0	P	0.25	0.21	0.22	0.18
	K	1.20	1.02	0.79	0.88
3. 0-20-20	P	0.23	0.17	0.23	0.17
	K	1.44	1.41	1.01	1.18
4. 0-0-20	P	0.18	0.23	0.24	0.17
	K	1.99	2.65	0.94	1.35
5. 5-20-20	P	0.20	0.20	0.23	0.17
	K	1.16	1.16	1.34	1.19
6. 0-20-40	P	0.21	0.23	0.25	0.21
	K	1.45	2.10	1.56	2.29
7. 0-20-20 + Mg, Mn, Fe, B, Cu	P	0.20	0.23	0.21	0.18
	K	1.25	1.48	1.06	1.31
8. 0-20-20 + Mn, Fe, B, Cu	P	0.21	0.21	0.23	0.21
	K	1.15	1.54	1.05	1.31

Table 5. Continued from page 32.

Soil treatment	Element	Emmet loamy sand	Gray-ling loamy sand	Allen-dale loamy sand	Allen-dale sandy loam
9. 0-20-20 + Mg, Fe, B, Cu	P	0.23	0.23	0.21	0.16
	K	1.25	1.45	1.10	1.17
10. 0-20-20 + Mg, Mn, B, Cu	P	0.18	0.20	0.26	0.16
	K	0.92	1.37	1.20	1.29
11. 0-20-20 + Mg, Mn, Fe, Cu	P	0.18	0.23	0.21	0.13
	K	2.34	1.47	1.06	1.06
12. 0-20-20 + Mg, Mn, Fe, B	P	0.21	0.21	0.24	0.17
	K	1.44	1.41	1.05	1.17
13. 0-20-20 + Mg	P	0.21	0.21	0.21	0.18
	K	1.00	1.29	1.67	1.50
14. 0-20-20 + Mn, Fe	P	0.20	0.20	0.23	0.17
	K	1.16	1.31	1.06	1.40
15. 0-20-20 + B	P	0.21	0.17	0.25	0.17
	K	1.44	1.45	1.15	1.52
16. 0-20-20 + Cu	P	0.20	0.23	0.23	0.16
	K	1.20	1.32	1.04	1.29

OBSERVATIONS DURING GROWTH OF SECOND ALFALFA PLANTING

1. Emmet and Grayling loamy sand soils

During early growth, the control and 0-20-0 treated plants appeared to be stunted on both soil types. The alfalfa that had been fertilized with 0-20-20 showed slightly more vegetative growth than where 0-0-20 had been applied, but by the time of the ~~bird~~ third cutting, there appeared to be little difference between the plants. Some nitrogen response was evident in the plants supplied with 5-20-20 on both soils. A response was also noted to the extra potassium supplied in treatment 6. The alfalfa was slightly restricted in growth on these soils where 0-20-20 + boron (treatment 15) had been applied. Aside from this, no conspicuous differences were exhibited by the alfalfa plants that had been supplied with minor elements.

After the second cutting had been removed, nitrogen deficiency symptoms appeared on several plants on both soils as evidenced by a yellowing of the lower leaves. This condition was apparent in the plants in treatment 5 in spite of the fact that nitrogen had been supplied. The alfalfa plants in treatments 3, 4, 5, 6, 7 and 8 on the Emmet soil ~~were~~ where calcium sulfate had been applied recovered more rapidly after harvest than did the plants that had not received calcium sulfate.

Before the third harvest, the control and the plants on these soils that had been fertilized with 0-20-0 were so chlorotic due to nitrogen and potassium deficiencies that many of the leaves turned brown and were dropping. Likewise potassium deficiency symptoms as evidenced by a yellowing of the leaf margins and appearance of white dots on the edges of the leaves had become apparent on a few scattered plants in several treatments on the Grayling soil.

Symptoms of boron deficiency (a reddening and yellowing of the terminal leaves) were evident by this time in treatments 3, 5, 6, 8 and 13 on the Grayling soil and in treatment 8 on the Emmet soil. Treatment 8 was the only one of this group which contained boron.

2. Allendale loamy sand and Allendale sandy loam soils

The alfalfa had grown only a few weeks when a yellowing of the leaf margins appeared in the control and 0-20-0 treated plants on both soils. After the second cutting, the alfalfa leaves turned brown and started dropping in these two treatments.

It was revealing to note that on both soils, although the control plants and those that had been supplied only with phosphorus lacked growth, the check plants appeared to be more vigorous than those that had received just phosphorus. This difference is shown in Plate 6.

Plant growth was considerably less on the first two treatments than where 0-20-20 and 0-0-20 had been supplied (treatments 3 and 4). Little or no plant response due to nitrogen occurred on either soil. The alfalfa did not respond noticeably to additional potassium or to calcium sulfate on the Allendale loamy sand, but the plants on the Allendale sandy loam were affected by these admendments. The plants showed more growth where 0-20-40 had been applied in comparison to the first five treatments. In addition, calcium sulfate may have been responsible for more vigorous alfalfa in treatments 3, 4, 6, 7 and 8. Maturity seemed to be hastened as the first blossoms of each cutting appeared on the replicates treated with calcium sulfate.

The plants which received the most complete ratio of nutrients (treatment 7) and those where magnesium was omitted (treatment 8) were more healthy and vigorous than the plants treated with other minor element mixtures on the Allendale sandy loam. In contrast, where either boron or copper was the only minor element applied (treatments 15 and 16), the alfalfa did not attain the growth that it did in the pots which received the more complete mixtures.

On the Allendale loamy sand, the alfalfa plants exhibited the largest growth as a result of treatments 12 and 13. These had received magnesium but not copper. In treatment 13, only magnesium was applied in addition to the 0-20-20. The application of boron or copper alone with 0-20-20 did not cause a growth response comparable to that produced by some other minor element mixtures.

Plate 5. Alfalfa growth on Emmet loamy sand at time of third cutting.

Plate 6. Alfalfa growth on Allendale sandy loam at time of third cutting.

1. Check
2. 0-20-0
3. 0-20-20
4. 0-0-20
5. 5-20-20
6. 0-20-40
7. 0-20-20 + Mg, Mn, Fe, B, Cu

RESULTS AND DISCUSSION OF ALFALFA CROP FROM SECOND PLANTING

As stated above, calcium sulfate was mixed with the soil of one replicate in each treatment throughout the experiment in the hopes of determing the effect of calcium on alfalfa growth without changing the soil pH. The first cutting of alfalfa was discarded as many of the plants had grown unevenly due to damping-off organisms. Thus yield data are for the second and third cuttings.

A statistical analysis of the second cutting results showed that significant increases in yield were obtained where the fertilizers were 0-20-20, 0-0-20, 5-20-20 or 0-20-40 (see Table 8). This was true on all four of the soil types under study. On the Emmet and Allendale loamy sands, minor elements caused significant increases in yield in many of the treatments. Through treatments 7 to 12, the practice of omitting single elements from the complete mixture showed some evidence of a response to copper on the Emmet soil. From the treatments 13 and 14 yields there was also evidence that magnesium, manganese and iron caused increases in yield. On the whole, perhaps it is only possible to say that a combination of elements other than phosphorus and potassium did cause increases in yield.

A very similar conclusion must be drawn from the results obtained on the Allendale loamy sand. In only one instance, that of treatment 9, did the extra nutrients fail to significantly increase yields. That was where manganese was omitted.

This would indicate that manganese was the effective element. However, significant increases were obtained from magnesium, boron and copper applied singly in addition to 0-20-20. Thus, again it seems sufficient to say only that extra nutrients did increase the yields.

On the Grayling soil, the mixture of all the extra elements failed to cause an increase in yield which was significantly greater than that obtained where only 0-20-20 was applied. Where magnesium or manganese was omitted, the increase in yield was significant. This would indicate that these nutrients were toxic. This, however, seems hardly probable.

On the Allendale sandy loam, the complete mixture of nutrients did cause a significant increase in yield. Likewise significant increases were obtained where magnesium and iron were omitted. None of the other yields were significantly greater than that obtained where only 0-20-20 was applied. This makes it seem that the other three elements in combination, manganese, boron and copper were responsible for the increased yield which occurred as a result of the complete application.

The alfalfa yields from the third cutting followed the same pattern as the previous cuttings in regards to the first six treatments. Significantly higher yields were obtained compared with no treatment where the plants had been fertilized with 0-20-20, 0-0-20, 5-20-20 and 0-20-40 on all four soil types. It is noteworthy that in neither cutting did phosphorus alone cause any significant differences in alfalfa yield.

A significantly higher yield of alfalfa was obtained as a result of some of the treatments which included minor elements on the Emmet and Grayling soils. This effect was exhibited in treatments 8, 9 and 12 on both soils which included, respectively; Mn, Fe, B, Cu; Mg, Fe, B, Cu; and Mg, Mn, Fe, and B as the minor elements. Iron and boron were the only elements common in all three treatments but it is doubtful that these elements alone were responsible for the higher yields.

In both cuttings, calcium sulfate probably caused increases in yield on three of the soils. The increases were significant to the 1% point on the two Allendale soils and to the 5% point on the Emmet. Significance is based on the fact that there was a difference between blocks. It is assumed that these differences between blocks were caused by the application of calcium sulfate to one of the replicates.

It is conceivable that since this apparent effect of calcium sulfate was very much the same as on the previous cutting, the calcium may actually have had a beneficial effect on the alfalfa growth. At the same time, the response may have been due to the sulfur rather than the calcium.

Table 6. The effect of fertilizer, minor elements and calcium sulfate on the growth of alfalfa on four problem soils. Second planting. Second cutting. All replicates. Dry weight in grams.

Soil treatment	Repl. number	Emmet loamy sand	Gray-ling loamy sand	Allen-dale loamy sand	Allen-dale sandy loam
1. Check	1#	3.7	3.1	4.7	5.5
	2	3.6	1.6	2.9	2.5
	3	1.4	2.3	3.5	4.0
2. 0-20-0	1	2.9	1.7	3.4	4.5
	2	2.4	2.5	2.1	3.9
	3	3.0	4.2	2.5	1.1
3. 0-20-20	1	6.6	6.1	7.1	7.6
	2	5.9	5.8	6.1	6.7
	3	6.4	6.4	7.4	6.9
4. 0-0-20	1	7.2	5.5	6.7	8.0
	2	5.2	7.2	5.6	6.9
	3	4.9	6.1	5.3	6.7
5. 5-20-20	1	7.0	6.7	7.7	7.5
	2	7.6	5.6	7.3	6.9
	3	7.6	6.2	6.9	6.7
6. 0-20-40	1	7.5	7.4	7.3	8.1
	2	6.8	6.1	7.0	7.8
	3	6.2	6.0	7.0	7.1
7. 0-20-20 + Mg, Mn, Fe, B, Cu	1	7.6	6.5	8.7	9.7
	2	7.5	7.5	7.4	7.7
	3	6.8	7.1	7.2	8.1
8. 0-20-20 + Mn, Fe, B, Cu	1	8.6	7.5	8.1	8.6
	2	8.0	8.1	7.9	7.6
	3	7.1	7.7	8.8	8.4

Replicate 1 received calcium sulfate at a rate of 1,000 pounds per acre. Replicate 2 and 3 did not receive calcium sulfate.

Table 6. Continued from page 41.

Soil treatment	Repl. number	Emmet loamy sand	Gray-ling loamy sand	Allen-dale loamy sand	Allen-dale sandy loam
9. 0-20-20 + Mg, Fe, B, Cu	1	7.9	7.7	7.3	7.7
	2	8.4	8.5	5.7	8.1
	3	8.3	6.9	6.1	7.8
10. 0-20-20 + Mg, Mn, B, Cu	1	7.7	6.9	8.2	9.0
	2	8.8	7.9	7.9	8.7
	3	8.2	7.4	7.7	8.2
11. 0-20-20 + Mg, Mn, Fe, Cu	1	8.6	7.2	9.0	8.3
	2	7.8	6.5	8.5	8.1
	3	7.8	7.7	9.9	7.4
12. 0-20-20 + Mg, Mn, Fe, B	1	7.3	7.2	10.0	7.9
	2	7.6	7.4	9.0	8.0
	3	6.7	7.0	7.7	7.9
13. 0-20-20 + Mg	1	7.2	6.8	8.4	8.0
	2	7.7	7.0	7.7	7.5
	3	7.4	7.7	8.4	7.7
14. 0-20-20 + Mn, Fe	1	7.7	6.7	8.5	7.9
	2	8.4	8.7	9.2	8.0
	3	6.5	7.0	7.6	7.8
15. 0-20-20 + B	1	6.9	6.2	9.0	7.7
	2	6.7	6.7	7.7	7.7
	3	6.8	7.0	7.2	6.9
16. 0-20-20 + Cu	1	7.6	7.1	8.3	6.9
	2	7.0	6.8	8.2	6.9
	3	7.1	4.1	7.7	6.6

Table 7. The effect of fertilizer, minor elements and calcium sulfate on the growth of alfalfa on four problem soils. Second planting. Third cutting. All replicates. Dry weight in grams.

Soil treatment	Repl. number	Emmet loamy sand	Gray-ling loamy sand	Allen-dale loamy sand	Allen-dale sandy loam
1. Check	1#	3.3	2.7	4.7	3.5
	2	3.3	2.1	2.3	0.7
	3	1.9	3.2	2.7	3.7
2. 0-20-0	1	3.7	1.9	2.7	3.3
	2	1.7	3.1	1.7	4.5
	3	2.5	6.4	0.9	1.1
3. 0-20-20	1	10.5	9.5	11.5	13.9
	2	8.5	10.7	10.3	13.5
	3	11.3	10.5	12.9	10.7
4. 0-0-20	1	9.1	8.7	10.0	11.9
	2	7.7	10.1	7.3	9.7
	3	8.1	8.7	5.4	10.5
5. 5-20-20	1	10.1	8.5	12.1	12.9
	2	10.5	7.3	10.7	11.7
	3	10.5	8.7	9.5	10.7
6. 0-20-40	1	14.1	10.7	9.7	12.5
	2	11.1	9.5	7.2	12.5
	3	10.7	8.5	9.0	10.7
7. 0-20-20 + Mg, Mn, Fe, B, Cu	1	13.3	12.5	13.8	15.1
	2	11.1	13.3	4.9	12.1
	3	11.7	13.0	11.5	11.1
8. 0-20-20 + Mn, Fe, B, Cu	1	15.7	13.7	11.7	12.2
	2	13.7	13.7	10.4	12.7
	3	9.5	13.6	10.5	11.7

\# Replicate 1 received calcium sulfate at a rate of 1,000 pounds per acre. Replicates 2 and 3 did not receive calcium sulfate.

Table 7. Continued from page 43.

Soil treatment	Repl. number	Emmet loamy sand	Grayling loamy sand	Allendale loamy sand	Allendale sandy loam
9. 0-20-20 + Mg, Fe, B, Cu	1	13.7	11.9	10.6	11.7
	2	13.3	13.3	2.5	13.2
	3	12.9	13.3	5.5	11.5
10. 0-20-20 + Mg, Mn, B, Cu	1	13.7	11.9	12.7	14.5
	2	14.1	11.7	11.5	12.7
	3	13.9	13.4	11.1	10.5
11. 0-20-20 + Mg, Mn, Fe, Cu	1	14.5	9.1	11.9	11.5
	2	13.3	11.0	16.5	11.7
	3	13.7	9.0	12.1	11.1
12. 0-20-20 + Mg, Mn, Fe, B	1	13.7	14.5	14.7	13.5
	2	13.2	12.1	14.7	10.7
	3	11.5	12.5	12.7	12.7
13. 0-20-20 + Mg	1	9.9	10.7	13.9	12.5
	2	10.7	9.8	10.7	11.1
	3	12.9	10.1	11.5	9.7
14. 0-20-20 + Mn, Fe	1	13.1	11.0	13.7	12.7
	2	10.7	11.7	9.9	10.9
	3	9.3	16.1	12.4	11.3
15. 0-20-20 + B	1	10.9	9.5	12.5	12.7
	2	9.7	12.0	9.9	12.3
	3	11.3	9.9	8.1	10.5
16. 0-20-20 + Cu	1	12.9	9.9	10.9	11.7
	2	11.5	4.1	10.0	10.5
	3	11.1	10.3	10.1	10.7

Table 8. The effect of fertilizer, minor elements and calcium sulfate on the growth of alfalfa on four problem soils. Second planting. Second cutting. Average of three replicates. Dry weight in grams.

Soil treatment	Emmet loamy sand	Grayling loamy sand	Allendale loamy sand	Allendale sandy loam
1. Check	2.9	2.3	3.7	4.0
2. 0-20-0	2.8	2.8	2.7	3.2
3. 0-20-20	6.3 *	6.1 *	6.8 *	7.1 *
4. 0-0-20	5.8 *	6.3 *	5.8 *	7.2 *
5. 5-20-20	7.4 * ©	6.2 *	7.3 *	7.0 *
6. 0-20-40	6.8 *	6.5 *	7.1 *	7.7 *
7. 0-20-20 + Mg, Mn, Fe, B, Cu	7.3 * ©	7.0 *	7.8 * ©	8.5 * ©
8. 0-20-20 + Mn, Fe, B, Cu	7.9 * ©	7.8 * ©	8.2 * ©	8.2 * ©
9. 0-20-20 + Mg, Fe, B, Cu	8.2 * ©	7.7 * ©	6.3 *	7.9 *
10. 0-20-20 + Mg, Mn, B, Cu	8.2 * ©	7.4 *	7.9 * ©	8.6 * ©
11. 0-20-20 + Mg, Mn, Fe, Cu	8.0 * ©	7.1 *	9.1 * ©	7.9 *
12. 0-20-20 + Mg, Mn, Fe, B	7.2 *	7.2 *	8.9 * ©	7.9 *
13. 0-20-20 + Mg	7.4 * ©	7.2 *	8.2 * ©	7.7 *
14. 0-20-20 + Mn, Fe	7.5 * ©	7.4 *	8.4 * ©	7.9 *
15. 0-20-20 + B	6.8 *	6.6 *	8.0 * ©	7.4 *
16. 0-20-20 + Cu	7.2 *	6.0 *	8.1 * ©	6.8 *
Significance				
Treatment	**	**	**	**
Block	*		**	**

* Significant at 5% level; ** Significant at 1% level.
© Significant at 5% level in respect to 0-20-20 treatment.

Table 9. The effect of fertilizer, minor elements and calcium sulfate on the growth of alfalfa on four problem soils. Second planting. Third cutting. Average of three replicates. Dry weight in grams.

Soil treatment	Emmet loamy sand	Grayling loamy sand	Allendale loamy sand	Allendale sandy loam
1. Check	2.8	2.7	3.2	2.6
2. 0-20-0	2.6	3.8	1.8	3.0
3. 0-20-20	10.1 *	10.2 *	11.6 *	12.7*
4. 0-0-20	8.3 *	9.2 *	7.6 *	10.7*
5. 5-20-20	10.4 *	8.2 *	10.8 *	11.8 *
6. 0-20-40	12.0 *	9.6 *	8.6 *	11.9 *
7. 0-20-20 + Mg, Mn, Fe, B, Cu	12.0 *	12.9 *@	10.1 *	12.8 *
8. 0-20-20 + Mn, Fe, B, Cu	13.0 *@	13.7 *@	10.9 *	12.2 *
9. 0-20-20 + Mg, Fe, B, Cu	13.3 *@	12.8 *@	6.2 *@	12.1 *
10. 0-20-20 + Mg, Mn, B, Cu	13.9 *@	12.3 *	11.8 *	12.6 *
11. 0-20-20 + Mg, Mn, Fe, Cu	13.8 *@	9.7 *	13.5 *	11.4 *
12. 0-20-20 + Mg, Mn, Fe, B	12.8 *@	13.0 *@	14.0 *	12.3 *
13. 0-20-20 + Mg	11.2 *	10.2 *	12.0 *	11.1 *
14. 0-20-20 + Mn, Fe	11.0 *	12.9 *@	12.0 *	11.6 *
15. 0-20-20 + B	10.6 *	10.5 *	10.2 *	11.8 *
16. 0-20-20 + Cu	11.8 *	8.1 *	10.3 *	11.0 *
Significance				
Treatment	**	**	**	**
Block	*		**	**

* Significant at 5% level; ** Significant at 1% level.
@ Significant at 5% level in respect to 0-20-20 treatment.

A comparison of the general effect of calcium sulfate on alfalfa growth is shown in Table 10. The individual plant yields from replicate 1 were averaged for each treatment in both cuttings and from the four soils. This was also done for replicate 3 of each treatment.

The plants which had received calcium sulfate yielded more in every treatment except where the fertilizer was 0-20-20. It is noteworthy that the largest increase was exhibited in the plants which had received only potassium or an additional amount of that element. This would indicate that there was a better balance between calcium and potassium in these treatments. The fact that the influence of calcium sulfate was consistant in all treatments exdept one would indicate that calcium was not sufficient on these problem soils for optimum growth.

Table 10. The effect of calcium sulfate on the yield of alfalfa on four problem soils. The yields are averages of two cuttings on four soils. Replicate 1 received calcium sulfate; replicate 3 did not.

Soil treatment	Replicate 1	Replicate 3
1. Check	3.9	3.2
2. 0-20-0	3.0	2.7
3. 0-20-20	9.1	9.1
4. 0-0-20	8.4	7.0
5. 5-20-20	9.1	8.3
6. 0-20-40	9.7	8.1
7. 0-20-20 + Mg, Mn, Fe, B, Cu	10.9	9.6
8. 0-20-20 + Mn, Fe, B, Cu	10.8	9.5
9. 0-20-20 + Mg, Fe, B, Cu	9.8	9.0
10. 0-20-20 + Mg, Mn, B, Cu	10.6	10.0
11. 0-20-20 + Mg, Mn, Fe, Cu	10.0	9.8
12. 0-20-20 + Mg, Mn, Fe, B	11.1	9.8
13. 0-20-20 + Mg	9.7	9.4
14. 0-20-20 + Mn, Fe	10.2	9.7
15. 0-20-20 + B	9.4	8.5
16. 0-20-20 + Cu	9.4	8.5

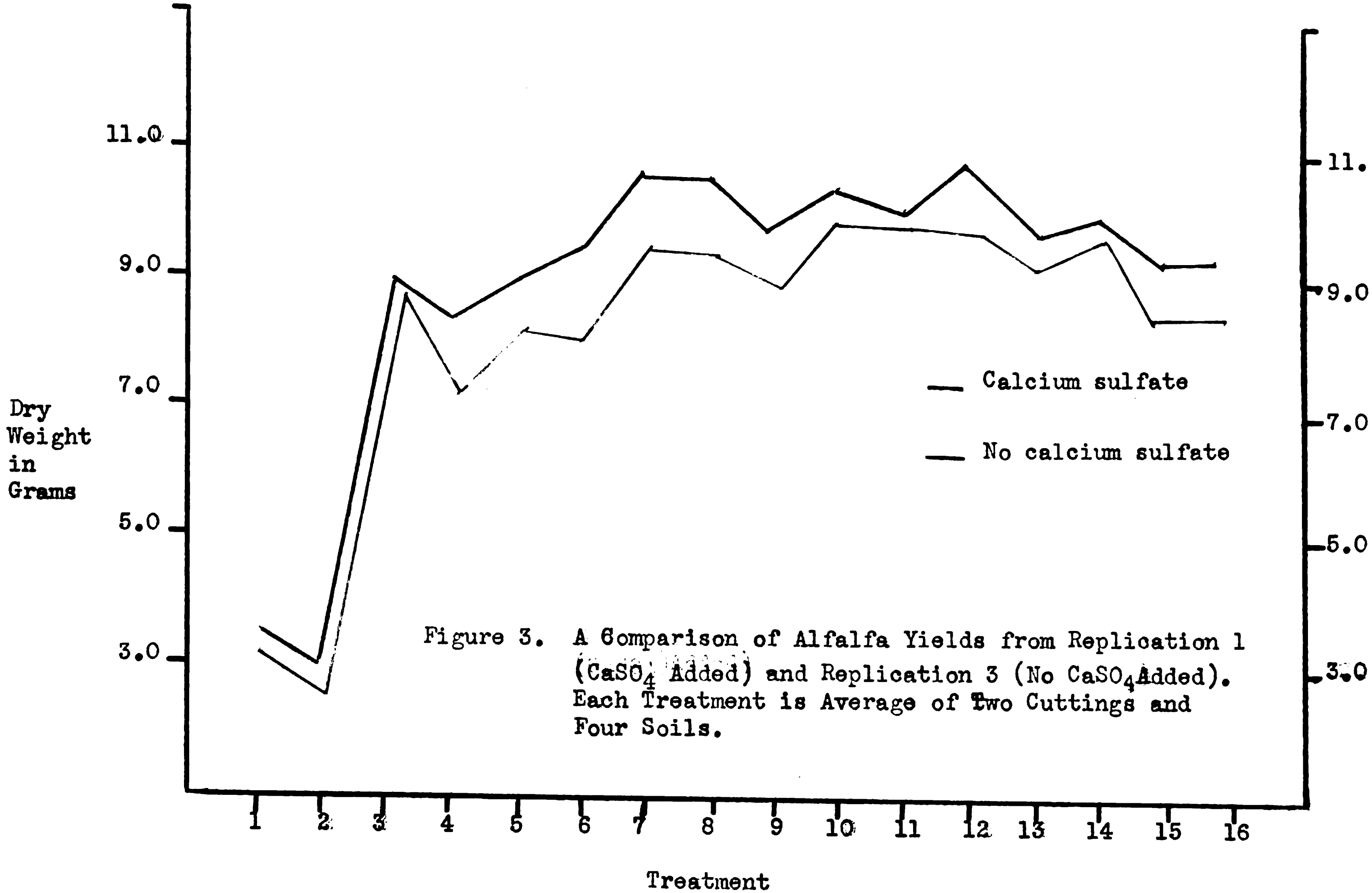

Figure 3. A Comparison of Alfalfa Yields from Replication 1 ($CaSO_4$ Added) and Replication 3 (No $CaSO_4$ Added). Each Treatment is Average of Two Cuttings and Four Soils.

SUMMARY AND CONCLUSIONS

This experiment was a continuation of an earlier investigation by Roy D. Bronson in the fall of 1948 to study alfalfa growth on four problem soils of Michigan. These soils had failed to produce and maintain alfalfa stands so a study was made to determine whether the problem was one of nutrients.

The design consisted of a control and 15 fertilizer treatments including minor elements all replicated three times using the four problem soils. The results of the first experiment were inconclusive so the experiment was conducted another year. In the meantime, two more cuttings of alfalfa were harvested and the data recorded. Before repeating the experiment, the author grew tomato plants to blossoming time in order to deplete the soil.

The plan of study was basically the same as followed by Bronson except that calcium sulfate was applied in one replicate throughout the experiment. The author conducted plant analyses of the alfalfa tissue for phosphorus, potassium, calcium and magnesium and of the tomato tissue for phosphorus and potassium.

The results of the alfalfa yields from the earlier experiment revealed the necessity of a balanced fertilizer. In the first planting, potassium alone resulted in higher yields than did phosphorus alone. A combination of both elements in the form of 0-20-20 was necessary for best results, however. Minor elements were responsible for some of the larger yields in the experiment, but no one individual element proved to be the determining factor.

The plant analyses of the alfalfa harvested from the first investigation showed no significant results. Potassium appeared to be absorbed in proportion to its concentration in the soil.

The tomato plants accomplished their purpose as growth was heavy and rapid during early stages but towards maturity, growth was depressed by a lack of nutrients. Phosphorus alone caused a larger growth than did potassium alone on the Grayling loamy sand and Allendale sandy loam. There was some response from minor elements,but for the most part, the yields resulting from these treatments were about the same as where 0-20-20 or 0-20-40 had been applied.

The analyses conducted on the tomato plant tissue showed about the same results as did those on the alfalfa tissue.

The results of this investigation did not vary significantly from the earlier investigation. The first two treatments (control and 0-20-0) produced only small spindling plants on all soil types. The plants fertilized with 0-20-20 or 0-0-20 were usually more vigorous than the first two treatments. Nitrogen and additional potassium that was present in the 5-20-20 and 0-20-40 respectively caused slightly more response than did the 0-20-20 or 0-0-20 alone. A wide variation in yields occurred in many of the treatments containing minor elements but no one element or group of elements appeared to be responsible for the significantly larger yields that occurred from some of the minor element treatments.

A statistical analysis showed a significant response from the addition of calcium sulfate on three of the four soil types in both cuttings.

This second alfalfa crop failed to produce results that were significantly different from the earlier results. Plant growth responses due to the various fertilizer elements followed a pattern that might have been predicted. The experiment did prove that the problem appears to be at least partly due to some other factors than nutrients.

There is a possibility that the problem is one of moisture as reflected by the type of profile that has developed. It appears that all of these soils are either excessively drained or contain a clay layer in the lower horizons that roots cannot penetrate. According to Veatch (19), the Emmet and Grayling soils are deep, dry sands both excessively drained with little or no clay present in the subsoil. Thus, it is logical that the establishment of any small seeded plants might be a problem unless rainfall was sufficient at intervals when it was needed.

In contrast, the Allendale soils are underlain by wet sand with clay at 18 to 36 inches. A hardpan or iron crust has accummulated above the clay. It is conceivable that if alfalfa was seeded in early spring, the roots would not pene-

deeply
trate because of too much moisture in close proximity to the surface. If a drought occurred during the summer, the roots would use up the available moisture in a short time. The roots would attempt to feed further down but would be prevented from doing so by the hardpan.

Naturally, if the problem is one of moisture, it can be solved only by conserving the precipitation that does fall and holding it by addition of organic matter. In the case of the Allendale soils, it might be desirable to raise the more shallow rooted legumes and be content with a smaller yield.

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