Depletion of Subsoil Moisture by Apple Trees and Other Woody Species

C. C. Wiggans

Follow this and additional works at: http://digitalcommons.unl.edu/ardhistrb

Part of the Agriculture Commons, Fruit Science Commons, and the Water Resource Management Commons

Wiggans, C. C., "Depletion of Subsoil Moisture by Apple Trees and Other Woody Species" (1964). Historical Research Bulletins of the Nebraska Agricultural Experiment Station (1913-1993). 152.
http://digitalcommons.unl.edu/ardhistrb/152

This Article is brought to you for free and open access by the Agricultural Research Division of IANR at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Historical Research Bulletins of the Nebraska Agricultural Experiment Station (1913-1993) by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.
Depletion of Subsoil Moisture by Apple Trees And Other Woody Species

by C. C. Wiggans
# CONTENTS

Summary ................................................................................................................................. 2  
Introduction ........................................................................................................................... 3  
Literature Review .................................................................................................................... 3  
Project History ....................................................................................................................... 6  
Definitions .............................................................................................................................. 6  
Material and Methods ............................................................................................................ 7  
  Sampling Equipment ............................................................................................................. 7  
  Soil Samples .......................................................................................................................... 8  
  Soil Drying Procedure .......................................................................................................... 8  
  Hygroscopic Coefficient Determination .............................................................................. 8  
  Conversion of Moisture Percentages to Inches of Water ..................................................... 8  
Results .................................................................................................................................... 9  
  Distance from the Tree as a Factor in Moisture Depletion .................................................. 9  
  Effect of Spacing Distances on Soil Moisture Depletion ...................................................... 11  
  Tree Age and Its Effect on Residual Moisture .................................................................... 12  
  Varietal Influence Upon Soil Moisture Usage .................................................................... 14  
  Effect of Soil Management Methods on Subsoil Moisture Supply ................................. 14  
  Annual Moisture Requirements of Mature Apple Trees .................................................... 16  
  The Replacement Problem ................................................................................................. 21  
  Effects of Other Woody Species on Subsoil Moisture ....................................................... 22  
  Restoration of Depleted Subsoil Moisture ......................................................................... 26  
Conclusions, Recommendations .......................................................................................... 29  
References .............................................................................................................................. 30

Issued April 1964, 2,500
SUMMARY

Moisture determinations made following drought years of the early thirties showed available moisture near exhaustion to depths of 30 feet or more in mature apple orchards. As distance from the tree trunk increased or lower levels were reached, the depletion was less severe. Moisture depletion was correlated with the number of trees per acre.

Short-lived varieties, such as Grimes, apparently depleted the soil moisture more rapidly or more completely than the long-lived Winesap group.

Subsoil moisture content varied with moisture demand of the cover crop but a litter mulch conserved moisture.

The effect of newly planted trees upon subsoil moisture was slight but with the approach of bearing age, depletion of available water was significant.

Replenishment of subsoil moisture in an old orchard site was so slow that newly planted trees were handicapped. Twenty-year-old Jonathan trees near Nebraska City had used more than 50 percent of the available water and two years later more than 70 percent. The actual annual water loss from the top 30 feet of this orchard site soil averaged more than 5 inches.

Under controlled conditions, 43 inches of irrigation water raised the soil moisture content to field capacity to a depth of at least 30 feet in a block of mature Delicious trees. Between November 1937 and October 1940, the available moisture content was reduced from 72 to 42 inches in this block of 18-21-year-old trees. The yearly evapotranspiration varied from 31.14 to 37.05 inches.

In another controlled experiment involving newly planted trees, there was little change in subsoil moisture content between 1943 and 1952, but in the following year there was noticeable depletion.

Vineyard moisture requirements apparently are lower than those for tree fruits.

Deciduous forest species, after exhausting all available moisture from the subsoil, must exist on annual precipitation if they are to survive.

White pines apparently exhaust the available moisture to about 25 feet. Removal of these trees resulted in considerable recovery of subsoil moisture in the upper 15 feet during the next two years.
Depletion of Subsoil Moisture by Apple Trees
And Other Woody Species

INTRODUCTION
By C. C. Wiggans

Apple production in Nebraska during the early decades of the twentieth century was quite heavy with a peak in 1906 when 3,900,000 bushels were reported. A decline in production since 1914 may be attributed to several factors. Weather Bureau records from Nebraska City show a variation in annual rainfall from 47.94 inches in 1902 to 20.97 inches in 1936 with an average annual precipitation of 31.21 inches for the 1900-1959 period.

A severe drought beginning about 1916 was followed by another in the early thirties. The first period was probably responsible for the decrease in apple production from 3,321,073 bushels in 1910 to 907,224 in 1920. Many of the bearing trees, particularly those on unsuitable soils and sites, died because of an inadequate water supply. During this period, according to the U.S. Census Reports, tree population decreased from 2,937,178 to 1,363,093.

Other factors which led to a decrease in apple production were: lack of interest in maintenance of home orchards; increase in disease and control problems; poor success in replacement of missing trees in old orchards; insufficient new plantings to counterbalance the loss of old trees, and the Armistice Day freeze of 1940 which killed or badly injured at least 60 percent of the trees then alive.

However, careful growers have continued to operate profitable orchards. The introduction of dwarf and/or semi-dwarf trees and spur-bearing varieties gives promise of earlier profits because of their shorter non-fruitful periods.

LITERATURE REVIEW

The relationship between soil moisture content and plant development has long been under study. It has been of particular concern to Nebraska orchardists. Saunders (30) recommended spacing apples 25-30 feet in double rows, 20 feet apart with the double rows 200 feet apart. Bessey (5, 6, 7, 8) stressed the need for adequate soil moisture. Platt (27) stated that an acre of 40 apple trees lifts 16 tons of water per day (4 gallons per tree per hour).

Kramer (18) divided soil moisture into four categories—gravita-
tional, capillary, hygroscopic and vapor—the latter two not being considered available for plant use. Methods of measuring the unavailable moisture vary. Briggs and Shantz (19, 11) used the wilting coefficient; Alway (2) and Alway, et al. (3, 4) used the hygroscopic coefficient while Burr and Russel (13) used the moisture equivalent. Kelley et al. (17), after comparing methods of determining total soil moisture, concluded that oven drying was preferable to methods such as tensiometers, Bouyoucos Blocks and sorption blocks.

Magness (21, 22) concluded that water withdrawal depends upon root density and the availability of moisture; root density is greatest in the first 18–20 inches of soil, but roots may penetrate to depths of 20 feet; the water supply for the plant is decreased proportionately if the soil moisture is exhausted in any part of the root zone and normal root functions are resumed after a temporary drought period. He recommended orchard irrigation when the soil is capable of holding only 4-5 inches of available water.

Soil moisture investigations have also involved studies in root density and penetration. Marth (24) reported roots extended 12 feet from the trunk, that fibrous roots were greatest in density within 6 feet of the trunk, and that they were most numerous at depths of 6 inches in light and about 9–12 inches in heavy soils. Aldrich, Work and Lewis (1) reported positive correlation between root concentration and soil moisture extraction with the most rapid moisture loss at distances of 2-8 feet from a pear tree.

Rogers (28) found that the five-foot root spread of a two-year-old tree became 25-30 feet in eight years. Most roots were in the second foot, but some reached depths of six feet or more. Schuster (31) and Stephenson (32) found that abundant pore space stimulated root penetration and that roots penetrated to 10 feet or more if pore space was at least 10 percent. An estimated 500–800 tons of water were needed to produce one ton of growth. Soils 5–6 feet deep could store enough water for tree growth, but a depth of 10 feet was needed for good crop production.

Boynton and Savage (9) reported an uneven directional development of apple tree roots but that distribution of large and small roots was quite similar. Surface root spread was as much as 13 feet but at a depth of 5 feet the spread was only 8 feet.

In contrast to these limited root spread and depth penetration figures are the findings of Yocum (45) who reported a spread of 12 feet and a depth of 8 feet for a one-year-old Delicious tree. These distances increased to 30 and 17 feet respectively after three growing seasons. He also found that the root pattern was influenced by competing crops, i.e., an intercrop of corn forced deeper penetration but lessened the lateral spread of tree roots under eastern Nebraska conditions. After three years of growth, nearly one half of the available
moisture beneath the tree had been exhausted to a depth of nine feet. Wiggans (35) excavated the root system of a 16-year-old Jonathan tree and found roots throughout a space 30 x 33 feet and 30 feet deep in a soil type conducive to deep root penetration. Deeper root penetration was prohibited by shale formation.

Viehmeyer and Hendrickson's (34) findings that uniform distribution of roots resulted in moisture usage at points midway between the trees as being comparable to that near the trees disagree with those reported by Conrad and Viehmeyer (15). In the latter case, conclusions were that soil water loss to tree roots is progressive and from progressively more distant zones unless the supply is replenished.

Wilcox, et al. (42, 43, 44) maintained that soil depth, root distribution and age of tree were involved in the relationship between distance from the tree and the loss of moisture in orchards.

Total precipitation figures are deceptive if considered as a true measure of moisture available for plant use. Busgen and Munch (14) estimated that at best only 50 percent of the rainfall is absorbed by the root system. They calculated that at least 30 percent was lost by direct evaporation from soil and plant surfaces but gave no figures for loss by runoff or underground water movement. Burr (12) figured that 33 percent of the annual rainfall was stored in the upper 5-6 feet of soil in favorable years and less than 10 percent in unfavorable years at North Platte, Nebraska.

Kiesselbach, et al. (16) concluded that alfalfa reduced soil moisture to 2 percent above the hygroscopic level to a depth of 35 feet in six years. Maximum production occurred in the third year on upland in eastern Nebraska with later yields closely correlated with annual rainfall. Fields replanted after an interval of eight years yielded only 50-55 percent of their former yields, thus emphasizing the slow restoration rate of subsoil moisture after it has once been exhausted.

McClatchie (25) in Arizona and Ladin (21) in Galilee indicate that water consumption of mature apple orchards approximates 33 to 36 inches annually but Magness (23) considered that Missouri River Valley apple orchards require 4 inches monthly for the five summer months.

Ruth (29) found that there was a loss of soil moisture in a 12-13-year-old planting, spaced 30 x 33 feet, in 1926, a year of average rainfall. He found less moisture present on the unshaded side of the tree. Oskamp (26) reported 21½ percent less moisture in the upper foot of a 7-year-old orchard than in the treeless area and that normal annual growth required 3.9 percent of the moisture in the planted area.

Viehmeyer and Hendrickson (33) concluded that soil moisture can fluctuate within wide limits without affecting tree growth or production so long as some available water is present. Trees with a 12-foot spacing showed drought effects after the fourth season and dropped
leaves 2–6 weeks earlier than in the 24-foot spacing. After 12 years only the 30 and 36-foot spaced trees were still alive.

Wiggans (36, 37, 38, 39, 40, 41) reported that apple trees dried out soils to depths of 30–35 feet, peaches were probably less demanding and grapes apparently affected the moisture content in only the upper 20 feet.

Lunt (20) showed that certain forest species of pines and oak also adversely affect subsoil moisture content at depths to 48 feet and distances up to 41 feet.

**PROJECT HISTORY**

This project began in 1934 and ended in 1955. The work of Kiesselbach, Russel and Anderson (16) indicated that depleted subsoil moisture might be the reason for the loss of many orchards and the injurious effects noted on native woody forest species.

Most of the work in apple orchards was done at the University Fruit Farm at Union, Nebraska. Samples were also secured from commercial plantings of apples and other woody species in areas ranging from Rulo, near the Kansas-Nebraska border, to Florence, just north of Omaha, to Lincoln and several points in central Nebraska.

Initial interest was in securing information on soil moisture content from many locations. Later a specific program was set up involving repeat samplings at yearly intervals. A definite project was organized under which samples were secured at frequent intervals from a controlled area. This project was abandoned after four years because of the 1940 Armistice Day freeze. A new planting in 1943 provided material for a further study which ended in 1953.

**DEFINITIONS**

*Soil moisture* refers to capillary or hygroscopic moisture. In only one instance was free or gravitational water encountered and that in a layer of gravel.

*Water holding capacity* refers to the total moisture which can be retained by a soil against the force of gravity.

*Total moisture percentage* is the relationship between the weight of the water in a given sample and the dry weight of that sample.

*Hygroscopic coefficient* is that portion of the total moisture content held so tenaciously by the soil particles that it cannot be extracted by the root hairs. Ordinarily this represents about 40 percent of the water holding capacity of a loessial soil. This figure is used in calculating the potential water holding capacity of a given soil sample.

*Available water* is that portion of the total soil moisture content which can be used for plant growth. In this investigation this figure seldom was closer than 2–3 percent to the hygroscopic percentage.

*Evapotranspiration* represents the total moisture required by the
growing crop, in this case woody fruit and forest species, by the cover crop, if present, and the direct evaporation into the air from the soil surface or from plant foliage immediately following a rain. This does not include any loss from runoff or subsurface drainage.

Sampling stations designate the particular location with respect to tree position. The tree station was as near the tree as the equipment could be set up; the midway station halfway between two trees in the same row and the intersection station equidistant from the four corner trees of the square or rectangle formed by them except where otherwise described.

Moisture chambers were 12 x 12 x 12-inch redwood boxes with a slit in one side to permit insertion and removal of shallow aluminum pans holding the soil samples upon which the hygroscopic coefficient was being determined. Screw eyes in the walls of these boxes held the sample pans at the desired level above a zinc pan containing water. Boxes were lined with blotting paper which extended into the water pans and water vapor loss was prevented by foam rubber gaskets around the lids closing the slits.

MATERIAL AND METHODS

Material consisted of one-foot samples taken from soil cores ranging in length from 8 feet to more than 40 feet. More than 900 cores usually to depths of 30 feet, were taken from more than 40 sites. Costs precluded duplicate sampling. Check samples from adjacent non-wooded areas were few because knowledge of previous site history was lacking.

One variable, for which no suitable adjustment could be found in most instances, was the precipitation occurring between sampling dates. However, rainfall affected primarily the moisture content of the upper 5-foot zone and had little effect on the average moisture content of 30-foot samples.

The data represent the determined total moisture percentages in one-foot sections of the soil cores. Graphs represent moisture percentages but in the tables and comments these percentages often have been converted into inches of water. (Detailed tabular data are available in mimeographed form to any investigator requesting it from the Department of Horticulture and Forestry, University of Nebraska College of Agriculture and Home Economics.

Sampling Equipment

Five-foot sections of one-inch inside diameter seamless steel tubing were threaded on the inside at both ends. A four-inch section of a threaded steel rod was riveted into the upper end of each section thus making possible the joining of two or more sections.
Two sections received special treatment. A driving head, 2½ feet long, had a heavy steel ring welded to the upper end. A five-foot point was constricted to a three-fourth-inch diameter and then machined to a cutting edge. A slight bulge on this section a few inches from the cutting end reduced friction between the soil and the tube. A shorter point was useful, particularly in wet soils in which soil compaction was often encountered if the longer point was used. Below the five-foot level the five-foot point served satisfactorily.

A 50-pound weight attached to a rope passing through a pulley at the upper end of a 20-foot gin pole was used to drive the sampling equipment into the soil.

Soil Samples

The soil core was divided into 12-inch sections which were placed in tightly lidded, evenly weighted tin cans. Cores taken in high moisture soils often compacted in the tube and had to be forced out with a ramrod. If the point was driven too far into the soil, the compacted sample was difficult to remove even with an auger.

Soil Drying Procedure

The soil samples were dried to a constant weight at 105° C. A 48-hour drying period was usually sufficient. Moisture percentages were then calculated on the dry weight basis.

Hygroscopic Coefficient Determination

Hygroscopic coefficient was determined by the method of Alway, et al. (4): removing all moisture from the samples; grinding the sample to a particle size of 1 mm or less; exposing a small sample of the ground material thinly spread in a shallow 4 x 6 inch aluminum tray at a temperature of 22–24° C. in a saturated atmosphere for 24 hours; weighing an appropriate sized sample in a glass stoppered bottle; drying for 48 hours at 103° C.; determining the moisture loss by difference and finally, calculating the moisture percentage on the basis of dry weight. A difference of more than 0.3 percent in the calculated moisture content of duplicate samples called for a rerun of the sample.

Hygroscopic coefficients varied from 4.0 percent in sandy soils to 12.0 percent in heavy soils. Loess soils were generally in the 10–12 percent range with the variation largely because of differences in organic matter content. The difference between the hygroscopic moisture percentage and the total moisture content of the soil has been assumed to represent moisture available for plant use.

Conversion of Moisture Percentages to Inches of Water

Water content of soils expressed as inches is much more easily
understood than moisture percentages. Moisture percentage was converted to inches of water by this formula.\(^3\)

\[
\text{Average moisture percentage} \times \text{depth of sample in feet} = \text{inches of water}
\]

Applying the above formula to a case in which the total soil moisture was 25.0 percent and the hygroscopic coefficient 10.0 percent, the maximum water holding capacity in a 30-foot sample would be 115.4 inches of which 46.1 inches would be the hygroscopic portion. The maximum available to the plant would be 69.3 inches.

**RESULTS**

All experimental data bearing upon a given factor have been assembled into a given unit regardless of the sampling date. Results are as follows:

**Distance From the Tree as a Factor in Moisture Depletion**

Samples were taken at varying distances from the trunks of selected apple trees in the summer of 1934 to determine the soil space occupied by the root system as measured by soil moisture content. The Lincoln samples were taken at distances of 2.5, 7.5, 12.5, 17.5, 22.5 and 27.5 feet from the trunk of a McIntosh tree at least 35 years old. Table 1 gives averages of three five-foot samples taken at indicated distances from the trunk.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Distance from trunk</th>
<th>Sample zone depths</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1-5 %</td>
<td>6-10 %</td>
</tr>
<tr>
<td>Mature tree—Lincoln McIntosh</td>
<td>2.5</td>
<td>16.6</td>
<td>16.1</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>17.1</td>
<td>16.4</td>
</tr>
<tr>
<td></td>
<td>12.5</td>
<td>15.6</td>
<td>15.4</td>
</tr>
<tr>
<td></td>
<td>17.5</td>
<td>18.5</td>
<td>18.8</td>
</tr>
<tr>
<td></td>
<td>22.5</td>
<td>18.1</td>
<td>18.3</td>
</tr>
<tr>
<td></td>
<td>27.5</td>
<td>19.4</td>
<td>23.6</td>
</tr>
<tr>
<td>17-year-old tree—Union Jonathan</td>
<td>2.5</td>
<td>15.5</td>
<td>13.6</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>14.6</td>
<td>12.9</td>
</tr>
<tr>
<td></td>
<td>12.5</td>
<td>14.2</td>
<td>13.2</td>
</tr>
<tr>
<td></td>
<td>17.5</td>
<td>13.8</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>22.5</td>
<td>13.4</td>
<td>13.9</td>
</tr>
</tbody>
</table>

\(^3\) The late H. F. Rhoades, Soils Scientist at The University of Nebraska, indicated that these conversion values, although somewhat low, were acceptable because of the great uniformity of the soils involved.

9
Samples secured at Union from a 17-year-old planting of Jonathans spaced 30 x 33 feet were similar (Table 1) to the Lincoln samples except that no sample could be obtained at the 27.5 foot distance from the trees.

In 1935 extensive sampling was done in the Union orchard with trees 18 years old. Four varieties were involved and a total of 25 samples were taken. Figure 1 shows the foot-by-foot findings from the tree, midway, intersection and non-tree area stations. The difference between the moisture percentages at these stations and the hygroscopic percentage represents the soil moisture available for tree use.

Converted to inches of water, the amounts still remaining in the upper 30 feet of this soil were 29.5, 36.0, 40.6 and 65.5 for the various stations, out of a maximum potential of 72.0 inches.

Thus, nearly 60 percent of the available water supply, assuming that the soil initially held field carrying capacity, was already gone from the tree station sample, slightly more than 50 percent from the midway station and less than 35 percent at the intersection. The non-tree area still had 90 percent of its carrying capacity.

Apple trees draw upon available soil moisture as it is needed,
using first a major share of that in the upper soil layers then gradu-
ually exhausting that in the deeper layers and to increasing distances
from the tree. The tree apparently dries out a bowl-shaped soil mass
with the tree trunk the focal point of the bowl.

**Effect of Spacing Distances on Soil Moisture Depletion**

Early apple plantings in Nebraska were generally closely spaced.
Undoubtedly more fruit was harvested during the first 10 years of
the orchard’s life. As yield declined, the so-called “filler” trees were
to be removed to provide more nutrients and water for the “perma-
nents.” In too many cases, however, development of the extra trees
resulted in the impairment of size, yield and longevity of permanent
trees.

Permanent trees in the University Fruit Farm orchard, planted
in 1918, were spaced 30 x 33 feet. In one half of the orchard an extra
tree was planted in the center of each 30 x 33 foot rectangle.

In the summer of 1934, 30-foot samples were taken in each plant-
ing. Data are presented in Figure 2.

![Figure 2. The effect of tree spacing and distance from the tree upon total soil moisture percentage in a 17-year-old orchard at Union, Nebraska, 1934.](image-url)
During the 17 growing seasons the available moisture content of the soil was reduced to 8.8, 22.2 and 41.1 inches at stations 15 feet from the filler tree, 15 feet from the permanent tree and 22.5 feet from the permanent tree, respectively. The potential water holding capacity of this soil was 75.4 inches. In the non-tree area sample, water content was below the maximum potential due possibly to earlier timber growth or other deep rooted crops.

**Tree Age and Its Effect on Residual Moisture**

The productive life of midwestern apple orchards is shorter than in some other fruit regions. Under Nebraska conditions the production decline begins at about 30–35 years. The usual explanations for the decline are lack of nutrients or prevalence of disease. Seldom has thought been given to the lack of an adequate water supply.

Soil samples were taken in 1934 from a mature orchard of uncertain age and a young planting just reaching production near Shubert, Nebraska. Soil conditions, slope, spacing and varieties (Jonathan) were comparable for the two orchards. Twenty-seven-foot samples were

![Graph](image-url)  
**Figure 3.** Total soil moisture percentages at comparable locations in a mature apple orchard and in a young planting, Shubert, Nebraska, 1934.
taken from the tree and intersection stations in each orchard and from an adjacent tilled non-tree area.

Data in Figure 3 show that relatively little available moisture remained for plant use at the tree station in the old planting but there was some at the intersection, particularly below the 10-foot level. In the young planting some moisture had been exhausted at the tree station but the intersection station had a moisture content similar to that of the non-tree area.

Soil moisture percentages in all cases were similar below the 18-foot level. A compact soil layer at this level effectively prevented deeper root penetration and no moisture was removed from lower depths.

Converting the available moisture supply into inches showed that of the 64.8 inches of potential available water supply only 5.0, 8.4, 8.4 and 14.1 percent were left at the mature tree station, mature intersection, young tree station and young tree intersection, respectively, above the 18-foot level.

In 1936 samples were secured from two old orchards and one young one in the Omaha area. Figure 4 shows data from the upper 38 feet of the old orchards. Twenty-foot samples were taken in the young orchard. Samples taken outside the orchard showed a moisture content more than twice that of the orchard sample.

Calculating the percentage of the maximum potential available water holding capacity still available for tree use, the old orchards had 35.9 and 31.6 percent, respectively, of the 76.6 inches theoretical

![Figure 4. The subsoil moisture situation, near the trunks, in orchards of varying ages in the Omaha, Nebraska, area, 1936.](image-url)
capacity. In the new orchard 77.5 percent of the theoretical 44.5 inches was still in the soil.

The data support the idea that Nebraska orchards begin to decline after 30-35 years largely because of lack of moisture to supply plant requirements.

**Varietal Influence Upon Soil Moisture Usage**

Certain apple varieties maintain vigor and fruitfulness longer than others. Disease susceptibility and differing inherited characteristics are often advanced as reasons for the difference. Little or no attention has been given to the water requirement differential.

The Banning orchard at Union, Nebraska was planted in 1918 and consisted of six commercial varieties: Arkansas, Delicious, Grimes, Jonathan, Stayman and Winesap. Spaced 33 x 40, the trees were on a gentle east slope in four row blocks. The soil was uniform and had been given excellent care.

Tree and intersection station samples to 30 feet were taken in 1935. Interior rows and adjacent rectangles were sampled to avoid any influence from adjacent varieties. Results shown in Table 2 suggest that varieties vary in their water requirements, particularly when soil moisture content from below the five foot level is considered. Grimes and Jonathan appeared to be the heaviest users while members of the Winesap group depleted the subsoil moisture at a slower rate. The Delicious occupied an intermediate position.

**Effect of Soil Management Methods on Subsoil Moisture Supply**

Cultural practices are designed to produce a large bearing surface but not to overstimulate vegetative growth. Clean culture generally

<table>
<thead>
<tr>
<th>Variety</th>
<th>Soil moisture percentages</th>
<th>Calculated reserve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample zone depths</td>
<td>Actual in.</td>
</tr>
<tr>
<td></td>
<td>1-5 %</td>
<td>6-10 %</td>
</tr>
<tr>
<td>Grimes</td>
<td>9.7</td>
<td>3.9</td>
</tr>
<tr>
<td>Jonathan</td>
<td>7.8</td>
<td>4.5</td>
</tr>
<tr>
<td>Delicious</td>
<td>10.7</td>
<td>3.6</td>
</tr>
<tr>
<td>Stayman</td>
<td>13.2</td>
<td>5.3</td>
</tr>
<tr>
<td>Arkansas</td>
<td>10.4</td>
<td>4.5</td>
</tr>
<tr>
<td>Winesap</td>
<td>14.7</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Table 2. Varietal effect on subsoil moisture content in the 18-year-old Banning orchard, Union, Nebraska, with 33 x 40 ft. spacing. Values are the average of tree and intersection sampling stations, 1935.
ends about the time fruiting begins and a sod forming crop is introduced to compete with the trees for water and nutrients and thus induce earlier fruiting.

The seven-year-old Tomlinson Delicious apple orchard near Omaha was half under clean cultivation and half in alfalfa sod in the summer of 1936 when soil samples were taken at the intersection station. Cultivated trees were larger, more vigorous and showed much less Buffalo Tree Hopper damage. Figure 5 shows the extent to which soil moisture had been exhausted at the two locations. In the alfalfa block 22.2 inches and in the clean culture block 39.7 inches of water remained out of the maximum potential water holding capacity of 65.5 inches. Clearly alfalfa, and by implication any other deep-rooted perennial crop, is not desirable in the apple orchard.

Cultural blocks were established in the Union Fruit Farm orchard when trees were eight years old. Blue grass was considered as a permanent crop, red clover was re-established as needed while lespedeza and vetch were treated as annuals. Arkansas, Jonathan, Virginia Beauty and Winesap varieties were involved. Thirty-foot samples taken in 1935 showed least exhaustion of moisture under the bluegrass and greatest under the vetch cover, but in no instance was the loss significant.
Table 3. Effect of straw mulch on orchard soil moisture, Union orchard, 1937.

<table>
<thead>
<tr>
<th>Soil depth (feet)</th>
<th>Total moisture percentage</th>
<th>Unmulched area</th>
<th>Mulched area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22.0</td>
<td>28.1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>23.5</td>
<td>25.1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>16.1</td>
<td>19.5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>14.3</td>
<td>14.1</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>13.7</td>
<td>13.4</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>13.1</td>
<td>13.2</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>13.1</td>
<td>13.1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>12.7</td>
<td>13.1</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>16.1</td>
<td>19.6</td>
<td></td>
</tr>
</tbody>
</table>

A small block of Arkansas, Virginia Beauty and King David trees at Union was mulched with 12–15 inches of wheat straw in the summer of 1936. The area was on a moderate east slope. Previous deep soil samples had disclosed that available soil moisture was at a low point in the upper 30 feet under these closely spaced trees.

This mulch was covered with a heavy sleet cover in the winter of 1936-37. Soil samples taken in May 1937 to depths of 30 feet revealed that considerably better moisture conditions existed in the upper 8 feet of the mulched area. Table 3 shows that the total moisture percentage averaged 3.5 percent greater in the mulched area. Translated into inches of water the difference is equivalent to 4.3 inches—an amount sufficient to carry the orchard through several weeks of summer growth. These results indicate that any method of soil management resulting in water retention is worth consideration.

Annual Moisture Requirements of Mature Apple Trees

As data accumulated indicating that subsoil moisture was approaching the critical stage, arrangements were made to resample a number of sites after an interval of one, two or even more years to determine if possible the total annual moisture needs of the trees, the cover crop and that lost by evaporation.

In August, 1934, four 30-foot soil samples were taken at Union, Neb., at distances varying from about 7 to 22 feet from the tree trunk. Twenty-seven and one-half months later a second set of samples was secured. Figure 6 shows the change in soil moisture content. Calculating the inch change during the period shows a loss of 34.2 inches even though the interval rainfall was 54.0 inches. Losses for the various stations were 6.1, 9.5, 7.1 and 11.5 inches at distances of 7.3, 12.3, 17.3 and 22.3 feet respectively from the tree trunk. Thus, the total moisture requirement to care for all water usage was 84.2 inches for the three growing seasons.

In a mature Jonathan orchard near Nebraska City, three 30-foot samples were taken at intervals of one year (Figure 7). The site was
Figure 6. Changes in available moisture in inches at varying distances from a 17-year-old Jonathan apple tree, Union, Nebraska, between Aug. 9, 1934 and Nov. 24, 1936.

* * * = INTERVAL LOSS OF MOISTURE

Figure 7. Annual withdrawal of subsoil moisture by mature Jonathan apple trees in Kimmel orchard, Nebraska City, Nebraska, 1935-1937—intersection stations.
relatively level and no runoff could occur. Slightly more than 50 percent of the maximum available potential was present in December 1935, less than 40 percent a year later and by November 1937, less than 30 percent. Actual rainfall during both seasons was somewhat below normal but calculations indicate that the subsoil moisture loss during the 1936 growing season was 8.3 inches and in the 1937 season, 7.2 inches. Combining these annual losses with the amount of interval precipitation, the water usage by the trees, the cover crop and that lost by direct evaporation, the total loss was more than 30 inches during the 1936 season and 35 for the 1937 season.

During 1935–39 samples were taken at different intervals from 12 orchards in various parts of the state. Table 4 shows age, spacing, variety, sampling depth, and findings with respect to the soil moisture situations. From the soil moisture data and the determined hygroscopic coefficients the available moisture potential and the actual soil water content have been calculated in inches for the various sampling dates. Thus, the interval change of soil moisture could be determined. With but few exceptions there was less moisture at the succeeding later sampling date or dates. Except as noted in Table 4, moisture figures are averages of the tree and intersection stations.

Not all soils involved were filled to maximum water holding capacity at the time the orchard was planted. For this discussion this has been assumed to be the case. Potentials varied from 44.1 inches in the upper 19 feet in the 7-year-old Sautter orchard to 75.8 inches in the upper 23 feet of the Keyser planting. The unused portion of this potential ranged from 70.3 percent in the Sautter planting to 8.1 percent in the 21-year-old Beaver orchard. Water usage by the trees undoubtedly accounts for most of the indicated losses but some variation could be expected from differences in tree age, slope, soil type and depth, spacing and general orchard management methods.

From a block of 16 Delicious apple trees planted in 1918 at the Union Fruit Farm on a fairly level site, 26 soil samples to a depth of 30 feet were taken at intervals between July 1, 1935, and June 3, 1941. Four samples, two from the intersection and two from the tree stations were secured at each sampling date and then combined for the moisture percentage. Figure 8 shows the calculated available moisture still remaining in the upper 30 feet of this soil while Table 5 shows the moisture percentage at the various dates, the interval rainfall and the apparent annual evapotranspiration rate. The abrupt change in the available water and moisture percentage between June 18 and Aug. 21, 1937, was due to the application of 43 inches of irrigation water which was added in an effort to bring the soil close to its water holding capacity.

With few exceptions the amount of available moisture decreased with each sampling date. Adding these losses to the interval precipi-
Table 4. Seasonal withdrawal of subsoil moisture by apple trees of varying ages, spacing distances and varieties in eastern Nebraska orchards at the intersection stations, 1935-36-37-38-39.

<table>
<thead>
<tr>
<th>Orchard &amp; location</th>
<th>Age (years)</th>
<th>Spacing (feet)</th>
<th>Variety</th>
<th>Sample zone</th>
<th>Aver. H. C.</th>
<th>Calculated available potential (inches)</th>
<th>Sampling dates</th>
<th>Actual water content</th>
<th>Interval change (inches)</th>
<th>Unused portion of potential (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beavers</td>
<td>19</td>
<td>30 x 30</td>
<td>Jonathan</td>
<td>1–30</td>
<td>9.8</td>
<td>5/36–5/37</td>
<td>12.5</td>
<td>12.5</td>
<td>0.0</td>
<td>18.5</td>
</tr>
<tr>
<td>Omaha</td>
<td>20</td>
<td>30 x 30</td>
<td>Jonathan</td>
<td>5/37–11/37</td>
<td>12.5</td>
<td>11.5</td>
<td>12.5</td>
<td>11.5</td>
<td>-1.0</td>
<td>17.1</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>30 x 30</td>
<td>Jonathan</td>
<td>11/37–11/38</td>
<td>11.5</td>
<td>5.5</td>
<td>11.5</td>
<td>5.5</td>
<td>-6.0</td>
<td>8.1</td>
</tr>
<tr>
<td>Sutters</td>
<td>7</td>
<td>25 x 35</td>
<td>Jon.-Del.</td>
<td>5/37–11/37</td>
<td>32.4</td>
<td>31.0</td>
<td>32.4</td>
<td>31.0</td>
<td>-1.4</td>
<td>70.3</td>
</tr>
<tr>
<td>Omaha</td>
<td>32</td>
<td>33 x 33</td>
<td>Jonathan</td>
<td>5/37–11/37</td>
<td>22.5</td>
<td>23.1</td>
<td>22.5</td>
<td>23.1</td>
<td>+0.6</td>
<td>36.1</td>
</tr>
<tr>
<td>Florence</td>
<td>34</td>
<td>33 x 33</td>
<td>Jonathan</td>
<td>5/37–11/37</td>
<td>23.1</td>
<td>18.0</td>
<td>23.1</td>
<td>18.0</td>
<td>-5.1</td>
<td>28.2</td>
</tr>
<tr>
<td>Banning Union</td>
<td>18</td>
<td>33 x 40</td>
<td>6 varieties</td>
<td>11/35–10/36</td>
<td>37.4</td>
<td>33.7</td>
<td>37.4</td>
<td>33.7</td>
<td>-3.7</td>
<td>44.6</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>10 x 32-12/37</td>
<td>Jonathan</td>
<td>10/36–12/37</td>
<td>33.7</td>
<td>32.8</td>
<td>33.7</td>
<td>32.8</td>
<td>-0.9</td>
<td>45.1</td>
</tr>
<tr>
<td>Sims</td>
<td>13</td>
<td>30 x 33</td>
<td>Jon.-Win.</td>
<td>5/37–11/37</td>
<td>26.2</td>
<td>19.3</td>
<td>26.2</td>
<td>19.3</td>
<td>-6.9</td>
<td>32.4</td>
</tr>
<tr>
<td>Nebr. City</td>
<td>15</td>
<td></td>
<td></td>
<td>4/39–11/39</td>
<td>18.5</td>
<td>20.8</td>
<td>18.5</td>
<td>20.8</td>
<td>+2.31</td>
<td>35.0</td>
</tr>
<tr>
<td>Stivers</td>
<td>9</td>
<td>16 x 23</td>
<td>Jon.-Win.</td>
<td>5/37–10/37</td>
<td>34.6</td>
<td>22.6</td>
<td>34.6</td>
<td>22.6</td>
<td>-2.0</td>
<td>32.3</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td>10/37–4/39</td>
<td>22.6</td>
<td>24.4</td>
<td>22.6</td>
<td>24.4</td>
<td>+1.8</td>
<td>35.2</td>
</tr>
<tr>
<td>Keyser²</td>
<td>23</td>
<td>28 x 32</td>
<td>Jonathan</td>
<td>5/37–10/37</td>
<td>21.8</td>
<td>22.9</td>
<td>21.8</td>
<td>22.9</td>
<td>+1.1</td>
<td>30.4</td>
</tr>
<tr>
<td>Lewis²</td>
<td>13</td>
<td>18 x 36</td>
<td>Jonathan</td>
<td>4/39–11/39</td>
<td>34.1</td>
<td>28.0</td>
<td>34.1</td>
<td>28.0</td>
<td>-6.1</td>
<td>60.1</td>
</tr>
<tr>
<td>Shubert</td>
<td>24</td>
<td>22 x 40</td>
<td>Jonathan</td>
<td>10/36–10/37</td>
<td>16.0</td>
<td>12.9</td>
<td>16.0</td>
<td>12.9</td>
<td>-3.1</td>
<td>26.4</td>
</tr>
<tr>
<td>Slocum²</td>
<td>24</td>
<td>22 x 40</td>
<td>Jon-Mo.</td>
<td>10/36–10/37</td>
<td>16.0</td>
<td>12.9</td>
<td>16.0</td>
<td>12.9</td>
<td>-3.1</td>
<td>26.4</td>
</tr>
<tr>
<td>Marshall</td>
<td>11</td>
<td>20 x 32</td>
<td>Jon-Mo.</td>
<td>10/36–10/37</td>
<td>16.0</td>
<td>12.9</td>
<td>16.0</td>
<td>12.9</td>
<td>-3.1</td>
<td>26.4</td>
</tr>
<tr>
<td>Arlington</td>
<td>12</td>
<td>20 x 32</td>
<td>Jon-Mo.</td>
<td>10/36–10/37</td>
<td>16.0</td>
<td>12.9</td>
<td>16.0</td>
<td>12.9</td>
<td>-3.1</td>
<td>26.4</td>
</tr>
<tr>
<td>Heppert &amp; Bowman</td>
<td>16</td>
<td>33 x 40</td>
<td>Jon.-Win.</td>
<td>5/37–11/37</td>
<td>17.2</td>
<td>12.8</td>
<td>17.2</td>
<td>12.8</td>
<td>-4.4</td>
<td>21.5</td>
</tr>
<tr>
<td>Barada</td>
<td>15</td>
<td>33 x 40</td>
<td>Jon.-Win.</td>
<td>5/37–11/37</td>
<td>17.2</td>
<td>12.8</td>
<td>17.2</td>
<td>12.8</td>
<td>-4.4</td>
<td>21.5</td>
</tr>
<tr>
<td>Heesch²</td>
<td>12</td>
<td>20 x 20</td>
<td>Cherries</td>
<td>5/37–11/37</td>
<td>14.6</td>
<td>13.9</td>
<td>14.6</td>
<td>13.9</td>
<td>-0.7</td>
<td>20.6</td>
</tr>
</tbody>
</table>

1 Two-year loss  
2 Midway between rows
Figure 8. A continuing record of the reduction of available subsoil moisture in a mature Delicious apple orchard, Union, Nebraska, 1935–1941.

tation reveals that the water usage for all purposes was 31.14, 37.05, 32.03 and 32.55 inches for the annual growth periods beginning Nov. 9, 1936, and ending Oct. 28, 1940. These figures are in close agreement with those reported by Ladin (19) and McClatchie (25). Loss of water by percolation to lower levels can be definitely eliminated and so the conclusion must be that mature apple orchards in eastern Nebraska require more moisture than is furnished by annual rainfall when spacing permits the planting of 43 trees per acre. Apparently the yearly per tree requirement is approximately three-fourth inch and the need would be higher in case of loss by runoff. Annual rainfall as well as the capacity of the soil to retain moisture for plant use should command first consideration in determining location and spacing of a new planting.

After the 1940 Armistice Day freeze all trees at the Union Fruit Farm were removed and the area replanted the following season. Spacing, 15 x 16.5 feet, allowed four times the usual planting rate with the idea that moisture exhaustion would occur earlier and at a much more rapid rate. Seventeen sampling dates were used between April 26, 1943, and Oct. 2, 1955. Initially eight sampling stations were involved on each side but these were later reduced to six.
Table 5. Apparent evapotranspiration occurring in a mature Delicious apple orchard as determined by calculated available soil moisture and interval rainfall, July 1935–June 1941.

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>Calculated available moisture (in.)</th>
<th>Interval rainfall (in.)</th>
<th>Interval change in calculated moisture (in.)</th>
<th>Apparent yearly evapotranspiration (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 1, 1935</td>
<td>47.5</td>
<td>33.05</td>
<td>−5.5</td>
<td>−5.5</td>
</tr>
<tr>
<td>Nov. 9, 1936</td>
<td>42.0</td>
<td>9.21</td>
<td>NC</td>
<td></td>
</tr>
<tr>
<td>June 18, 1937</td>
<td>74.9</td>
<td>52.71¹</td>
<td>+32.8</td>
<td>31.14</td>
</tr>
<tr>
<td>Aug. 21, 1937</td>
<td>72.5</td>
<td>30.1</td>
<td>−2.5</td>
<td>−2.5</td>
</tr>
<tr>
<td>Nov. 24, 1937</td>
<td>70.0</td>
<td>4.58</td>
<td>−4.9</td>
<td></td>
</tr>
<tr>
<td>April 15, 1938</td>
<td>65.1</td>
<td>2.80</td>
<td>−3.1</td>
<td>37.05</td>
</tr>
<tr>
<td>May 31, 1938</td>
<td>62.0</td>
<td>12.44</td>
<td>−2.0</td>
<td></td>
</tr>
<tr>
<td>July 1, 1938</td>
<td>58.0</td>
<td>9.38</td>
<td>−2.0</td>
<td></td>
</tr>
<tr>
<td>Oct. 24, 1938</td>
<td>56.0</td>
<td>1.20</td>
<td>−2.0</td>
<td></td>
</tr>
<tr>
<td>May 3, 1939</td>
<td>55.0</td>
<td>8.76</td>
<td>−1.0</td>
<td></td>
</tr>
<tr>
<td>July 15, 1939</td>
<td>51.0</td>
<td>2.21</td>
<td>−4.0</td>
<td>32.03</td>
</tr>
<tr>
<td>Aug. 8, 1939</td>
<td>52.9</td>
<td>.90</td>
<td>+1.9</td>
<td></td>
</tr>
<tr>
<td>Sept. 20, 1939</td>
<td>50.0</td>
<td>.40</td>
<td>−2.9</td>
<td></td>
</tr>
<tr>
<td>Oct. 6, 1939</td>
<td>52.0</td>
<td>1.18</td>
<td>+2.0</td>
<td></td>
</tr>
<tr>
<td>Oct. 30, 1939</td>
<td>55.0</td>
<td>6.57</td>
<td>+3.0</td>
<td></td>
</tr>
<tr>
<td>April 3, 1940</td>
<td>56.0</td>
<td>4.37</td>
<td>+1.0</td>
<td></td>
</tr>
<tr>
<td>May 3, 1940</td>
<td>53.0</td>
<td>1.74</td>
<td>−3.0</td>
<td></td>
</tr>
<tr>
<td>July 6, 1940</td>
<td>49.0</td>
<td>2.58</td>
<td>−4.0</td>
<td>32.55</td>
</tr>
<tr>
<td>Aug. 6, 1940</td>
<td>48.0</td>
<td>5.22</td>
<td>−1.0</td>
<td></td>
</tr>
<tr>
<td>Sept. 3, 1940</td>
<td>47.0</td>
<td>4.72</td>
<td>−1.0</td>
<td></td>
</tr>
<tr>
<td>Oct. 28, 1940</td>
<td>46.0</td>
<td>1.35</td>
<td>−1.0</td>
<td></td>
</tr>
<tr>
<td>April 3, 1941</td>
<td>48.0</td>
<td>6.06</td>
<td>+2.0</td>
<td></td>
</tr>
<tr>
<td>May 3, 1941</td>
<td>46.0</td>
<td>4.00</td>
<td>−2.0</td>
<td></td>
</tr>
<tr>
<td>June 3, 1941</td>
<td>42.0</td>
<td>2.78</td>
<td>−4.0</td>
<td></td>
</tr>
</tbody>
</table>

¹ Includes 43 inches of supplemental water

Moisture percentages remained fairly constant for the first several years except for variations accounted for by the interval precipitation. There was evidence during the latter part of the period that some depletion was taking place. These findings agree closely with those reported for other young plantings. The conclusion is that young trees do not draw heavily upon stored moisture, but if the initial moisture content is low the critical point, so far as moisture supply is concerned, will be reached much sooner.

The Replacement Problem

A vacant space in an orchard lowers the productive capacity. In Nebraska replanting is too often a failure. The usual reason offered is lack of nutrients or the prevalence of diseases. Little or no thought is given to the soil moisture supply.

The Franklin orchards near Shubert, Nebraska, contained a new 7-year-old planting, a 7-year-old planting where an earlier orchard had grown, and a 35-year-old area. All spacings were 22 x 33 feet. After several crops of corn or other cultivated crops the former orchard
Figure 9. Soil moisture percentages in a 35-year-old orchard, in a 7-year-old replanted area and in a new 7-year-old planting. Franklin orchard. Spacing 22 x 34 feet. 1934 (Curves based on average percentages of tree and intersection stations)

had been replanted to apples on the theory that the land was ready for a second orchard crop.

In the fall of 1934, samples were secured from each of the three areas. Results are presented in Figure 9, as averages of the tree and intersection stations. The actual available water content in the 35-year-old planting was 31.0 inches, in the replanted area 42.3 inches and in the new 7-year-old planting 57.3 inches. These represent 43, 59 and 80 percent, respectively, of the potential available water holding capacity of 71.4 inches.

Soil moisture percentages here, as in other determinations made in this area, reach a more or less common level at about the 18-feet depth due to soil conditions. Results strongly suggest that replanted trees are at a great disadvantage.

Effects of Other Woody Species on Subsoil Moisture

Grapes

Numerous vineyards in the Missouri River hills area have been in production for 50 years or more. Although plantings are usually on
a slope with rows at a right angle to the slope, clean cultivation has resulted in much soil erosion. Annual pruning has renewed the top many times but the same root system has continued to function.

Several deep soil samples were taken in vineyards in the Omaha area. The results suggest that grapes use subsoil moisture. In one 33-year-old planting at least 50 percent of the available moisture had been used in the upper 15 feet. A sample taken one year later showed a still further reduction. In no case did this depletion equal that caused by apple trees.

In a vineyard established in 1923 at the University Fruit Farm, soil samples taken annually from 1934 to 1955 from mulched and unmulched areas revealed relatively little changes in moisture content that could be attributed to increased age of the plants. Figure 10 shows that at the beginning of the sampling, some seven years after the mulch was first applied, the moisture content of the cultivated area was lower than in the mulched row. However, in time the moisture content of the two areas became similar.

These facts would seem to indicate that the evapotranspiration rate of grapes is somewhat less than for apples. The removal of a great part of the annual growth at pruning time may explain this variance.
Forestry Plantings

Soil samples were taken in 1934 from 35-year-old forestry plantings growing adjacent to the Lincoln apple orchard for comparison with the orchard samples and those from a non-tree area. Both forestry species had more nearly exhausted all the available moisture supply than had apples (Figure 11).

Green Ash: Almost all moisture above the hygroscopic level had been removed by these 35-year-old trees, spaced 4 x 4 feet, to a depth of 35 feet. Samples from the 4 x 6 spaced plot did not show such extreme depletion. The green ash grove at Arlington was at least 70 years old but even though the stand was not heavy more than 70 percent of the potential available moisture had been used.

Catalpa: This species had used almost all water above the hygroscopic level, especially below the 20-foot level. Below this point the moisture curve and that for the hygroscopic coefficient were almost identical.

The moisture curve for the non-tree area is well above those for the orchard and forestry plots above the 20-foot level. The dip at this level could possibly be due to an earlier timber crop removed before the land came under clean cultivation. In the forestry plots

![Figure 11. Total soil moisture percentages under mature forestry plantings and in a mature orchard, Lincoln, Nebraska, 1934.](image-url)
Table 6. Subsoil moisture usage by desiduous forest species at various points in Nebraska, 1936.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Catalpa</td>
<td>30–35</td>
<td>4 x 4</td>
<td>16.5 14.9 14.0 16.4 16.0 7.6 14.2 10.1 19.0 81.8 76.9</td>
<td>21.4 14.3 14.7 14.0 13.3 13.5 22.5 16.3 11.1 28.0 89.9 68.9</td>
<td>22.3 14.6 12.8 12.8 14.1 15.4 15.7 15.4 11.1 23.1 89.9 74.3</td>
<td>12.9 11.1 10.7 10.7 5.1 2.0 20.0 10.5 10.0 1.8 63.2 97.2</td>
<td>15.0 11.5 11.2 16.9 11.2 10.3 12.3 12.6 12.4 10.8 78.3 76.2</td>
</tr>
<tr>
<td>Green Ash</td>
<td>30–35</td>
<td>4 x 6</td>
<td>14.9 14.3 13.6 12.0 16.9 12.8 4.6 12.7 10.1 10.3 81.8 87.4</td>
<td>17.3 14.3 15.7 15.3 14.5 14.7 21.0 16.1 11.1 26.9 89.9 70.0</td>
<td>17.9 14.4 15.7 15.9 15.3 15.2 21.7 16.6 11.1 29.6 89.9 66.0</td>
<td>13.4 10.3 8.9 16.9 14.5 15.3 6.7 13.2 12.4 37.0 78.3 52.7</td>
<td></td>
</tr>
<tr>
<td>Black Locust</td>
<td>70</td>
<td>?</td>
<td>21.4 14.3 14.7 14.0 13.3 13.5 22.5 16.3 11.1 28.0 89.9 68.9</td>
<td>17.3 14.3 15.7 15.3 14.5 14.7 21.0 16.1 11.1 26.9 89.9 70.0</td>
<td>17.9 14.4 15.7 15.9 15.3 15.2 21.7 16.6 11.1 29.6 89.9 66.0</td>
<td>13.4 10.3 8.9 16.9 14.5 15.3 6.7 13.2 12.4 37.0 78.3 52.7</td>
<td></td>
</tr>
<tr>
<td>Green Ash</td>
<td>60</td>
<td>?</td>
<td>17.3 14.3 15.7 15.3 14.5 14.7 21.0 16.1 11.1 26.9 89.9 70.0</td>
<td>17.9 14.4 15.7 15.9 15.3 15.2 21.7 16.6 11.1 29.6 89.9 66.0</td>
<td>17.9 14.4 15.7 15.9 15.3 15.2 21.7 16.6 11.1 29.6 89.9 66.0</td>
<td>13.4 10.3 8.9 16.9 14.5 15.3 6.7 13.2 12.4 37.0 78.3 52.7</td>
<td></td>
</tr>
<tr>
<td>Black Walnut</td>
<td>70</td>
<td>?</td>
<td>17.9 14.4 15.7 15.9 15.3 15.2 21.7 16.6 11.1 29.6 89.9 66.0</td>
<td>17.9 14.4 15.7 15.9 15.3 15.2 21.7 16.6 11.1 29.6 89.9 66.0</td>
<td>17.9 14.4 15.7 15.9 15.3 15.2 21.7 16.6 11.1 29.6 89.9 66.0</td>
<td>13.4 10.3 8.9 16.9 14.5 15.3 6.7 13.2 12.4 37.0 78.3 52.7</td>
<td></td>
</tr>
<tr>
<td>Russian Olive</td>
<td>10–12</td>
<td>7 x 10</td>
<td>22.3 14.6 12.8 12.8 14.1 15.4 15.7 15.4 11.1 23.1 89.9 74.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Honey Locust</td>
<td>18</td>
<td>3 x 8</td>
<td>12.9 11.1 10.7 10.7 5.1 2.0 20.0 10.5 10.0 1.8 63.2 97.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Honey Locust</td>
<td>18</td>
<td>3 x 16</td>
<td>14.4 10.5 10.5 10.6 9.1 2.1 1.0 11.4 10.0 5.1 63.2 91.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chinese Elm</td>
<td>5</td>
<td>8 x 8</td>
<td>15.0 11.5 11.2 16.9 11.2 10.3 12.3 12.6 12.4 10.8 78.3 76.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chinese Elm</td>
<td>4</td>
<td>8 x 11</td>
<td>13.4 10.3 8.9 16.9 14.5 15.3 6.7 13.2 12.4 37.0 78.3 52.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
considerable variation in the soil type and texture accounts for the wide swings in the hygroscopic values.

Details concerning the other forest area samples are found in Table 6.

**Black Locust:** This 70-year-old planting had undoubtedly been renewed a number of times by sprout growth as the usable trees had been removed for fence posts and other needs. Only about 30 percent of the potential available moisture remained.

**Honey Locust:** An 18-year-old planting near Minden had 3 x 8 and 3 x 16-foot spacings. Soil samples showed that 91.2 percent and 97.2 percent respectively of the potential available moisture had been used. Many trees in the closer spacing were dead. Survivors in both areas were existing on annual rainfall which had to be shared with the heavy grass cover.

**Chinese Elm:** A 4-5-year-old planting near Pleasanton, with 8 x 8-foot spacing, had used 76.2 percent of the moisture potential.

**Pines:** Samples from the White Pine planting at Nebraska City and the Austrian Pine windbreak around the Lincoln orchard showed a reduction of available moisture to depths of 20-25 feet. Pines do not extend roots much below the 25-foot level—a conclusion substantiated by trench excavation at Lincoln.

**Mixed Native Forests:** Soil samples from a mature mixed oak-hickory forest near Rulo had a very low moisture content in the upper six to eight feet and there was much exhaustion at lower levels. A dense ground cover effectively prevented runoff.

These trees seemed to be surviving almost entirely on annual rainfall and were making only limited annual growth.

### Restoration of Depleted Subsoil Moisture

Restoration of depleted subsoil moisture can be accomplished by:

1. Annual rainfall over and above moisture needs of the plant, provided runoff is prevented.
2. Moisture conserving practices such as limiting crop growth.
3. The addition of supplemental water.

Moisture content in the upper few feet of soil varies with amount of rainfall. For annual crops it can be improved by summer fallow in alternate years. For tree growth, however, summer fallow is out of the question and needs above those supplied by annual rainfall must be met by drawing upon the available water in the deeper soil layers.

In the White Pine planting at Nebraska City 10,000 White Pine seedlings, spaced 4 x 4 feet, were planted by J. Sterling Morton in 1892. The site was fairly level and dense shade precluded the growth of competing species. Heavy ground cover and shade also kept direct evaporation at a low level. Moisture loss could be attributed almost wholly to tree use.
Figure 12. Subsoil moisture recovery on a white pine grove site after removal of 40-year-old trees, Nebraska City, Nebraska, 1934–36.

Tree development was more or less normal for 40 years; but hot, dry seasons in the early thirties damaged so many of the trees that the entire planting was removed after 1933. In December of 1934, 1935, and 1936 30-foot soil samples were taken.

Figure 12 shows the foot-by-foot total moisture content for the three sample dates. The available water reserve in 1934 was 28.3 inches. This reserve increased to 43.8 after one year and to 49.8 inches after another season. On the basis of 51.76 inches of rainfall during the two seasons, 21.5 inches apparently were retained by the subsoil. Water accumulation during the first year affected the moisture content of the upper 15 feet and extended 4 feet deeper the second year. The lower water content of the upper eight feet in 1936 was caused by a heavy growth of weeds that used up some available water which otherwise might have been stored in the subsoil.

Supplemental moisture provides a sure way of replenishing a low subsoil moisture supply. Daily, weekly or even monthly changes in the surface soil moisture content are more vital to the grower of annual crops than to the orchardist since trees withdraw moisture from deep soil layers.

Installation of an irrigation system on the University Fruit Farm during the winter of 1956–57 provided means of supplementing the
Table 7. The effect of supplemental water on subsoil moisture content in small areas, Union, 1937.

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil moisture percentages</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-5</td>
<td>6-10</td>
</tr>
<tr>
<td>Near irrigated tree</td>
<td>28.4</td>
<td>29.1</td>
</tr>
<tr>
<td>2 feet outside basin</td>
<td>18.6</td>
<td>26.8</td>
</tr>
<tr>
<td>7 feet outside basin</td>
<td>16.8</td>
<td>13.7</td>
</tr>
<tr>
<td>22 1/2 feet from tree</td>
<td>16.4</td>
<td>15.0</td>
</tr>
<tr>
<td>Near unirrigated tree</td>
<td>16.3</td>
<td>14.0</td>
</tr>
</tbody>
</table>

natural rainfall. Two methods of application were used. The “basin” test determined how fast and how far water would penetrate both vertically and laterally from a small basin constructed around each tree. In the “flood” test water was applied in sufficient amount to fully restore the water content of the soil to a depth of 30 feet. The block to be flooded consisted of sixteen 16-year-old Delicious trees spaced 30 x 33 feet.

Table 7 shows total moisture percentages as found in succeeding five-foot zones near an irrigated tree and near an unirrigated tree in the closely spaced portion of the orchard. Water penetration and restoration extended to the 15-foot level near the irrigated tree (center of the basin) and to a lesser depth at a distance of two feet outside the basin perimeter. There was no apparent effect at a point seven feet from the basin and conditions here were only slightly better than those found under the non-irrigated tree even though in the latter case the tree station sample was used. Complete water stabilization had occurred during the several-week interval between application and sampling.

Five water applications were made to the “flooded” area between July 1, and July 23, 1937. The area had been diked to prevent runoff. As much as 13 inches of water were applied at one time but no water was added until the previous application had been completely absorbed. A total of 43 inches was applied.

Table 8. Replenishment of deep subsoil moisture by supplemental water, Union, Delicious block, 1937.

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>Soil moisture percentages</th>
<th>Calculated water reserve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample zones</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>1-5</td>
<td>6-10</td>
</tr>
<tr>
<td>June 18, 1937</td>
<td>21.8</td>
<td>17.7</td>
</tr>
<tr>
<td>Aug. 25, 1937</td>
<td>26.4</td>
<td>27.0</td>
</tr>
<tr>
<td>Nov. 9, 1937</td>
<td>25.1</td>
<td>26.0</td>
</tr>
<tr>
<td>Hygroscopic coefficient</td>
<td>10.6</td>
<td>10.4</td>
</tr>
</tbody>
</table>
Soil samples taken before any water was applied showed an available reserve of 42.6 inches. Five weeks later, after stabilization had occurred, the amount was 72.9 inches. The same situation prevailed six weeks later. Confirming data are presented in Table 8. These figures indicate that depleted subsoil moisture can be restored by proper management practices.

The discrepancy between the theoretical potential water holding capacity and the actual calculated reserve is of no great significance.

CONCLUSIONS, RECOMMENDATIONS

Apple trees grown under normal orchard conditions in eastern Nebraska deplete the deep subsoil layers of much of the available moisture. The extent to which this depletion occurs varies depending upon the age of the trees, spacing distances and soil management methods. Variety plays a less important role in this moisture loss but may have some significance. The effect of tree size upon the depletion rate is slight.

This exhaustion effect begins shortly after the planting of a new tree, particularly in the soil immediately below the tree. The depleting effect decreases as distance from the tree trunk increases.

Subsoil moisture depletion is a continuing process until it is practically all gone, after which time the tree must depend upon annual precipitation to supply its needs.

The more closely trees are spaced the more quickly the soil moisture is depleted. This explains the decline of most Nebraska orchards after 30 or 35 years of production.

Subsoil moisture depletion proceeds at a much faster rate where deep-rooted competing crops are used as orchard cover crops. Alfalfa should not be used in an orchard unless supplemental water is available.

Short-lived varieties, such as the Grimes, apparently dry out the soil more rapidly than those of the Winesap group.

Forestry species and grapes have a similar need for subsoil moisture but may vary somewhat because of pruning practices, etc.

Nebraska apple growers should:

1. Investigate soil depth and the subsoil moisture situation of any prospective orchard site before planting. A root zone constricted by layers of sand, rock, chalk or extremely compact soil will handicap orchard development. Subsoil moisture removed by former deep-rooted crops will probably never be replaced unless special cultural practices or supplemental water applications are used.

2. Make sure surface soil is receptive to rapid water intake and that deeper layers can retain large amounts of water.
3. Contour land to restrict runoff. Sloping land otherwise suitable is acceptable if proper measures such as contour planting are practiced.

4. Regulate planting distances in accordance with the average annual precipitation and the fruit species involved.

5. Avoid use of alfalfa or other deep-rooted cover crops or intercrops. Row-tilled crops are acceptable in young plantings but an increased tree row area is needed as the trees grow older. For the bearing orchard some sod forming crop is generally used. Water usage may be lessened by frequent close clipping.

6. Use the pruning practice most conducive to moisture conservation. However, excessive removal of leaf surface will reduce the fruit bearing performance of the plant.

7. Take advantage of any supplemental water supply available.

REFERENCES


14. Busgen, M. and Munch, E.
1929. Structure and life of forest trees. (English translation by T. Thomsen.)
436 pp. illus. N.Y.

15. Conrad, J. P. and Viehmeyer, F. J.


18. Kramer, P. J.

19. Ladin, C. H.

20. Lunt, H. A.

21. Magness, J. R.

22. ———.

23. ———.

24. Marth, P. C.

25. McClatchie, A. J.


27. Platt, Rutherford.

28. Rogers, W. S.

29. Ruth, W. A.

30. Saunders, William.

31. Schuster, G. E.

32. Stephenson, R. E.

33. Viehmeyer, F. J. and Hendrickson, A. H.
34. Wiggans, C. C.  
36. ————. 
37. ————. 
38. ————. 
39. ————. 
40. ————. 
41. ————. 
42. Wilcox, J. C. and Knight, A. T. 
43. ———— and Mason, J. L. 
44. ————, Mason, J. L. and McDonald, J. M. 
45. Yocum, W. W. 