EFFECTS OF SOIL COMPACTION ON ROOT DISTRIBUTION OF TRANSPLANT TOMATOES

by

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INTRODUCTION

A compacted soil is one whose apparent density is sufficiently high to adversely influence crop production. A soil may be compacted naturally during the process of soil formation or artificially during normal tillage, planting, and harvesting operations. Trends to bigger and heavier farm machinery add to this compaction. The problem is also aggravated by working the soil early in the spring while it is still wet in an attempt to meet an early market for vegetable crops for example.

In 1959, the Department of Agronomy at Kansas State University conducted an exploratory investigation to observe the effects of soil compaction on plant loss and plant recovery rate of transplant annuals. Banded and bare rooted plants of the Glamour variety of tomatoes grown by the Department of Horticulture were included in this exploratory work. Tomatoes were chosen as the crop to study on the basis of their importance as a transplanted crop and because they are considered intermediate in their response to poor aeration. The study was continued in 1960 in cooperation with the Department of Horticulture, comparing the effects of a non-compacted soil, a moderately compacted soil, and a severely compacted soil on several aspects of growth and production of tomatoes using banded and bare rooted transplants.

A study of the tomato root systems was made to determine the effect of soil compaction on root growth as determined by root weight.

Improved techniques for separating plant roots from the soil were also studied. A study was also conducted to evaluate the effect of time on the depth of rooting of tomato plants grown in soils of different densities in a greenhouse.

REVIEW OF LITERATURE

Pavlychenko (9) stated that the objective in a root study of any kind should be to determine the underground development with respect to at least one of three cardinal points; (1) the habit of growth as indicated by the natural spread and penetration of roots, (2) the quantity of root material found at different soil levels, (3) the performing capacity of root systems as indicated chiefly by the amount, extent, and location of the fine root branches on the main root of each species.

After an extensive review of soil compaction, Fuller (5) stated there were two classes of soil compaction, (1) "genetic" compaction formed during the natural development of the soil, and (2) "induced" compaction caused by mechanical pressure of farm implements and by the weight of water. He defined a compacted soil as one whose apparent density is sufficiently high to adversely influence crop production.

Flocker, Vomocil, and Howard (4) stated that with soil compaction, the soil air spaces were reduced and plant growth was affected. There was an overall slowing of the metabolic processes of plant growth with no isolated or specific plant symptoms.

Weaver (13) reported that in investigations of the root systems of 3 week old tomato plants, they are characterized by a taproot which tapered gradually from a width of 10-13 mm. near the soil surface to only 2 mm. at a depth of 6 inches. The surface soil for about 1 foot on all sides of the plant was thoroughly ramified with rootlets. At 8 weeks of age, the most prominent part of the root system consisted of strong laterals. Many of these laterals extended outward to 2 feet and then turned downward.

Locascio and Warren (6), using radioactive phosphorus at various depths and lateral distances in greenhouse pots, found the rate of growth of tomato seedling roots to be much slower than reported by Weaver (13). They found the initial root growth was of the taproot type, penetrating about an inch by the time the cotyledons emerged. The growth after this relatively shallow penetration was as rapid laterally as vertically.

In an extensive study of soils used for tobacco production, De Roo (1) found that a compaction zone just below the plowsole severely retarded root penetration. The soil was a Merrimac sandy loam and analysis showed that the bulk density increased sharply from 1.44 to 1.65 in the upper subsoil. When roots were extracted by use of soil monoliths, it was found that a compaction zone with a bulk density of 1.65 acts as a physical barrier to root penetration of most plant species.

In other studies, De Roo (1) found no correlation between root depth and organic matter, soil acidity, or the fertility status below the plow depth. Loosening or lowering the mechanical resistance of the compaction zone in these well drained soils, without the deep placement of lime and/or fertilizer would generally promote deeper root penetration.

Sunflower roots were unable to penetrate some compacted soils in experiments conducted by Veihmeyer and Hendrickson (12). The soil density above which roots do not penetrate was not the same for all soils. Roots were not found at densities of 1.9 or above in any soil and roots were not found in clay soils when the density reached 1.6 or 1.7. They concluded the failure of roots to penetrate compacted soils must have been due to the small size of pores rather than lack of oxygen as roots penetrated a similar non-compacted soil when most of the oxygen had been expelled by heating.

In work with potatoes in Merrimac sandy loam soil, De Roo and Waggoner (2) found that complete shattering of the plowsole hardpan promoted deeper and heavier rooting in the soil layers below the plow layer. Deep fertilization did not produce a significant concentration of roots in the subsoil layer, nor did deep fertilization retard deeper rooting. Apparently, density of the subsoil and not the lack of fertility was the primary factor in causing a reduction in plant growth.

Flocker, Vomocil, and Howard (4) used three soil types with a progressively higher degree of compaction in their experiments, rather than specific levels of compaction. It was found that no level of compaction gave a marked decrease in seed germination. There was no effect on blossoming of tomatoes up to a point, then there was a decrease. Plant growth measured by height, fresh weight, and dry weight, decreased at higher levels of compaction.

Velocity of emergence steadily decreased as density increased.

They concluded that reduction in growth was due to any one or a combination of (1) poor water utilization, (2) restricted nutrient uptake, (3) lack of oxygen, (4) accumulation of carbon dioxide, and (5) root impediment.

Meredith and Patrick (8) studied soil compaction using cylinders 4 inches in diameter and compacted 4 inches deep with 6 inches of loose soil on top. An increasing range of compaction, expressed in foot pounds per cubic inch, showed that with medium textured soils, at 10 to 15 foot pounds of compaction, root penetration of sudan grass was severely restricted. However, they found on clay soils, roots would penetrate a soil compacted by 15 foot pounds per cubic inch if aeration was adequate. They contributed this result to the plastic properties of the clay soil.

In his extensive study of previous root study methods, Pavlychenko (9) considered the main objection to each one was the time consuming factors or the loss of small roots which are important in nutrient and water uptake from the soil.

When studying corn root systems, a shaker type washer was used by Fehrebacker and Alexander (3). It consisted of a heavy wooden stand which held a rack containing eight pans, that could move back and forth on rollers made of pipe. The pans which held the soil samples had a bottom made of 16 mesh screen. These pans were lowered into a large vat of water and moved at about twenty-two, 4 inch strokes per minute. The soil particles went into suspension, the roots floated to the top and were skimmed off with small screens. Any soil that remained was pushed through the screens by hand and any organic matter or debris that was left was removed with tweezers.

The soil-elution method of root study used by Upchurch (11) employed the use of a 33 gallon drum, open at the top, with a 3 by 4 inch opening made 3 inches below the top. The opening was fitted with a 16 mesh screen. The soil containing the roots was placed in the drum and a stream of water directed on the matrix in the drum. After sufficient time, the soil went into suspension, passed through the screened opening and left the roots behind. The length of time required to obtain a soil free root sample varied from 1 to 4 hours, depending on the soil structure and texture. After the samples of roots were obtained, they were floated in a small pan and any foreign matter present was removed.

A flotation method for studying roots used by McKell, Wilson and Jones (7) was similar to the soil-elution method employed by Upchurch (11). This involved using 5 gallon cans with openings cut at the top and screens placed under the openings to catch any roots that floated over. Water under pressure and broken into a spray was directed on the soil samples placed in the cans. This method proved to be very satisfactory on relatively small samples. It had the advantages of being fast, economical to construct and operate and furthermore, all the roots from the samples were collected since small screens were used.

MATERIALS AND METHODS

Field Study

Both a field study and a greenhouse study were conducted using a Geary silt loam soil. Preliminary soil preparation and compaction of the soil was done by personnel from the Department of Agronomy.

The plots were chiseled 12 inches deep, 8 inches apart and disced several times. The top 4 to 6 inches of 4 plots were compacted to a bulk density of 1.7 or greater with three passes of a small, self-propelled asphalt roller. Four plots were compacted to a bulk density of 1.6 with a portable Barco rammer. The remaining four plots were not compacted. Packing was completed on May 19, 1960.

Transplanting was accomplished by making holes only large enough to receive the roots of the transplants and the soil removed was packed back around the plant roots. Both the banded and non-banded plants were spaced $2\frac{1}{2}$ x $2\frac{1}{2}$ inches apart in flats. Asphalt type bands were used. Planting was completed on May 26, 1960.

Records of plant growth and fruit production were kept on a plant basis. Plants used for the root study were selected from plants that had an average yield of fruit for the particular compaction level.

Several methods have been used to take root samples (3), (7), (9), and (11). Since this was a comparative study, it was not considered necessary to collect the entire root system of each plant, but desirable to get relatively large samples of equal volume at the different depths studied. To accomplish this, a column of soil 12 inches by 12 inches by 27 inches was excavated with the plant centered in the column (Plate I). This column was excavated by the use of a four bladed tool, with the sharpened blades welded into a square, the inside dimensions of the square being 12 inches (Plate I). To this square, four steel posts were welded and braced so the blades could be driven through the soil.

To get samples at the different depths, the following procedure was used. The plant was centered in the square tool. Soil was dug away from the outside of the tool to facilitate driving the tool into the soil with a sledge hammer. Care was taken not to dig into the profile to be studied. The blades were then driven down until the resulting 12 inch square profile protruded above the blades the amount desired for the depth sampled. At each depth, the soil and roots were cut off flush at the top of the blades with a sharp knife. The soil samples were then put in bags and labeled.

To separate the roots from the soil, some difficulty was encountered on samples of this size. A common washing machine that had been used on small samples was first tried. The samples were placed in the machine, covered with water and agitated for about 30 minutes. The machine was then drained and the roots and soil slurry were caught in screens at the drain. This resulting soil slurry was then decanted several times to get the roots. This proved too slow and many roots were left in the soil.

EXPLANATION OF PLATE I

Fig. 1. Sketch of soil profile used in field study.

Fig. 2. Tool used to measure and dig the soil profile during extraction of root samples.

PLATE I

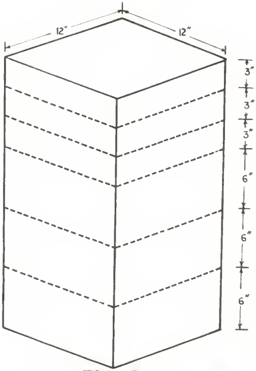


Fig. 1

Fig. 2

As the roots tended to float to the top, the washing machine was modified to take advantage of this situation. A 2 inch drain pipe was fitted near the top of the washer, and water was run into the bottom through the old drain. Water entered continually as the soil was agitated, and most of the roots floated to the top and out the drain where they were caught on a screen. This still proved to be slow and some roots still remained in the water in the washing machine, particularly around the edges where agitation was poor.

A third method was tried, still using the flotation principle. Two 5 gallon cans were welded together and a fitting for a water hose installed in the bottom (Plate II). A spout was welded on top so the roots could be collected on screens as they floated out. This provided clean samples and worked relatively fast. However, it was necessary to keep the soil stirred in the bottom so the water stream would be effective in floating the roots to the top.

This system of soil-root separation by flotation was further modified by using only one 5 gallon can with a cone shaped bottom section (Plate II). A water hose connection was placed in the bottom of the cone and the stream of water directed vertically up the center. When the heavier soil particles settled out of the upward moving column of water they returned to the bottom where the velocity was greatest and had the best soil breaking action.

Roots floated to the top and were caught on a 0.50 mm. screen. The roots were removed from the screen under a spray of water and decanted twice to remove any soil which may not have passed through the screen. In the top sample where the root system was still intact, it was necessary to remove it from the washer by hand. This was an easy matter, as very little of the soil was left in the washer at the end of the washing period. The time required to separate the roots from a 6 inch by 12 inch by 12 inch sample was about 20 minutes. In all methods, the samples were soaked 8 to 12 hours previous to washing.

The root samples were oven dried at 80° C. and weighed. Other organic matter was present with the roots. This was assumed to be uniform on all plots and any differences in the weight of the samples was due to the amount of roots.

Greenhouse Study

Soil for the greenhouse study was obtained from the top 6 inches of a site adjacent to the plots used in the field study. The soil was taken to the greenhouse and spread in 3 inch layers and allowed to dry. The dry soil was run through a soil shredder to facilitate the mixing and compaction operations. After shredding, the soil was taken to a constant humidity chamber where the humidity was 95 per cent and the temperature 55° F. This kept the soil moisture content from changing during the compacting operation. Since soil moisture is a major factor in compacting a soil, the soil was stirred several times and moisture percentages determined to insure the moisture content was uniform throughout the soil.

Soil was placed in cans 12 inches deep and 9½ inches in diameter. To get the desired compaction level, the volume of the can to the 10 inch depth was found and the pounds of soil needed for a bulk density of 1.1, 1.4, and 1.7 was computed. The cans were marked off in five, 2 inch intervals starting at the bottom. The total soil needed for a particular compaction level was divided into five equal parts and each of these parts were pressed into the measured 2 inch segments in the can.

Pressing the soil into the cans was done with a small screw type press (Plate II). Two round, steel ½ inch plates, just smaller than the diameter of the cans were used. One was placed under the can to prevent bulging of the bottom. The second plate was placed on the soil and pressed down until the soil was level with the appropriate mark in the can. The soil surface was scratched uniformly with a pointed instrument to prevent a hard interface between the layers.

The cans were placed in the greenhouse using a randomized complete block design as described by Snedecor (10). Four blocks were used, the compaction levels and dates were randomized in each block.

Tomato seedlings were transplanted to the cans April 17, 1961. Holes 1 inch deep and 3/8 inch in diameter were made for the plants. Three plants, with shoots approximately 6 centimeters long and roots 6-7 centimeters long, of the Glamour variety, were started in each can. A 10-10-10 starter solution was used, 150 milliliters being applied to each can at planting. No other fertilizer was used.

A black plastic film was used on top of the soil to prevent evaporation of the soil moisture and drying and cracking of the soil. Sphagnum moss was placed on the plastic to shade it and help maintain a cooler soil temperature.

On April 21, one plant was removed from each can. All cans were thinned to one plant on April 24.

All cans were weighed at the beginning of the experiment. They were reweighed regularly and water added to maintain the original weight (Plate II).

To get a representative sample of an entire root system for each compaction level, a can of soil for each treatment was compacted similar to those used in the rest of the study. However, a 1/16 inch mesh screen just smaller than the diameter of the can was placed at each 2 inch interval. The screen held the roots in place while the soil was washed away with a hose. The screens were cut away and removed from the roots before the photographs were made.

Shoots and roots were collected at three week intervals, the dates being May 10, May 31, and June 21. Height of plant was determined by measuring from the soil level to the shoot apex. Shoots and roots were oven dried for 24 hours at 75^{o} C. and weighed.

To study the roots the cans were cut open and one side removed. The soil profile was measured off in 2 inch segments, each segment was separated with a sharp knife and placed in a can to soak.

Root extraction techniques were similar to the modified flotation method used in the field study. Each sample was placed

EXPLANATION OF PLATE II

Fig. 1. Flat bottom washer used to extract roots from soil samples.

Fig. 2. Cone-shaped washer used to extract roots from soil samples.

Fig. 3. Screw-type press used to compact soils for greenhouse study.

Fig. 4. Technique used to weigh cans to determine amount of water to supply to each treatment.

PLATE II

Fig. 1

Fig. 2

Fig. 3

Fig. 4

in the washer and the roots floated out and caught on a 0.50 mm. screen. The roots were then flushed from the screen under a water tap into a gallon can. This can containing the roots was then set inside an 8 inch diameter screen with 0.149 millimeter openings. This was placed under a small stream of water and the roots again floated over the top of the can and any soil particles left in the sample remained in the can. The roots were caught on the fine screen. This proved to give very clean root samples easily and quickly. However, any foreign organic matter in the soil remains with the roots.

The foreign organic matter had been thoroughly mixed in the soil before the compaction operation. At the first root extraction period (three weeks), roots had not reached the lower levels. Average weights of the foreign material in these samples was found and the average per gram of soil computed. This value was multiplied by the grams of soil in each compaction level to find the average weight of foreign material in a particular compaction level. This average foreign organic material weight was subtracted from the total weight of the individual samples and these values were assumed to represent the root weight. This provided a correction factor covering the additional foreign material in the compacted soils.

RESULTS

Field Study

Data from the study of the effects of banding and compaction on marketable fruit production indicated that both have a significant effect (Table 1). Analysis showed that there was no difference statistically between the non-compacted and medium compacted soils on marketable fruit production. There was a highly significant reduction in marketable fruit weight due to severe compaction (Table 2).

Root weights at the end of the growing season showed no significant differences due to compaction. However, significant differences occurred in quantity of roots found at different depths. Banding apparently had no effect on root growth of mature plants under any compaction level.

Greenhouse Study

In the greenhouse study, the effects of soil compaction were measured on plant height, and dry weights of shoots and roots. Data were gathered at 3 weeks, 6 weeks, and 9 weeks from the transplanting date to determine the effect of time on root penetration of soils with different densities. The root samples were taken at 2 inch increments.

At the third week there was no significant difference in weight of the shoots (Table 5). At this stage of development, the plants on the heavy compaction treatments were slightly heavier (Table 6). Plant height was nonsignificant among treatments (Table 7); however, the plants were taller on the heavy compacted soil (Table 8). Although there were significant differences in the root weights among the three soil treatments (Table 9), these differences were probably due to organic matter

Table 1. Analysis of variance for fresh weight of marketable tomato fruits from banded and non-banded plants grown on soils of different compaction levels. 1/

Source of variation	Degrees of freedom	Sum of squares	Mean square
Compaction	2	21.7466	10.873***
Banding	1	.8140	.814*
Comp. X Band	2	.3740	.184
Replications	3	.2527	.084
Error	15	2.3822	.159

1/ Data from the field study made by the Departments of Agronomy and Horticulture.

Table 2. Summary of average yield of marketable tomato fruit in pounds per plant from banded and non-banded plants grown on soils of different compaction levels.

No compaction		Medium compaction		Severe compaction	
Banded	Non-banded	Banded	Non-banded	Banded	Non-banded
4.00	3.51	3.62	3.04	1.57	1.55
3.75		3.33		1.56	

L.S.D. .05 = 0.34 for banding
L.S.D. .05 = 0.43 for compaction

Table 3. Analysis of variance of dry weight (in grams) of tomato roots from banded and non-banded plants grown on soils of different compaction levels.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Replications	2	129.0823	64.5412
Compaction	2	105.4648	52.7324
R X C	4	106.7656	26.6914
Banding	1	7.2800	7.2800
B X C	2	6.9483	3.4742
R X B	6	196.1769	32.1962
R X B X C			
Depths	5	14,284.4957	2,856.8991***
D X C	10	410.8403	41.0840
R X D	30	1,135.2689	37.8423
R X D X C			
D X B	5	16.6580	3.3316
D X B X C	10	44.8577	4.4858
R X D X B	30	842.9120	28.0971
R X D X C			

Table 4. Mean dry root weight (in grams) at different depths for tomato plants grown on soils of different compaction levels.

Depth in inches	No compaction	Medium compaction	Heavy compaction
0-3	36.78	32.81	28.66
3-6	7.86	16.97	8.64
6-9	3.47	4.98	4.03
9-15	1.27	1.53	0.88
15-21	0.88	0.90	0.69
21-27	0.78	0.69	0.53

L.S.D. .05 = 6.44 for depth

Table 5. Analysis of variance of dry weights (in grams) of tomato plant shoots grown with soils of different compaction levels for 3 weeks.

Source of variation	Degrees of freedom	Sum of squares	Mean Square
Blocks	3	0.60	0.20
Compaction	2	0.23	0.12
Error	6	0.97	0.16

Table 6. Average dry weight (in grams) of tomato plant shoots grown with soils of different compaction levels for 3 weeks.

No compaction	Medium compaction	Heavy compaction
0.87	0.57	0.90

Table 7. Analysis of variance of plant height (in inches) of tomato plants grown with soils of different compaction levels for 3 weeks.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Blocks	3	1.2	0.4
Compaction	2	0.5	0.25
Error	6	2.8	0.47

Table 8. Average height (in inches) of tomato plants grown with soils of different compaction levels for 3 weeks.

No compaction	Medium compaction	Heavy compaction
3.47	3.27	3.80

Table 9. Analysis of variance of root weight (in grams) of tomato plants grown with soils of different compaction levels for 3 weeks.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Blocks	3	2.22	.74
Compaction	2	6.06	3.03*
Depth	4	5.43	1.36**
Error	50	11.33	.23

Table 10. Average dry weight of roots (in grams) of tomato plants grown with soils of different compaction levels for 3 weeks.

Depth in inches	No compaction	Medium compaction	Heavy compaction
0-2	1.96	1.48	2.22
2-4	1.05	1.55	0.94
4-6	1.61	1.59	1.83
6-8	0.62	1.53	1.46
8-10	0.95	1.50	1.04

L.S.D. .05 = .39

rather than actual root weights. The proportion of organic matter to root weights was very high at this stage of growth (Table 10).

The results at six weeks showed the compaction treatment was affecting plant growth. The dry weight of the shoots differed significantly (Table 11); and the heavy compaction treatment caused a marked decrease in weight (Table 12).

Plant height was in accordance with the dry weight (Table 13). There was little difference in the non-compacted and medium compacted treatments; however, the heavy compacted treatment significantly reduced plant height.

An analysis of root weights showed differences due to treatments and differences in depths (Table 15). Weights differed significantly at the 0-2 inch level, the medium compaction treatment had the most roots, the non-compacted and heavy compacted did not differ significantly. At the 2-4 inch level there was no significant difference due to treatment but the medium and heavy compacted treatments were significantly decreased between the 0-2 inch and the 2-4 inch depths (Table 16).

The data at nine weeks indicated differences in growth due to compaction treatments. Analysis of the dry weight of the shoots (Table 17) showed no significant difference between the plants on the non-compacted and medium compacted soils; although a highly significant reduction in weight was found on the heavy compaction treatment (Table 18).

Significant differences were found in plant height (Table 19). Plants from the heavy compaction treatment were

Table 11. Analysis of variance of dry weights (in grams) of tomato plant shoots grown with soils of different compaction levels for 6 weeks.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Blocks	3	2.50	0.83
Compaction	2	32.95	16.47**
Error	6	2.97	0.49

Table 12. Average dry weight (in grams) of tomato plant shoots grown with soils of different compaction levels for 6 weeks.

No compaction	Medium compaction	Heavy compaction
14.41	13.48	9.93

L.S.D. .05 = 2.10

Table 13. Analysis of variance of plant height (in inches) of tomato plants grown with soils of different compaction levels for 6 weeks.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Blocks	3	4.42	1.47
Compaction	2	17.53	8.76**
Error	6	5.68	0.95

Table 14. Average height (in inches) of tomato plants grown with soils of different compaction levels for 6 weeks.

No compaction	Medium compaction	Heavy compaction
21.1	21.5	18.8

L.S.D. .05 = 1.57

Table 15. Analysis of variance of root weight (in grams) of tomato plants grown with soils of different compaction levels for 6 weeks.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Blocks	3	10.03	3.3
Compaction	2	43.02	21.5 **
Depth	4	26.80	6.7 **
Error	50	20.22	.40

Table 16. Average dry weight of roots (in grams) of tomato plants grown with soils of different compaction levels for 6 weeks.

Depth in inches	No compaction	Medium compaction	Heavy compaction
0-2	3.23	4.39	2.83
2-4	2.39	2.48	1.82
4-6	1.69	2.33	1.26
6-8	1.63	3.12	0.56
8-10	1.96	2.95	0.33

L.S.D. .05 = 0.89

Table 17. Analysis of variance of dry weight (in grams) of tomato plant shoots grown with soils of different compaction levels for 9 weeks.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Blocks	3	4.92	1.64
Compaction	2	448.55	224.27**
Error	6	53.88	8.98

Table 18. Average dry weight (in grams) of tomato plant shoots grown with soils of different compaction levels for 9 weeks.

No compaction	Medium compaction	Heavy compaction
32.39	27.77	17.75

L.S.D. .05 = 5.98

Table 19. Analysis of variance of plant height (in inches) of tomato plants grown with soils of different compaction levels for 9 weeks.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Blocks	3	12.50	4.16
Compaction	2	16.56	8.28**
Error	6	7.28	1.21

Table 20. Average height (in inches) of tomato plants grown with soils of different compaction levels for 9 weeks.

No compaction	Medium compaction	Heavy compaction
26.1	25.9	23.5

L.S.D. .05 = 1.7

Table 21. Analysis of variance of root weight (in grams) of tomato plants grown with soils of different compaction levels for 9 weeks.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Blocks	3	1.36	0.45
Compaction	2	16.17	8.08*
Depth	4	263.25	65.81***
Error	50	79.10	1.58

Table 22. Average dry weight of roots (in grams) of tomato plants grown with soils of different compaction levels for 9 weeks.

Depth in inches	No compaction	Medium compaction	Heavy compaction
0-2	6.08	7.37	8.51
2-4	3.14	2.84	2.55
4-6	2.04	2.44	1.50
6-8	1.58	3.12	0.66
8-10	2.93	3.03	0.08

L.S.D. .05 = 1.78

significantly shorter than plants from the non-compacted and the medium compaction treatments (Table 20).

The weight of roots differed in response to compaction at the various depths (Table 21). When the 0-2 inch depth was considered, the heavy compacted soil contained the most roots and differed significantly from the non-compacted soil but not the medium compacted soil. At the 2-4 inch depth, there was no significant difference in root weights but the non-compacted soil contained the most roots. At the 4-6 inch depth there was no significant difference in root weight statistically, but the heavy compaction had sharply reduced root weights. At the 6-8 and 8-10 inch depth, there was no difference between non-compacted and medium compacted treatments, but heavy compaction caused a significant reduction in root weight (Table 22).

DISCUSSION OF RESULTS

Field Study

Since heavy soil compaction had proved detrimental to top growth and fruit production, the primary purpose of the field root study was to determine if increased soil compaction adversely affected root quantity or depth.

Soils with a bulk density of 1.1 and 1.6 had produced equally well in regard to vine growth and fruit production. Apparently a bulk density of 1.6 on Geary silt loam was not sufficiently high to adversely affect growth. However, a bulk density of 1.7 was high enough to reduce fruit production and vine growth of tomatoes. Flocker, Vomicil, and Howard (4) reported a reduction in blossoming rate at higher compaction levels. This probably explained part of the reduction in fruit production. As early growth was delayed on the heavily compacted soil, apparently the plants were under stress and fruit set was delayed. Higher temperatures occurred later in the season which was probably unfavorable for fruit set.

At the end of the growing season, soil compaction had not significantly influenced root weights. De Roo (1) found that root penetration was not retarded in most plant species until a bulk density of 1.65 was reached. This coincides with the results of the non-compacted and medium compacted treatments, however, it does not agree with the results on the heavily compacted soil.

The large amount of roots found in the heavily compacted soil as compared to the top growth probably resulted from any one or a combination of the following factors. As the season progressed under normal conditions, the bulk density in the heavily compacted plots decreased and the bulk density in the non-compacted plots increased, however, this change was probably slight. At the beginning of the season, on the heavy compaction plots, all new roots that formed were concentrated in the upper compaction layer and grew with difficulty. However, by the end of the growing season they had penetrated the compaction layer and reached the subsoil which was approximately of the same bulk density on all plots. On the heavily compacted soil, pore space was reduced to the point where air movement was restricted and conditions for the decomposition of organic matter was less favorable. In the method of analysis used, the additional organic matter would have favored the heavy compaction treatment.

Greenhouse Study

As adverse effects of soil compaction on root growth were not evident at the end of the season, the greenhouse study was designed to determine the extent of root penetration at various time intervals. Effects on top growth measured by height of the plant and dry weight of the plant were also studied.

At the end of the third week there were no significant differences in vine growth or plant height due to compaction levels. During the root extraction process, no roots were found in the lower soil samples. Root growth had not exceeded 6 inches in depth under any of the treatments (Plate VII). At this stage of growth the proportion of roots to organic matter was so small, that although significant differences occurred, this was probably due to organic matter rather than to root weight. Visual observation of the samples indicated roots had not penetrated deeper than 6 inches in depth at the end of three weeks. This was not as rapid as the rate of growth reported by Weaver (13). Growth rates of roots in greenhouse pots observed by Locascio and Warren (6) were similar to those found in the noncompacted and the medium compacted soil.

At the end of the sixth week, plants on the heavy compaction treatment showed a reduced growth rate, both in height and dry weight (Plate VIII). The plants on the heavy compaction treatment had no visual signs of nutrient deficiencies. The only symptom caused by heavy soil compaction on top growth was reduced growth rate (Plate III). Flocker, Vomocil, and Howard (4) also found that there were no isolated symptoms of soil compaction on plant growth. They reported that an apparent slowing of the metabolic processes of growth occurred.

The heavy compaction treatment reduced the rate of root penetration by the end of the sixth week. Evidently, since soil moisture and the level of fertility was the same in all treatments, a silty loam soil compacted to a bulk density of 1.7 acts as a physical barrier to root penetration. This was also the case found by De Roo (1) and (2) when working with tobacco and potatoes. Only 29.6 per cent and 28.8 per cent of the total roots formed in six weeks were found in the upper 2 inches of soil in the non-compacted and the medium compacted soil treatments respectively; however, 41.6 per cent of the total roots formed in the heavily compacted soil was in the top 2 inches of soil (Plate VIII).

At the end of the ninth week, plant height and dry weight of the plant did not differ significantly between the non-compacted and medium compacted treatments. The plants in the heavy compaction treatments were reduced in height and dry weight and had acquired a weak, spindly appearance when compared to the plants on the other soil compaction treatments (Plate IV).

More roots were found in the upper 2 inches of soil in the heavy compacted soil at the end of 9 weeks. However, there were more roots found in the lower soil levels (2 inches to 10 inches)

EXPLANATION OF PLATE III

Closeup of plants at sixth week interval. 0 - no compaction; 1 - medium compaction; and, 2 - heavy compaction.

PLATE III

EXPLANATION OF PLATE IV

Closeup of plants at ninth week interval. 0 - no compaction; 1 - medium compaction; and, 2 - heavy compaction.

PLATE IV

EXPLANATION OF PLATE V

Closeup of root systems of plants at nine weeks. 0 - no compaction; 1 - medium compaction; and, 2 - heavy compaction. Small mark indicates depth of taproot.

PLATE V

EXPLANATION OF PLATE VI

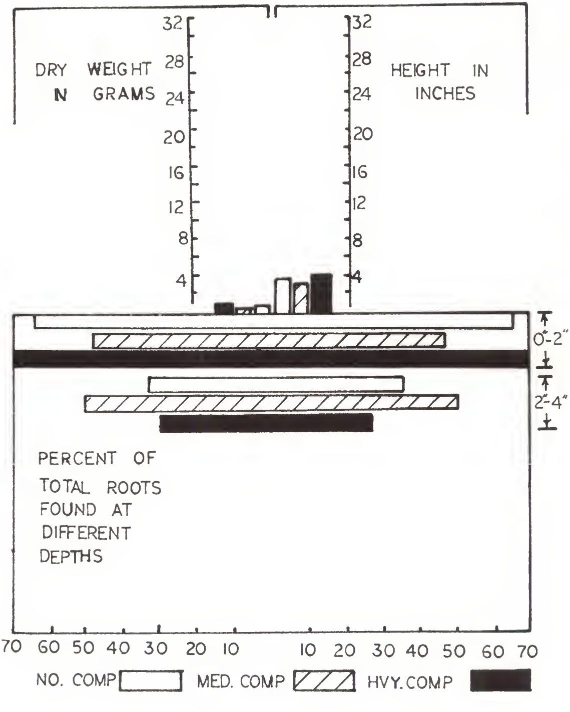
Closeup of root systems of plants from 0 - non-compaction; 1 - medium compaction; and, 2 - heavy compaction, with small marks to indicate depth of taproots.

PLATE VI

EXPLANATION OF PLATE VII

Bar graph showing dry weight in grams, height of plant tops in inches and per cent of total roots found at different depths for plants grown in three compaction treatments in the greenhouse for three weeks.

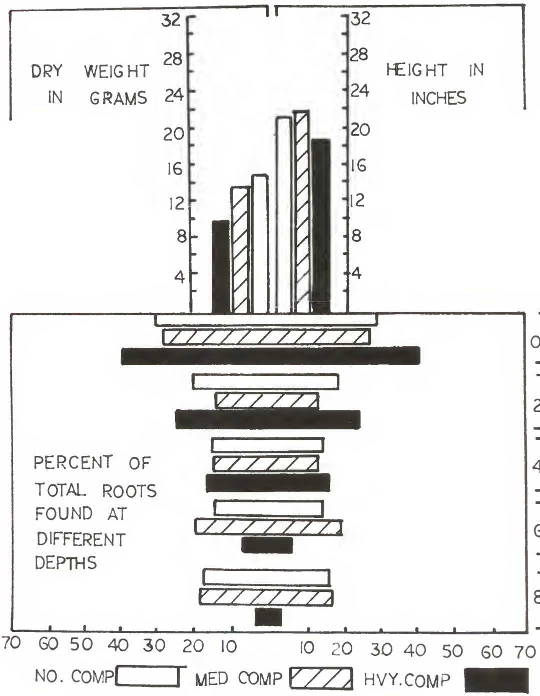
PLATE VII


DRY WEIGHT
N GRAMS
32
28
24
20
16
12
8
4
32
28
24
20
16
12
8
4
HEIGHT IN
INCHES
0"-2"
2"-4"
PERCENT OF
TOTAL ROOTS
FOUND AT
DIFFERENT
DEPTHS
70 60 50 40 30 20 10
10 20 30 40 50 60 70
NO. COMP
MED. COMP
HVY. COMP

EXPLANATION OF PLATE VIII

Bar graph showing dry weight in grams, height of plant tops in inches and per cent of total roots found at different depths for plants grown in three compaction treatments in the greenhouse for six weeks.

PLATE VIII


DRY WEIGHT IN GRAMS
HEIGHT IN INCHES
32
28
24
20
16
12
8
4
PERCENT OF TOTAL ROOTS FOUND AT DIFFERENT DEPTHS
0-2"
2"-4"
4"-6"
6"-8"
8"-10"
70 60 50 40 30 20 10
10 20 30 40 50 60 70
NO. COMP
MED COMP
HVY.COMP

with the non-compacted and the medium compacted soils (Table 22). Plants on the non-compacted and the medium compacted soil treatments displayed a uniformly distributed root system (Plate V). The plants on the heavily compacted soil had a very short, thick root system as shown by Plate V, with 64 per cent of the total roots formed in the upper 2 inches of the soil (Plate IX).

Length of the taproot was one major difference found when the entire root system was extracted from the soil. In each case, with a decrease in bulk density of the soil, the length of the taproot increased (Plates V and VI). The total amount of water added for the 9 week old plants was 5,450 ml. per plant. There were no apparent differences in water utilization among treatments.

SUMMARY AND CONCLUSIONS

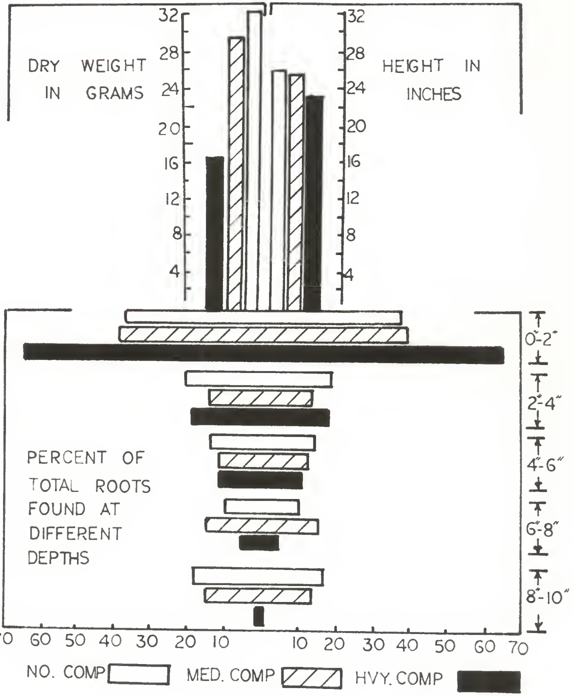
Root extractions from soil samples can be difficult and time consuming. A method should be used whereby all roots can be collected. The extraction process should be fast enough so many samples can be extracted before the roots deteriorate. Of the methods tried in this study, the flotation method using a washer with a cone shaped bottom was far superior to a common agitator type washing machine or a flotation type washer with a flat bottom. Less time was required to extract roots from a soil sample; all roots were recovered from the soil due to the action of water on soil caused by the cone; furthermore, small screens could be used so the smallest roots were not lost.

Compaction of Geary silt loam to a bulk density of 1.7

EXPLANATION OF PLATE IX

Bar graph showing dry weight in grams, height of plant tops in inches and per cent of total roots found at different depths for plants grown in three compaction treatments in the greenhouse for nine weeks.

PLATE IX


DRY WEIGHT IN GRAMS
32
28
24
20
16
12
8
4
HEIGHT IN INCHES
32
28
24
20
16
12
8
4
PERCENT OF TOTAL ROOTS FOUND AT DIFFERENT DEPTHS
0"-2"
2"-4"
4"-6"
6"-8"
8"-10"
70 60 50 40 30 20 10 10 20 30 40 50 60 70
NO. COMP
MED. COMP
HVY. COMP

adversely affected vine growth and marketable fruit production of tomato plants, under field conditions. Soil compacted to a bulk density of 1.6 (about average for most agricultural soils under good management practices) was not detrimental to tomato production. Total yield from soil with a bulk density of 1.6 did not differ significantly from a non-compacted soil.

Under field conditions, tomato roots readily penetrated a silty loam soil compacted to a bulk density of 1.6 and apparently to the same extent and at the same rate as roots in a non-compacted soil. Soil compacted to a bulk density of 1.7 decreased vine and fruit production. It did not reduce the total weight of the roots when measured at the end of the growing season. Root growth in the compacted soil probably increased before the end of the growing season because the bulk density decreased slightly and/or eventually the roots penetrated the subsoil where the bulk density was less. Under greenhouse conditions, when the soil was compacted to a 10 inch depth, roots did not penetrate the heavily compacted soil as readily as the other compaction treatments. Soil compaction had more influence on rate of penetration than on total root growth when measured by dry weight.

Tomato plants showed no symptoms due to soil compaction other than reduced growth.

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EFFECTS OF SOIL COMPACTION ON ROOT DISTRIBUTION OF TRANSPLANT TOMATOES

by

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AN ABSTRACT OF A MASTER'S THESIS

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During the 1960 growing season, a field study was conducted to determine the effects of different levels of soil compaction on some aspects of growth of transplant tomatoes. The Glamour variety was used.

A Geary silt loam soil was compacted to a bulk density of 1.6 and 1.7 or above, one treatment was left uncompacted. Tomato plants were transplanted to the plots on May 26. Production of marketable fruit was recorded on a plant basis.

Results of this study showed no significant difference between non-compacted soil and a soil compacted to a bulk density of 1.6 when marketable fruit production was considered. However, soil compaction to a bulk density of 1.7 severely reduced marketable fruit production.

A study of the root systems was made at the end of the growing season to determine the weight of roots that had penetrated to various depths on the different compaction treatments. A 12 inch by 12 inch soil profile was excavated. This profile was divided into depths of 0-3, 3-6, 6-9, 9-15, 15-21, and 21-27 inches. Roots were first separated from the soil by a washing machine. This method was not satisfactory for soil samples this large. A flotation type washer with a flat bottom was constructed. This was an improvement over the washing machine, but was still inferior in design. A flotation type washer with a cone-shaped base was constructed. It produced results much superior to the other methods tried. After separating the roots from the soil, they were oven dried and weighed.

Results of the root study showed that soil compaction had no effect on total root weight when measured at the end of the growing season.

Geary silt loam soil was used in the greenhouse study as well. Soil was compacted into cans to a depth of 10 inches by 2 inch increments with a small press to bulk densities of 1.1, 1.4, and 1.7. Tomato plants of the Glamour variety were grown in these cans. The soil surface was covered with plastic and sphagnum moss to prevent evaporation. Water was added frequently to maintain the original weight of the soil.

Plant heights and dry weights of the vines and roots were determined at the end of 3, 6, and 9 weeks. Root extraction techniques were the same as those used in the field study. Depths of root penetration were divided into 0-2, 2-4, 4-6, 6-8, and 8-10 inches.

Results of the greenhouse study indicated no significant difference among compaction levels for vine growth or depth of root penetration at the end of 3 weeks. At the end of 6 weeks there was no significant difference in plant height and dry weight of the plants between plants grown on the non-compacted and the medium compacted soil. However, heavily compacted soil had significantly reduced vine growth and weight of the roots.

At the end of nine weeks, there was no significant difference in vine growth and root growth between plants grown on the non-compacted and the medium compacted soil. Roots did not penetrate the heavily compacted soil as readily as the other soil treatments and heavy soil compaction significantly reduced vine growth.

Soil compaction had more effect on rate of root penetration than total root weight.

Reduced growth was the only indication of abnormality that resulted from soil compaction.