THE EFFECT OF SOIL AERATION, MOISTURE, AND COMPACTION ON NITRIFICATION AND OXIDATION AND THE GROWTH OF SUGAR BEETS FOLLOWING CORN AND LEGUMES IN POT CULTURES

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INTRODUCTION

Observations of growth exhibited by sugar beets in field fertility experiments have shown that a leguminous crop in the rotation preceding this crop is less beneficial if unfavorable soil tilth and moisture conditions exist at planting time or shortly thereafter. Actual plot yields obtained during seasons of excessive rainfall show that these observations were not erroneous.

It was, therefore, deemed advisable to attempt a controlled investigation of this problem with the purpose of verifying these observations and to obtain, if possible, an explanation of the factors associated therewith.

Inasmuch as alfalfa and sweet clover are two leguminous crops frequently produced immediately prior to the sugar beets in a rotation and since corn is the non-leguminous crop often produced immediately before sugar beets when the leguminous crop occupies some other place in the rotation, it was decided that any consideration of the effect of physical factors on sugar beets should take these three crops into consideration. A greenhouse experiment, including these considerations and involving those additional methods and techniques to be described herein was decided upon. In the following pages is described a greenhouse experiment in which sugar beets were grown after these three crops at different moisture levels and degrees of compaction and aeration.

METHODS OF EXPERIMENTATION

The soil used in this experiment was a Brookston Clay Loam, similar in nature to that on which the above noted observations had been made. The containers were four gallon glazed, earthenware jars. Sixteen kilograms of soil were placed in each jar and during the growth of the three preliminary crops all cultures were maintained at the moisture equivalent by frequent weighings and additions of distilled water. The moisture equivalent was determined by the Bouyoucos (2) suction tension method. Each of the three initial crops was planted on February 7, 1946 and allowed to continue growth for somewhat more than two months. Inasmuch as each jar within a given crop series was treated exactly alike, the growth of these crops appeared quite uniform at the time of harvest. Excellent growth existed in every jar. The alfalfa and sweet clover series were inoculated at the time of seeding. Numerous nodules were observed when the crops were later incorporated with the soil. The mean green weights of these three preliminary crops are recorded in Table 1.

The green plant tissue, including the roots grown in each culture, was finely chopped with scissors and incorporated with the entire mass of soil in the jar. Each mass of soil was then returned to the jar from which it came.

Prior to returning each soil mass to its respective jar half of the jars, selected at random, were fitted with a glass tube in the bottom to permit subsequent aeration by a technique to be described later. This glass tube was permitted to extend from the center of the jar through a hole in the side at the bottom to permit the attachment of a rubber hose leading to the air pump. This tube was held in place by a cork through which it was inserted. A layer of glass wool was placed in the bottom of the jars and over the glass tube. This was included to permit an even distribution of the air under the entire mass of soil and to prevent the clogging of the tube by the soil particles.

Upon refilling the jars, half of them had the soil compacted by tamping firmly with the handle of a laborer's pick. In order to insure uniformity in this procedure, one individual tamped all the cultures. It is believed that the soil in the various jars was rather uniformly packed. During the tamping process the moisture content of the soil was below the moisture equivalent.

The average volume weight of the soil within those jars which were not given this mechanical packing has been calculated to be 1.0. The corresponding value for those jars which received the compaction treatment and in which the volume occupied by the soil was reduced by approximately thirty percent was determined to be 1.43.

Both the jars containing compacted soil and those in which the soil was not compacted were divided into two groups. One-half of the jars in each group was continued at the normal moisture content which had been maintained throughout the growth of the three preliminary crops. The other half was given an additional application of 500 milliliters of water and these moisture contents were maintained by frequent weighings and additions of water throughout the remainder of the experiment. The moisture contents, expressed on the basis of oven dry soil, were maintained at 25 percent and 28.2 percent, respectively, for the normal and excess water treatments.

The jars which were artificially aerated through the glass tube in the bottom of the jar were treated in the following manner. The glass tube was connected by means of rubber hose to an air pump. Eight jars were connected simultaneously to the pump and aerated daily for a period of two hours. This aeration process was continued during the entire period during which sugar beets occupied the jars. Six such groups were aerated daily and the sequence of aeration among these series was rotated between such cycles of treatment to prevent the influence of the time factor during any given portion of the cycle. The air pump used was that type employed in the compression system of an ordinary household mechanical refrigerator. This device is illustrated in Figure 1.

Sugar beets of the variety U.S. 216 were planted on all jars on May 3. An excellent stand was obtained from this original planting. All jars were subsequently thinned to three plants each.

The oxidation studies to be discussed herein were conducted by the technique described by Hoffer (3). Samples of soil were taken by means of a one inch soil sampling tube and a sample obtained at the bottom of a three inch core was used for the ferric and ferrous iron determinations.

Nitrate nitrogen determinations were made on samples collected by taking three such cores as described above and making a composite sample from which a water extract was made on a fifty gram sample of the moist soil. Simultaneously, a twenty-five gram sample was taken for moisture determinations. The phenoldisulfonic acid method, as described by Prince (5), was employed in making the nitrate determinations. Results of these determinations are expressed in parts per million of the elemental nitrogen existent in the form of nitrates and based on the amount of oven dry soil.

Harvest of the sugar beets was accomplished on July 2. The beets were removed from the soil, carefully freed of all clinging particles of soil and roots were then separated from the tops and crowns. Green weights were recorded, the plant material was dried at 180° F, and dry weights were taken.

DISCUSSION

The green weights of the three preliminary crops, alfalfa, corn, and sweet clover; are recorded in Table 1. The weights have been arranged according to the physical treatments subsequently employed and means of the yields in each replicate are presented in this table.

Oxidation Status of the Soil

Hoffer (4) has attributed the failure of corn plants to make proper utilization of fertilizer elements to the deficiency of oxidation processes in some soils. Inasmuch as certain differences were known to exist among the various physical treatments of this experiment, due both to a controlled supply of air furnished the soil and to differences brought about by mechanical disturbance of the soil, it was decided that a consideration of the oxidation status of the soils used in these trials would be highly desirable.

The presence of ferric iron and the absence of ferrous iron was detected in every culture in which the soil was not compacted. This was true regardless of whether or not these jars received an excess amount of water and whether or not additional air was supplied. No differences caused by the other physical treatments of the non-compacted soil in the relative amount of ferric iron present were detected by the technique employed.

For those jars in which the soil was compacted, several facts were apparent. Without exception, every jar that received the compaction treatment but did not receive aeration, had ferrous iron present and none of those receiving the excess water treatment contained a trace of ferric iron. One jar in the corn series that had been compacted but received no excess of water contained both ferric and ferrous iron. There was also indication that the relative amount of ferrous iron in the soil receiving the normal amount of water was lower than that on the jars receiving excess water.

In the cultures, where the sugar beets followed corn or alfalfa, which were compacted, but received the additional air, there was a consistent tendency to contain ferric iron as well as ferrous iron. For the normal water treatment, the cultures in these series showed almost no ferrous iron and almost wholly the ferric iron present. In the cultures following sweet clover there was a tendency to show more ferrous iron, even when the additional air was applied. That additional air was somewhat less efficient in removing the ferrous iron in those cultures receiving additional water is indicated for all series. This apparent decrease in efficiency was particularly evident in the sweet clover series. A complete record of the results obtained in these studies, and an explanation of the quantitative evaluation thereof, is shown in Table 2.

Nitrate Nitrogen Studies

Upon the finding of such marked differences in the relative amounts of ferric and ferrous iron as a result of the various physical treatments, it was decided that a study of nitrification as affected by the various treatments was desirable.

The results of the June 6 determinations reveal that significant differences in the nitrate nitrogen content of the cultures had been brought about by certain of the physical treatments and by certain of the previous crops. It can be seen in Table 3 that cultures in both the alfalfa series and the sweet clover series had significantly higher amounts of nitrate nitrogen, if an average of all treatments within a preceding crop series is considered, than did the cultures within the corn series. A better comparison is afforded if crop series are compared individually by treatment. This comparison reveals that the cultures in the alfalfa and sweet clover series are higher than the corn series only for those physical treatments that did not include compaction. Among the compacted cultures, those where alfalfa or sweet clover had been the preceding crop did not contain significantly greater amounts of nitrate nitrogen than did those following corn. Therefore, it is apparent that compacted soil in which large amounts of nitrogenous material had been incorporated had been prevented from rendering these nitrogenous substances available as nitrates, at least to a level comparable to that which might normally be expected and which is demonstrated on the same soil which was not compacted.

A similar consideration applied to physical treatments within a preceding crop series is desirable. It may be observed in the alfalfa series that as a result of both the normal and the aeration treatments the cultures contained more nitrate nitrogen on June 6 than they did in any of the four compacted treatments of the same series. In the uncompacted cultures with excess water the nitrate nitrogen content was slightly, though not significantly, higher than in those which received normal moisture. The reverse of this condition was true among the compacted cultures of the alfalfa series.

Nitrification in the sweet clover series was significantly benefitted by additional aeration both in the cultures which were not compacted and maintained at normal water content and in those which were not compacted but maintained at excess water content, the difference being particularly marked for the latter treatment. It may also be noted that the nitrate nitrogen content was somewhat lower in the cultures which contained additional water than it was in those which contained the normal amount. This, though of questionable significance, indicates a different trend than was true on the alfalfa series. All cultures in the sweet clover series, as in the alfalfa series, which were compacted contained much less nitrate nitrogen than did those which were not compacted.

Differences did exist in the nitrate nitrogen content of the cultures in the corn series but are probably of little significance. However, indications are that a relatively higher level of nitrate nitrogen may be expected in soil following corn crop if compaction of the soil is avoided and if excess water is not permitted on these same compacted soils.

Reference to Table 4 reveals that certain differences still were existent with regard to nitrate accumulation in the soil on July 2. The marked variations between certain treatments with a series and also between certain series within a physical treatment were not so apparent but significant differences still existed. The average nitrate nitrogen content of all the cultures in the sweet clover series was higher than the average for the corn series and the average for the alfalfa series was in turn even higher than that of all cultures in the sweet clover series. The treatments in the sweet clover series which resulted in significantly higher nitrate nitrogen content than the corresponding treatments in the corn series were aeration, compaction, and excess water plus aeration. In the alfalfa series, as compared to the corn series, higher nitrate nitrogen contents resulted from the aeration and excess water plus aeration treatments. Likewise the nitrate nitrogen content of the alfalfa series cultures was higher than those of the sweet clover series in the excess water plus aeration treatment. This latter treatment in the alfalfa series for this date resulted in so much higher nitrate nitrogen level than did any other treatment that it is outstanding. In the sweet clover series, nitrate nitrogen contents were higher than for the alfalfa series in the cultures of aeration, compaction plus aeration, and excess water plus compaction treatments. The nitrate nitrogen levels for the corn series were significantly above those for the alfalfa series in the cultures involving excess water, compaction, and aeration. These differences were probably not important inasmuch as no consistent variation, as was apparent in the earlier studies, then existed. It seems likely that the vigorous growth of sugar beets as a result of certain treatments had resulted in utilization of most of the available nitrate nitrogen and for that reason certain marked differences, previously noted, were absent on July 1.

YIELD DATA AND HARVEST RESULTS

Root Yields

The ultimate practical interpretation of an experiment of this nature rests fundamentally in its value as an aid to an evaluation of factors influencing the yield of the crop concerned. In the production of sugar beets the value of a given crop is determined to a considerable extent by the weight of the roots. Dry root weights were taken and are recorded in Table 5.

It is particularly noteworthy that a consideration of the average yields indicates essentially no variation as affected by the preceding crops, alfalfa, sweet clover, or corn. However, an evaluation of the data as a result of the various treatments reveals that for the normal soil treatment both the alfalfa and corn series produced a significantly higher yield of roots than did the sweet clover series. This same marked difference exists for that physical treatment involving compaction and aeration. Yields of beets following corn were markedly less than where they followed the legumes where the cultures received excess water. The differences obtained between series were probably not significant for other physical treatments, but it is interesting that the yields following corn were higher than those following legumes on the compacted soils.

An evaluation of differences which existed as a result of various physical treatments shows spectacular variation.

The highest average yield, all series included, was obtained by the employment of aeration and excess water, while the next highest yields occurred where the cultures received normal moisture and air. The third highest yield was obtained where the cultures received excess water. The yields on the normal soil were the fourth highest. The increase in yield caused by additional water is probably of questionable significance but the other increases, obtained by comparison with the yields resulting from the normal treatment, are significant.

A similar consideration for those physical treatments involving compaction indicates that yields obtained on compacted soil were, without exception, significantly lower than those obtained on soils not compacted. The differences were not only significant but were really spectacular. Therefore, a consideration of the various physical treatments involving compaction seems desirable. The yields resulting from the excess water plus compaction treatment were, without serious competition, the lowest recorded. These plants were so small that harvest and subsequent weighings were very difficult. The yields from cultures where the soil received normal water after compaction and those from cultures which were aerated after receiving additional water and compaction were somewhat higher than yields from cultures which were compacted and received excess water but were not aerated. Especially it is interesting that significant increases in yield resulted from the aeration of compacted cultures.

Considering only the results for the alfalfa series the highest yields resulted from the application of excess water and the inclusion of additional air. All yields were markedly reduced by compaction and where this treatment was followed by the addition of excess water the yields were reduced to practically nothing.

Aerating the compacted cultures in this series caused considerable stimulation of root growth both in the absence and in the presence of the excess water. This stimulation was striking in the absence of the excess water and its significance is apparent from the statistical evaluation accompanying Table 5.

For the corn series, the highest yield of roots was also obtained as a result of that treatment in which additional water and air were provided. The addition of excess water without aeration resulted in a significant decrease in yields. Sugar beets on compacted soil following corn yielded more roots than they did on similar soil following the legumes. Aeration again markedly stimulated the yield of roots both where there was excess water and where the soil had been compacted without excess water.

Aeration plus excess water also resulted in the highest yield in the sweet clover series, only slightly higher, however, than those obtained where the cultures received excess water without aeration. Aeration alone resulted in yields significantly greater than those obtained from cultures which received the normal treatment. In the compacted soils, the application of excess water again resulted in lower yields than were obtained as a result of any other treatment.

Top Yields

The data contained in Table 6 show that after alfalfa and sweet clover sugar beet top yields were considerably greater where the soils were not packed than were those obtained after corn despite the fact that almost no variation was previously noted for root yields. Where the soils were packed the reverse condition tended to be true. There were two exceptions in the sweet clover series where the cultures received excess water plus compaction and the combination of excess water, aeration, and compaction. Thus compaction seemed to retard top growth more where the beets followed the legumes than it did where corn was the preceding crop.

A general review of these data with regard to physical treatment indicates little variation among those soils which were not compacted. On those soils which were compacted, aeration provided a noticeable increase in top growth, both in the presence and absence of additional water.

In the alfalfa series a slightly greater yield of tops was harvested from those cultures which received additional water than from those which received the normal moisture, without compaction in both cases. A noticeable decrease in top yield occurred in the corn series on those soils which were aerated but not compacted. The data for the sweet clover series suggests an opposite trend inasmuch as aeration resulted in an increase in top growth.

Root/Top Ratios

Data already presented indicate considerable variation among root and top yields and these variations are not always parallel. It is, therefore, suggested that a consideration of the ratio of root yields to top yields might be significant. These data are presented in Table 7.

That the yield of roots for sugar beets is an important factor has previously been stated. The highest average yield of sugar beet roots, all series considered, was obtained for that treatment involving the application of both additional water and aeration. The average root top ratio for this treatment is 0.662. The corresponding lowest average yield of roots was resultant from a combination of compaction and excess water. The average root/top ratio for this treatment is 0.269. Similar relationships are suggested for the varying degrees of yield between these two extremes by a consideration of that data contained in both Tables 5 and 6. That a relatively high ratio of roots to tops is necessary for maximum sugar beet yields is seemingly suggested by these data.

A consideration of individual series indicates that in the corn series root/top ratios averaged slightly higher than they did in either of the legume series. This behavior suggests that individual attention should be devoted to the various series.

The data for the alfalfa series show less variation among the different treatments than do the data for the other series. In all cultures where comparatively high yields were obtained and where the soils were not compacted the root/top ratios were over 0.5. For this same series and for those cultures where the soils were compacted, aeration resulted in a marked rise in root growth as compared to top growth. The addition of water resulted in a small increase in this ratio on the compacted soil which was not aerated, but resulted in a decrease on that soil which was aerated.

According to Table 7 data for the corn series include the highest and the lowest root/top ratios, so extremes for this series were great. The beets grown on soils which were not compacted, and which produced comparatively uniform and high yields all have root/top ratios exceeding 0.8. The treatment involving excess water and compaction resulted in the lowest root/top ratios of any treatment, all series included, and, as previously noted, this same treatment caused the lowest yield of roots for all treatments on all series. Similarly the root/top ratios obtained as a result of all the other treatments involving compaction are very low as are the yields of roots, except for that soil which was compacted and aerated. The ratio for this soil is 0.653 and the yield for this treatment is higher than that for any other compaction treatment, all series included.

A comparison of root/top ratios resulting from the various treatments in the sweet clover series suggests that in this series variation is intermediate. For the two treatments which were provided additional water but not compaction root/top ratios were higher than for those two which were maintained at normal water levels. For the normal water treatments, the one which was also aerated caused the highest yield of roots and a similar increase in root/top ratio. Ratios for all compacted soils were rather uniformly low as were yields of roots. That ratio for the treatment which included both compaction and additional water was significantly lower than the others as was also the yield of roots.

SUMMARY AND CONCLUSIONS

Certain facts become evident with a review of the discussion already presented. A consideration of these facts and an evaluation of such in terms of practical application to the production of sugar beets is considered essential.

Comparatively good and uniform yields of sugar beet roots were obtained as a result of any physical treatment of the soil considered herein and succeeding either corn, alfalfa, or sweet clover so long as that treatment did not involve compaction. It was found that slight increases in yield were obtained where additional water and air were provided normal soils. This benefit was considerable where the preceding crop was sweet clover. Additional water, without additional air was detrimental to the growth of sugar beets on soil which previously produced corn.

Compaction of the soil, following all crops, resulted in a considerable reduction in yield of sugar beets. This reduction was evidenced both in root and top growth, but to a greater extent in the former as indicated by an accompanying decline in root/top ratios. That the effect of compaction on a soil is more serious than the addition of excess water was also demonstrated. Additional water, without compaction, stimulated yields in some cases. Additional water, accompanying compaction, however, caused an additional decline in productivity. Additional aeration materially increased yields on compacted soils where normal moisture levels were maintained but failed to cause increases in yields on soils which had been packed and also received excess water.

The ratio of roots to tops needs to be relatively high for maximum yield of sugar beet roots. All physical treatments which reduced the yield of roots, disturbed the normal oxidation processes, and inhibited nitrification also lowered the root/top ratios. Root/top ratios for the corn series reflect extreme variation and since maximum yields on this series occured only where this ratio was very high, the importance of maintaining this high level is indicated.

All physical treatments which included compaction resulted in a marked accumulation in the soil of ferrous iron and a consistent absence of ferric iron, indicating that normal oxidation processes were inhibited. The additional aeration afforded a compacted soil apparently tended to restore these processes to a normal level, but the restoration was only partial. Additional water in a compacted soil apparently inhibited oxidation beyond that accomplished by compaction alone.

Nitrification processes were markedly curtailed by compaction alone or by excess water in addition to compaction. The cultures which had grown alfalfa and sweet clover and were for that reason high in nitrogenous material did not contain more nitrate nitrogen than did cultures in the corn series in the physical treatments which included compaction. In the cultures not compacted much higher nitrate levels were obtained where the preceding crop had been alfalfa or sweet clover. Aeration tended to restore normal nitrification processes in a compacted soil. There was evidence that additional aeration and additional water significantly increased nitrification in a normal soil particularly where sweet clover had previously been grown.

For the alfalfa series, that physical treatment combining both additional water and additional air resulted in the highest yield of sugar beet roots, the highest nitrate level on June 6, and a very favorable root/top ratio. The application of excess water to a soil which was not compacted resulted in the lowest yield, though not the lowest root/top ratio or the lowest nitrate level on June 6. It may thus be concluded that compaction of a soil succeeding the growth of alfalfa is particularly detrimental to the succeeding sugar beet yield and such detrimental effects are magnified by the addition of excess water.

For the corn series, the same physical treatment as mentioned for the alfalfa series resulted in maximum yields of sugar beet roots, though not the highest root/top ratio or the highest nitrate level on June 6. Excess water on a non-compacted soil resulted in a significant reduction in yield of sugar beets, the only reduction on such a soil to be noted for any series. The inclusion of additional aeration on a compacted soil succeeding corn resulted in a yield more nearly approaching those yields for a non-compacted soil than did any other similar treatment on any series. It may thus be concluded that excess water on a soil succeeding a corn crop is particularly objectionable. It may also be assumed that compaction, though highly undesirable, is probably less detrimental on a soil succeeding corn than on a similar soil succeeding either alfalfa or sweet clover. There is even a suggestion that such is true in the absence of any special effort to restore normal oxidation relationships on such compacted soils.

For the sweet clover series, aeration and additional water each caused increases in yields of sugar beet roots and a combination of the two treatments caused an even larger increase. Additional water on the compacted soil resulted in proportionately smaller decreases in yields than was true for the other series. There is a possibility that additional aeration or the combination of additional aeration and excess water might materially aid nitrification processes following sweet clover.

A practical evaluation of these data and discussions is suggested. Even if it is granted that a greenhouse experiment has numerous restrictions for field application, it may be assumed that certain common considerations are possible. It may be concluded that any cultural practice which results in marked compaction of the soil, is objectionable. Compaction of the soil in the presence of excess water is even more detrimental to succeeding sugar beet yields than where moisture levels are normal. There is no good evidence that additional water in a soil, to the extent used in this experiment, is at all detrimental to a crop of sugar beets following a leguminous crop. There is no evidence that additional aeration, as provided by these investigations, will result in spectacular increases in yields. It is suggested that compaction of the soil is probably less damaging after a crop of corn than after a crop of legumes and for that reason particular care should be afforded the soil succeeding a legume crop. This necessity is emphasized by due consideration of nitrification processes and the state of oxidation existent therein.

The need for a careful evaluation of root growth as a criterion for evaluation of sugar beet yields is emphasized. Inasmuch as physical treatments may markedly reduce root/top ratios, such observations as include only top growth are probably meaningless.

Figure 1. The mechanism employed in aerating those jars so treated is illustrated above. A total of eight jars was connected in series and attached by rubber hose to the pump. A total of six such series were employed and each series was aerated two hours per day.

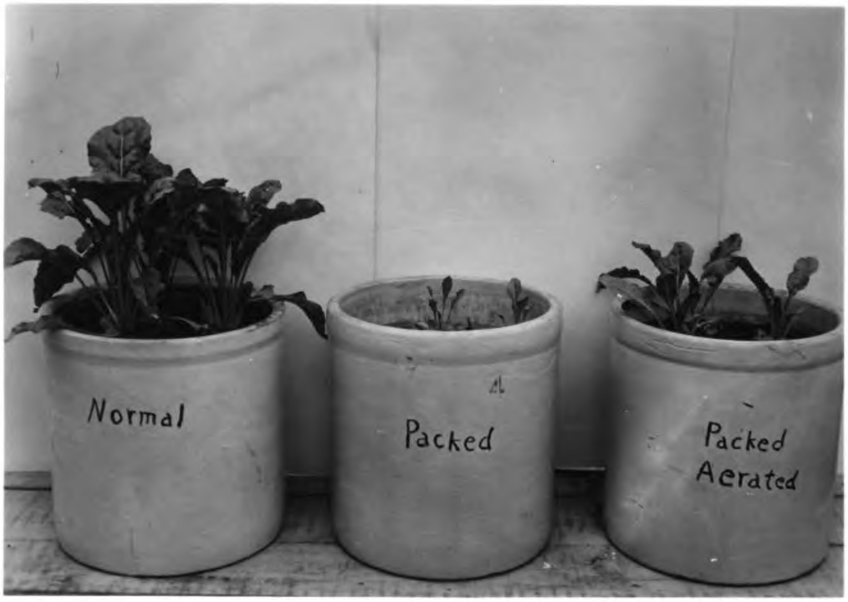

Figure 2. This photograph of three jars of the corn series was taken June 14, 1946. The vigorous and abundant growth evidenced on all soils not compacted is noticeable in the jar on the left. The small, stunted, and spindly growth evident on all compacted soils, not aerated is evident in the center jar. The rather abundant growth produced by aeration on a compacted soil of this series is to be noted on the right.

Figure 3. The top growth of sugar beets for the alfalfa series on July 2 is illustrated above. The vigorous growth of tops in soils which were not compacted is apparent. The depressed growth in the compacted soil is also shown and the stimulation provided by aeration in the compacted soil is apparent.

Figure 4. The top growth of sugar beets for the corn series on July 2 is illustrated above. The vigorous growth in soils which were not compacted and the much depressed growth in compacted soil is obvious. The approach to normal of the top growth in soil which was compacted and aerated is demonstrated for this series.

[redacted]

Figure 5. The top growth of sugar beets for the sweet clover series on July 2 is illustrated above. The same general appearance as indicated for both the alfalfa and corn series is again demonstrated.

Figure 6. The cultures already presented in Figures 3, 4, and 5 are presented for comparison. There is abundant top growth for all cultures in which the soil was not compacted and a very much depressed growth where compaction was employed. The stimulation provided by aeration in the compacted soils is also illustrated for all series, and particularly for the sweet clover and corn series.

Figure 7. This photograph was taken on July 3 of one sugar beet from each culture presented in Figure 6. The number 1 beet in each series is from the normal soil, the number 2 beet is from the compacted soil, the number 3 beet is from the aerated soil, and the number 4 beet is from the soil which was compacted and provided with additional aeration. Very good root growth is apparent for both the normal and compacted soils and almost no growth is apparent for the compacted soil. The stimulation of root growth by aeration on a compacted soil is demonstrated.

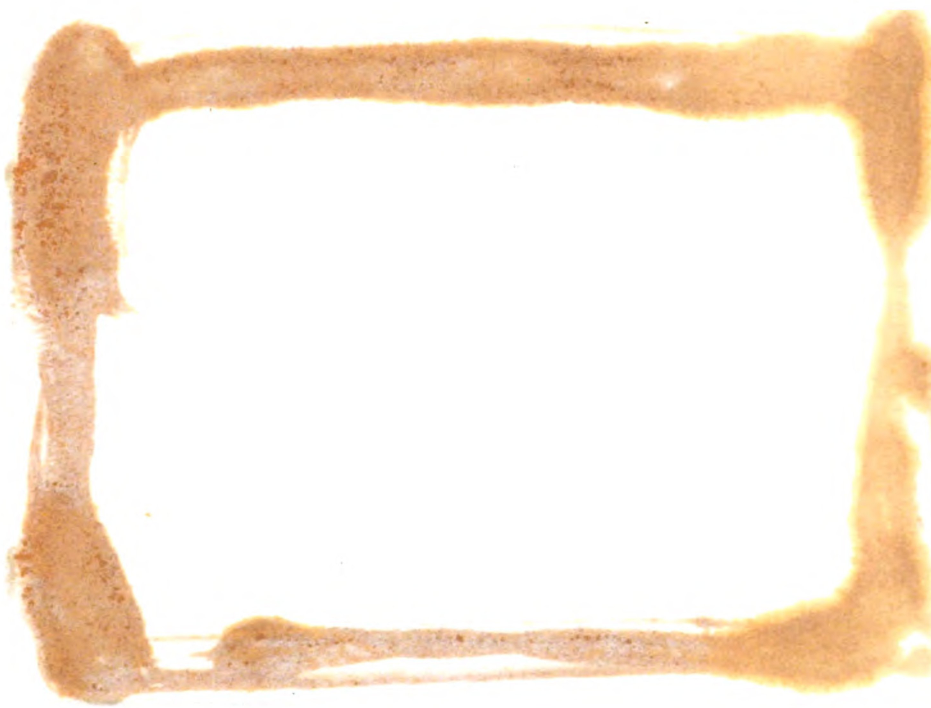

Table 1. Yield of green material for three initial crops arranged by physical treatments subsequently employed on sugar beets, April 24, 1945.

Physical[1] Treatment	Mean Yield[2] of Alfalfa, grams	Mean Yield of Corn, grams	Mean Yield of Sweet Clover, grams
1. Normal	94.8	358.5	130.5
2. Aeration	89.3	371.0	127.8
3. Compaction	87.3	409.3	143.5
4. Aeration and Compaction	86.8	367.8	146.8
5. Excess Water	94.3	364.5	148.3
6. Excess Water and Aeration	101.3	401.0	137.8
7. Excess Water and Compaction	85.5	408.8	137.8
8. Excess Water, Aeration, and Compaction	101.8	373.8	133.8

[1]Physical treatment listed in this table has reference only to such treatments as used on subsequent crops and was not employed for these crops listed herein.

[2]Mean yields represent average of four replicates.

Table 2. Oxidation status of soil on May 28, 1946 as indicated by relative abundance of ferric and ferrous iron in soil.

Physical Treatment	Replicate	Alfalfa series, Ferric	Alfalfa series, Ferrous	Corn series, Ferric	Corn series, Ferrous	Sweet Clover series, Ferric	Sweet Clover series, Ferrous
1. Normal	1	++	-	++	-	++	-
	2	+	-	++	-	++	-
	3	++	-	++	-	++	-
	4	++	-	++	-	++	-
2. Aeration	1	++	-	++	-	++	-
	2	++	-	++	-	++	-
	3	++	-	++	-	++	-
	4	++	-	+	-	++	-
3. Compaction	1	-	+	+	+	-	+
	2	-	+	-	++	-	+
	3	-	++	-	++	-	++
	4	-	++	-	++	-	+
4. Aeration and Compaction	1	+	-	++	-	-	++
	2	+	+	++	-	-	-
	3	-	++	+	-	-	+
	4	+	-	+	++	-	+
5. Excess Water	1	++	-	++	-	+	-
	2	++	-	+	-	+	-
	3	+	-	+	-	+	-
	4	++	-	+	-	+	-
6. Excess Water and Aeration	1	++	-	+	-	++	-
	2	++	-	+	-	+	-
	3	++	-	+	-	++	-
	4	+	-	+	-	+	-
7. Excess Water and Compaction	1	-	++	-	++	-	++
	2	-	++	-	++	-	++
	3	-	++	-	++	-	+
	4	-	++	-	++	-	++
8. Excess Water, Aeration, and Compaction	1	-	++	+	+	-	++
	2	+	+	+	++	-	++
	3	-	+	-	++	-	++
	4	+	-	-	++	-	++

++ = High amount of substance tested for
\+ = Medium amount of substance tested for
\- = No trace of substance detected

Table 3. Nitrate nitrogen data for June 6, 1946.

Physical Treatment	Mean[1] nitrate nitrogen content for Alfalfa series ppm	Corn series ppm	Sweet Clover series ppm	Series Average ppm
1. Normal	33.21	2.42	41.94	26.05
2. Aeration	33.42	6.33	62.98	34.92
3. Compaction	2.33	1.29	1.99	1.82
4. Aeration and Compaction	2.66	1.67	2.60	2.31
5. Excess Water	40.80	4.70	22.16	22.56
6. Excess Water and Aeration	52.10	2.49	53.94	36.00
7. Excess Water and Compaction	2.19	.67	2.37	1.74
8. Excess Water, Aeration, and Compaction	1.96	1.19	2.76	1.97
Average for all treatments	21.09	2.59	23.82	15.83

[1]Mean of four replicates

Difference required for significance:	1%	5%
Between physical treatments	16.27	12.27
Between physical treatments, within series	27.60	21.60
Between series	10.30	7.53
Between series, within treatments	27.60	21.60

Table 4. Nitrate nitrogen data for July 1, 1946.

Physical Treatment	Mean[1] nitrate nitrogen content for Alfalfa series ppm	Corn series ppm	Sweet Clover series ppm	Series Average ppm
1. Normal	.935	.873	1.010	.939
2. Aeration	1.043	.805	1.345	1.064
3. Compaction	1.15	.763	1.185	1.033
4. Aeration and Compaction	.833	1.080	1.150	1.021
5. Excess Water	.985	1.058	.893	.978
6. Excess Water and Aeration	6.458	1.100	1.470	3.009
7. Excess Water and Compaction	.768	1.040	1.128	.978
8. Excess Water, Aeration, and Compaction	.978	1.280	1.175	1.144
Average for all treatments	1.685	1.000	1.167	1.271

[1]Mean of four replicates

Difference required for significance:

	1%	5%
Between physical treatments	.1875	.1418
Between physical treatments, within series	.3256	.245
Between series	.1142	.086
Between series, within treatments	.3256	.245

Table 5. Yield of sugar beet roots, July 2, 1946.

Physical Treatment	Mean[1] dry weight of sugar beet roots for Alfalfa series grams	Corn series grams	Sweet Clover series grams	Series Average grams
1. Normal	16.75	17.93	11.88	15.45
2. Aeration	17.00	17.80	18.23	17.68
3. Compaction	.88	2.23	1.18	1.43
4. Aeration and Compaction	6.04	7.07	2.47	5.19
5. Excess Water	16.18	13.90	19.18	16.42
6. Excess Water and Aeration	17.95	19.20	19.98	19.04
7. Excess Water and Compaction	.18	.16	.37	.24
8. Excess Water, Aeration, and Compaction	2.06	1.49	1.98	1.84
Average for all treatments	9.61	9.97	9.40	9.66

[1]Mean of four replicates

Difference required for significance:	1%	5%
Between physical treatments	2.94	2.14
Between physical treatments, within series	4.92	3.72
Between series	1.86	1.36
Between series, within treatments	4.92	3.72

Table 6. Yield of sugar beet tops, July 2, 1946.

Physical Treatment	Mean[1] dry weight of sugar beet tops for Alfalfa series grams	Corn series grams	Sweet Clover series grams	Series Average grams
1. Normal	27.6	20.6	30.3	26.2
2. Aeration	27.9	16.7	32.6	25.7
3. Compaction	3.4	9.2	2.7	5.1
4. Aeration and Compaction	12.7	11.8	6.3	10.3
5. Excess Water	31.4	24.2	29.2	28.3
6. Excess Water and Aeration	33.9	16.1	33.7	27.9
7. Excess Water and Compaction	.5	.6	1.3	.8
8. Excess Water, Aeration, and Compaction	4.6	4.5	6.0	5.0
Average for all treatments	17.7	13.0	17.8	16.2

[1]Mean of four replicates

Table 7. Ratio of dry weight of roots to dry weight of tops for sugar beets harvested July 2, 1946.

Physical Treatment	Mean[1] root/top ratio for Alfalfa series	Corn series	Sweet Clover series	Series Average
1. Normal	.593	.933	.408	.644
2. Aeration	.598	1.065	.553	.738
3. Compaction	.213	.268	.398	.292
4. Aeration and Compaction	.498	.653	.368	.506
5. Excess Water	.555	.833	.695	.694
6. Excess Water and Aeration	.515	.865	.608	.662
7. Excess Water and Compaction	.375	.150	.283	.269
8. Excess Water, Aeration, and Compaction	.400	.263	.340	.334
Average for all treatments	.468	.629	.457	.518

[1]Mean of four replicates

Difference required for significance:	1%	5%
Between physical treatments	.135	.078
Between physical treatments, within series	.182	.137
Between series	.062	.047
Between series, within treatments	.182	.137

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