EFFECT OF CULTURAL TREATMENTS ON INFILTRATION RATE
AND RELATED PHYSICAL PROPERTIES OF A
GRAPEFRUIT ORCHARD SOIL IN
THE SALT RIVER VALLEY

by

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INTRODUCTION

All of our production practices must be continually examined in order to determine to what degree the food, which we seek to produce, may be obtained without exposing the soil to some form of deterioration. One characteristic of the soil, the vulnerability of which was formerly underestimated but which is now receiving an increasing attention, is the structure of the soil, which is dependent upon management practices and which itself affects the physiological responses of plants as well as related chemical and physical properties of the soil.

Thus, one should approach any management practice with a full understanding and appreciation of the importance placed upon the maintenance of a good soil structure or a satisfactory arrangement of the soil particles, both primary and secondary (3). This satisfactory arrangement of the soil particles, being related to the number, size, distribution, and configuration of the voids in the soil, leads to an intimate association with certain soil phenomena, such as aeration and the movement and storage of water.

Striving towards better soil management, the farmer as well as the soil scientist have been carrying on in practice and on an experimental basis the following main soil management practices.

Non-Tilled Weed-Control by Chemical Sprays. This method probably began with weed-control by oil along highway rights-of-way. Oil, which was once thought to injure soil for plant growth even in light application,
was found to be of no danger at all. Donnelly et al. (14) reported of organisms living in soils, which use oil as food. Hence, the normal light applications employed in weed-killing are not likely to result in a build-up of oil in the soil. Workers of the California Extension Service report a generally improved water penetration and reduced erosion in an orchard placed under non-tillage and oil-sprayed weed-control. Hilgeman (24) reports superior fruit production from trees of non-tilled oil-sprayed weed plots.

The above discussed method is now spreading rapidly in all citrus growing areas of the U. S. and the rest of the world.

Non-Tilled and Perennial Cover Cropping. A perennial cover crop, generally composed of a pure stand of Bermuda grass, is allowed to grow throughout the year. The grass is mowed periodically to keep it from climbing the skirts of trees. Perennial cover cropping undoubtedly eliminates soil erosion and maintains a desirable soil structure, but the system has several disadvantages. Donnelly (14) reports that the rodent damage is increased, and severe water competition is introduced because the peak demand for water by the tree and the cover crop come at the same time of the year, that is in summer. Hilgeman (24) reports a significant fruit production decrease from trees of non-tilled and perennial cover cropped plots.

Weed-Control by Tillage and Cover Cropping. This system is used in one form or another. Summer weed growth is controlled by tillage, generally with a heavy double-disc or spring-tooth harrow. The basic reasons for cover cropping are improvement of soil structure and to a certain ex-
tent erosion control by using the cover crop as green manure. The long-term trend in this system has been to eliminate all forms of deep tillage and also reduce tillage to a minimum. This system is considered to have one drawback. Stirring and compaction by tillage produces a plowsole which slows any movement of water and also reduces the effective root zone of the trees.

Continuous Tillage. This method has been the most prominent one through the past hundreds of years. It has been practiced to a much smaller extent since the realization of all factors concerned of the rapid deterioration of orchard soils and accordingly the reduced yields produced by orchards under this system. Continuous tillage throughout the major part of the year is carried on by a great variety of plows, discs, harrows, etc. The two main reasons for practicing continuous tillage are to control weeds and to promote a satisfactory rate of infiltration.

This system is now considered to have serious drawbacks because it promotes plowsole formation and a deterioration of the soil upper layer's structure.

Any one of the above mentioned soil management practices might prove to be a major factor in the deterioration or the improvement of soil structure. In some of the practices, soil is cultivated or tilled while in others the soil is not tilled.

Many are the reasons attributed to soil cultivation. Bayer (3) and Harris et al (21) summarize the important reasons for cultivation to:

1. The eradication of weeds.

2. The control of erosion.
3. The introduction of the different organic and inorganic fertilizers and amendments to the soil.

4. The increased infiltration of water.

Other workers, especially in the past 20 years, have recommended new management practices that will eliminate soil cultivation. These workers have claimed that: 1. The eradication of weeds is not essential in orchards especially if a permanent sod is allowed to establish itself. In case the eradication of weeds is found to be essential, it can be done with oil-sprays. 2. Erosion is almost completely prevented when a permanent sod covers the soil. If the weeds are controlled by oil-spray, the soil is exposed to elements that promote soil erosion. 3. Fertilizers can be introduced by way of irrigation water.

Thus, out of the above mentioned pros and cons of cultivation or non-cultivation management practices, the most important point remaining to be established is the effect of the soil management practice on the increased infiltration of water.

Infiltration is designated as the downward water flow from the soil surface into the surface soil (27) or in practice the rate of water entry into the soil.

Factors governing the entry of water into a system as complex as the soil are very involved. The rate of water infiltration into the soil is a variable rather than a constant factor, changing within the soil profile. These changes chiefly relate to the structure of the soil, but also to such factors as air, water, and soil temperature, soil moisture content and the biological activity. All of these factors will
vary seasonally or during the course of a single storm or irrigation.

Despite these facts, the relative infiltration rate of water into the soil is chiefly associated with such physical properties as its degree of aggregation, total porosity, non-capillary porosity, bulk density, and others.

Being related as such, a knowledge of the infiltration rate of the soil could lead the farmer or the soil scientist to a better understanding of the soil profile and moreover to a well adjusted soil management practice based upon the soil's physical properties.

A knowledge of infiltration rates and the factors influencing it are of prime importance in the establishment of any rational irrigation practice which must consider not only the infiltration rate at a particular time, but also the probable influence of cultural practices on future infiltration rates. It is not an uncommon experience to find a farmer irrigating his field and assuming he has given it sufficient water, where as the soil may be wet only to a shallow depth. A sound soil management practice which will include a basis for a better and more economical irrigation, must promote a better infiltration rate.
PURPOSE OF THE INVESTIGATION

At present, the State of Arizona has 19,000 acres in citrus orchards growing under the favorable localized climate and soils.

These orchards, grown mainly in the Salt River Valley and on the Yuma-Mesa, are being cultivated under different management practices. However, some of these orchards have been showing signs of decline related to several factors, one of them being the deterioration of the soil structure.

The effects of the different cultural practices on citrus trees are under investigation by the Citrus Experiment Station of the University of Arizona. Nevertheless, these investigations, in particular the one carried on at the Tempe Citrus Farm, were not followed by studies of the changes occurring in the soil under the various cultural practices.

It was the purpose of this investigation to study the effect of different cultural practices on soil structure, which is considered to be a very important factor in the growth behavior of citrus.

Infiltration rate of irrigation water into the soil was chosen as the criterion of soil structure. In addition to its value as such, the infiltration rate is of prime importance in the irrigation practice of the Arizona farmer, who always faces a shortage of water. Thus, any deterioration or improvement in the soil structure bears its influence on the behavior of the citrus tree as well as on the efficiency of the irrigation practice.
Physical properties of the soil that could lead to a better understanding of the different infiltration rates were examined. It was the purpose of this part of the investigation to find at what depths in the soil profile the rate of infiltration of water is being affected by the cultural practices employed.
Different criteria for the evaluation of soil structure have been used by investigators; the percentage of soil aggregates (57), the total porosity (36), the ratio of non-capillary to capillary pore space and others have been used with relative success. Buehrer (11) in his work on the movement of gases through the soil as a criterion of soil structure states,

"that only such spaces or channels in the soil which permit relatively free movement of air or soil solution are of importance in plant nutrition. The capillary pores are of little importance in so far as the mechanism of feeding by the root is concerned because of the difficulty of their penetration by the root and also because water as well as nutrients contained in such capillary pores are not available to the plant. From the standpoint of aeration and water movement, the capillary pore spaces offer so much more resistance to the flow of these fluids than the non-capillary pores, that their participation in the mechanism of soil processes, as compared with the latter would appear to be very slight if at all appreciable".

Buehrer explains,

"the difficulty of interpreting data on actual soil structure in terms of a physical phenomenon which is itself a function of structural characteristics. Structural features resulting from particle arrangement determine in large measure the rates of flow of fluids as well as the rates of other processes; thus, the converse reasoning might be equally valid, namely that the property of resistance-to-flow might be employed to determine relative structure."

Buehrer (11) developed a method by which flow of air through soil can be used as a criterion soil structure.

Other workers with a clear view of the importance of infiltration
rates in relation to soil structure have given positive recognition of the physical principles involved in the water movement into the soil. Slater (46) explained the phenomenon of soil water movement as a result of the combined forces of gravitation and capillarity: flow of water even through a wet soil takes place under tension or negative pressure. Water tends to move from areas of low tension to higher ones. Bodman and Colman (5) have suggested that the moisture potential within the infiltration zones represent the fundamental factor influencing the change in the infiltration rate in relation to time. Different factors were cited as modifying influences on the decrease of infiltration rate in relation to time. Duley and Kelly (15) have found one of the factors to be the gradual compaction of the soil surface under the impact of water. Horton (25) has blamed inwashing of colloids, soil swelling, and surface compaction, while Baver (4) and Powers (44) found the compression of air in the soil pores below the wet zone as another factor attributed to the decreasing infiltration rates in relation to time.

Fletcher (18) in determining the infiltration rates of dry soils defined the properties of water solutions that influence infiltration rates. He found the following relationships: Viscosity decreases hyperbolically with infiltration rate; pore size increases infiltration rate parabolically; and temperature increases the infiltration rate linearly. In the discussion following Fletcher's presentation (18), Aronovici said that it appears to be questionable logic to isolate any single principle of water movement into and through the soil and apply it to actual conditions.
Edlefsen (18) explains that when water is first applied to a field plot, the rate of infiltration is comparatively rapid and gradually decreases with time to an asymptotic or approximately steady value which seems to be more or less characteristic of the plot at the particular time. Hence, it seems difficult to choose any particular point on the infiltration rate curve as a function of time as having any particular meaning other than the asymptotic or "steady" value. The difficulty with using this value, however, is that it is only reached after considerable time. The time required to reach the steady rate is usually longer than required for an ordinary irrigation water to penetrate into the soil.

Many workers have emphasized in their writings the close and important relationship between the infiltration rate and the physical characteristics of soils.

Free et al (19) related the physical characteristics of certain soils to their infiltration rates. They chose 63 sites representing 39 soil series and 6 of the great soil groups. The sites were distributed in all humidity provinces from wet to arid and all of the precipitation provinces. Results of their extensive work are summarized in Table 1.

The results of this work show a definite correlation of infiltration rate with all indices associated with large pores or with those factors affecting pore size. Non-capillary porosity, degree of aggregation, organic matter, and amount of clay in the subsoil in particular were found to be determinants of infiltration rate. Similarly those factors that determine the permanency of large pores, such as dispersion and suspension
Table 1. Correlation coefficients\(^1\) of certain soil characteristics
(After Free et al) (19)

<table>
<thead>
<tr>
<th>Aggregation</th>
<th>Volume</th>
<th>Total Porosity</th>
<th>Non-capillary porosity</th>
<th>Organic Matter</th>
<th>Moisture Equivalence</th>
<th>Dispersion</th>
<th>pH</th>
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<td>&gt; 0.20 mm.</td>
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Surface Soils

| 0.30 | -0.24 | 0.24 | 0.36 | 0.50 | 0.02 | -0.29 | 0.16 |

Subsoils

| 0.07 | -0.33 | 0.36 | 0.54 | 0.40 | -0.30 | -0.03 | 0.16 |

\(^1\)Value of r at the 1-per cent point (odds 99 to 1) is 0.31; at the 5-per cent point (odds 19 to 1) is 0.24.
ratios, were found to be closely associated with infiltration rates. Free et al. (19) indicate in their study that the maintenance or the increase of infiltration rate of field soils can mainly be achieved in the following ways: Incorporation of organic matter and its maintenance at a reasonably high level and soil management that will tend to increase the degree and the stability of aggregates and to reduce the turbidity of water flowing over the soil.

The conclusions of other investigators working throughout the years are substantially the same as those of Free et al. Yung (58) found a close correlation between changes brought about in the physical properties and the actual measurements of water infiltration, runoff, and moisture content in the profile. Yung's results showed that a permanent sod on orchard soils was associated with the highest organic matter content and greatest structural stability and permeability in the surface 3 inch layer. This resulted in excellent infiltration rates. Alderfer and Merkle (1), Burr and Russel (12), and Jenny (29), all attach great significance to the influence of organic matter upon the development of good soil structure that leads to reasonable infiltration rates.

Pillsbury and Huberty (42) also found great beneficial effects of organic matter application. They also point out that the retarding effect of water infiltration is confined in the main to the surface soil.

The beneficial effect of organic matter as a vegetative cover, both living and dead, on the infiltration rates of soils has been studied by many workers (15), (1), (6), (10), (53), (23), (34). Their studies have clearly demonstrated the effect of surface application of mulching ma-
terial and dense vegetative cover on greatly increased infiltration rates and correspondingly reduced rates and quantities of runoff and erosion.

Uhland (50) showed the correlation between porosity and infiltration rate and also the increase of porosity and infiltration rate in relation to crops having a well developed root system, such as alfalfa. The same was found to be true for crop residues that were kept on the soil surface.

Johnson et al (31) determined the influence of different cropping systems on the size distribution of soil aggregates, and found that a good vegetative cover maintains a great number of large sized aggregates and a high percentage of non-capillary pores that usually bring about a high infiltration rate.

Havis (22) (23) reported on the aggregation of a Wooster silt loam that had been mulched with straw continuously for 44 years in an apple orchard. He found the mulched soil to be more aggregated than the soil under blue grass. Havis also showed that the organic matter content, total porosity, and rate of water permeability of the surface soil was higher in the mulched soil than for the soil in blue grass sod. Both of these orchard treatments were superior in each of these soil qualities to that of the cultivated soil where the aggregates were broken into smaller particles.

Sudds (48) compared cultivated with undisturbed sod covered orchard soils in West Virginia. He found that cultivation has significantly reduced the organic matter content, the percentage of the larger sized
aggregates, the non-capillary porosity, and the infiltration rate; it has increased the volume weight and the dispersion ratio. Permanent straw mulch on the soil had significantly increased the infiltration rate in comparison with cultivated soils. Sudds' data emphasize the importance of protecting the soil surface with vegetation or with ample organic mulches that form adequate protection against mechanical compaction, as well as protection from the dispersive action of the water as it falls on or flows over the surface soil.

Parker and Jenny (41) emphasize the fact that growers of citrus and other fruits in California face the difficulty in obtaining satisfactory penetration of irrigation water. They summarized as follows:

"Water infiltration is good in young orchards, especially in those on land not long in cultivation, but within the few years after the orchard was planted, the infiltration capacity of the soil often declines. Such unfavorable developments seriously effect the management practices as well as the performances of the orchards".

Results of their work indicate that the water infiltration rate is directly related to the quantity of organic matter applied to the soil. The differences in water infiltration rate were found to be corroborated by differences in resistance values (the energy, in foot lbs. per inch, required to force a sampling tube into the soil) and apparent densities of the soil. Cultivation practices and traffic in the orchard brought about lower rates of infiltration and greater compaction, especially at a depth of 6 to 12 inches. Elimination of all cultivation in conjunction with the growing of any cover crops produced marked improvement in water infiltration, and a decrease of resistance values as well as a decrease
in apparent density during a period of 8 years.

Inspite of the continued and extended use of the oil-sprayed non-tilled practice, few critical long term experiments have been made in which the tree and soil characteristics have been studied in detail. A great part of the information available has been obtained by surveys made by workers of the California Extension Service. The most noticeable influence reported has been the increased rate of water infiltration.

Kimball et al (32), La-Rue (35), Moore (39), Johnston and Sullivan (30), and others report that non-tillage resulted in a high infiltration rate and also in about twice as many rootlets in the surface foot of soil as was the case in the tilled soil.

Miller (38) observed that the infiltration rate of a sandy loam soil which had been planted to lemons for almost 40 years had been reduced significantly between rows where diskig or other cultural practices took place. Infiltration rates at an orchard where the non-tillage system has been practiced for 5 years were found to be low between rows as a direct result of orchard traffic.

Swanson and Jacobson (49) investigated changes in soil properties as a result of two different management practices, cultivation and non-cultivation. They found that cultivation improves soil tilth as measured by an increase in total and macroporosity, and a decrease in microporosity and volume weight in the surface two inches in comparison with the non-cultivated soil. The non-cultivated surface soil was packed by the raindrops forming a crust. This crust was broken by cultivation,
allowing air and water to enter the soil.

Williams (55) reported on a marked decrease in water penetration rate on a non-tilled vineyard soil. This decrease was explained by the traffic sole that included 30 per cent of the surface that was compacted to such an extent that the percolation rate through the surface soil was negligible. When the top soil was removed, the infiltration rate of the non-tilled soil was found to be much higher than that of the tilled soil because of the compacted sub-surface layer formed by the tillage implements.

Frith (20) found that trees from weed-control oil-spray plots gave increased yields over other plots, while the infiltration rate was significantly decreased in all oil-spray plots.

Pillsbury and Richard (43), Stephenson and Schuster (47), Moser (40) and others found that the infiltration rates progressively increased as the amounts of organic matter increased. Weed-control oil-spray soils had smaller infiltration rates than those covered with permanent sod.

Duley (16), Huberty and Pillsbury (26), Free (19), and Martin (37) have demonstrated that the condition of the soil surface is the principle factor affecting infiltration rates in uniform soils, frequently more important than the soil type itself. Knight (33) demonstrated the importance of the soil surface in regards to aeration and infiltration of water. Penetration of alfalfa roots followed the well developed cleavage planes, root and worm holes, and other natural passages within the soil. Bayer (3) and Boynton and Reuther (8) found that in dense and compact layers there is little penetration of roots except along the cleavage channels. There is likewise a very restricted air capacity
and drainage of free water.

Weaver (54) and Jamison (28) demonstrated the increase in compaction effects caused by farm tractors and heavy machinery in tillage, harvesting and other farm operations. They found that maximum compaction of Cecil clay and Davidson loam under tractor tires occurred at a moisture content which is optimum for plowing. They also found that tracks made by an 11-38 U. S. Royal Farm Tractor compacted the soil, as shown by bulk density measurements, on a 15-inch width and to a depth of 10 inches.

Diebold (13) suggests that the degree of compaction of limiting layers in the surface foot is a major factor affecting infiltration rates. Diebold found that both tillage pans and travelling farm machinery were responsible for formation of compacted layers.
DESCRIPTION OF EXPERIMENTAL PLOTS

The staff of the Citrus Experiment Station of the University of Arizona in the Salt River Valley is studying the effect of four different cultural practices and three types of fertilization upon trunk growth, yield, and fruit size of grapefruit trees.

The experiment that was set up for this study included the following:

I. Cultural treatments:
   A. Weed-control oil-spray (See Plate I)
   B. Weed-control mow and disc
   C. Weed-control deep-disc (See Plate I)
   D. Permanent sod (See Plate I)

II. Fertilization treatments:
   1. 200 lbs. manure per tree per year
   2. 3 lbs. ammonium-nitrate per tree per year
   3. 10 lbs. ammonium-phosphate (11-48) per tree per year

The current investigation was limited to the cultural treatments A, C, and D and to the fertilization treatment Number 2.

Plan of Experimental Plots*

Each of the above mentioned cultural treatments is replicated in three different plots (1, 2, and 3).

A cultural treatment plot consists of five rows, two of which are the bordering guard rows. All the results relating to the behavior of

*See Figure 1.
PLATE I.  VIEW OF ORCHARD UNDER DIFFERENT CULTURAL TREATMENTS.
the trees under the different cultural treatments are based on the behavior of the three middle rows that are separated from the neighboring treatments by the two guard rows.

The cultural treatment plots were 154 ft. long and 88 ft. wide. The spacing of trees was 22 ft. x 22 ft., providing four borders per plot and seven trees in each plot row.

The plan of the project was revised in 1949 so as to make it possible to analyze the results statistically. The major changes introduced left but a few plots unchanged and the current investigation was limited to these original plots only. Thus, the following plots were chosen for this investigation.

Weed-control oil-spray----plot A3 (Rows 22, 23, and 24--Trees 1-7)
Weed-control deep-disc-----plot C1 (Rows 6, 7, and 8--Trees 1-7)
Permanent sod-------------plot D2 (Rows 14, 15, and 16--Trees 1-7)

Each cultural treatment plot included the three different fertilization treatments. The fertilization treatments were applied to one-third of the total number of trees under each cultural treatment.

**History of Experimental Plots**

The trees were planted in 1931, but the orchard was purchased by the citrus growers in the Salt River Valley and presented to the University of Arizona in 1942.

The weed-control oil-spray plot was disked four times per year throughout the period of 1931 to 1944. In 1945 it was disked once and since then weeds have been controlled by spraying with oil five to six times per year.

Movement of motorized machinery in the plot consisted of the oil spraying
Figure 1. - DIAGRAMATIC PLAN OF BLOCK "C", UNIVERSITY OF ARIZONA CITRUS EXPERIMENT STATION, TEMPE

A - Weed-control oil-spray plot
B - Weed-control mow and disc plot
C - Weed-control deep-disc plot
D - Permanent sod plot
O - Tree
"Double ring"
Small field plot for infiltration study
Basin ridge
Pit

Rows 10-12
Rows 18-20
Rows 26-29
88'
equipment and other implements related to routine orchard activities such as tree spraying and fruit picking. (See Table 2.)

The weed-control deep-disc plot was disked three to four times per year throughout the period of 1931 to 1951. Biennial White Sweet Clover has been seeded and disked under throughout the period of 1952 to 1955. Weeds were controlled by 3 to 4 additional diskings per year. (See Table 2.)

The permanent sod plot was disked four times per year throughout the period of 1931 to 1942. In 1943 the plot was planted to Giant-Pairie grass, and from then on the soil was not disked. During the first three years the Giant-Pairie was mowed and raked with Bermuda grass gradually taking over to establish itself as a permanent sod. The Bermuda grass was mowed four to seven times per year, but was not removed from the plot. (See Table 2.)

Table 2. Example of cultural management of the plots for the year 1950.

<table>
<thead>
<tr>
<th>Weed-Control</th>
<th>Weed-Control</th>
<th>Permanent Sod</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil-Spray</td>
<td>Deep-Disc</td>
<td></td>
</tr>
<tr>
<td>Spray - Feb. 10</td>
<td>Disc - Mar. 21</td>
<td>Mow - Mar. 13</td>
</tr>
<tr>
<td>Spray - Mar. 17</td>
<td>Disc - June 12</td>
<td>Mow - Apr. 29</td>
</tr>
<tr>
<td>Spray - Apr. 11</td>
<td>Disc - June 12</td>
<td>Mow - June 8</td>
</tr>
<tr>
<td>Spray - May 10</td>
<td>Disc - Aug. 23</td>
<td>Mow - July 12</td>
</tr>
<tr>
<td>Spray - June 10</td>
<td>Disc - Oct. 25</td>
<td>Mow - Aug. 10</td>
</tr>
<tr>
<td>Spray - July 17</td>
<td>Disc - Oct. 25</td>
<td>Mow - Sept. 19</td>
</tr>
<tr>
<td>Spray - Aug. 8</td>
<td>Disc - Oct. 25</td>
<td>Mow - Oct. 23</td>
</tr>
<tr>
<td>Spray - Oct. 20</td>
<td>Disc - Oct. 25</td>
<td></td>
</tr>
</tbody>
</table>

Irrigation for all plots, 3/7 to 11/6: 11 irrigations, 62 acre-inches
Irrigation of Experimental Plots

Water was applied in well ridged and uniform borders or modified basins, with a slope of 1 inch to 100 ft. The amount to be applied in the specific irrigation is usually diverted to the basin and is held there until all of it enters the soil. On the average, 60 acre-inches of water are applied each year, partly through full irrigation of each basin and partly through a system of alternate basins. (Sometimes all the borders are irrigated while at other times only alternate basins are irrigated.) This system is thought to be more economical and beneficial for the trees.

Results Reported by the Citrus Experiment Station*

Trunk Growth: While there were no significant statistical differences in trunk growth which could be associated with the different cultural treatments, there was a tendency toward a reduced rate of trunk growth of the trees on the permanent sod plot (D2). This conclusion is based on the trunk growth during the years of 1949 to 1954.

Yields: As the course of the experiment progressed, the trees of the permanent sod plot (D2) have gradually produced relatively less fruit. Trees from the two other treatments produced significantly higher yields, but did not differ much one from the other. There was no significant difference in fruit size. (See Figure 2*)

* Unpublished data.
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year</th>
<th>'43</th>
<th>'44</th>
<th>'45</th>
<th>'46</th>
<th>'47</th>
<th>'48</th>
<th>'49</th>
<th>'50</th>
<th>'51</th>
<th>'52</th>
<th>'53</th>
<th>'54</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weed control (deep disk)</td>
<td>Fruits</td>
<td>311</td>
<td>262</td>
<td>241</td>
<td>138</td>
<td>610</td>
<td>412</td>
<td>212</td>
<td>136</td>
<td>875</td>
<td>552</td>
<td>208</td>
<td>754</td>
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<td></td>
<td>Boxes</td>
<td>7.1</td>
<td>6.4</td>
<td>5.9</td>
<td>1.2</td>
<td>2.0</td>
<td>12</td>
<td>8.6</td>
<td>12</td>
<td>6.5</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent sod (Dg)</td>
<td>Fruits</td>
<td>227</td>
<td>205</td>
<td>79.6</td>
<td>54.2</td>
<td>218</td>
<td>128</td>
<td>246</td>
<td>406</td>
<td>161</td>
<td>632</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Boxes</td>
<td>7.1</td>
<td>6.2</td>
<td>1.7</td>
<td>3.9</td>
<td>2.4</td>
<td>1.4</td>
<td>2.1</td>
<td>1.2</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Weed control (oil spray)</td>
<td>Fruits</td>
<td>263</td>
<td>252</td>
<td>195</td>
<td>449</td>
<td>430</td>
<td>134</td>
<td>919</td>
<td>521</td>
<td>270</td>
<td>51</td>
<td></td>
<td>1.0</td>
</tr>
<tr>
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<td>Boxes</td>
<td>4.8</td>
<td>4.4</td>
<td>3.3</td>
<td>10.3</td>
<td>9.8</td>
<td>12.4</td>
<td>9.3</td>
<td>11.4</td>
<td>5.1</td>
<td>12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2.** Grapefruit yields for the years 1943-54 from trees of different cultural treatments.
Soil Profile Description

The typical Adelanto soil profile from block "C" of the Citrus Experiment Station at Tempe, where the current investigation took place is described below.

0-7 inches-------A calcareous light brown loam with plowsole at an average depth of 7 inches. The depth varies with the cultural practice.

7-15 inches-------A gritty fine sandy loam. Calcareous but contains no segregated lime.

15-22 inches-------A calcareous fine gravelly sandy loam weakly cemented with silica. Occasionally large gravel is found.

52-60 inches-------Similar to above layer but stratified with more fine gravel. Lime is both disseminated and segregated.

There are slight variations in the thickness of the profile layers in other parts of the block. In the northern part of the block, for example, the upper two layers are shallower than in the southern part of the block. It is doubtful whether differences in profile characteristics had any significance in this study.

The laboratory mechanical analysis (See Page 29) gave the following average results:

0-7 inches-------55.0% sand and gravel
                 15.6% clay
                 29.4% silt

7-15 inches-------60.4% sand and gravel
                 12.6% clay
                 27.0% silt
The investigation was conducted on the plots that have been under the cultural treatments for more than ten years. These plots were specified previously as:

1. Plot $A_3$----Weed-control oil-spray treatment
2. Plot $C_1$----Weed-control deep-disc treatment
3. Plot $D_2$----Permanent sod treatment

Most of the investigations were on the "nitrogen fertilization treatment" (2); but because of the limited number of trees that were available for the investigation, a small part of the infiltration rates were studied on the "nitrogen and phosphorous fertilization treatment" (3). The "manure fertilization treatment" (1) trees were not used for any investigation.

**INFILTRATION STUDIES**

Infiltration Studies by Means of the "Double Ring" Apparatus. (See Plate II.) This method consists of studying infiltration rates of water contained in a ring. The rings are constructed of galvanized steel and the ones that were used for this investigation were of two different sizes. Some of the rings were 16 inch long with an 8 inch diameter, while others were 18 inch long with a 10 inch diameter. Fletcher (17), irrigation expert in Arizona, found no difference in infiltration rates because of the slightly different size of the rings.

Each ring is driven into the soil by hammering with a thick steel
The sharp pounding with the plate makes it possible to drive the ring evenly and easily into place without disturbing the soil. Once the ring is hammered to the proper depth, a groove of approximately 4 inch in width and 2 to 3 inch deep is dug around the ring with a spade. A plastic sheet was placed on the surface of the soil inside the ring to minimize the disturbance of the surface soil when filling the ring with water. During all early studies, the constant depth of water was maintained in the ring by different means. However, it was found later that variations in the magnitude of 1 or 2 inches made little or no difference in infiltration rates. Thus, in the current investigation water was added to form a head of 3 to 4 inches, and was maintained as such by adding given quantities when needed. Immediately after filling the ring, water was added to the groove filling it to its capacity, and it was maintained at this level throughout the entire investigation. The water surrounding the ring served as a buffer zone and counteracted any lateral movement of the water infiltrating from the inside of the ring.

A hook gage was used to measure the intake rates of water at convenient times. When taking a reading the hook gage was always placed at the same point on the ring.

For the study of the infiltration rates of each cultural treatment plot, 12 rings were used. Eight of the rings were set in a basin (See Figure 1) on an area of 484 ft. sq. (22 ft. x 22 ft.) bordered by 4 grapefruit trees. The other 4 rings were set in another basin separated from the first basin by a third basin. The same scheme of ring distribution and their respective numbers was applied to the three different cultural treatment plots. Rings 1 to 8 represented that portion of the
(A) Arrangement of rings in the basin.

(B) Reading water intake from a ring.

(C) Ring, hook gage and hammering plate.

PLATE II. THE "DOUBLE RING" APPARATUS AS USED FOR INFILTRATION STUDIES IN ORCHARD SOIL
plots that did not suffer from excessive traffic. Rings 9 to 12 represented part of the plots which was subjected to excessive traffic.

All rings were driven into the sub-surface layer or to a depth of 7 to 10 inches, where the plowsole was most prominent.

The distribution of the rings in the different plots was as follows:

Plot C₁: A. Rings 1, 2, 5, 6, 9, 10, 11 and 12 in the basin bordered by rows 7 and 8.

B. Rings 3, 4, 7 and 8 in the basin bordered by rows 5 and 6.

All rings were placed between tree numbers 5 and 6.

Plot A₃: A. Rings 1, 2, 5, 6, 9, 10, 11 and 12 in the basin bordered by rows 23 and 24.

B. Rings 3, 4, 7 and 8 in the basin bordered by rows 21 and 22.

All rings were placed between tree numbers 2 and 3.

Plot D₂: A. Rings 1, 2, 5, 6, 9, 10, 11 and 12 in the basin bordered by rows 15 and 16.

B. Rings 3, 4, 7 and 8 in the basin bordered by rows 13 and 14.

All rings were placed between tree numbers 6 and 7.

(See Figure 1.)

Infiltration Studies by Means of Small Field Plots. This method gives the closest results to the actual infiltration rate in an irrigated basin. However, it is seldom used because of the great deal of work and large amounts of water required.

Each of the small field plots contained 242 ft. sq. (22 ft. x 11 ft.). One wall of the plot consisted of the basin's border with the tree in its midst. The three other walls were erected in the basin itself. One foot
plastic rulers placed in the ground at easily accessible locations were used to measure the intake rates of the water. A magnifying glass helped in taking exact readings.

The study began by filling the basin with water but keeping the small field plots dry. The water surrounding these plots on three sides served as a buffer zone, and counteracted any lateral movement of the down flowing water inside the small plot.

Once the small field plots were surrounded by water, the wall was cut permitting water to enter the plot to the same water level as the outside which was 3 to 4 inches high. The wall was then rebuilt and the intake of water from the plot was measured.

Rulers were also placed in the basin itself in order to follow the water intake thereto (area: 3388 ft. sq. or 154 ft. x 22 ft.).

Infiltration rates were investigated in four small field plots of any one of the three cultural treatment plots which had the following distribution:

Plot A with small field plots adjacent to:
1. Tree #2, row #22 - In the same basin
2. Tree #3, row #23
3. Tree #4, row #24 - In the same basin
4. Tree #3, row #25

Plot C with small field plots adjacent to:
1. Tree #5, row #6 - In the same basin
2. Tree #6, row #7
3. Tree #6, row #8 - In the same basin
4. Tree #5, row #9
Plot D2 with small field plots adjacent to:

1. Tree #2, row #14) - In the same basin
2. Tree #6, row #15) - In the same basin
3. Tree #2, row #16)
4. Tree #6, row #17) - In the same basin

(See Figure 1.)

PERMEABILITY STUDIES

Soil permeability is defined as the capacity of soil to transmit water and air. It can be measured quantitatively in terms of percolation as the rate of flow of water through a unit cross section of soil in a unit time per hydraulic gradient unit.

Undisturbed soil cores were collected with a sampler described by Uhland (51) from the surface (0 to 3 inches) and the sub-surface (7 to 10 inches) soils. Six replicates of each layer were taken from pits 1 and 2 of all cultural treatment plots. (See Page 28.)

The samples were contained in aluminum cylinders, 3 inch long with a 3 inch inside diameter. One-pint cylindrical ice-cream cartons were used for transporting the aluminum cylinders containing the soil cores, from the field to the laboratory. In the laboratory the cylinders were removed from the carton and 1 x 3 inch aluminum cylinders were placed on top of the 3 x 3 inch cylinders containing the soil cores. The cylinders were placed on top of funnels arranged for convenient observation. One hundred cc. of water were added on top of the soil cores, and was allowed to percolate through the core samples. The cores were placed in a pan of water allowing the soil cores to saturate over night. The cores were remove after 14 to 16 hours, placed on the funnels and a half inch head
of water was maintained throughout the study. Percolation rates were measured for one hour periods.

**STUDIES OF PROPERTIES RELATED TO INFILTRATION AND PERMEABILITY RATES**

As stated previously the purpose of these investigations was to follow the factors that gave rise to different infiltration rates. These factors were to be found in the properties of the layers composing the soil profiles of the three different cultural treatment plots.

As the activities related to the different treatments were confined to the surface 12 inches, it was assumed that the factors affecting infiltration rate could be found in this portion of the soil profile.

Three pits were dug in each experimental plot for soil sampling. The pits were located as follows:

**Plot A3:**
1. Row #21, between trees #1 and #2.
2. Row #23, 
3. Row #24, 

**Plot C1:**
1. Row #5, between trees #6 and #7.
2. Row #6, 
3. Row #7, 

**Plot D2:**
1. Row #13, between trees #5 and #6.
2. Row #14, 
3. Row #15, 

All pits were dug mid-way between the two trees and 6 to 7 ft. from the basin's border. (See Figure 1.)

**Collection of Samples.** All pits were dug and sampled on the same day. The different cultural treatments influenced the soil profile to the extent that visual differences could be detected. Accordingly the different layers were not the same in their properties and depths; and were
therefore sampled as follows:

- **Plot A:**
  - Layer (a) 0 to 3 inches
  - Layer (b) 3 to 12 inches

- **Plot C:**
  - Layer (a) 0 to 6 inches
  - Layer (b) 6 to 12 inches

- **Plot D:**
  - Layer (a) 0 to 6 inches
  - Layer (b) 6 to 12 inches

The soil samples were subjected to the following tests: 1. Mechanical analysis. 2. Bulk density. 3. Aggregate-size distribution. 4. Aggregation of particles less than 50 microns. 5. Moisture equivalent. 6. Organic matter content.

**Mechanical Analysis.** Soil structure was determined by the hydrometer method of mechanical analysis (7).

The soil suspension to which 10 ml. of sodium hexametaphosphate solution were added was stirred for 10 minutes with a mixing machine. The suspension was transferred to a sedimentation cylinder and brought to volume. Hydrometer readings were taken at 40 seconds, 1 hour and 2 hours. Temperature corrections were made in calculating the percentage of sand, silt and clay.

**Bulk Density.** The bulk density (apparent density) of the soil is the mass of soil per unit volume.

The "Paraffine Coat" method was used for the bulk density determinations. Three undisturbed clods of soil from each layer were brought to the laboratory. Each clod was divided into two parts, one of which was placed in a can, weighed, and dried in the oven for 48 hours for the moisture percentage of the clod. A thin thread was tied around the
other part of the clod, weighed, immersed in hot paraffine, and weighed again with its paraffine coating. The paraffine coated clod was weighed again in water.

Weight of clod minus moisture in the clod (as determined on dry basis) equals the mass of the clod. Weight of the coated clod minus the weight of the clod equals the weight of the paraffine which when multiplied by its density (0.9) equals the volume of the paraffine coating the clod. The weight of the coated clod in the air minus its weight when immersed in water equals the volume of the coated clod. When subtracting the volume of the paraffine from the volume of the coated clod, the volume of the clod is obtained.

The bulk density of the clod equals the weight of the clod divided by its volume.

Aggregate-Size Distribution. (56). The soil samples were passed through a 4 mm. sieve, and all primary material larger than 4 mm. was discarded. Sixty gm. samples were weighed and the moisture content was determined by drying separate samples at 105 degrees C. Duplicate samples were placed on the upper sieve on the agitating machine and left to oscillate in water for 30 minutes. The stroke of the machine was 3.8 cm., and it agitated at a rate of 30 cycles per minute.

The sieves were removed from the water and left to dry at 105 degrees C. The dried aggregates plus the gravel remaining on each sieve were weighed and then washed with a strong stream of water, so as to allow all of the soil aggregates to disperse and leave only the gravel. The gravel was dried and weighed, and its weight on each sieve subtracted
from the total weight of material gave the weight of the true aggregates on each of the 4 sieves (diameters of sieve's pores: 0.21 mm; 0.5 mm.; 1.0 mm.; 2.0 mm.)

Aggregation of Particles Less Than 50 Microns. (52). A modification of the Bouyoucos hydrometer method was employed. Two samples of 50 gm. each of air-dried soil were used. One was dispersed and the other one was not. Only 40 second readings that were corrected for temperature were taken. The per cent of aggregation of the silt and clay was calculated by dividing the per cent of silt and clay in the non-dispersed suspension by the per cent of silt and clay in the dispersed soil.

Moisture Equivalent. The moisture equivalent of soil samples was determined by the method of Briggs and McLane (9). It involves the use of a centrifuge that subjects wetted samples to a force of 1000 times gravity for 30 minutes. Moisture percentage was determined on the centrifuged samples.

Organic Matter Content. The modified procedure of Walkley-Black wet combustion method was used. End point of the titration was determined by the use of an equivalence meter. The organic carbon was multiplied by a factor of 1.724 to obtain an estimated organic matter content.

BEARING PRESSURE MEASUREMENTS

In spite of the weaknesses of the penetrometer when used as a research tool (45), it was used in this investigation to get comparative readings between the different plots as well as the compaction pattern within single basins.
The penetrometer used was the standard Procter needle. The point was 0.25 inch in diameter and was introduced into the surface 3 inch of soil. The soils in all basins were of the same relative wetness.
RESULTS

Infiltration Studies by Means of the "Double Ring" Apparatus. (See Tables 3 to 6 and Figure 3a.) The total length of time for this part of the investigation is divided into 3 to 4 periods, and the rates of infiltration per hour are given for each of these periods.

The "double ring" method gave a clear picture of the initial infiltration rates. The variability in infiltration rates was great, even though distances between the rings were relatively small.

The results show no significant differences between infiltration rates obtained from rings on any one treatment placed in corresponding positions even though at separate basins. There were no significant differences between infiltration rates from rings, irrespective of its position in the plot, except for the rings placed on the diagonal across the weed-control oil-spray plot (A3), which had the lowest infiltration rates of all rings studied.

The rings placed diagonally across the basin were planned to represent all of the conditions prevailing in the basin, between the two rows. Table 6 and Figure 3a summarize the averages of infiltration rates from these rings at any one treatment, rings 1, 6, 9, 10, 11 and 12. (See also Figure 1.)

During the period 170-290 minutes the infiltration rate was essentially constant, therefore the average rate for this period of time was used to typify the infiltration rate of each treatment. The high-
est infiltration rate was in plot D₂, permanent sod, and the rate for the weed-control oil-spray and deep-disc plots, A₃ and C₁ respectively, were significantly lower but of the same order of magnitude.

**Infiltration Rates from Small Field Plots.** (See Table 7 and Figure 3b). Infiltration rates from small field plots were measured 3 to 4 times during the investigation.

The variability of infiltration rate from small field plots was smaller than for measurements by "double ring" method. The highest initial rate (0 to 49-52 minutes) was from the weed-control deep-disc plot (C₁). The corresponding initial rate for the permanent sod plot (D₂) was lower but much greater than the initial rate for the weed-control oil-spray plot (A₃).

The largest decrease of infiltration rate with time was on the weed-control deep-disc plot (C₁) (2.84 - 0.79 = 2.05); the smallest for the weed-control oil-spray plot (A₃) (1.42 - 0.52 = 0.90); and the intermediate for the permanent sod (D₂) (2.41 - 1.00 = 1.41).

The average total amount of water infiltrating into the soil in 400 minutes was found to be as follows:

- Weed-control oil-spray (A₃) ......................... 4.9 cm.
- Weed-control deep-disc (C₁) ......................... 7.3 cm.
- Permanent sod (D₂) ............................... 8.5 cm.

The rates for the final period were highest for the permanent sod plot (D₂); lowest for the weed-control oil-spray plot (A₃); and intermediate for the weed-control deep-disc plot (C₁).

Infiltration rates from the basins, as measured by the Citrus
Figure 3a. Studies of infiltration rates by the use of small field plots.

Figure 3b. Studies of infiltration rates by the use of small field plots.
Experiment Station staff* show results very similar to those arrived at in the current investigation. Their values are given below in terms of the average for 6 basins. These basins have been treated for periods of time varying between 6-13 years.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average Rate for 215-240 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weed-control oil-spray (A₃)</td>
<td>0.55</td>
</tr>
<tr>
<td>Weed-control deep-disc (C₁)</td>
<td>0.87</td>
</tr>
<tr>
<td>Permanent sod (D₂)</td>
<td>0.95</td>
</tr>
</tbody>
</table>

*Unpublished data.

Permeability Studies by Measurement of Percolation Rate Through Undisturbed Soil Core. (See Table 8 and Figure 5). The surface soil samples (0-3 inches) taken from the weed-control oil-spray (A₃) had the lowest percolation rates. The top 2 inches of soil that formed a compacted layer were the direct cause of this significantly low permeability. Percolation rates were high in the cores taken from the permanent sod (D₂) and deep-disc (C₁) plots. A large part of the high percolation rate may be attributed to the activities of earthworms in these cores. Earthworms and signs of their activity were absent in the weed-control oil-spray (A₃) samples. Earthworms were abundant in the permanent sod (D₂) and to a lesser extent in the weed-control deep-disc
(C₁) samples.

The sub-surface soil samples were taken from a depth of 7-10 inches which represented a compacted layer. This layer was most prominent in the weed-control deep-disc plot (C₁) and the percolation rates obtained from this layer were the lowest of all the sub-surface soil cores. The compacted layer was barely noticeable in the permanent sod (D₂) and the weed-control oil-spray (A₃) plots. Percolation rates obtained from cores of plots D₂ and A₃ were identical, and they were both higher than the ones obtained from cores of the weed-control deep-disc plot (C₁).

Bulk Density. (See Table 8 and Figure 5). Bulk density values were large in the surface soil (0-3 inches) of the weed-control oil-spray plot (A₃). Bulk density values for the surface soil (0-6 inches) of the permanent sod (D₂) and weed-control deep-disc (C₁) plots were identical, and they were both smaller than the ones obtained from cores of the weed-control oil-spray (A₃).

The bulk density of the sub-surface soil of the weed-control oil-spray plot (A₃) was smaller than its surface soil. It was also smaller than the bulk density of the permanent sod (D₂) and weed-control deep-disc (C₁) sub-surface soils. The largest bulk density of any of the sub-surface soils was that of the weed-control deep-disc plot (C₁).

Assuming the specific density to be 2.65 for all samples, the percent of total pore space was computed and given in Table 6.

Per cent total pore space = 100 \left( \frac{1 - \text{bulk density}}{\text{specific density}} \right)
Aggregation of Particles Less Than 50 Microns. (See Table 8 and Figure 5). The permanent sod (D2) surface soil had the highest aggregation percentage, while the lowest was that of weed-control deep-disc (C1). The surface soil of the weed-control oil-spray plot (A3) was more aggregated than that of the weed-control deep-disc plot (C1). This result does not reflect a better structure of this surface soil. The high aggregation percentage may be theoretically explained by the effects that such factors as compaction and oil used for the spray had on the soil. Sub-surface soil samples of the weed-control deep-disc plot (C1) show the highest aggregation percentage while there were no significant differences between aggregation values of the sub-surfaces of the two other treatments.

Aggregate-Size Distribution. Both surface and sub-surface soils of the weed-control deep-disc (C1) and oil-spray (A3) plots showed no significant quantities of water stable aggregates larger than 0.21 mm. (0.0 to 4.6 per cent of water stable aggregates).

However, the percentage of the water stable aggregates larger than 0.21 mm. was 21.0 in the surface soil and 1.2 per cent in the sub-surface soil of the permanent sod plot (D2).

It should be pointed out, however, that the per cent of gravel material in both surface and sub-surface soils was high and varied between 40 and 45 per cent.

Organic Matter. (See Table 8 and Figure 5). The organic matter content of surface soil in all treatments was found to be higher than that of
the sub-surface soils. The surface soil of the permanent sod (D₂) treatment had the highest organic matter content, while the lowest was that of weed-control oil-spray (A₃) treatment.

The organic matter contents of the permanent sod (D₂) and weed-control oil-spray (A₃) sub-surface soil were identical and both were lower than that of the weed-control deep-disc (C₁) sub-surface soil.

**Moisture Equivalent.** (See Table 8 and Figure 5). The moisture equivalent percentage was influenced only by the permanent sod (D₂) treatment where its value was increased in the surface soil.

**Bearing Pressure Measurements.** (See Figure 4). Bearing pressure readings were taken diagonally across the basin between two trees. Each result in Figure 4 represents an average of 4 readings.

Very high bearing pressures (more than 120 lbs. per 0.05 sq. inch) were required to drive the penetrometer into the center part of the weed-control oil-spray (A₃) basin. The bearing pressures were low on both sides of the center (40 to 70 lbs. per 0.05 sq. inch). Out of the 32 ft. between the two diagonal trees, 13 ft. had high bearing pressures.

The weed-control deep-disc surface soil had low bearing pressures (50 lbs. per 0.05 sq. inch). However, two tracks left behind by a tractor compacted the surface soil in the center of the basin, bearing pressures increased to 100 to 120 lbs. per 0.05 sq. inch in these two-feet-wide-tracks.

Bearing pressures in the permanent sod (D₂) plot were quite uniform across the basin and were between 60 to 90 lbs. per 0.05 sq. inch.
Figure 4. - BEARING PRESSURES FOR THE DIFFERENT TREATMENTS
(Read diagonally across the basin)
Table 3. Infiltration rates from all rings on plot A₃ (Weed-control oil-spray).

<table>
<thead>
<tr>
<th>Ring No.</th>
<th>Time</th>
<th>Rate</th>
<th>Time</th>
<th>Rate</th>
<th>Time</th>
<th>Rate</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>min.</td>
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<td>min.</td>
<td>cm/hr.</td>
<td>min.</td>
<td>cm/hr.</td>
</tr>
<tr>
<td>1</td>
<td>0-37</td>
<td>3.83</td>
<td>37-69</td>
<td>1.48</td>
<td>69-169</td>
<td>0.99</td>
</tr>
<tr>
<td>2</td>
<td>0-31</td>
<td>4.65</td>
<td>31-64</td>
<td>2.00</td>
<td>64-162</td>
<td>1.02</td>
</tr>
<tr>
<td>3</td>
<td>0-39</td>
<td>3.00</td>
<td>39-58</td>
<td>4.57</td>
<td>58-154</td>
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</tr>
<tr>
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<td>0-35</td>
<td>4.20</td>
<td>35-55</td>
<td>1.29</td>
<td>55-154</td>
<td>1.08</td>
</tr>
<tr>
<td>5</td>
<td>0-34</td>
<td>3.60</td>
<td>34-63</td>
<td>0.93</td>
<td>63-181</td>
<td>0.72</td>
</tr>
<tr>
<td>6</td>
<td>0-38</td>
<td>1.99</td>
<td>38-55</td>
<td>1.38</td>
<td>55-138</td>
<td>0.72</td>
</tr>
<tr>
<td>7</td>
<td>0-36</td>
<td>4.10</td>
<td>36-78</td>
<td>1.63</td>
<td>78-162</td>
<td>1.38</td>
</tr>
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<td>31-73</td>
<td>0.90</td>
<td>73-156</td>
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</tr>
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<td>0-44</td>
<td>4.08</td>
<td>44-69</td>
<td>1.80</td>
<td>69-163</td>
<td>1.02</td>
</tr>
<tr>
<td>10</td>
<td>0-43</td>
<td>1.88</td>
<td>43-69</td>
<td>0.69</td>
<td>69-162</td>
<td>0.33</td>
</tr>
<tr>
<td>11</td>
<td>0-41</td>
<td>1.75</td>
<td>41-66</td>
<td>0.86</td>
<td>66-166</td>
<td>0.42</td>
</tr>
<tr>
<td>12</td>
<td>0-40</td>
<td>4.08</td>
<td>40-66</td>
<td>1.38</td>
<td>66-159</td>
<td>0.84</td>
</tr>
</tbody>
</table>

Average: 0-37 3.33 37-66 1.57 66-159 0.84
Table 4. Infiltration rates from all rings on plot C1 (Weed-control deep-disc).

<table>
<thead>
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<th>Ring No.</th>
<th>Time Range</th>
<th>Infiltration Rate</th>
</tr>
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<tbody>
<tr>
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<td>0-15 cm/hr.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0-19 min.</td>
<td>5.50 cm/hr.</td>
</tr>
<tr>
<td>2</td>
<td>0-16 min.</td>
<td>3.72 cm/hr.</td>
</tr>
<tr>
<td>3</td>
<td>0-18 min.</td>
<td>1.84 cm/hr.</td>
</tr>
<tr>
<td>4</td>
<td>0-19 min.</td>
<td>2.46 cm/hr.</td>
</tr>
<tr>
<td>5</td>
<td>0-16 min.</td>
<td>0.71 cm/hr.</td>
</tr>
<tr>
<td>6</td>
<td>0-12 min.</td>
<td>2.21 cm/hr.</td>
</tr>
<tr>
<td>7</td>
<td>0-18 min.</td>
<td>4.20 cm/hr.</td>
</tr>
<tr>
<td>8</td>
<td>0-15 min.</td>
<td>2.40 cm/hr.</td>
</tr>
<tr>
<td>9</td>
<td>0-12 min.</td>
<td>3.02 cm/hr.</td>
</tr>
<tr>
<td>10</td>
<td>0-14 min.</td>
<td>1.39 cm/hr.</td>
</tr>
<tr>
<td>11</td>
<td>0-14 min.</td>
<td>1.38 cm/hr.</td>
</tr>
<tr>
<td>12</td>
<td>0-11 min.</td>
<td>3.38 cm/hr.</td>
</tr>
<tr>
<td></td>
<td>15-25 cm/hr.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>19-29 min.</td>
<td>9.30 cm/hr.</td>
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<tr>
<td>2</td>
<td>19-29 min.</td>
<td>3.20 cm/hr.</td>
</tr>
<tr>
<td>3</td>
<td>18-26 min.</td>
<td>3.08 cm/hr.</td>
</tr>
<tr>
<td>4</td>
<td>18-26 min.</td>
<td>1.44 cm/hr.</td>
</tr>
<tr>
<td>5</td>
<td>18-26 min.</td>
<td>1.22 cm/hr.</td>
</tr>
<tr>
<td>6</td>
<td>12-24 min.</td>
<td>2.40 cm/hr.</td>
</tr>
<tr>
<td>7</td>
<td>15-26 min.</td>
<td>3.04 cm/hr.</td>
</tr>
<tr>
<td>8</td>
<td>15-26 min.</td>
<td>1.21 cm/hr.</td>
</tr>
<tr>
<td>9</td>
<td>15-26 min.</td>
<td>1.20 cm/hr.</td>
</tr>
<tr>
<td>10</td>
<td>17-26 min.</td>
<td>2.10 cm/hr.</td>
</tr>
<tr>
<td>11</td>
<td>16-26 min.</td>
<td>2.22 cm/hr.</td>
</tr>
<tr>
<td>12</td>
<td>11-24 min.</td>
<td>3.36 cm/hr.</td>
</tr>
<tr>
<td></td>
<td>26-75 cm/hr.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>18-30 min.</td>
<td>1.38 cm/hr.</td>
</tr>
<tr>
<td>2</td>
<td>19-29 min.</td>
<td>1.12 cm/hr.</td>
</tr>
<tr>
<td>3</td>
<td>18-26 min.</td>
<td>0.81 cm/hr.</td>
</tr>
<tr>
<td>4</td>
<td>18-26 min.</td>
<td>0.84 cm/hr.</td>
</tr>
<tr>
<td>5</td>
<td>18-26 min.</td>
<td>0.60 cm/hr.</td>
</tr>
<tr>
<td>6</td>
<td>12-24 min.</td>
<td>0.60 cm/hr.</td>
</tr>
<tr>
<td>7</td>
<td>15-26 min.</td>
<td>0.69 cm/hr.</td>
</tr>
<tr>
<td>8</td>
<td>12-24 min.</td>
<td>0.77 cm/hr.</td>
</tr>
<tr>
<td>9</td>
<td>15-26 min.</td>
<td>0.73 cm/hr.</td>
</tr>
<tr>
<td>10</td>
<td>17-26 min.</td>
<td>0.68 cm/hr.</td>
</tr>
<tr>
<td>11</td>
<td>16-26 min.</td>
<td>0.57 cm/hr.</td>
</tr>
<tr>
<td>12</td>
<td>11-24 min.</td>
<td>0.56 cm/hr.</td>
</tr>
<tr>
<td></td>
<td>75-151 cm/hr.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>75-151 min.</td>
<td>0.71 cm/hr.</td>
</tr>
<tr>
<td>2</td>
<td>74-150 min.</td>
<td>0.91 cm/hr.</td>
</tr>
<tr>
<td>3</td>
<td>68-145 min.</td>
<td>0.86 cm/hr.</td>
</tr>
<tr>
<td>4</td>
<td>69-180 min.</td>
<td>1.00 cm/hr.</td>
</tr>
<tr>
<td>5</td>
<td>70-180 min.</td>
<td>0.55 cm/hr.</td>
</tr>
<tr>
<td>6</td>
<td>71-174 min.</td>
<td>0.97 cm/hr.</td>
</tr>
<tr>
<td>7</td>
<td>70-174 min.</td>
<td>0.72 cm/hr.</td>
</tr>
<tr>
<td>8</td>
<td>72-172 min.</td>
<td>0.57 cm/hr.</td>
</tr>
<tr>
<td>9</td>
<td>70-174 min.</td>
<td>0.57 cm/hr.</td>
</tr>
<tr>
<td>10</td>
<td>71-170 min.</td>
<td>0.72 cm/hr.</td>
</tr>
<tr>
<td>11</td>
<td>72-172 min.</td>
<td>0.35 cm/hr.</td>
</tr>
<tr>
<td>12</td>
<td>70-174 min.</td>
<td>0.72 cm/hr.</td>
</tr>
<tr>
<td></td>
<td>170-280 cm/hr.</td>
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</tr>
<tr>
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<tr>
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<td>1.40 cm/hr.</td>
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</tr>
<tr>
<td>3</td>
<td>1.94 cm/hr.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.37 cm/hr.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.72 cm/hr.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.35 cm/hr.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.94 cm/hr.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1.01 cm/hr.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1.04 cm/hr.</td>
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</tr>
<tr>
<td>10</td>
<td>1.10 cm/hr.</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>1.17 cm/hr.</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>1.20 cm/hr.</td>
<td></td>
</tr>
</tbody>
</table>

Average: 0-15 4.37 cm/hr. 15-28 1.94 cm/hr. 23-71 1.01 cm/hr. 71-170 0.70 cm/hr.
Table 5. Infiltration rates from all rings on plot D2 (Permanent Sod)

<table>
<thead>
<tr>
<th>Ring No.</th>
<th>Time</th>
<th>Rate</th>
<th>Time</th>
<th>Rate</th>
<th>Time</th>
<th>Rate</th>
<th>Time</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min.</td>
<td>cm/hr.</td>
<td>min.</td>
<td>cm/hr.</td>
<td>min.</td>
<td>cm/hr.</td>
<td>min.</td>
<td>cm/hr.</td>
</tr>
<tr>
<td>1</td>
<td>0-14</td>
<td>6.66</td>
<td>14-39</td>
<td>1.65</td>
<td>39-60</td>
<td>1.22</td>
<td>60-185</td>
<td>0.89</td>
</tr>
<tr>
<td>2</td>
<td>0-13</td>
<td>6.48</td>
<td>13-38</td>
<td>1.74</td>
<td>38-59</td>
<td>1.20</td>
<td>59-183</td>
<td>0.96</td>
</tr>
<tr>
<td>3</td>
<td>0-17</td>
<td>6.36</td>
<td>17-42</td>
<td>1.38</td>
<td>42-65</td>
<td>1.98</td>
<td>65-179</td>
<td>1.06</td>
</tr>
<tr>
<td>4</td>
<td>0-15</td>
<td>5.52</td>
<td>15-39</td>
<td>2.80</td>
<td>39-62</td>
<td>0.78</td>
<td>62-175</td>
<td>0.71</td>
</tr>
<tr>
<td>5</td>
<td>0-13</td>
<td>6.66</td>
<td>13-28</td>
<td>2.04</td>
<td>28-64</td>
<td>1.26</td>
<td>64-181</td>
<td>1.05</td>
</tr>
<tr>
<td>6</td>
<td>0-15</td>
<td>5.46</td>
<td>15-39</td>
<td>1.20</td>
<td>39-60</td>
<td>1.26</td>
<td>60-177</td>
<td>0.77</td>
</tr>
<tr>
<td>7</td>
<td>0-14</td>
<td>8.10</td>
<td>14-48</td>
<td>5.93</td>
<td>48-63</td>
<td>1.95</td>
<td>63-178</td>
<td>0.75</td>
</tr>
<tr>
<td>8</td>
<td>0-15</td>
<td>3.96</td>
<td>15-33</td>
<td>2.40</td>
<td>33-62</td>
<td>1.32</td>
<td>62-176</td>
<td>0.67</td>
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<td>5.88</td>
<td>18-35</td>
<td>2.80</td>
<td>35-60</td>
<td>1.56</td>
<td>60-177</td>
<td>0.98</td>
</tr>
<tr>
<td>10</td>
<td>0-17</td>
<td>4.15</td>
<td>17-28</td>
<td>3.24</td>
<td>28-61</td>
<td>1.65</td>
<td>61-176</td>
<td>0.69</td>
</tr>
<tr>
<td>11</td>
<td>0-12</td>
<td>9.75</td>
<td>12-37</td>
<td>5.05</td>
<td>37-72</td>
<td>1.75</td>
<td>72-177</td>
<td>0.80</td>
</tr>
<tr>
<td>12</td>
<td>0-18</td>
<td>2.58</td>
<td>18-44</td>
<td>2.34</td>
<td>44-66</td>
<td>1.64</td>
<td>66-166</td>
<td>0.79</td>
</tr>
</tbody>
</table>

Average: 0-15 5.96 15-33 2.54 38-63 1.45 63-177 0.84
Table 6. Summary of average infiltration rates from rings on the diagonal across the basin. Rings 1, 6, 9, 10, 11 and 12. (See Figure 1).

<table>
<thead>
<tr>
<th>Plot No.</th>
<th>Period</th>
<th>Rate</th>
<th>Period</th>
<th>Rate</th>
<th>Period</th>
<th>Rate</th>
<th>Period</th>
<th>Rate</th>
<th>Period</th>
<th>Rate*</th>
</tr>
</thead>
<tbody>
<tr>
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<td>cm/hr.</td>
<td>min.</td>
<td>cm/hr.</td>
<td>min.</td>
<td>cm/hr.</td>
<td>min.</td>
<td>cm/hr.</td>
<td>min.</td>
<td>cm/hr.</td>
</tr>
<tr>
<td>Weed-control oil-spray (A3)</td>
<td>0-41</td>
<td>2.32</td>
<td>41-65</td>
<td>1.26</td>
<td>65-159</td>
<td>0.72</td>
<td>159-317</td>
<td>0.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weed-control deep-disc (C1)</td>
<td>0-14</td>
<td>3.20</td>
<td>14-29</td>
<td>1.68</td>
<td>29-71</td>
<td>0.74</td>
<td>71-173</td>
<td>0.61</td>
<td>170-271</td>
<td>0.48</td>
</tr>
<tr>
<td>Permanent sod (D2)</td>
<td>0-16</td>
<td>5.74</td>
<td>16-37</td>
<td>2.71</td>
<td>37-63</td>
<td>1.49</td>
<td>63-176</td>
<td>0.82</td>
<td>177-309</td>
<td>0.79</td>
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</tbody>
</table>

*Refers only to rings 6, 9, 10, 11 and 12.
Table 7. Infiltration rates from small field plots.

<table>
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<th>Plot No.</th>
<th>Period</th>
<th>Rate</th>
<th>Period</th>
<th>Rate</th>
<th>Period</th>
<th>Rate</th>
<th>Period</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
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<td>min.</td>
<td>cm/hr.</td>
<td>min.</td>
<td>cm/hr.</td>
<td>min.</td>
<td>cm/hr.</td>
<td>min.</td>
<td>cm/hr.</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plot D₂ - Permanent Sod</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0-42</td>
<td>2.42</td>
<td>42-128</td>
<td>1.60</td>
<td>128-241</td>
<td>1.27</td>
<td>241-379</td>
<td>0.86</td>
</tr>
<tr>
<td>2</td>
<td>0-55</td>
<td>2.51</td>
<td>55-140</td>
<td>1.55</td>
<td>140-254</td>
<td>1.21</td>
<td>254-390</td>
<td>1.19</td>
</tr>
<tr>
<td>3</td>
<td>0-54</td>
<td>2.44</td>
<td>54-141</td>
<td>1.03</td>
<td>141-252</td>
<td>0.81</td>
<td>252-389</td>
<td>1.05</td>
</tr>
<tr>
<td>4</td>
<td>0-58</td>
<td>2.27</td>
<td>58-144</td>
<td>1.25</td>
<td>144-261</td>
<td>1.02</td>
<td>261-398</td>
<td>0.96</td>
</tr>
<tr>
<td>Average:</td>
<td>0-52</td>
<td>2.41</td>
<td>52-138</td>
<td>1.35</td>
<td>138-252</td>
<td>1.07</td>
<td>252-389</td>
<td>1.00</td>
</tr>
</tbody>
</table>

| Plot C₁ - Weed-Control Deep-Disc |
| 1        | 0-49   | 3.67  | 49-134 | 0.91 | 134-252 | 0.86 | 252-380 | 0.68 |
| 2        | 0-49   | 2.45  | 49-133 | 0.71 | 133-248 | 0.78 | 248-380 | 0.68 |
| 3        | 0-49   | 2.57  | 49-132 | 1.37 | 132-248 | 0.82 | 248-381 | 0.85 |
| 4        | 0-47   | 2.68  | 47-132 | 1.34 | 132-248 | 0.98 | 248-382 | 0.98 |
| Average: | 0-49   | 2.84  | 49-133 | 1.08 | 133-249 | 0.86 | 249-381 | 0.79 |

| Plot A₂ - Weed-Control Oil-Spray |
| 1        | 0-41   | 0.75  | 41-105 | 1.21 | 105-271 | 0.68 | 271-412 | 0.60 |
| 2        | 0-49   | 1.30  | 49-108 | 0.60 | 108-274 | 0.54 | 274-412 | 0.52 |
| 3        | 0-46   | 1.70  | 46-105 | 0.61 | 105-271 | 0.65 | 271-409 | 0.56 |
| 4        | 0-54   | 1.88  | 54-122 | 0.53 | 122-179 | 0.61 | 179-417 | 0.39 |
| Average: | 0-49   | 1.42  | 49-110 | 0.74 | 110-273 | 0.62 | 273-412 | 0.52 |
Table 8. Miscellaneous properties of the soil which may effect the infiltration rate*.

<table>
<thead>
<tr>
<th>Plot No.</th>
<th>Organic Matter</th>
<th>Bulk Density</th>
<th>Total Porosity (By Computation)</th>
<th>Aggregation of Particles 50</th>
<th>Moisture Equivalent per cent</th>
<th>Permeability (cm/hr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>per cent</td>
<td>gm/cc.</td>
<td>per cent</td>
<td>per cent</td>
<td>per cent</td>
<td></td>
</tr>
<tr>
<td>Surface Soil **</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weed-control oil-spray (A3)</td>
<td>0.41</td>
<td>1.83</td>
<td>31.0</td>
<td>44.2</td>
<td>17.3</td>
<td>0.13</td>
</tr>
<tr>
<td>Weed-control deep-disc (C1)</td>
<td>0.86</td>
<td>1.58</td>
<td>40.4</td>
<td>36.2</td>
<td>18.3</td>
<td>3.34</td>
</tr>
<tr>
<td>Permanent sod (D2)</td>
<td>1.67</td>
<td>1.61</td>
<td>39.3</td>
<td>59.2</td>
<td>22.3</td>
<td>16.48</td>
</tr>
<tr>
<td>Sub-Surface Soil (6&quot; to 12&quot;)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weed-control oil-spray (A3)</td>
<td>0.23</td>
<td>1.74</td>
<td>34.4</td>
<td>38.9</td>
<td>13.6</td>
<td>0.70</td>
</tr>
<tr>
<td>Weed-control deep-disc (C1)</td>
<td>0.16</td>
<td>1.85</td>
<td>30.2</td>
<td>49.1</td>
<td>12.9</td>
<td>0.47</td>
</tr>
<tr>
<td>Permanent sod (D2)</td>
<td>0.27</td>
<td>1.79</td>
<td>32.5</td>
<td>43.9</td>
<td>13.2</td>
<td>0.66</td>
</tr>
</tbody>
</table>

Each of the results represents an average of the 3 locations sampled from any one of the investigated plots.

**Top 3" in plot A3 and 6" in plots C1 and D2.
FIGURE 5. INFILTRATION RATES & RELATED PROPERTIES OF CITRUS ORCHARD SOIL UNDER DIFFERENT CULTURAL TREATMENTS
(Surface Soil)

Plot number → A3 → C1 → D2

Cultural Treatment → Weed control oil spray → Weed control deep disk → Permanent sod
DISCUSSION

The surface soil of the permanent sod treatment ($D_2$) had the highest organic matter content, per cent of aggregation, percolation rate and total porosity. Its sub-surface soil had no plowsole that could be distinguished in the field. Low and uniform bearing pressure measurements indicated a stable surface structure.

The surface soil of the weed-control oil-spray treatment ($A_3$) had a high bulk density (low total porosity) and a very low percolation rate. Bearing pressure measurements indicate that the large part of the plot was covered by a 2 to 3 inch highly compacted crust of a platy structure. Its sub-surface soil had a good percolation rate, a total porosity of the same order of magnitude as that of the permanent sod ($D_2$) and no plowsole could be distinguished.

The surface soil of the weed-control deep-disc ($C_1$) was well aerated and of an open structure, its organic matter content, percolation rate and total porosity were high. Bearing pressure was low except for two tracks where a motorized vehicle passed. The sub-surface soil had a high bulk density (low total porosity) and percolation rate in comparison to the sub-surface soil of the other treatments. A distinct plowsole was distinguished.

By way of review we find that the favorable soil structure developed on the permanent sod plot ($D_2$) was conducive to water and air penetration because of the lack of a compacted layer. The dense cover of the permanent sod ($D_2$) (See Plate III) provided an efficient protection
against any crust formation at the surface while the elimination of
tillage prevented the formation of a plowsole.

The surface soil of the weed-control oil-spray plot (A$_3$) (See
Plate III) was barren for the last 12 years, and exposed to compacting
agents, such as raindrops, water flow, and traffic. This resulted in
the formation of the compacted surface layer which impedes the movement
of water and air. As all forms of tillage were excluded in this treat-
ment, the sub-surface was not disturbed and was found to have a good
structure resembling that of the permanent sod treatment (D$_2$).

The surface soil of the weed-control deep-disc treatment (C$_1$)
(See Plate III) was disturbed by the disking, thus exposing it to any
compacting and erosive agents. A good example of the damaging effects
of one of these agents was provided in the compaction caused by a
tractor that travelled through this plot, and as shown by the high bear-
ing pressure readings in the tracks left behind the tractor. However,
the damaging effects of both compacting and erosive agents were effi-
ciently controlled by the limited number of diskings (4 to 6 per year)
and by the incorporated green manure. The sub-surface soil of the
weed-control deep-disc plot (C$_1$) was slightly compacted by the diskings
allowing a plowsole to be formed.

The infiltration rates of the various plots were closely related
to the different structures. The infiltration rates were higher where
the organic matter, aggregation, total porosity and percolation were
high.

The permanent sod (D$_2$) that improved the structure of both surface
and sub-surface soils, also caused the infiltration rate to be the highest. The weed-control oil-spray treatment ($A_3$) that allowed the formation of the surface crust also resulted in the lowest infiltration rate of the three investigated treatments. The weed-control deep-disc treatment ($C_1$) resulted in the highest initial infiltration rate, but in a constant infiltration rate lower than that of the permanent sod ($D_2$), but higher than that of the weed-control oil-spray ($A_3$); the plowsole could have well been the cause for this low infiltration rate. (See Figure 3).

The significance of the different infiltration rates is shown in Table 9 where the time required for a 4-inch irrigation to enter the soil was calculated on the basis of the initial and constant infiltration rates (See Table 7). The amounts of the 4-inch irrigation entering the soil in the periods of 275 and 504 minutes, from the beginning of an irrigation, were also calculated and given in Table 9.

Table 9. Time for 4-inch irrigation to enter the soil, and percentage of a 4-inch irrigation entering in 275 and 504 minutes.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Time for 4-inch irrigation to enter the soil</th>
<th>Per cent of 4-inch irrigation entering the soil in:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>275 min.</td>
</tr>
<tr>
<td>Weed-control oil-spray ($A_3$)</td>
<td>16.7</td>
<td>38.0</td>
</tr>
<tr>
<td>Weed-control deep-disc ($C_1$)</td>
<td>10.0</td>
<td>57.4</td>
</tr>
<tr>
<td>Permanent sod ($D_2$)</td>
<td>8.4</td>
<td>61.9</td>
</tr>
</tbody>
</table>
Table 9 is based on infiltration rates from the small field plots (Table 7). Results from the "double ring" method did not completely compare with those of the small field plots. Infiltration rates from the permanent sod plot (D2) as studied by the "double ring" method were the highest, and those of the weed-control deep-disc (C1) were lower while rates from the weed-control oil-spray (A3) were intermediate although decreasing rapidly to a rate similar to that of the weed-control deep-disc treatment (C1). The high infiltration rates for the weed-control oil-spray treatment (A3) can be explained in the cracking of the surface crust that took place when the rings were pounded into the soil. Once the surface crust was cracked, water could infiltrate in a rapid rate that did not represent the real infiltration rate in the basins when they are irrigated by the farmer.

Although the current investigation did not aim at an evaluation of the two methods of measuring infiltration, the results show that the "double ring" method requires many rings on any one site in order to get a statistically significant mean of infiltration rate. The deviation between results, as mentioned previously, is great while it is much smaller in the small field plot method. The "double ring" method was found to have a value as a qualitative measurement, but is not capable of establishing relative quantitative values of infiltration rates in the basins. The small field plot method was found to be of great value as a quantitative measurement of infiltration rates. Aronovici (2) came to the same conclusion in his study of the "double ring" as a diagnosis to furrow irrigation.
There was no attempt in this investigation to obtain any correlation between the soil structure and the yields of the grapefruit tree. However, it should be noted by the reader that the high infiltration rates and the stable structure of the permanent sod plot (D2) did not result in high yields. As shown in Figure 2, the yields of the permanent sod plot (D2) were the lowest. One should try to find the reason for this phenomenon in such factors as severe competition between the tree and the permanent sod (D2) on nutrients and water.

The lower infiltration rate in the weed-control deep-disc plot (C1) did not have any effect on the yields which were the highest of all the other plots. The compaction of the sub-surface was apparently of a very small order of magnitude.

The highly compacted surface soil of the weed-control oil-spray plot (A3) affected the rate of infiltration, and accordingly the efficiency of irrigation; but there was no effect on the growth of the tree and the yields, as the irrigation water did enter the soil although some of it was lost by evaporation because of the low infiltration rate. However, one should bear in mind that in the sprinkler and the furrow irrigation systems water would not enter the soil because of the surface crust, but would run off. There is no doubt that this will result in lower yields.
(A) Surface soil of weed-control oil-spray treatment ($A_3$).

(B) Surface soil of weed-control deep-disc treatment ($C_1$).

(C) Surface soil of permanent sod treatment ($D_2$).

PLATE III. SURFACE SOIL OF ORCHARD UNDER DIFFERENT CULTURAL TREATMENTS
SUMMARY

1. The Tempe citrus farm of the University of Arizona is studying the effect of cultural practices on grapefruit trees.

2. The effect of three cultural treatments, weed-control oil-spray, weed-control deep-disc, and permanent sod, on the infiltration rates and on related soil properties was studied.

3. Infiltration rates were studied by the "double ring" method and in small field plots.

4. Permeability of the surface and sub-surface soils was studied by the percolation rate through undisturbed soil cores.

5. Related physical properties studies included: Bulk density, degree of aggregation, organic matter content, and moisture equivalent.

6. Bearing pressures, needed to force a penetrometer into the surface soil, were measured.

7. Close correlation was found between infiltration and percolation rates, and organic matter content and degree of aggregation.

8. Infiltration rate was the highest on the permanent sod plot (1.00 cm. per hour), the lowest on the weed-control oil-spray plot (0.52 cm. per hour), and intermediate on the weed-control deep-disc (0.79 cm. per hour).

9. Permeability was very low in the surface soil of the weed-control oil-spray, while in the sub-surface soil the weed-control deep disc was lower than in the other treatments.
10. Bulk density was high (low total porosity) in the weed-control oil-spray surface soil.

11. Bearing pressure measurements were highest in the weed-control oil-spray plot and in the tracks of the tractor between the tree rows of the weed-control deep-disc plot.
BIBLIOGRAPHY

1. Alderfer, R. B., and Merkle, F. G.
   1941.  The measurement of soil structural stability and
          permeability and the influence of soil treatments
          upon these properties.  Soil Sci.  51:201-212.

2. Aronovici, V. S.
   1954.  The application of the ring infiltrometer to diagnosis
          of irrigation problems in Southern California.
          Amer. Geophys. Union Trans.  35:813.

3. Bayer, L. D.
   1948.  Soil Physics.

4. Bayer, L. D.
   1937.  Soil characteristics influencing the movement and
          1:431-437.

5. Bodman, G. B., and Colman, E. A.
   1943.  Downward entry of water into soils.

6. Borst, H. L. and Woodburn, C.
   1942.  The effect of mulching and method of cultivation on

7. Bouyoucos, G. S.
   1951.  A recalibration of the hydrometer method for making

8. Boynton, D., and Reuther, W.
   1938.  Seasonal variations of oxygen and carbon-dioxide in
          three different orchard soils and its possible

   1907.  The moisture equivalent of soils.

10. Browning, G. M., and Milam, F. W.
    1942.  Rate of application of organic matter in relation to
11. Buehrer, T. F.  


14. Donnelly, D.  

15. Duley, F. L., and Kelly, L. L.  

16. Duley, F. L.  

17. Fletcher, J. E.  
1956. Personal communication.

18. Fletcher, J. E.  


20. Frith, H. J.  

21. Harris, Karl, Hawkins, R. S., Cords, H. P., and Aepli, D. C.  

22. Havis, A. L.  

24. Hilgeman, R. H.
   1955. Citrus field day notes.

25. Horton, R. E.


27. Israelsen, O. W.

28. Jamison, V. C., Weaver, H. A., and Reed, I. F.

29. Jenny, H.

30. Johnston, J. C., and Sullivan, W.


32. Kimball, L.

33. Knight, A. T.

34. Lamb, J., and Chapman, J. E.

35. La Rue, R. G.
36. Leamer, R. W., and Shaw, B.  

37. Martin, J. P., and Waksman, S. A.  

38. Miller, M. P.  


40. Moser, F.  

41. Parker, E. R., and Jenny, H.  

42. Pillsbury, A. F., and Huberty, M. R.  

43. Pillsbury, A. F., and Richards, S. J.  

44. Powers, W. L.  

45. Shaw, B. T., Hayse, H. R., and Farnsworth, R. E.  

46. Slater, C. S.  

47. Stephenson, R. E., and Schuster, C. E.  
48. Sudds, H. H.
1941. The effect of soil management on certain physical and
chemical properties in relation to the infiltration
rate in West Virginia orchard.

49. Swanson, C. L. W., and Jacobson, H. G. M.
1950. Weed killers and soil structure.

50. Uhland, R. E.
1949. Physical properties of soils as modified by crops and

51. Uhland, R. E., and O'Neal, A. M.
1951. Soil permeability determinations for use in soil and
water conservation.

52. U. S. Salinity Laboratory Staff.
1954. Diagnosis and improvement of saline and alkali soils.

1944. Effect of crop and surface mulchers on runoff, soil
losses, and soil aggregation.

54. Weaver, H. A., and Jarmison, V. C.
1951. Moisture effects on tractor tire compaction.
Soil Sci. 71:15-23.

55. Williams, W. O.
Comparison of the effects of spray weed control of
summer cover crops and of clean tillage on the grape-
vine, its fruit and on the soil.

56. Yoder, R. E.
Jour. Amer. Soc. Agron. 28:337-351.

57. Yoder, R. E.
1937. The significance of soil structure in relation to the

58. Yung, L., Anthony, R. D., and Merkle, F. G.
1941. Physical characteristics of orchard soils.
Soil Sci. 53:65.