THE EFFECT OF FERTILIZERS INCLUDING SEVERAL MINOR ELEMENTS ON THE GROWTH OF ALFALFA ON FOUR PROBLEM SANDY SOILS

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by

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INTRODUCTION

Factors contributing to the culture of vigorous and productive stands of alfalfa have engaged the attention of crop specialists for a number of years. Great effort has been directed to improvement of yield and quality, to insect and disease resistance, and to varietal adaptation to varying climatic conditions. Realization of the value of alfalfa as a productive, soil-conserving crop and the recognition of the importance of maintaining a large percentage of farm acreage in sod-forming crops have lead to its widespread use in crop rotations.

A large portion of the agricultural land of Michigan is of a nature which supports healthy and productive stands of winter-hardy alfalfa without supplemental irrigation. Large centers of population in the central and southern parts support a thriving dairy industry. As a result, alfalfa has come to be one of the more important agricultural crops of the state.

Parts of the upper peninsula, and much of the northern half of the lower peninsula of Michigan, including some areas farther south along the shores of Lake Michigan, are characterized by considerable areas of light-textured soils which originally supported fine stands of coniferous and deciduous forest. Nearly all of this land was depleted of its timber reserve during the early exploitive days of the lumber barons, and most of the soils are unsuited to the type of general agricultural enterprise which is common to the outlying areas of the state. However, some of the adjoining areas of slightly heavier texture and of greater moisture retaining ability are able to produce good yields of such crops as potatoes, small grains, and hay through the use of generous amounts of fertilizers, manure, and liming materials. In these instances, the excellent, sometimes excessive, internal drainage and the open nature of the soil make the maintenance of organic matter difficult, if not impossible, without the aid of a thrifty, nitrogen-fixing legume. These are the very areas in which the farm operators and owners have experienced great difficulty in establishing and maintaining productive stands of alfalfa or alfalfa-grass mixtures.

The greenhouse investigations which are reported in this paper were undertaken as a means of gaining some indication of a limiting nutrient element or elements which could be supplied to enable the farmers in these problem areas to use alfalfa effectively in their rotations.

REVIEW OF LITERATURE

The nature of this problem is rather general, and the literature which may logically pertain to the subject matter is so voluminous as to preclude the practicability of a comprehensive review. No attempt is made to include all such work on minor or major elements, but rather to highlight the more fundamental contributions by previous workers, and to at least mention some of the more recent works which may have a direct bearing on the nature of this experiment.

If there is one point of agreement on the nutritional requirements of alfalfa, it is that this legume needs frequent medium to heavy applications of potash (23). Owens (34) states that nutrient deficiencies due to lack of phosphates are possibly more widespread than those due to lack of any other essential element. The agreement among agronomists as to the use of potassium and phosphorus fertilizers is relatively widespread, and with modification for the particular locality, the same major nutrients are used in growing alfalfa across the United States.

The fact that these two nutrients are required in rather large amounts has been well established, but the fact of the relationship of some of the minor or micro-elements to the phosphorus and potassium nutrition of alfalfa in particular, and to the nutrition of plants in general is less well established.

Truog and others (40) suggest that magnesium functions as a carrier of phosphorus and that there is a positive correlation between the amount of available magnesium and the efficiency of phosphate fertilizers. Lucas and Scarseth (28) found a reciprocal relationship between potassium, calcium, and magnesium in the plant which may be influenced by the relationship of these elements in the soil. Excess potassium in the soil may increase the potassium content of the plants, but decrease the content of magnesium and calcium. Overliming may decrease the content of potassium and magnesium in the plant.

This is in agreement with work by Bear (4) which showed that the total cation-equivalent of alfalfa plants remained constant for a given crop, and that an increase in one cation was made at the expense of those others present. Wallace and others (44) lend credence to the work of Bear in suggesting that calcium, magnesium, potassium, and possibly other nutrient elements have at least two functions, one specific and the other general. One cation may be replaced to a degree by one or more others, yet a certain minimum amount of each essential nutrient cation must be present for normal growth.

Jamison (24) investigated the relationship of potassium and magnesium in several soils. Hunter (23) found that variations in the calcium-magnesium ratio of the soil affected the composition of the alfalfa but not the yield. Other workers have cited the relationship of calcium to boron; of iron-manganese redox systems and calcium in relation to iron chlorosis (9). Henderson (22) studied the interrelationship of manganese and boron.

<u>Magnesium</u> is essential to plant growth. It is a part of the chlorophyll molecule. Its essential nature has been known since the early work of Wilstatter in 1906, but the fact that some soils were deficient in magnesium was not brought out until Garner and others (18) described sand

drown of tobacco in 1922. Chlorosis of cotton due to magnesium deficiency was reported by Garner (18) and by Cooper (15).

<u>Manganese</u> is shown to be essential to the growth of plants and is associated with the oxidation-reduction systems within the plant, often in relationship with iron, even though its specific functions within the plant are not well established. Early reports by Mazé (29) and McHargue (30) pointed out chlorosis due to manganese deficiency. Later, manganese deficiency in various horticultural and field crops was noted and described by other investigators (10, 19, 31, 38). Olsen (33) brought out the fact that the total quantity of manganese in the soil does not usually indicate the nutrient status of the plants in relation to that element, but that the availability of manganese is rather more directly related to the soil reaction and the reducing ability of the soil.

<u>Iron</u> is directly related to the function of chlorophyll even though it has not been shown to be a part of the chlorophyll molecule. It was perhaps the earliest of the nutrient elements to be reported lacking and the first of the secondary elements to be recognized as essential to plants growing under field conditions. Iron chlorosis of pineapples in Hawaii (25, 26) is reportedly due to an iron deficiency induced by excess manganese. Under other conditions, the chlorosis due to iron deficiency may be the result of overliming (21). Work by Chandler and Scarseth (11)

with legumes on alkaline clay soils showed that additions phosphates caused no chlorosis of alfalfa, but that the iron content of the leaves was reduced. The availability of iron in the soil is governed to a large extent by the soil reaction and by the reducing ability of the soil.

Boron was originally reported as an essential element by Agulhon (1) in 1910. Later, Warington (45) showed the effect of boron on the broad bean. Boron deficiency has since been shown to be the cause of such nutritional diseases as cracked stem of celery (35), heart rot of sugar beets (8), internal cork of apples (3), and internal browning of cauliflower (16). Robbins (36) points out the essentiality of boron in the root environment. Rogers (37) related the boron requirement of alfalfa to calcium supply in the soil and also observed that symptoms of boron deficiency have been seen in alfalfa before any reduction in yield of hay occurs. Berger and Truog (5) discuss the relationship of boron availability to organic matter content and active calcium of the soil, and to the soil texture. Cook (13) reported boron deficiency symptoms in alfalfa on soils where sugar beets had previously suffered from heart rot.

Copper apparently occurs in most normal agricultural soils in sufficient quantity for normal plant growth. As a result, easily-recognized copper deficiency symptoms do not generally occur except in regions of Florida, some locations on the Atlantic coastal plain, and on certain muck and peat soils (20). Copper compounds do function in plant nutrition. Muckenhirn (32) found that copper increased growth of onions, sweet clover, and potatoes on peat. Anderssen (2) found that a chlorosis which occurred on sandy, well-drained soils in South Africa was remedied by application of copper compounds, but not by application of potassium, magnesium, manganese, sulfur, or iron. Knott (27) also found that copper improved color and thickness of scales of onions. Floyd (17) described die-back of citrus in Florida as caused by copper deficiency.

HISTORY OF SOILS STUDIED

The farms from which the soils to be investigated were taken, were chosen from a large number which have been cooperating with the soils program of Michigan State College. Field experiments and demonstration plots on these particular farms had failed to show consistent response to management and soil amendment.

Emmet loamy sand was selected from the Clifford Shantz farm near Fairview in Oscoda County. In this case, the seedings of alfalfa were successful insofar as the establishment of the young plants was concerned. The stand which resulted was uniform, but the crowns of alfalfa were relatively sparser than is acceptable for Michigan.

Field experiments on this farm using phosphate and potash, alone and in combination, and with magnesium or borax added, showed that neither potash or phosphate alone gave appreciable increase, but that phosphate and potash together showed response wherever applied, but especially where magnesium was supplied as well. Borax added to potash and phosphate showed a slight decrease in hay yield compared to phosphate and potash alone.

Grayling loamy sand was supplied by the Martin Goodroe farm near Sterling in Arenac County. On this soil type, poor stands were obtained upon seeding and, after established, failed to show vigorous growth or productive yields. This soil suffered from an acid condition which was remedied after the field plots were established. Consequently, the soil for the greenhouse study had the benefit of this liming treatment.

Data from the field experiments, using the same treatments as with the Shantz farm, showed marked response to phosphate and potash together and with magnesium added. Borax with the phosphate and potash resulted in considerably lower yields than the control plot.

The Allendale loamy sand and the Allendale sandy loam came from the P. J. Rood farm near Covert in Van Buren County. In the period of eighteen years preceding this experiment, only once was a successful seeding made. In every case, high germination, tested and inoculated seed was sown. The topography is slightly rolling with sufficient slope to provide adequate surface drainage for alfalfa. A favorable soil reaction varying from pH 6.3 to pH. 6.5 has been established by liming.

The problem in this case is that of establishment of the seeding. At one time, rough experimental strips were laid out by the owner using combinations of potash and phosphate fertilizers in an attempt to discover a soil amendment which would give a satisfactory seeding. In no case did the fertilizer benefit the seeding.

EXPERIMENTAL

Plan of study

The soils studied were taken from the problem areas described in the preceding section. The soils were prepared and potted for a study of the response of alfalfa to various fertilizer treatments under greenhouse conditions.

Various combinations of nitrogen, phosphorus, and potassium were compared. In addition, several combinations of minor elements including magnesium, manganese, iron, boron, and copper were used as a supplement to the basic phosphate and potash fertilizer which is currently considered most beneficial for growth of alfalfa on the more productive soil types in Michigan.

Various physical and chemical characteristics of the chosen soils were determined and their relationship to the growth of the alfalfa observed.

Results of this experiment were recorded as observations on the growth, deficiency symptoms, and yield data of the plant top growth.

Soil descriptions

Emmet (41, 43). The area of sampling lies on a gravelly phase of Emmet loamy sand. Under cultivation, the original three immediate surface layers are combined to form a light-brown loamy sand, most of which is medium or fine in texture. Beneath the plow layer, lies a layer of dark-brown or dull-yellow sand grading into the parent glacial sandy drift.

The soil is low in fertility, as compared to clay soils, but apparently has a little higher content of available magnesium and calcium than other sands of the pinelands, and possibly slightly more moisture owing to the strong development of the brown sub-surface layer. In most places the soil reaction is acid, but in some cases it is neutral or slightly alkaline in one or more layers.

The surface relief of the land is that of a plateau of smooth, long, broad, sweeping slopes with locally level to choppy and broken areas. Owing to the texture and structure of the soil and underlying drift, and to the generally sloping surface, the land is well drained and sometimes dry. The water table lies at great depth in most cases.

The soil used in the experiment showed a pH of 6.7 and an organic matter content of 2.0%. See Table 1.

Grayling (42, 43). Under cultivation this soil is grayish or very light brown in the plow layer underlain by a dull yellowish loamy sand which becomes lighter in color at a depth of 20 to 30 inches and grades downward to a substratum of coarser sand, or mixed sand and fine gravel. This series is distinguished by its loose sandy texture and pervious nature. The average moisture content is low and the fertility is correspondingly low. The land is nearly level, but it is well drained or even dry due to its open nature.

Grayling sand has little agricultural value and though there are a few small farms on this land, most cultivation attempts have been unsuccessful. Liberal use of lime, fertilizer, and manure have resulted in fair yields of some crops including alfalfa, sweet clover, and potatoes.

Acid reactions are obtained to a depth of two to three feet, but liming of this particular soil has brought the pH to 6.1. The organic content is relatively low, falling at 1.4%. See Table 1.

<u>Allendale</u> (43, 46). The surface layer consists of a yellowish fine sandy loam to loamy sand of varying depths depending on location. Below, there appears a mottled gray, yellowish, and brown sandy loam to clay which passes rather abruptly into a pale-gray and rusty brown mottled clay.

In these particular areas of sampling, the depth of the sandy overlay which is considered typical of the Allendale series is shallow and of limited distribution. As a result, the soil is mapped as the heavier Napanee, but the presence of the sandy surface layer carries the textural classification into the range of sandy loam and loamy sand in these two cases.

These soils occur on level to gently undulating or rolling plains, and the drainage is variable according to topographic location. Although the surface or plow layer is of light texture, the presence of the underlying, heavy clay layer **prevents** excessive percolation.

Allendale is considered to be productive and well adapted to the culture of both small and tree fruits and, in some cases, to general farming.

Mechanical analyses of these soils show one to be a sandy loam and the other a loamy sand, both having a pH of 6.4. The sandy loam has 2.5% organic matter and the loamy sand has 1.8% organic matter, as shown in Table 1.

<u>Sampling and preparation of soil</u>

Soils for the greenhouse experiment were taken from the plow layer of the area adjacent to the field plots located on the individual farms. The field soil was sacked, transported to a drying room, allowed to become air dry, and then was screened through a 4-mesh sieve.

Weighed amounts of each of the four soils were placed in 2-gallon, glazed earthenware pots. In order to secure equal volumes of soil for root development, different wieghts of the different textured soils were used. 9000 grams of Grayling and Emmet soils were used per pot, and 8000 grams of Allendale soils. The pots were then brought to moisture equivalent, as determined by Bouyoucos (6), with distilled water. A period of forty-eight hours was allowed for the soils to come to uniform moisture conditions before planting.

Soil treatments

Fertilizers for the different treatments were compounded in the dry salt form from analytical grade chemicals, using pure quartz sand as a filler. The 0-20-20 fertilizer, used alone and in all minor element treatments, was mixed and used throughout. Stock fertilizers for each treatment were compounded and the individual portions were weighed from the stock mixtures.

Each soil received the following sixteen treatments. Each treatment on each soil was replicated three times. This required 48 pots for each soil or a total of 192 for the four soils.

Fertilizer treatments were as follows:

1. Control, no treatment.
2. 0-20-0, 1000 lb. per acre
3. 0-20-20, 1000 lb. per acre
4. 0-0-20, 1000 lb. per acre
5. 5-20-20, 1000 lb. per acre
6. 0-20-40, 1000 lb. per acre
7. 0-20-20, 1000 lb. per acre + Mg, Mn, Fe, B, Cu
8. 0-20-20, 1000 lb. per acre + Mn, Fe, B, Cu

9. 0-20-20, 1000 lb. per acre ≠ Mg, Fe, B, Cu
10. 0-20-20, 1000 lb. per acre ≠ Mg, Mn, B, Cu
11. 0-20-20, 1000 lb. per acre ≠ Mg, Mn, Fe, Cu
12. 0-20-20, 1000 lb. per acre ≠ Mg, Mn, Fe, B
13. 0-20-20, 1000 lb. per acre ≠ Mg
14. 0-20-20, 1000 lb. per acre ≠ Mn, Fe
15. 0-20-20, 1000 lb. per acre ≠ B
16. 0-20-20, 1000 lb. per acre ≠ Cu

Minor elements were supplied at the following rates, in pounds per acre of salts as listed on page 14 (below) Mg - 200 lb. of magnesium sulfate, Mn - 100 lb. of manganous sulfate, Fe - 100 lb. of ferrous sulfate, B - 10 lb. of sodium tetraborate, and Cu - 10 lb. of cupric sulfate.

The following carrier salts were used in supplying major and minor elements:

Nitrogen	Ammonium nitrate	NH_4NO_3
Phosphorus	Monocalcium phosphate	$CaH_4(PO_4)_2.H_2O$
Potassium	Potassium chloride	KCl
Magnesium	Magnesium sulfate	$MgSO_4 . 3H_2O$
Manganese	Manganous sulfate	$Mn SO_4. 2H_2O$
Iron	Ferrous sulfate	$FeSO_4 . 7H_2O$
Boron	Sodium tetraborate	$Na_2B_4O_7$
Copper	Cupric sulfate	$CuSO_4 . 5H_2O$

The fertilizer was placed in a circular trench 1¼ inches deep and four inches in diameter and concentric with the lip of the pot. This trench was made by simply inverting a four-inch flower pot on the surface of the moist soil and rotating the flower pot while applying downward pressure.

Fertilizer computations were based on the soil surface area of the average pot.

Greenhouse technique

After the fertilizer had been applied, the pots were again brought to moisture equivalent (distilled water was used throughout this experiment) and allowed to reach equilibrium. Evaporation from the pots was kept at a minimum during this period through the use of heavy, waxed paper.

On September 15, 1948, about thirty seeds of certified Hardigan alfalfa were placed in a shallow, circular trench, six inches in diameter, similar to that used for fertilizer placement and fashioned in an identical manner using a six inch flower pot. Through this device, all the seeds in the pot occupied the same position relative to the band of fertilizer which was about one inch below and one inch to the side of the seed.

In order to insure sufficient moisture for the germination of the seed and growth of the seedlings under the prevailing conditions of bright sunlight and high temperature, the evaporation rate was reduced by keeping the germinating seeds covered with a somewhat translucent, heavily-waxed paper.

Moisture was maintained as near moisture equivalent as possible throughout the early growth of the plants. Random selections of pots were made from each soil and from various treatments within these soils. These were weighed before each watering and the moisture loss determined. The average of these weighings for each soil was taken as indicative of the water required. This procedure was followed until the plants reached a weight which made the process inaccurate. By this time the plants had reached a stage of root development in which they were able to utilize more of the moisture in the pot. From this point, distilled water was supplied as the need was apparent.

From time to time, the position of the movable benches was changed to minimize the influence of variations in temperature and sunlight. During the short day period of the winter months, the cloudy weather obscured the sun for a number of days. Correspondingly, the growth of the alfalfa plants was excessively vegetative and the development of the plants was slow. At the age of sixteen weeks, no blossoms had appeared, so in order to bring the plants to blossom, they were placed under a bank of fluorescent lights and the photoperiod increased to fourteen hours. The first blossoms began to form eleven days later.

At twenty and one half weeks the plants, in about one tenth bloom, were harvested two inches above the crown.

The second cutting was made five weeks after the first and the third cutting followed five weeks after the second.

In harvesting, the top growth of the plant was cut at the level of the top of the pot which was about two inches above the crown. The green plant material was placed in paper bags and dried at 150-160 degrees Farenheit for seventy-two hours. The dried samples were weighed.

Samples for green tissue testing of the third cutting were taken, weighed green, placed in moisture-proof cellophane bags, and stapled closed. Outdoor temperatures at the time of cutting were suitable for refrigeration and the samples remained in excellent condition until tissue tests were made. The remaining top growth was cut, weighed and dried, and weighed again to determine percent moisture from which the total dry matter was computed.

Of the soil treatments where only nitrogen, phosphorus, and potassium were used, each replicate was sampled and tested individually, but where minor elements were added, samples from three pots were composited and tested as a unit.

Green tissue tests were made according to the method of Cook and others (14) using reagents from the Simplex soil testing kit of Spurway (39).

During the course of the development of the alfalfa plants prior to the first cutting, considerable difficulty was experienced with red spider. This pest was controlled through use of 15% parathion dry powder in distilled water. Spraying caused injury to the young, actively growing portions of the plants which may have masked some deficiency symptoms. Later, it was discovered that spraying immediately following harvest would control the red spider until the next harvest, without serious injury to the plants.

OBSERVATIONS DURING GROWTH

Throughout the growth of the alfalfa, from planting until time for the first harvest, no conspicuous differences appeared. The control plants were apparently the same as those on the treated soils.

Initially, those plants which received 0-20-40 showed poor germination and stunted growth. The barren spaces were replanted ten days after the original planting. At four weeks all pots were thinned to fifteen plants. When the plants were six weeks old, the stand was reduced to ten plants per pot. This was the final thinning.

At the time of the first harvest, no deficiency symptoms had appeared; foliage was normal, dark green, and vigorous. Plants on Emmet loamy sand seemed slightly delayed in maturity as evidenced by the lack of blossoms on many pots.

After the first cutting, the recovery growth of those plants receiving only phosphorus showed definite retardation when compared to those which had been treated with 0-20-20. In addition, the lower leaves showed a row of small white spots roughly parallel to the leaf margin. Later, a marginal yellowing of the leaflets appeared. This phenomenon showed only on those plants growing on Allendale sandy loam and Grayling loamy sand. As the plants progressed, the differences in growth grew less and less distinct, but were still noticeable at the time of harvest.

About two weeks prior to the second harvest, at the time when the first blossoms were appearing, many of the plants growing on Grayling loamy sand began to exhibit a yellowing of the terminal growth, rosetting, and dying back of the terminal bud. These symptoms coincide with those described by Colwell and Lincoln (12) and by Cook (13) as caused by deficiency of boron. These indications appeared only on those treatments which had received at least some potash and no boron. The fact that these symptoms did not show on those pots which had received neither boron nor potassium suggests that potassium was the first limiting factor. While these symptoms did not occur in every replication of every treatment having no boron, they did appear in 79 percent of the replications. In no case did they appear where boron had been applied.

Previous to the second harvest, potassium deficiency symptoms had appeared on the control plants and those where the treatment had included phosphorus alone on all soils except the Allendale loamy sand. The height of the plants ~~were~~ was noticeably less than that of those which received both phosphorus and potassium.

Those treatments having phosphorus, potassium, magnesium, manganese, iron and boron but no copper resulted in shorter growth than did other minor element treatments on Grayling loamy sand and on Allendale sandy loam. The plants on these pots were otherwise normal.

Following the second cutting, conspicuous differences in growth began to appear. These were most apparent where either phosphate or potash or both had been omitted.

Grayling loamy sand

Definite potassium deficiency showed both on the control plants and on those where phosphorus alone had been supplied. That phosphorus alone was not sufficient as a fertilizer is shown by Plate 1. Marginal yellowing began to show on the lower leaves of even the 0-20-20 treated plants. Potassium alone caused reduced growth but the plants were of normal color as were the plants of the remaining treatments. The plants seemed to be restricted in growth where copper was omitted (treatment 12) and where boron was added without the other minor elements (treatment 15). See Plates 2 and 3.

The yellowing and rosetting of the terminal growth which had been conspicuous just previous to the second cutting failed to appear before the third cutting except where 5-20-20 had been applied and where copper had been used in addition to 0-20-20 (treatment 16). No differences were apparent as a result of the other minor element treatments.

Emmet loamy sand

Except that potassium deficiency symptoms appeared, the plants grown on this soil were much the same as those on the Grayling loamy sand. Noticeably reduced growth occurred where both potassium and phosphorus or either element singly were omitted from the fertilizers. The control plants were definitely of shorter growth than any except those grown where the treatment included only potassium or only phosphorus. These differences in growth are shown in Plates 4 and 5. All plants were a normal healthy green color.

Allendale loamy sand

On this soil, conspicuous suppression of growth occurred only where one or the other, or both of the principal nutrients (phosphorus or potassium) were lacking. Other plants appeared normal and vigorous.

Allendale sandy loam

In the heavier Allendale soil, the differences which resulted from the treatments were less noticeable but were of the same nature as those which occured on the loamy sand, with one exception. Where copper was omitted (treatment 12) the plants were smaller than those where it was included with 0-20-20 and all the other secondary elements (treatment 7). This is indicated by the cultures shown in Plate 6.

RESULTS AND DISCUSSION

Emmet loamy sand

Evidently the supply of potassium in this soil was sufficient to produce a healthy first cutting, but in subsequent cuttings the potassium supplied to the plants progressively decreased. As shown in Figure 1 and Table 2, phosphorus alone produced growth equal to phosphorus plus potassium, but potassium alone caused reduced growth. In the second and third cuttings, as shown in Tables 3 and 4, neither phosphorus nor potassium alone supported a growth of plants comparable to that induced by the 0-20-20 treatment.

All treat~~ø~~ments which included minor elements caused significantly greater yields than did 0-20-20 alone in the third cutting. See Table 4. Among the minor elements, there appears to be no single nutrient which consistently accounts for the benefits drived from the mixture. It would appear that those treatments which, in addition to 0-20-20, included magnesium or at least four of the minor elements resulted in greater yields than did those receiving no magnesium or less than four of the minor elements. This effect showed in both the second and third cuttings, but was obscured in the totals (Table 5). Progressively increasing benefit due to nitrogen (treatment 5) shows in Figure 1 and Tables 3, 4 and 5.

Some depression of growth appears to result from the addition of boron to phosphorus and potassium (treatment 15). In both the second and third harvests, the yield from this treatment was significantly less than from phosphorus and potassium alone and was not different from the control, as is shown in the curve for the total of the first two cuttings, Figure 1.

A study of Tables 2, 3, 4, and 5 shows how the response to fertilizer on this soil increased with each successive cutting. In the first cutting, phosphorus and potash fertilizer did not, in any combination, significantly increase yields, but when extra elements were added, the increases in yield became significant. In the second cutting, phosphorus and potash combinations did increase yields and the effect of nitrogen began to show up. Still further increases in yield resulted from the minor elements. At the third cutting all fertilizer treatments resulted in yields which were significantly larger than those from the unfertilized pots. Furthermore, all cultures treated with minor elements yielded significantly more than did those treated only with 0-20-20 fertilizer. This accumulative effect even resulted in the 5-20-20 treated plants (treatment 5) yielding enough more than those which received 0-20-20 that the difference was significant for the three cuttings. This is shown in Table 5.

Green tissue tests, reported in Table 18, showed that in all cases but one where potassium had been applied, the potassium in the plant was medium, high, or very high at the time of the third cutting. The exception was where 0-20-20 plus copper was used. It appears, then, that potassium is not likely to be a limiting element when applied at rates equal to 1000 pounds of 0-0-20 per acre. Tissue tests for phosphorus showed medium or high phosphorus where phosphorus had been applied in all but two cases; one, where all minor elements except magnesium were applied (treatment

8), and the other, where only boron was added to the 0-20-20 (treatment 15).

Grayling loamy sand

There were no significant differences in the results from the first cutting (Table 6). As shown by the second cutting results presented in Figure 2 and Table 7, all treatments which included the 0-20-20 fertilizer resulted in yields which were significantly greater than those obtained from the control cultures. The yields obtained where minor elements were applied were all about the same and were not significantly greater than those obtained where only 0-20-20 was applied. See Table 7. Only where 0-20-40 was applied was there a significant increase in yield over that obtained where the fertilizer was 0-20-20. The total yields showed that 0-20-20 plus boron was the only treatment including both phosphorus and potassium which failed to cause a significant increase over the control. See Table 9.

Again on this soil, it is interesting that in the first crop there were no signficiant differences in yield caused by treatment, but on the second and third crops, all treatments which included both phosphorus and potash caused significant increases in yield. It is noteworthy that in the total for the three cuttings (Table 9) potash alone was no different than the control and gave significantly less yield than did the 0-20-20 treatment. This had not shown on the individual cuttings. See Tables 6, 7, and 8.

Allendale loamy sand

The treatments did not cause significant differences in the yields of the first and second cuttings of alfalfa on this soil. All treatments receiving potassium caused highly significantly greater increases in yields, as compared to the control yields, on the third cutting, as shown by the curve for the third cutting in Figure 3 and the data in Table 12. No differences in yields resulted from the application of minor elements. The treatments did not cause significant differences in total yield (Table 13).

Potassium appears as the first limiting element among those used in this experiment on the Allendale loamy sand. Indications are that potassium alone was equal to potassium plus phosphorus at least for the first three cuttings.

The data presented in Tables 10, 11, and 12 show the delayed response to potassium. Not until the third cutting did this effect show up.

Allendale sandy loam

On this soil, the fertilizer treatments did not affect the yields of alfalfa until the third cutting, at which time all cultures which had received potassium yielded significantly more than did the controls. Those which received both phosphorus and potassium yielded highly significantly greater than the controls. The minor element treatment including all but iron (treatment 10) resulted in yields which were significantly greater than those obtained from pots treated only with 0-20-20, while that having copper omitted (treatment 12) significantly reduced the yields. Plants which received only 0-20-20 plus magnesium (treatment 13) or 0-20-20 plus copper (treatment 16) were significantly suppressed in growth. See Figure 4.

This soil seemed almost identical to the Allendale loamy sand so far as response to fertilizer was concerned. Not until the third cutting, as shown in Tables 14, 15, and 16, did significant differences in yield show up as a result of the fertilizer treatments. Then, all fertilized alfalfa yielded more than did that not fertilized. These differences do not show in the total of the three cuttings. See Table 17. Again it is very likely that subsequent crops of alfalfa on this soil may show benefit from some elements other than phosphorus and potassium.

SUMMARY AND CONCLUSIONS

From four fields in areas where alfalfa production is a problem, sandy soils were selected for a greenhouse study to determine the effect of several combinations of nutrient elements on the growth of alfalfa. Fifteen treatments and the control were set up, each treatment on each soil consisting of three replicate pots. Each 2-gallon pot supported ten alfalfa plants which were harvested three times when in one-tenth bloom. Chemical and physical properties of the soils were determined, green tissue tests were made of the top growth, and the yield of top growth was measured as dry matter. Growth and development were observed and noted as were any abnormalities such as deficiency symptoms. Yield data for each cutting on each soil was statistically analyzed as a randomized block.

The incidence of significant differences increased with each successive cutting.

Results of this work agree with those of other workers on the need for large quantities of phosphorus and potassium. In each soil, the greatest differences in yield were due to the influence of potassium and phosphorus.

Results with Emmet loamy sand indicated that there was a limitation due to lack of nitrogen as shown by the increasing response to nitrogen with successive cuttings. There was also a marked response to minor elements and magnesium on this soil. The response to these elements increased from cutting to cutting. It was impossible to pick out any individual element which was entirely responsible for the increase in yield which resulted from elements other than phosphorus and potassium.

On Emmet loamy sand and on Grayling loamy sand there was some reduction in growth where boron was applied with phosphorus and potassium without the other minor elements.

On Grayling loamy sand and Allendale sandy loam yields of alfalfa were depressed where copper was omitted but all other minor elements were added.

Boron deficiency symptoms appeared on plants grown in Grayling loam sand in the second crop but failed to show on the subsequent recovery growth. Possibly growth was limited by some other nutrient deficiency in the third crop to the extent that there was sufficient boron in the soil for the crop produced.

On all soils, the need for phosphorus and potassium became more noticeable in the second and third crops than in the first. On the Emmet soil this same thing was true with respect to the minor elements and magnesium. It was suggested that on the other soils, the Grayling and the two Allendale soils, subsequent crops may show a need for elements other than for phosphorus and potassium. That possibility is being studied but time does not permit the results to be included in this report.

The work reported in this thesis is intended as preliminary to field investigations. It is the thought of the author that these data do indicate places where minor elements may be lacking or may be present in injurious quantities, but that further investigation is required for conclusive evidence of the effect of these deficiencies or toxicities under field conditions.

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APPENDIX

Plate 1. Third crop of alfalfa on Grayling loamy sand.

1. No treatment
2. 0-20-0
3. 0-20-20 + Mg, Mn, Fe, B, Cu
4. 0-20-20 + B

Plate 2. Third crop of alfalfa on Grayling loamy sand.

1. 0-20-20 + Mg, Mn, Fe, B, Cu
2. 0-20-20 + Mg, Mn, Fe, B
3. 0-20-20 + Cu

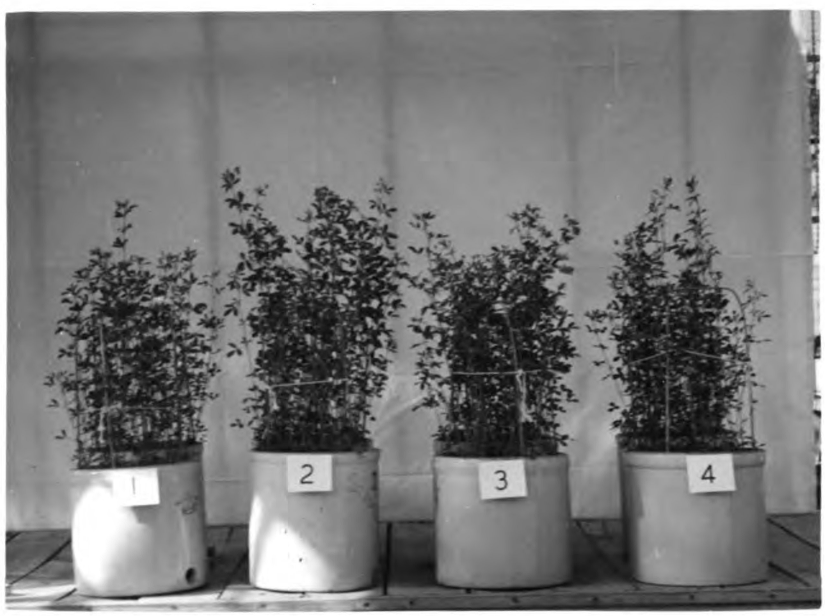

Plate 3. Third crop of alfalfa on
Grayling loamy sand.

1. No treatment
2. 0-20-20
3. 0-20-20 ≠ Mg, Mn, Fe, B, Cu
4. 0-20-20 ≠ B

Plate 4. Third Crop of alfalfa on Emmet loamy sand.

1. No treatment
2. 0-20-0
3. 0-20-20
4. 0-0-20

Plate 5. Third crop of alfalfa on
Emmet loamy sand.

1. No treatment
2. 0-20-20
3. 0-20-20 + Mg, Mn, Fe, B, Cu
4. 0-20-20 + B

Plate 6. Third crop of alfalfa on Allendale sandy loam.

1. No treatment
2. 0-20-20
3. 0-20-20 + Mg, Mn, Fe, B, Cu
4. 0-20-20 + Mg, Mn, Fe, B

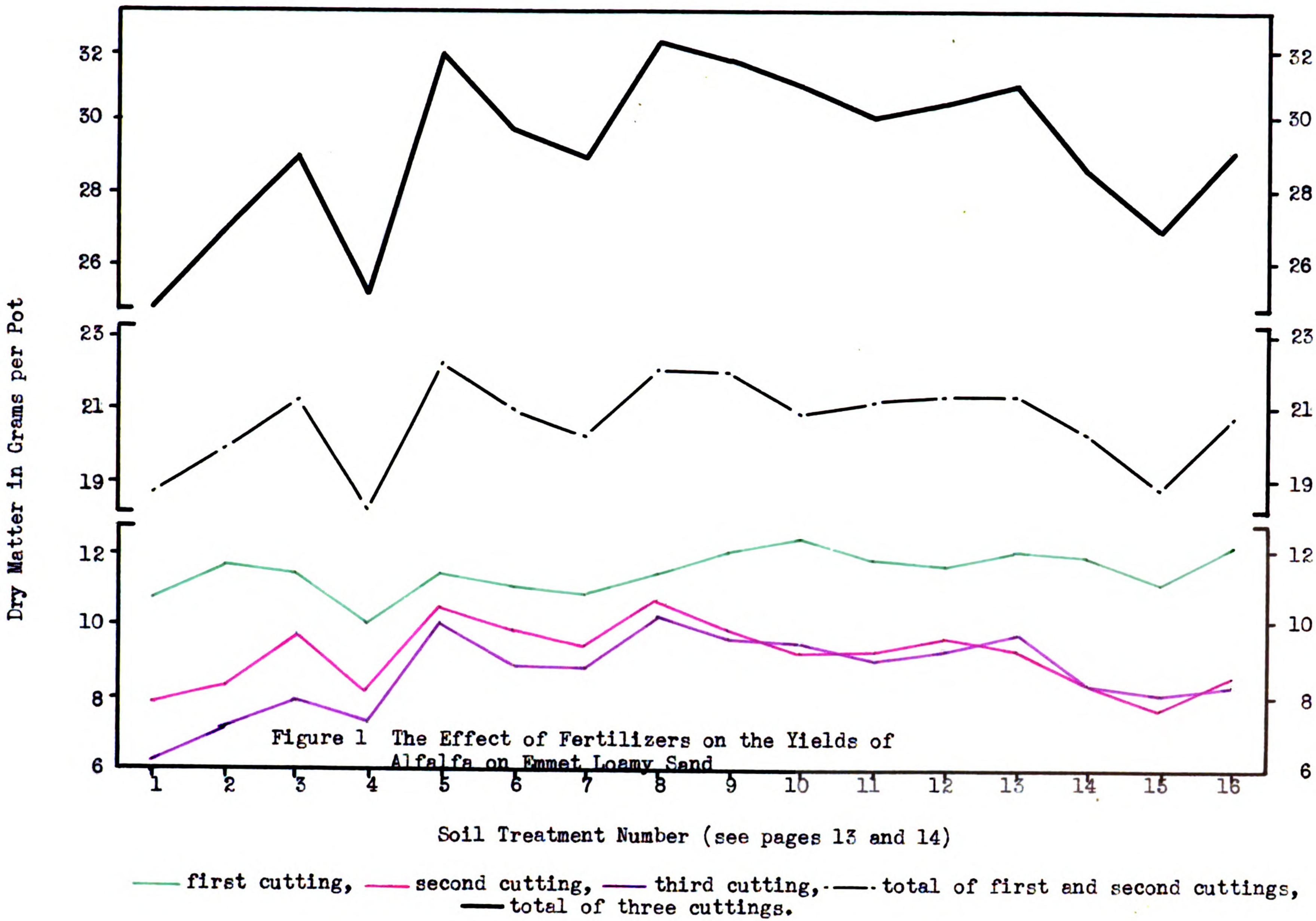

Figure 1 The Effect of Fertilizers on the Yields of Alfalfa on Emmet Loamy Sand

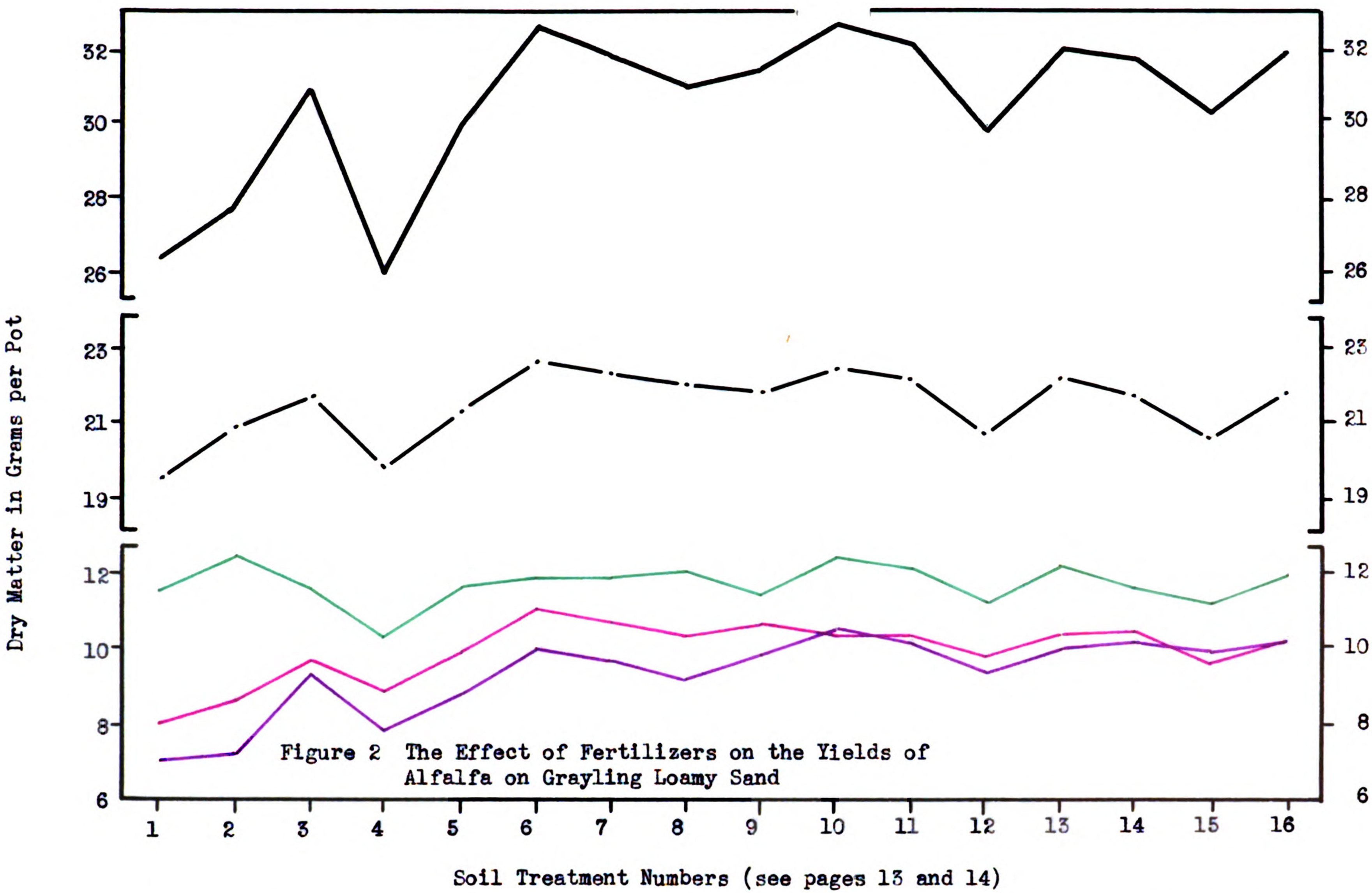

Figure 2 The Effect of Fertilizers on the Yields of Alfalfa on Grayling Loamy Sand

first cutting, second cutting, third cutting, total of first and second cuttings, total of three cuttings.

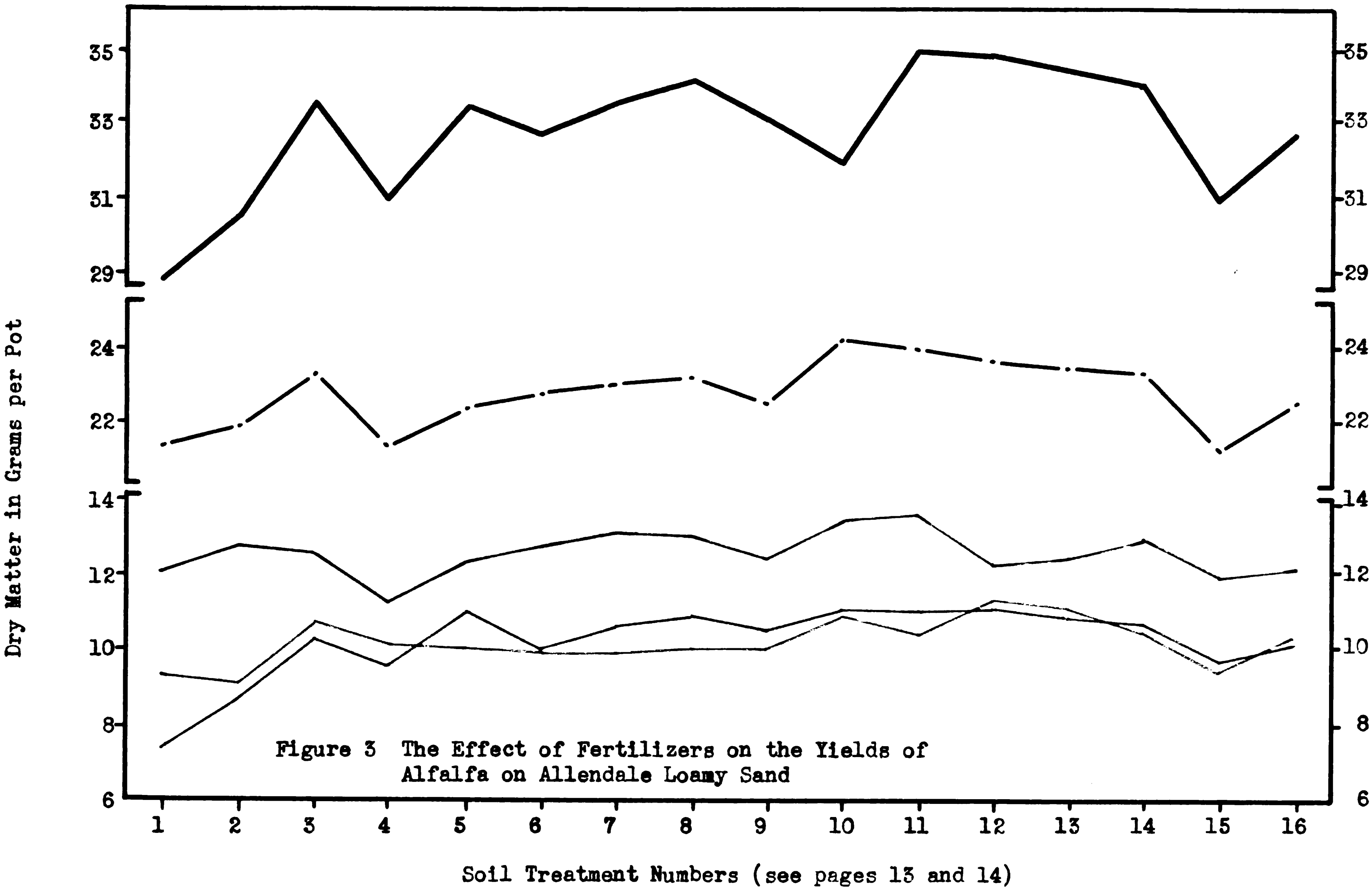

Figure 3 The Effect of Fertilizers on the Yields of Alfalfa on Allendale Loamy Sand

—— first cutting, —— second cutting, —— third cutting, ·—·total of first and second cuttings, ▬▬ total of three cuttings.

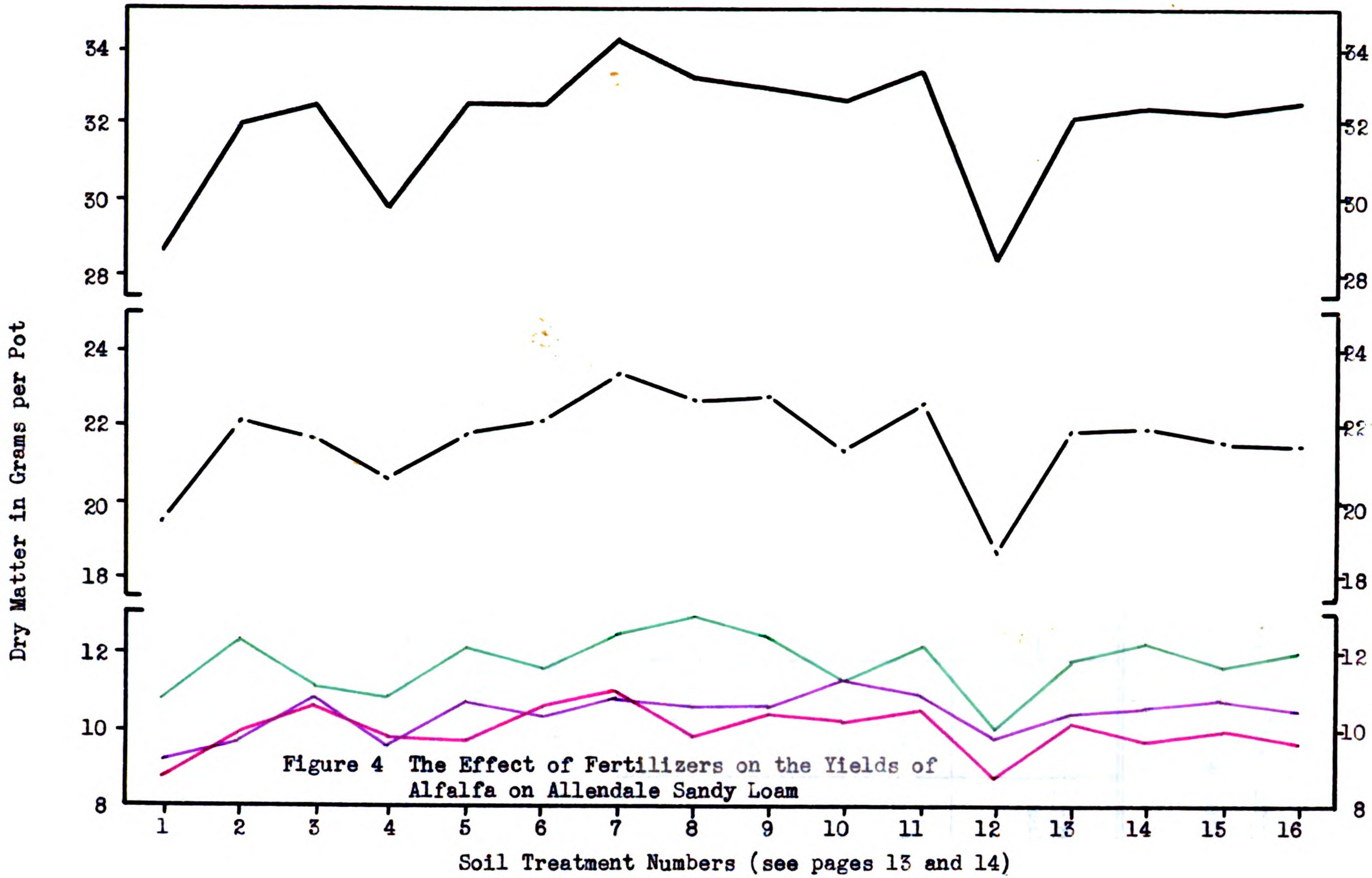

Figure 4 The Effect of Fertilizers on the Yields of Alfalfa on Allendale Sandy Loam

first cutting, second cutting, third cutting, total of first and second cuttings, total of three cuttings.

Table 1. Chemical and physical properties of Grayling, Emmet and Allendale loamy sands and of Allendale sandy loam.

Soil	Mechanical analysis			pH	% organic matter
	% sand	% silt	% clay		
Emmet loamy sand	81.0	13.0	6.0	6.62	2.0
Grayling loamy sand	89.5	5.7	4.8	6.05	1.4
Allendale loamy sand	86.7	6.8	6.5	6.42	1.8
Allendale sandy loam	67.5	16.7	15.8	6.36	2.5

Mechanical analyses were made according to the hydrometer method of Bouyoucos (7).

pH determinations were made with the Beckman glass electrode.

Organic matter was determined by the wet combustion method with modification for photoelectric colorimeter.

Table 2. Emmet loamy sand. First cutting yield of alfalfa top growth.

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	10.80	0.00	-6.09
2. 0-20-0	11.66	7.96	1.39
3. 0-20-20	11.50	6.48	0.00
4. 0-0-20	10.07	-6.76	-12.44*
5. 5-20-20	11.46	6.11	-0.35
6. 0-20-40	11.06	2.41	-3.83
7. 0-20-20 + Mg, Mn, Fe, B, Cu	10.90	0.92	-5.22
8. 0-20-20 + Mn, Fe, B, Cu	11.50	6.48	0.00
9. 0-20-20 + Mg, Fe, B, Cu	12.16	12.59*	5.74
10. 0-20-20 + Mg, Mn, B, Cu	12.23	13.24*	6.35
11. 0-20-20 + Mg, Mn, Fe, Cu	11.90	10.17*	3.48
12. 0-20-20 + Mg, Mn, Fe, B	11.73	8.61	2.00
13. 0-20-20 + Mg	12.03	11.39*	4.61
14. 0-20-20 + Mn, Fe	11.96	10.74*	4.00
15. 0-20-20 + B	11.23	3.98*	-2.35
16. 0-20-20 + Cu	12.23	13.24*	6.35

1 Fertilizer rates and carriers are described on pages 13-14.

* Significant at the 5% level.

Table 3. Emmet loamy sand. Second cutting yield of alfalfa top growth

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	7.90	0.00	-19.39-**
2. 0-20-0	8.30	5.06	-15.31-**
3. 0-20-20	9.80	24.05**	0.00
4. 0-0-20	8.20	3.80	-16.32-**
5. 5-20-20	10.53	33.29**	7.44
6. 0-20-40	9.96	26.08**	1.63
7. 0-20-20 + Mg, Mn, Fe, B, Cu	9.43	19.36**	-3.78
8. 0-20-20 + Mn, Fe, B, Cu	10.66	34.93**	8.77
9. 0-20-20 + Mg, Fe, B, Cu	9.93	25.78**	1.33
10. 0-20-20 + Mg, Mn, B, Cu	9.30	17.72**	-5.10
11. 0-20-20 + Mg, Mn, Fe, Cu	9.30	17.72**	-5.10
12. 0-20-20 + Mg, Mn, Fe, B	9.66	22.28**	-1.43
13. 0-20-20 + Mg	9.36	18.48**	-4.49
14. 0-20-20 + Mn, Fe	8.40	6.33	-14.29-**
15. 0-20-20 + B	7.66	-3.04	-21.84-**
16. 0.20-20 + Cu	8.60	8.86	-12.24-*

1 Fertilizer rates and carriers are described on page 13-14.

* Significant at the 5% level.

** Significant at the 1% level.

Table 4. Emmet loamy sand. Third cutting yield of alfalfa top growth.

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	6.20	0.00	-21.52**
2. 0-20-0	7.16	15.48*	-9.37
3. 0-20-20	7.90	27.42**	0.00
4. 0-0-20	7.33	18.23**	-7.22
5. 5-20-20	10.10	62.90**	27.84**
6. 0-20-40	8.93	44.03**	13.04*
7. 0-20-20 + Mg, Mn, Fe, B, Cu	8.86	42.90**	12.15*
8. 0-20-20 + Mn, Fe, B, Cu	10.27	65.54**	30.00**
9. 0-20-20 + Mg, Fe, B, Cu	9.73	56.94**	23.17**
10. 0-20-20 + Mg, Mn, B, Cu	9.56	54.19**	21.01**
11. 0-20-20 + Mg, Mn, Fe, Cu	9.03	45.65**	14.03**
12. 0-20-20 + Mg, Mn, Fe, B	9.31	50.16**	17.85**
13. 0-20-20 + Mg	9.80	58.06**	24.05**
14. 0-20-20 + Mn, Fe	8.43	35.91**	6.70*
15. 0-20-20 + B	8.13	31.13**	2.91*
16. 0-20-20 + Cu	8.46	37.45**	7.09*

1 Fertilizer rates and carriers are described on page 13-14.

* Significant at the 5% level.

** Significant at the 1% level.

Table 5. Emmet loamy sand. Total yield of alfalfa top growth, three cuttings.

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	24.90	0.00	-14.72-**
2. 0-20-0	27.13	8.96*	-7.09
3. 0-20-20	29.20	17.27*	0.00
4. 0-0-20	25.26	1.45	-13.49-**
5. 5-20-20	32.10	28.92**	9.93*
6. 0-20-40	29.96	20.32**	2.60
7. 0-20-20 ≠ Mg, Mn, Fe, B, Cu	29.20	17.27**	0.00
8. 0-20-20 ≠ Mn, Fe, B, Cu	32.43	30.24**	11.06**
9. 0-20-20 ≠ Mg, Fe, B, Cu	31.83	27.83**	9.01*
10. 0-20-20 ≠ Mg, Mn, B, Cu	31.16	25.14**	6.71
11. 0-20-20 ≠ Mg, Mn, Fe, Cu	30.26	21.53**	3.63
12. 0-20-20 ≠ Mg, Mn, Fe, B	30.70	23.29**	5.14
13. 0-20-20 ≠ Mg	31.20	25.30**	6.85
14. 0-20-20 ≠ Mn, Fe	28.80	15.66**	-1.37
15. 0-20-20 ≠ B	27.03	8.56	-7.44
16. 0-20-20 ≠ Cu	29.30	16.59**	-0.58

1. Fertilizer rates and carriers are described on page 13-14.

* Significant at the 5% level.

** Significant at the 1% level.

Table 6. Grayling loamy sand. First cutting yield of alfalfa top growth.

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	11.50	0.00	1.15
2. 0-20-0	12.40	7.83	9.07
3. 0-20-20	11.46	-0.35	0.00
4. 0-0-20	10.20	-11.30	-10.39
5. 5-20-20	11.56	0.52	1.68
6. 0-20-40	11.80	2.61	3.79
7. 0-20-20 ≠ Mg, Mn, Fe, B, Cu	11.80	2.61	3.79
8. 0-20-20 ≠ Mn, Fe, B, Cu	11.93	3.74	4.93
9. 0-20-20 ≠ Mg, Fe, B, Cu	11.30	-1.74	-0.61
10. 0-20-20 ≠ Mg, Mn, B, Cu	12.33	7.22	8.45
11. 0-20-20 ≠ Mg, Mn, Fe, Cu	12.03	4.61	5.81
12. 0-20-20 ≠ Mg, Mn, Fe, B	11.13	-3.22	-2.10
13. 0-20-20 ≠ Mg	12.10	5.22	6.43
14. 0-20-20 ≠ Mn, Fe	11.53	0.26	1.42
15. 0-20-20 ≠ B	11.03	-4.09	- 2.98
16. 0-20-20 ≠ Cu	11.90	3.48	4.67

1 Fertilizer rates and carriers are described on page 13-14.

Table 7. Grayling loamy sand. Second cutting yield of alfalfa top growth.

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	7.93	0.00	-17.14-**
2. 0-20-0	8.47	6.80	-11.50-**
3. 0-20-20	9.57	20.68**	0.00
4. 0-0-20	8.76	10.46**	1.98
5. 5-20-20	9.80	23.58**	2.40
6. 0-20-40	10.96	38.20**	14.52*
7. 0-20-20 + Mg, Mn, Fe, B, Cu	10.63	34.04**	11.07
8. 0-20-20 + Mn, Fe, B, Cu	10.20	28.62**	6.58
9. 0-20-20 + Mg, Fe, B, Cu	10.56	33.16**	10.34
10. 0-20-20 + Mg, Mn, B, Cu	10.23	29.00**	6.89
11. 0-20-20 + Mg, Mn, Fe, Cu	10.20	28.62**	6.58
12. 0-20-20 + Mg, Mn, Fe, B	9.66	21.81**	0.94
13. 0-20-20 + Mg	10.23	29.00**	6.89
14. 0-20-20 + Mn, Fe	10.30	29.88**	7.62
15. 0-20-20 + B	9.66	21.81**	0.94
16. 0-20-20 + Cu	10.06	26.86**	5.12

1 Fertilizer rates and carriers are described on page 13-14.

* Significant at the 5% level.

** Significant at the 1% level.

Table 8. Grayling loamy sand. Third cutting yield of alfalfa top growth.

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	6.93	0.00	-25.48-**
2. 0-20-0	7.06	1.87	-24.08-**
3. 0-20-20	9.30	34.19**	0.00
4. 0-0-20	7.77	12.12	-16.45
5. 5-20-20	8.70	25.54**	-6.45
6. 0-20-40	9.93	43.28**	6.77
7. 0-20-20 + Mg, Mn, Fe, B, Cu	9.60	38.52**	3.23
8. 0-20-20 + Mn, Fe, B, Cu	9.07	30.88**	-2.47
9. 0-20-20 + Mg, Fe, B, Cu	9.77	40.98**	5.06
10. 0-20-20 + Mg, Mn, B, Cu	10.40	50.07**	11.83
11. 0-20-20 + Mg, Mn, Fe, Cu	10.03	44.73**	7.85
12. 0-20-20 - Mg, Mn, Fe, B	9.27	33.77**	-0.32
13. 0-20-20 + Mg	9.87	42.42**	6.13
14. 0-20-20 + Mn, Fe	10.03	44.73**	7.85
15. 0-20-20 + B	9.80	41.41**	5.38
16. 0-20-20 + Cu	10.17	46.75**	9.36

1 Fertilizer rates and carriers are described on page 13-14.

* Significant at the 5% level.

** Significant at the 1% level.

Table 9. Grayling loamy sand. Total yields of alfalfa top growth, three cuttings.

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	26.43	0.00	-14.74-**
2. 0-20-0	27.93	5.68	-9.90
3. 0-20-20	31.00	17.29**	0.00
4. 0-0-20	26.07	-1.36	-15.90-**
5. 5-20-20	30.07	13.88*	-3.00
6. 0-20-40	32.70	23.92**	5.48
7. 0-20-20 + Mg, Mn, Fe, B, Cu	32.00	21.09**	3.23
8. 0-20-20 + Mn, Fe, B, Cu	31.20	18.05**	0.64
9. 0-20-20 + Mg, Fe, B, Cu	31.63	19.68**	2.03
10. 0-20-20 + Mg, Mn, B, Cu	32.90	24.48**	6.13
11. 0-20-20 + Mg, Mn, Fe, Cu	32.27	22.10**	4.10
12. 0-20-20 + Mg, Mn, Fe, B	30.00	13.51*	-3.23
13. 0-20-20 + Mg	32.20	21.83**	3.87
14. 0-20-20 + Mn, Fe	31.97	20.96**	3.13
15. 0-20-20 + B	30.50	15.40*	1.63
16. 0-20-20 + Cu	32.13	21.56**	3.64

1 Fertilizer rates and carriers are described on page 13-14.

* Significant at the 5% level.

** Significant at the 1% level.

Table 10. Allendale loamy sand. First cutting yield of alfalfa top growth.

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	12.17	0.00	-3.41
2. 0-20-0	12.83	5.42	1.96
3. 0-20-20	12.60	3.53	0.00
4. 0-0-20	11.27	-7.40	-10.56
5. 5-20-20	12.36	1.56	-1.90
6. 0-20-40	12.80	5.18	1.59
7. 0-20-20 ≁ Mg, Mn, Fe, B, Cu	13.03	7.06	3.41
8. 0-20-20 ≁ Mn, Fe, B, Cu	13.13	7.89	4.21
9. 0-20-20 ≁ Mg, Fe, B, Cu	12.50	2.71	-0.79
10. 0-20-20 ≁ Mg, Mn, B, Cu	13.50	10.93	7.14
11. 0-20-20 ≁ Mg, Mn, Fe, Cu	13.63	12.00	8.17
12. 0-20-20 ≁ Mg, Mn, Fe, B	12.43	2.14	-1.35
13. 0-20-20 ≁ Mg	12.50	2.71	-0.79
14. 0-20-20 ≁ Mn, Fe	12.96	6.49	2.86
15. 0-20-20 ≁ B	12.00	-1.40	-4.77
16. 0-20-20 ≁ Cu	12.23	0.49	-2.94

1 Fertilizer rates and carriers are described on page 13-14.

Table 11. Allendale loamy sand. Second cutting yield of alfalfa top growth.

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	9.37	0.00	-13.24
2. 0-20-0	9.13	-2.57	-15.40
3. 0-20-20	10.80	15.25	0.00
4. 0-0-20	10.23	9.17	-5.28
5. 5-20-20	10.10	7.79	-6.48
6. 0-20-40	10.03	7.04	-7.13
7. 0-20-20 ≁ Mg, Mn, Fe, B, Cu	9.96	6.29	-7.78
8. 0-20-20 ≁ Mn, Fe, B, Cu	10.16	8.43	-5.93
9. 0-20-20 ≁ Mg, Fe, B, Cu	10.06	7.36	-6.85
10. 0-20-20 ≁ Mg, Mn, B, Cu	10.90	16.32	0.93
11. 0-20-20 ≁ Mg, Mn, Fe, Cu	10.43	11.31	-3.43
12. 0-20-20 ≁ Mg, Mn, Fe, B	11.36	21.23	5.19
13. 0-20-20 ≁ Mg	11.10	18.46	2.78
14. 0-20-20 ≁ Mn, Fe	10.53	12.38	-2.50
15. 0-20-20 ≁ B	9.43	0.63	-12.69
16. 0-20-20 - Cu	10.36	10.56	-4.07

1 Fertlizer rates and carriers are described on page 13-14.

Table 12. Allendale loamy sand. Third cutting yield of alfalfa top growth.

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	7.40	0.00	-28.37-**
2. 0-20-0	8.67	17.16	-16.10
3. 0-20-20	10.33	39.59**	0.00
4. 0-0-20	9.60	29.73**	-7.07
5. 5-20-20	11.13	50.41**	9.38
6. 0-20-40	10.07	36.09**	-2.52
7. 0-20-20 ≁ Mg, Mn, Fe, B, Cu	10.67	44.19**	3.29
8. 0-20-20 ≁ Mn, Fe, B, Cu	10.97	48.25**	6.20
9. 0-20-20 ≁ Mg, Fe, B, Cu	10.57	42.84**	2.32
10. 0-20-20 ≁ Mg, Mn, B, Cu	11.10	50.00**	7.45
11. 0-20-20 ≁ Mg, Mn, Fe, Cu	11.07	49.60**	7.16
12. 0-20-20 ≁ Mg, Mn, Fe, B	11.20	51.36**	8.42
13. 0-20-20 ≁ Mg	10.97	48.25**	6.20
14. 0-20-20 ≁ Mn, Fe	10.70	44.60**	3.58
15. 0-20-20 ≁ B	9.70	31.09**	-6.10
16. 0-20-20 ≁ Cu	10.27	38.79**	-0.58

1 Fertilizer rates and carriers are described on page 13-14.

* Significant at the 5% level.

** Significant at the 1% level.

Table 13. Allendale loamy sand. Total yield of alfalfa top growth, three cuttings.

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	28.93	0.00	-14.24
2. 0-20-0	30.63	5.87	-9.20
3. 0-20-20	33.73	16.59	0.00
4. 0-0-20	31.10	7.50	-7.80
5. 5-20-20	33.60	16.14	-0.39
6. 0-20-40	32.90	13.72	-2.47
7. 0-20-20 + Mg, Mn, Fe, B, Cu	33.73	16.59	0.00
8. 0-20-20 + Mn, Fe, B, Cu	34.26	18.42	1.57
9. 0-20-20 + Mg, Fe, B, Cu	33.20	14.75	-1.57
10. 0-20-20 + Mg, Mn, B, Cu	32.06	10.81	-4.95
11. 0-20-20 + Mg, Mn, Fe, Cu	35.13	21.43	4.15
12. 0-20-20 + Mg, Mn, Fe, B	34.96	20.84	3.65
13. 0-20-20 + Mg	34.56	19.46	2.46
14. 0-20-20 + Mn, Fe	34.20	18.21	1.39
15. 0-20-20 + B	31.13	7.60	-7.71
16. 0-20-20 + Cu	32.86	13.58	-2.58

1 Fertilizer rates and carriers are described on pages 13-14.

Table 14. Allendale sandy loam. First cutting yield of alfalfa top growth.

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	10.80	0.00	-2.56
2. 0-20-0	12.40	14.81	12.10
3. 0-20-20	11.06	2.40	0.00
4. 0-0-20	10.87	0.65	-1.72
5. 5-20-20	12.13	12.31	9.67
6. 0-20-40	11.63	7.68	5.15
7. 0-20-20 ≁ Mg, Mn, Fe, B, Cu	12.50	15.74	13.02
8. 0-20-20 ≁ Mn, Fe, B, Cu	12.96	12.00	17.18
9. 0-20-20 ≁ Mg, Fe, B, Cu	12.43	15.09	12.39
10. 0-20-20 ≁ Mg, Mn, B, Cu	11.26	4.26	1.81
11. 0-20-20 ≁ Mg, Mn, Fe, Cu	12.20	12.96	10.31
12. 0-20-20 ≁ Mg, Mn, Fe, B	9.96	-7.78	-9.95
13. 0-20-20 ≁ Mg	11.83	9.54	6.96
14. 0-20-20 ≁ Mn, Fe	12.30	13.89	11.21
15. 0-20-20 ≁ B	11.63	7.68	5.15
16. 0-20-20 ≁ Cu	12.00	11.11	8.50

1 Fertilizer rates and carriers are described on page 13-14.

Table 15. Allendale sandy loam. Second cutting yield of alfalfa top growth.

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	8.77	0.00	-18.27
2. 0-20-0	9.86	12.43	-8.10
3. 0-20-20	10.73	22.35	0.00
4. 0-0-20	9.83	12.09	-8.39
5. 5-20-20	9.76	11.29	-3.97
6. 0-20-40	10.60	20.87	-1.21
7. 0-20-20 ≁ Mg, Mn, Fe, B, Cu	11.00	25.43	2.52
8. 0-20-20 ≁ Mn, Fe, B, Cu	9.83	12.09	-8.39
9. 0-20-20 ≁ Mg, Fe, B, Cu	10.43	18.93	-2.80
10. 0-20-20 ≁ Mg, Mn, B, Cu	10.20	16.31	-4.96
11. 0-20-20 ≁ Mg, Mn, Fe, Cu	10.50	19.73	-2.14
12. 0-20-20 ≁ Mg, Mn, Fe, B	8.73	-0.45	-18.64
13. 0-20-20 ≁ Mg	10.10	15.17	-5.87
14. 0-20-20 ≁ Mn, Fe	9.70	10.61	-9.60
15. 0-20-20 ≁ B	10.00	14.03	-6.80
16. 0-20-20 ≁ Cu	9.60	9.47	-10.53

1 Fertilizer rates and carriers are described on page 13-14.

Table 16. Allendale sandy loam. Third cutting yield of alfalfa top growth.

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	9.20	0.00	-15.05-**
2. 0-20-0	9.76	6.09**	-9.85-**
3. 0-20-20	10.83	17.72**	0.00
4. 0-0-20	9.60	4.35*	-11.36-**
5. 5-20-20	10.77	17.07**	-0.55
6. 0-20-40	10.43	13.37**	-3.69
7. 0-20-20 + Mg, Mn, Fe, B, Cu	10.90	18.48**	0.65
8. 0-20-20 + Mn, Fe, B, Cu	10.57	14.90**	-2.41
9. 0-20-20 + Mg, Fe, B, Cu	10.57	14.90**	-2.41
10. 0-20-20 + Mg, Mn, B, Cu	11.27	22.50**	4.06*
11. 0-20-20 + Mg, Mn, Fe, Cu	10.87	18.16**	0.37
12. 0-20-20 + Mg, Mn, Fe, B	9.83	6.85**	-9.23-**
13. 0-20-20 + Mg	10.40	13.05**	-3.97-*
14. 0-20-20 + Mn, Fe	10.53	14.46**	-2.77
15. 0-20-20 + B	10.77	17.07**	-0.55
16. 0-20-20 + Cu	10.43	13.37**	-3.69-*

1 Fertilizer rates and carriers are described on page 13-14.

* Significant at the 5% level.

** Significant at the 1% level.

Table 17. Allendale sandy loam. Total yield of alfalfa top growth, three cuttings.

Soil treatment[1]	Dry matter grams	% incr. over no trtmt.	% incr. over 0-20-20
1. None	28.77	0.00	-11.83
2. 0-20-0	32.03	11.33	-1.65
3. 0-20-20	32.63	13.42	0.00
4. 0-0-20	29.97	4.17	-8.16
5. 5-20-20	32.67	13.55	-1.41
6. 0-20-40	32.70	13.66	0.21
7. 0-20-20 + Mg, Mn, Fe, B, Cu	34.40	19.57	5.43
8. 0-20-20 + Mn, Fe, B, Cu	33.37	15.99	2.27
9. 0-20-20 + Mg, Fe, B, Cu	33.10	15.05	1.44
10. 0-20-20 + Mg, Mn, B, Cu	32.73	13.76	0.31
11. 0-20-20 + Mg, Mn, Fe, Cu	33.57	16.68	2.88
12. 0-20-20 + Mg, Mn, Fe, B	28.53	-0.84	-12.56
13. 0-20-20 + Mg	32.33	12.37	-0.96
14. 0-20-20 + Mn, Fe	32.53	13.07	-0.31
15. 0-20-20 + B	32.40	12.61	-0.70
16. 0-20-20 + Cu	32.70	13.65	0.22

1 Fertilizer rates and carriers are described on page 13-14.

Table 18. Green tissue tests[1] for potassium and phosphorus at the time of the third cutting.

Soil treatment[2]	Emmet loamy sand		Grayling loamy sand		Allendale loamy sand		Allendale sandy loam	
	P	K	P	K	P	K	P	K
1. None	L	M	L	L	L	L	L	L
2. 0-20-0	H	L	M	L	H	B	H	L
3. 0-20-20	M	H	H	L	H	L	H	L
4. 0-0-20	L	VH	L	L	L	H	L	M
5. 5-20-20	M	H	M	H	H	L	M	M
6. 0-20-40	M	VH	L	VH	H	M	M	H
7. 0-20-20 ≠ Mg, Mn, Fe, B, Cu	M	M	L	M	M	L	M	L
8. 0-20-20 ≠ Mn, Fe, B, Cu	L	H	L	H	M	L	H	M
9. 0-20-20 ≠ Mg, Fe, B, Cu	M	H	M	H	H	M	H	L
10. 0-20-20 ≠ Mg, Mn, B, Cu	M	M	L	L	H	M	H	M
11. 0-20-20 ≠ Mg, Mn, Fe, Cu	H	H	L	M	M	H	H	L
12. 0-20-20 ≠ Mg, Mn, Fe, B	M	M	H	M	L	L	H	M
13. 0-20-20 ≠ Mg	M	M	H	L	H	M	H	M
14. 0-20-20 ≠ Mn, Fe	H	M	H	H	H	L	H	M
15. 0-20-20 ≠ B	L	M	L	M	H	H	H	L
16. 0-20-20 ≠ Cu	H	L	M	L	H	H	H	L

1 According to Cook and others (14)

2 Fertilizer rates and carriers are described on page 13-14.

H = high, VH = very high, M = medium, L = low, B = blank.