Effect of Soil Compaction on Development and Yield of Sugar Beets[1]

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The object of this study was to observe soil and crop effects of deliberate and severe soil compaction in field plots.

Sugar beets are known to respond to desirable physical conditions (5, 10)[3]. Cook (4) found that packing of greenhouse pots reduced yield of beets more than tomatoes and much more than corn, soybeans, wheat, or oats. Joritsma (7) has shown the influence of soil structure on germination and root development. Rietberg (9) discussed this and other work in Holland showing that soil structure affects sprangling. He also stated that their work showed a negative correlation between early development of fangy roots and final yield. Also sugar content of fangy roots was lower than roots of good shape. Rietberg pointed out the disadvantages of sprangled beets in terms of difficulty of topping, high tare, and handling problems in the factory. He stated that several pests and diseases such as blackrot and wireworm are associated with poor soil structure but that it is not clear whether this is due to stronger parasite development or weakening of the beet.

Farnsworth and Baver (5) have shown that on fine textured soil beet yield decreased sharply as "non-capillary" pore space dropped below 8 to 10%. Pendleton (8) got unrestricted root growth at 14% and 18% air space on two soils but greatly restricted growth at 6.5% and 11.7% on the same soils in greenhouse pots. He found improvement in the shape of taproots as "non-capillary" porosity increased in field trials. Gaseous diffusion measurements in soils have led to acceptance of a tentative limiting porosity in field soils between 10% and 15% (1, 11). At values below this, gaseous diffusion approaches zero and root damage may occur even if these values exist only for short periods (2).

Guilbert (6) raised, but did not answer, the question: "Is there a possible correlation between the sugar content (of beets) and the compactness of the soil?" He found that high penetrability, owing to drouth or root pressure, promoted synthesis of

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[3] Numbers in parentheses refer to literature cited.

sucrose. The question of whether high penetrability, or factors related to it, promoted sucrose synthesis is open to question as Guilbert indicated.

Methods

Plots were located at the American Crystal Sugar Company farm at East Grand Forks, Minnesota, on Bearden silty clay loam soil. This soil is formed on lacustrine sediments of prehistoric Lake Agassiz in the Red River Valley of the North. It is high in organic matter, 9.6%, decreasing with depth but extending 20-24 inches deep. It has excellent natural structure and, considering the flatness of topography and fineness of underlying sediments, internal drainage is generally good.

Sugar beets were grown in a rotation of potatoes, wheat-clover, clover-fallow, beets. Each crop appeared each year in a randomized block with six replicates. Recommended fertilizer rates were used uniformly on all plots.

The soil packing treatments were imposed on half of each plot each year before planting. In 1955 this consisted of surface packing by running a tractor weighing about 2800 pounds back and forth across the packed plots. A second treatment consisted of loosening the soil three inches deep in the bottom of each plow furrow. The check plot had neither packing nor loosening.

In 1957 and 1958 half of each plot was surface packed with a partially loaded truck driven across the plowed soil so as to cover the whole surface twice. The truck had a rear axle load of 15,010 pounds with an estimated applied pressure at the soil surface of between 60 and 100 pounds per square inch. The soil surface was dry and loose when packed but was essentially at field capacity below the surface few inches. After packing, the soil was dragged lightly before planting.

Regular field equipment was used for seedbed preparation, planting, and cultivating. At harvest, beets were hand topped after loosening with mechanical digger.

Aggregation was determined by a single-sieve wet sieving procedure. Air permeability was measured through metal cans driven into the soil. These were removed after the measurements for use in laboratory determination of porosity at 60 cm. tension and for bulk density by wax coating. Penetrometer determinations were made with a recording penetrometer.

Results and Discussion

Sugar beet yields were lowered by surface soil packing in both 1957 and 1958 (Table 1). In 1957 this amounted to 1.7 tons and in 1958, 4 tons per acre. The nearly three tons per acre average reduction on packed plots represented a 13% yield decrease.

Table 1.—Effect of Surface Soil Compaction on Sugar Beet Yields (T./A.)

Year	Not Packed	Packed	L.S.D. .05	L.S.D. .01
1957	23.5	21.8	NS	
1958	19.7	15.7	2.3	3.6

Only in 1958 was the yield reduction statistically significant at p. 0.05. However, in 1957, one replicate of six showed a higher yield (one T./A.) for compact soil. This is believed accounted for by the much higher population in this replicate with 31,100 vs 25,626 harvestable beets per acre. Over-all stand was not significantly different due to packing either year. On the other hand there may have been an accumulative effect of packing on yield due to annual packing, resulting in the greater yield decline on pack soil the second year.

Packing the surface soil much less severely in 1955 gave no yield differences. Nor did loosening the soil three inches in the bottom of each plow furrow affect yields over a nonpacked and nonloosened check.

Table 2 shows the extent to which packing affected soil physical properties when measured in midsummer. Percent

Table 2.—Effect of Surface Soil Compaction Prior to Planting on Soil Physical Properties in Late Summer.

Property	Not Packed	Packed	L.S.D. .05	L.S.D. .01
	1957			
Aggregation, %	15.8	16.0	NS	
Bulk density, gr./cc.	1.02	1.17	.03	.05
Aid permeability u^2	54.1	12.8	28.5	
Porosity, %, 60 cm. suction	14.9	8.4	1.4	2.3
Penetrability, lbs./inch^2				
6 inch depth	916	1160		**
10 inch depth	935	1175		**
	1958			
Aggregation, %	11.4	9.9	NS	
Bulk density, gr./cc.	1.06	1.16	.04	.07
Air permeability, u^2	5.56	1.26	NS	
Porosity, %, 60 cm. suction	13.6	9.4	1.14	1.8
Cloddiness ratio*	0.42	0.57	0.15	
Penetrability, lbs./inch^2	54	105	10.6	16.6

*Ratio of clods to fines determined by 8 mm. sieve.

**Significant difference at .01 level.

aggregate stability was unaffected by the treatment. It is lower in all cases in this soil than one would expect from the high organic matter content. Nor did soil tilth appear to be poor probably due to flocculation resulting from a high $CaCO_3$ and $CaSO_4$ content (3).

Bulk density in the 1 to 4 inch layer was highly significantly affected by compaction. It averaged in the two years 1.04 and 1.17 for non-packed and packed plots respectively (Table 2). Subsequent studies have shown that packing affected bulk density to at least 18 inches. Air permeability in the 1 to 4 inch layer was lower each year on packed plots but was significantly lower only in 1957.

Porosity at 60 centimeters moisture suction, roughly equivalent to "capillary" pore space, was lower at the .01 level both years (Table 2). Averages for the two years show a reduction from 14.3 to 8.9 percent from packing. It has been shown (1, 11) that 10% to 15% air space is a threshhold for aeration. The shock due to lack of air at critical periods, when air space was lowest due to rain, possibly accounts for the lower yields on packed soil. Furthermore, the time, following rain, for air space to reach the critical 15% level would be greater on packed plots.

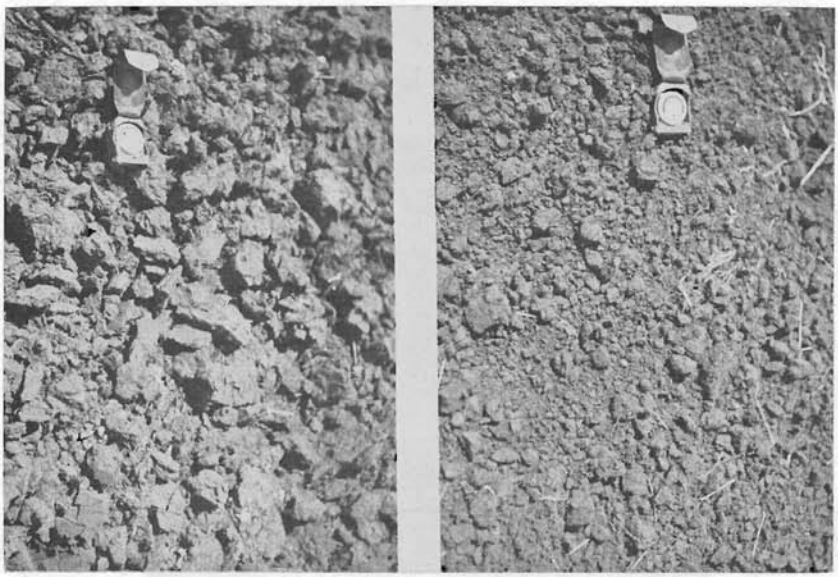

Figure 1.—Seedbed after plowing packed plot, left, and nonpacked plot right. Soil in left photograph had been packed 14 months and two months previously. Both were plowed and dragged just before photographs were made.

Penetrometer measurements show higher values on packed plots significant at the .01 level. Packed plots had a higher percentage of large clods in April 1958 (before 1958 packing) even after the wetting-drying and freezing-thawing action of the severe winter. Figure 1 shows a comparison of the soil surface of packed and nonpacked plots following plowing of sweet clover June 19, 1958. The packing treatment had been imposed in 1957 in a wheat crop and again in April 1958. Both were plowed and dragged just prior photographing. The unfavorable seedbed would be expected to seriously affect beet stands except for the fact that sugar beets were planted only after the cloddy surface weathered a year after packing.

Table 3.—Effect of Surface Soil Compaction on Sugar Beet Sprangling

Year	Not Compacted	Compacted	L.S.D. .05	L.S.D. .01
		Percent by Number		
1957	19.3	34.9	8.9	14.0
1958	15.3	38.5	4.5	7.1
		Percent by Weight		
1957	19.0	36.2	10.2	16.0
1958	18.2	41.5	10.7	16.8

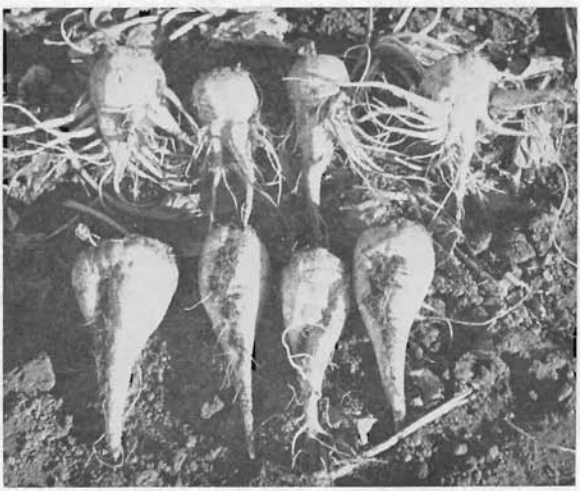

Figure 2.—Selected beets showing typical sprangled and non-sprangled beets.

Sprangling was noticeably more severe on packed plots (Table 3). Both percent by weight and number were higher on packed plots. A lower percent by weight than by number of sprangled beets would be expected if sprangled beets weighed less per beet. There is no indication that this is true. Figure 2 shows selected beets from packed and nonpacked plots.

Table 4.—Effect of Surface Soil Compaction on Percent Sucrose in Sugar Beets.

Year	Not Compacted	Compacted
1957	14.6	14.5
1958 Sprangled	17.6	17.6
Not Sprangled	17.9	17.7

Packing had no significant effect on percent sucrose in beets (Table 4). However, a separation of sprangled and nonsprangled beets gave an indication that sucrose content of sprangled beets may be slightly lower than nonsprangled. This effect, if real, confirms the finding of Rietberg (9) but is opposite to that inferred in the question raised by Guilbert (6).

Summary

Severe packing of the soil surface before planting reduced air permeability and percent of air-filled pores at 60 cm. moisture tension when measured in midsummer. Air space porosity on packed plots was lower than a commonly accepted threshhold value indicating this may have been a deciding factor in lowering yields and causing sprangling.

Sprangling was much higher on packed plots. Also sprangled beets had slightly lower sugar content though this was not statistically significant for packing treatment. Over all, beets on packed plots had a sucrose percentage about equal to those on nonpacked plots.

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