Soil Compaction and Tillage Operation Effects on Sugar Beet Root Distribution and Seed Yields[2]

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INTRODUCTION

Numerous studies have been made of the relation of soil aeration to size and shape of sugar beet roots when grown for sugar production. Less attention has been given to the subject where the beets are grown for seed. Proper air-water-nutrient proportions in the soil are critical factors in plant growth. Suitable tilth or soil structure, which to a considerable extent controls aeration, is perhaps of greater importance where the root is the desired product than where the top of the plant is the crop. However, good soil aeration is necessary for good root distribution and normal top growth could not be expected if the feeder roots could not function properly.

Various expressions such as granular, crumb, porous, etc., are used to designate good soil tilth or good structure. The depth to which plant roots penetrate will be determined by the plant type and the physical limitations of the soil. Compact layers such as hard pans, plowsoles, or water logged may be partially or completely impervious to certain types of roots.

The pore space of soils, that portion not actually filled with solid material, may be differentiated as capillary and non-capillary depending on the size of the pores. Soils vary widely in their total as well as non-capillary porosity. The capillary portion would be filled with water under conditions of field capacity moisture. The non-capillary portion, i.e., the size of the pores as well as total porosity, is important in aeration. The major influencing factors are soil texture, organic matter content and soil tilth. The texture is more or less fixed by the soil formation processes and cannot be changed. Organic matter content and tilth are subject to manipulation. The proportion of non-capillary pore space necessary for good growth may vary considerably with different soils.

In the Willamette valley it has frequently been observed that the main tap roots of sugar beets tend to branch or turn abruptly (Fig. 1) after penetrating the soil to a depth of 2 to 4 inches. In occasional instances the main tap root was found to grow laterally for a distance of several feet

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Figure 1.
Left: Root turned abruptly at about 2" depth, typical of many plants in this area.
Center: Result of restricted penetration at about 6" depth.
Right: Normal growth.

without penetrating the soil to a depth of more than 2 to 3 inches. If the feeder roots follow a similar pattern, they would be subject to injury from even shallow cultivation and to desiccation in periods of low rainfall. However, shape of the root, which is highly important for tonnage yields, may be much less significant where only the seed is harvested.

Willamette silt loam soils used for sugar beet seed production have shown 45 to 55 per cent total and 7 to 20 per cent non-capillary porosity. Chehalis sandy loam soils have a similar wide range of pore space. Impeded root development indicating poor tilth has resulted frequently with sugar beets in these Willamette valley soils. Samples of Medford loam soils from southern Oregon showed a relatively low range of 44 to 48 per cent total porosity but proportionally high non-capillary porosity. In none of the Medford soils studied has there been any tendency toward restricted sugar beet root development.

LITERATURE REVIEW

Baver (1) states that the ideal soil would have about half the total pore space as non-capillary. Farnsworth and Baver (2) in studying one of the clay soils of Ohio found high total porosity but relatively low non-capillary porosity. They concluded that for good sugar beet growth the non-capillary porosity should be about 8 to 10 per cent. Below 8 per cent both yields and stand of beets dropped off sharply. Corresponding values of 15 to 20 per cent have been suggested for some European soils. Farnsworth and Baver further found that soils which had become compacted by tillage often had non-capillary pore space values as low as 2 to 4 per cent. Considerable improvement in structure was obtained in their work by incorporating 20 tons of manure per acre and further improvement by soil ridging.

Stephenson and Schuster (4) in investigating some orchard soils in Oregon found 44 to 48 per cent total porosity and 11 to 17 per cent non-capillary porosity in a sample of Willamette silt loam. The same authors found for a sample of Newberg loam about 54 per cent total and 15 per cent non-capillary porosity in the surface 6 inches. They reported greatly decreased pore space in cultivated orchards as compared to non-cultivated. A sample of uncultivated Newberg silt loam which they were investigating had 64 per cent total and 30 per cent non-capillary porosity. Under cultivation this was reduced to 50 and 3 per cent respectively. Powers (3) noted 52.5 per cent total and 21.0 per cent non-capillary porosity in a sample of Chehalis fine sandy loam.

Veihmeyer and Hendrickson (5) working with some California soils made compaction tests on soils of the Bale, Yolo, and Madera series on which sunflowers were grown as the test crop. They found no growth of roots in Bale and Yolo soils when compacted to a density of 1.8 and only a minor amount of root growth in the Madera soil with a density of 1.75. However, they found that roots seemed to extract water about normally from a Holland soil when compacted to a density of 1.8.

METHODS OF INVESTIGATION

Field Experiments

In 1947, field trials were made with four tillage operations and two rates of manure, and in 1948, six tillage operations were used to determine their effect on soil pore space and tap root penetration. The tillage operations were in randomized block design with 6 replications. In both 1947 and 1948, the tillage operations consisted of: (1) shallow spring-toothing,

(2) duck foot shovels operated about 8 inches deep, (3) chisel points operated 8 to 9 inches deep directly beneath the row location, in 24-inch spacing, (4) rotary tillage to a depth of 8 to 9 inches. In 1948 only, there were two additional operations of: (1) shallow discing and rolling, and (2) chisel points operated 8 to 9 inches deep on 12-inch spacing. Where the chisel points were used the fall fertilizing was placed at the bottom of the tillage before seeding. In all other operations the fall fertilizer was side dressed at the first cultivation.

TABLE 1. Effect of Tillage and Manure Treatment < Pore Space of Chehalis Sandy Loam Soil.

		Pore space in soil		
	Soil	Total		Non-capillary
Tillage treatment	depth	fall	spring	spring
	(inches)		(percent)	
. Shallow springtoothing	1-3	51.2	47.2	8.2
	4-6	49.0	44.7	5.7
	6-8	47.7	44.2	5.2
2. Rotary tilled	1-3	53.2	52.0	15.0
	4-6	52.7	52.0	13.0
	6-8	52.2	51.0	12.0
3. Rotary tilled following tractor wheels	1-3	—	48.0	9.0
	4-6	—	47.2	8.2
	6-8	—	49.0	10.0
4. Manure at 10 tons/acre	1-3	—	52.6	13.6
	4-6	—	50.6	11.6
	6-8	—	46.8	7.8
5. Manure at 10 tons/acre following tractor wheels	1-3	—	49.0	10.0
	4-6	—	49.6	10.6
	6-8	—	46.0	7.0
6. Manure at 100 tons/acre				

For the spring fertilizer treatment, the tillage plots were divided and on one portion the spring fertilizer was broadcast and irrigated into the soil, while on another portion the fertilizer was side dressed at 4 to 5 inches deep.

Tests for porosity were made for some of the treatments in the fall and again in the spring. The spring tests were made both in the wheel tracks of the cultivating tractor and in the row where there were no tracks. Only spring tests were made for the manure plots since this product would not be expected to produce an immediate effect.

Greenhouse Trials

With a view to determining what degree of compaction in these soils would prevent sugar beet root development, Chehalis sandy loam was placed in greenhouse pots and compacted by hand tamping small portions at a time to make the whole mass as uniform as possible. Conditions were made for total porosity of 42.5, 45.5 and 53.5 per cent respectively. This represented approximately 3.5, 6.5, and 14.5 per cent non-capillary porosity, or a density of about 1.95 for the most compact condition and 1.85 for the medium compaction. Similar pots were filled with Willamette silt loam and tamped to provide four degrees of porosity of about 46.5, 50.7, 57.2, and 62 per cent. These represented respectively about 7.5, 11.7, ,18.2, and 23 per cent non-capillary porosity. Five replications of each treatment were made. Beet seed was planted on the surface of the soils, covered lightly with sand and permitted to germinate. A single plant was grown in each pot to a size of one-half to 1 inch diameter of the main root. The pots were then dumped and the soil carefully washed away to expose the root systems. Figure 2 shows some of the conditions observed.

EXPERIMENTAL RESULTS

Field Trials

Porosity studies—The rotary tillage treatment was especially helpful in relieving soil compaction in the surface 8 inches and provided conditions for excellent root penetration and distribution to this depth. Beet top growth was noticeably better on this treatment than on the shallow worked soil during the fall growing period. Deep chiseling directly under the row with the fall fertilizer placed at the bottom was only slightly less effective than rotary tillage. The better tilth of the rotary tillage treatment persisted through the winter rains.

Manure at 10 tons per acre disced into the surface provided good tilth in the surface 3 to 6 inches but the effect did not extend much deeper. This treatment made very little difference in the fall growth of beets. Manure at 100 tons per acre improved the tilth to a depth of 6 inches or more. Beets made very good fall growth on this, probably due to the extra nitrogen carried by such a large quantity of manure.

Driving tractor wheels over the rotary-tilled soil when in moist condition resulted in compacting the surface 3 to 6 inches to about the original tilth. However, the 6 to 9 layer remained in good condition following such compaction. Table 1 gives some data on porosity in these soils under the different tillage treatments.

Seed yields—All of the deeper tillage treatments which provided better soil aeration resulted in some improvement in seed yield. This effect was a little more obvious in 1947 than in 1948, as shown in Table II. Differences in seed yield from the manure plots would, of course, be influenced by the extra fertilizer value of the manure and consequently would not be a measure of the effect of this material as a soil conditioner. None of the tillage treatments resulted in severe compaction of the surface soil or serious inhibition of root penetration. However, such small yield differences as were obtained indicate the desirability of deep tillage for this crop.

Placing the fall fertilizer at the bottom of the 8-inch tillage cut directly under the row location resulted in better early fall growth of the beets but not in seed yield.

In the 1948 season, deep side dressing of the spring fertilizer produced about 8 per cent, or 200 pounds more seed per acre, than the same amount

Figure 2.

A. Left: Root development in Willamette soil 62.5% total porosity.
Right: Root development with only 46.5 percent total porosity.

B. Left: Beet root development in Chehalis soil with 45.5% total porosity.
Center and right: Root development with 53.5 percent total porosity.

of fertilizer broadcast on the surface and irrigated into the soil. Differences in seed yield due to fertilizer placement were less in 1947.

Greenhouse trials

Where either Chehalis or Willamette soil was compacted to a density of about 1.95 no roots penetrated it. Under medium compaction of density of about 1.8, the main tap root usually penetrated through the soil mass but there was very little feeder root development. With about 14 per cent noncapillary porosity for the Chehalis and 18 per cent for the Willamette soil and with density around 1.5, root penetration and distribution seemed to be unrestricted. The greater porosity of about 23 per cent non-capillary space in the Willamette soil did not materially further improve root growth. This condition was difficult to maintain with surface watering.

TABLE 2. Seed **Yields** Obtained **with** Varying Tillage and Fertilizer Placement **Conditions.**

	Seed per acre			
	1947		1948	
	Spring fertilizer placement			
Tillage treatment	Broadcast	Side dressed	Broadcast	Side dressed
	(pounds)			
1. Shallow springtoothing	1,348	1,335	2,460	2,640
2. Disced and rolled	-------	-------	2,500	2,740
3. Duckfoot shovels at 8" deep	1,580	1,751	2,560	2,820
4. Chisel points 8" deep	1,677	1,741	2,510	2,710
5. Rotary tilled 8" deep	1,405	1,568	2,660	2,890
6. Manure at 10 tons/acre	1,610	1,694	------	------
7. Manure at 100 tons/acre	------	2,043	------	-------
Placement means	1,525	1,614	2,538	2,760
Diff. for significance between placement means at 5% odds.	166		67	
Diff. for significance between tillage means at 5% odds.	317		143	

SUMMARY AND CONCLUSIONS

Chehalis sandy loam soil which had been compacted by conventional tillage operations to a point of only about 5 per cent non-capillary porosity in the plow depth could be improved considerably by deep tillage or with heavy applications of barnyard manure.

Results were characterized by better shaped tap roots, faster fall growth and a little improvement in seed yields.

Rotary tillage to 8 inches deep, duck foot shovel tillage to the same depth, or chisel points directly under the row were about equally effective in improving shape of tap roots and increasing seed yields.

The small differences secured in seed yields suggest that the shape of the main beet root is not as important for seed yields as where the root is harvested for sugar.

Compacting Chehalis sandy loam soil in greenhouse pots to a non-capillary porosity of 3.5 per cent restricted all beet root development. Feeder root distribution and development was much better with a non-capillary porosity of 14 per cent than with only 6.5 per cent.

In Willamette silt loam soil, beet root development was restricted when the non-capillary porosity was 11.7 per cent but was good at 18 per cent. These figures would likely not characterize all soils o£ these series since the amount of organic matter and other factors might alter conditions.

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