IRRIGATION
OF APPLES
IN THE HUDSON VALLEY

G. G. Forshey and B. A. Dominick, Jr.

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Acknowledgments

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Irrigation of Apples in the Hudson Valley

C. G. FORSHEY * and B. A. DOMINICK, JR. †

Irrigation is not an established practice in Eastern apple orchards. Interest in this practice has traditionally been inversely proportional to rainfall and the weather of the area has not necessitated periods of sustained concern. As a result, irrigation research has not been pursued with the zeal accorded to regularly recurring problems, but unfortunately, those questions that do arise periodically can be satisfactorily answered only through continuing studies.

The investigations described herein were conducted in the Hudson Valley of New York State in the years 1955 through 1964. This work was confined to soils normally considered "droughty," that is, shallow or very coarse soils of low total water-holding capacity. It was assumed that these soils would be most responsive to irrigation and a lack of response would preclude the possibility of profitable irrigation of soils of greater depth or more desirable texture.

This was a practical study rather than a fundamental investigation, and the objectives were 3-fold. First of all, the physiological response of the trees was evaluated, with major emphasis on the effects of irrigation on fruit growth. Secondly, an effort was made to develop efficient irrigation practices, the most important factor of which was the timing of the water applications. The third area of investigation, and the most important from the fruit grower's point of view, was an economic analysis of the practice.

It is emphasized that the results reported here apply only to the conditions under which these studies were conducted, since the response might be markedly different with other varieties, growing on other soils, and under different climatic conditions. Equally important is the fact that the net return from irrigation is determined largely by the price received for the apples. Because of the capricious nature of the fresh fruit market, a growth response that was highly profitable in one year might fail to cover costs in a less favorable marketing situation.

Experimental Methods

The study of irrigation in an area such as the Hudson Valley is fraught with frustrations. Many of the sites that present the most

* Associate professor of pomology, Hudson Valley Laboratory, New York State Agricultural Experiment Station, Highland, N. Y.
† Professor of marketing, Department of Agricultural Economics, New York State College of Agriculture at Cornell University, Ithaca, N. Y.
interesting problems in soil moisture lack the water for irrigation. The sites that combine a soil moisture problem and the water to correct it sometimes produce only a partial crop in a year of inadequate rainfall. Mechanical problems or the urgency of other orchard operations may prevent critical timing of irrigation, and untimely rains may force the abandonment of elaborate plans after substantial effort has already been expended. Because of these uncontrollable variables, the combination of circumstances necessary for the study of some questions may occur only once in several years, and some rather obvious questions have not yet been satisfactorily investigated in the Hudson Valley.

All trees included in these studies were standard-sized, seedling rootstock trees, and treatment was confined to those carrying a full commercial crop. The experimental design was a randomized block with 8 to 12 replicates. Where other factors were to be studied simultaneously, a split-plot design was used. Soil moisture was measured twice weekly by the electrical resistance method. The gypsum soil moisture blocks were buried at the drip line of the branches of each experimental tree at depths of 12 and 18 inches and, in some cases, at 24 inches. Fruit growth was compared by tagging 20 fruits per tree, at random, on or about July 1, and measuring the diameter of these tagged fruits at that time and at intervals of approximately 10 days thereafter until harvest. At harvest, the yield of each tree was recorded and 4 boxes of fruit were selected at random from each tree for fruit size determinations.

Rainfall

In areas of appreciable summer rainfall, the potential plant response to irrigation is determined by the amount and distribution of rainfall. In years in which precipitation in the Hudson Valley approaches the long-term average, both in amount and seasonal distribution, significant response of deep-rooted crops such as apples is improbable. Profitable response is expected only in years of marked rainfall deficits.

Rainfall records provide an excellent example of the vagaries of nature. The Poughkeepsie and Poughkeepsie Airport weather stations, near the geographical center of the Hudson Valley, are less than 5 miles apart, but they consistently report substantial differences in precipitation, both in amount and distribution (table 1). Because of this variation, no one weather station can be truly representative of an area as large as the Hudson Valley. However, it is not the entire valley, but only the fruit acreage that is of importance here. For the 10 years of this study, the precipitation records of the Poughkeepsie Airport (table 2) were in good agreement with rainfall measurements in experimental orchards, and the records of this station are therefore used as the basis for comparison of the different growing seasons included. It is conceded, of course, that in any one year, or in all years, some orchards
### Table 1. A comparison of 1968 precipitation* at 2 Hudson Valley weather stations

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<td>2.59</td>
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</table>

* Monthly totals in inches.

### Table 2. Monthly precipitation totals at the Poughkeepsie, N. Y. airport for the years 1955 through 1964

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<td>1.88</td>
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<td>1.91</td>
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<tr>
<td>1963</td>
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<td>3.52</td>
<td>2.62</td>
<td>34.05</td>
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<tr>
<td>1964</td>
<td>2.85</td>
<td>2.67</td>
<td>3.06</td>
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<td>3.82</td>
<td>7.22</td>
<td>3.45</td>
<td>2.09</td>
<td>37.58</td>
</tr>
</tbody>
</table>

**Growing season total:** 180.24 inches

**Total Normal:** 189.37 inches

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*Inches*  
† Months from April through September.

† 16-year average.
may have received significantly more or less precipitation than that recorded at the Poughkeepsie Airport.

Annual precipitation for the 10-year period covered a wide range, with the total for the wettest year (1955) nearly double that of the driest year (1964). However, from the agricultural point of view, it is not the total for the year, but the rainfall during the growing season that is most important. When a disproportionate amount of the year’s precipitation falls in winter, extended periods of extreme drought can develop during the growing season, even though the total for the year is well above the long-term average. The effects of seasonal distribution are well illustrated by the years 1962 and 1963. The totals for these 2 years were almost identical, but 30 percent more rain fell during the growing season in 1963 than in the previous year. The long-term average for the growing season at the Poughkeepsie Airport is slightly more than 3 inches per month, but in 3 of these 10 years (1957, 1962, and 1964), the average was approximately 2 inches per month.

However, it is exceedingly difficult to establish water requirements in terms of inches of rain. For one thing, monthly totals are sometimes deceptive and rainfall distribution may be much less favorable than they indicate. When heavy rains fall at the beginning of one month and at the end of the next one, with no rain between, the monthly totals may be impressive, but there will also be a period of 6 to 7 weeks without rain. This is sufficient time for a soil moisture deficit to develop. Another limitation of the monthly totals is that light rains may be of little benefit to deep-rooted crops in hot, dry weather. Under such conditions, much of the rain that falls may be lost through surface evaporation, but these rains may nonetheless contribute substantially to total rainfall. In an experimental orchard at LaGrangeville, N. Y., 1957, rainfall from May 1 to harvest (October 17) totalled 10.85 inches. In this 5½-month period, rain fell on 26 different days, but there were only 3 rains of 1.00 inch or more, and 4 of 0.50 to 0.99 inches. In this orchard, light rains of doubtful value contributed more than one-third to the total. These data are presented, in part, in figure 2.

In addition to distribution, certain other factors influence the effectiveness of the rain that falls during the growing season. The value of some rains may be reduced to a fraction of the potential by excessive run-off. Losses may be substantial during very heavy rains, on steep slopes, or on sites with soil conditions unfavorable for rapid infiltration. In periods of high temperature and low humidity, the rate of transpiration increases markedly and water requirements increase proportionately. Because of these effects of distribution, run-off, temperature, and humidity, it is impractical to attempt to establish exact minimum rainfall requirements. The adequacy of a season’s precipitation can best be measured on the scale of plant performance.
Soil Moisture

When rainfall during the growing season is significantly less than the long-term average, the usual consequence is relatively low levels of available moisture in Hudson Valley soils. The normal seasonal distribution is such that available soil moisture (ASM), that is, the between range field capacity and the permanent wilting percentage (PWP), is likely to be relatively low in late July or in August. In this respect, the seasonal soil moisture pattern for 1961 (fig. 1) could be considered typical or average. By comparison, both 1957 and 1962 were well below average in terms of available soil moisture.

![Graph showing percent available soil moisture over months for 1957, 1961, and 1962.](image)

*Figure 1.—Available soil moisture, at a depth of 18 inches, in experimental orchards in 3 years of markedly different summer rainfall.*

Precise estimation of the soil moisture requires numerous and frequent moisture determinations and there are problems attendant to such measurements. Direct determination of the moisture content of the soil is impractical; the speed and convenience necessary for careful observation of large acreages requires some type of moisture-measuring
device. Meters utilizing either the electrical resistance (4, 5) or the capillary tension principles (14, 20, 21) are commonly used. Both are satisfactory and both are available in models calibrated directly in percent of available soil moisture. These devices are quite accurate for a wide variety of soils over a wide range in moisture content, but they do lose accuracy in soils that are very light or very heavy in texture, and in soil that is close to the permanent wilting percentage. However, on soils suitable for apple trees, they are sufficiently accurate to provide guidance in the timing of irrigation. It must be emphasized that the usefulness of these devices is determined largely by the care employed in their installation. For best results, the depth of installation must be carefully controlled; they must be firmly embedded in soil characteristic of the depth; they must not be in direct contact with stones, undecomposed organic materials, or other nonsoil entities; and the surface of the soil directly above must not be radically different from the surrounding surface.

The practical problem for the agriculturist is to determine the point at which a lack of water is adversely affecting plant performance. It has been demonstrated (15, 26) that trees can obtain water with equal facility between field capacity and the permanent wilting percentage. Growth is not adversely affected as long as no roots are in soil at the PWP, and there is no advantage to applying water until this point is reached. Unfortunately, this critical point is not easily detected and it becomes more a matter of academic than of practical interest. Trees may have extensive root development to a depth of several feet and both root concentration and soil moisture can vary considerably with depth. Numerous studies of root distribution of apple trees have indicated that rooting to a depth of 6 to 8 feet is not uncommon in well-drained soils. However, in even the deepest soils, most of the roots develop within 2 feet of the surface with the greatest concentration near the 1 foot level (1, 2, 7, 10, 19, 24).

If the initial soil moisture level is the same throughout the root zone, soil moisture is first depleted in the area of greatest root concentration (1). Since this is relatively close to the surface, surface evaporation and withdrawal by the cover crop contribute to the rapid loss of soil moisture from this area. The soil at this depth should reach the wilting percentage long before soil at greater depths. However, many of the rains that fall in summer are but light showers that do not penetrate to great depths. As a result, moisture is replenished more frequently in the first foot of soil than at lower levels and there may be little or no difference in soil moisture at different depths. This is particularly true in very shallow soils. With 2 feet or less of soil, the roots may have almost completely permeated the usable soil and may, therefore, draw moisture rather uniformly from the entire soil mass (6). However, unless the soil is extremely shallow and the trees are severely "root-
bound,” it is unlikely that the permanent wilting percentage would be reached in all parts of the root zone at the same time.

Theoretically, efficient irrigation would require the application of water when the soil within any part of the root zone first reached the PWP. However, variation in root distribution is such that the exact depth at which this would first occur might vary from tree to tree and in various parts of the root zone of the same tree. The frequency and amount of rainfall would introduce additional complications. It would obviously be impractical for the commercial fruit grower to use this elusive critical point as the criterion for timing irrigation applications. A more expedient approach would be the determination of soil moisture at a uniform depth that was representative of a large part of the root zone and deep enough to escape the influence of rains that do not penetrate to the major part of the root zone. In the studies conducted in the Hudson Valley, soil moisture was regularly determined at depths of 12, 18, and 24 inches. In soils 2 to 3 feet in depth (Cossayuna, Dutchess, and Hoosic gravelly loams), fruit growth could best be correlated with the moisture determinations at 18 inches. However, in a badly eroded Nassau slate loam, with a maximum depth of 18 inches, differences between 12 and 18 inches were negligible.

The concentration of roots varies, not only with depth, but also with distance from the trunk. The greatest concentration is usually 2 to 4 feet from the trunk (1, 19, 23), but the exact distance varies with tree size. As with depth, the precise point at which the soil would first reach the PWP may be difficult to locate. For this reason, soil moisture determinations in these studies were made at the drip line of the branches. This provides a convenient point of reference, regardless of tree size, and does offer some very practical advantages. Installation of soil moisture meters can be exceedingly difficult if there are numerous low branches and fewer of them are damaged by the mowing machine when more conspicuously located at the drip line of the branches.

If the soil moisture readings are not taken at the depth or at the distance from the trunk at which the PWP is likely to be reached first, it then becomes necessary to use some point other than the PWP as the critical level. Experience with Hudson Valley soils has indicated that there is no advantage to maintaining a moisture level higher than 25 percent ASM, at the drip line of the branches, and a depth of 18 inches. Typical fruit growth data at this and higher soil moisture levels are presented in table 4. However, fruit growth seems to be adversely affected when available soil moisture, at a depth of 18 inches at the drip line of the branches, is less than 25 percent (table 5). In studies covering 7 years and involving 3 varieties on 4 soil types, the rate of fruit growth, with a single exception, was significantly less below 25 percent ASM than at higher moisture levels. The exception was with Golden Delicious in 1960–61, and the lack of significance in this case may be
Table 1. Successive diameter measurements of Golden Delicious apples under different irrigation treatments—1957

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<th>Minimum soil moisture level*</th>
<th>Fruit diameter</th>
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<td>7/3 †</td>
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<tr>
<td>50</td>
<td>1.51</td>
</tr>
<tr>
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<td>1.54</td>
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<td>25</td>
<td>1.53</td>
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<td>Unirrigated</td>
<td>1.46</td>
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<tr>
<td>LSD 5%</td>
<td>.05</td>
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</table>

* Percent available soil moisture at 18-inch depth at the drip line of the branches. Water was applied when soil moisture dropped to indicated level.
† Initial differences between treatments due to irrigation before first fruit diameter measurement.

due to the fact that there was no extended period below 25 percent ASM in either year. In fact, soil moisture remained above this level throughout the entire 1960 growing season.

In selecting 25 percent available soil moisture at a depth of 18 inches at the drip line of the branches as the point at which supplemental irrigation should be applied if a reduction in fruit growth is to be avoided, it is emphasized that this desired minimum is the result of compromise with the practical problems of determining the true critical point. In all probability, 18 inches is not the most sensitive depth nor is the drip line of the branches the ideal point for estimating the moisture status of apple trees in all soils. Differences in depth, texture, and root distribution would certainly exert measurable influences. At the same time, frequency, amount, and depth of penetration of rainfall would affect the depth at which the soil within the root zone would first reach the wilting percentage. Under other circumstances, a different depth, a different distance from the trunk, or a different soil moisture level might be more closely correlated with fruit growth. However, this level has provided a good, practical guide for the timing of irrigation on the soils under study and the objectives of this study were practical rather than theoretical. On this basis, a soil moisture level of less than 25 percent ASM, at a depth of 18 inches at the drip line of the branches, will hereafter be considered a soil moisture deficit. The relationship between this point and fruit growth is illustrated in figure 2.

In view of the uneven distribution of rainfall, it is no surprise to find substantial variation between locations at the time when moisture deficits develop, and in their duration. Factors other than rainfall also contribute to this disparity. One of the most important of these is the texture of the soil. Coarse, light-textured soils, such as gravelly and sandy loams, have low water-holding capacity and are, therefore, rapidly depleted of available moisture. Soil depth exerts an important influence through its effect on root distribution. In very shallow soils,
Table 5. Rate of apple fruit growth at different soil moisture levels

<table>
<thead>
<tr>
<th>Variety</th>
<th>Years</th>
<th>Soil type</th>
<th>100-75 †</th>
<th>75-50 †</th>
<th>50-35 †</th>
<th>35-25 †</th>
<th>25-15 †</th>
<th>&lt;15 †</th>
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<td>1961-64</td>
<td>Nassau slate loam</td>
<td>0.092</td>
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<td>0.097</td>
<td>0.095</td>
<td>0.069</td>
<td>0.060</td>
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<td>Duchess gravelly loam</td>
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<td>0.098</td>
<td>0.101</td>
<td>0.098</td>
<td>0.078</td>
<td>0.081</td>
</tr>
<tr>
<td>McIntosh</td>
<td>1962-64</td>
<td>Cossayuna gravelly loam</td>
<td>0.107</td>
<td>0.097</td>
<td>0.100</td>
<td>0.102</td>
<td>0.078</td>
<td>0.081</td>
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<td>Hoosic gravelly loam</td>
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<td>0.124</td>
<td>0.120</td>
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<td>1960-61</td>
<td>Cossayuna gravelly loam</td>
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<td>0.100</td>
<td>0.106</td>
<td>0.109</td>
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<td>0.087</td>
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<td>Delicious</td>
<td>1960-62</td>
<td>Cossayuna gravelly loam</td>
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<td>0.101</td>
<td>0.106</td>
<td>0.109</td>
<td>0.085</td>
<td>0.080</td>
</tr>
</tbody>
</table>

* Average daily increase in volume (cu. in.) for July and August. Difference between underlined values and growth rates at other soil moisture levels is statistically significant at 5% level.
† Percent available soil moisture, at 18-inch depth at the drip line of the branches.
the concentration of roots is greater within the usable soil mass than at comparable levels in soils with deeper root growth. The management of the cover crop, and the species composition of it, are likewise elements of significance (12, 22). The adequacy of the available soil moisture may also be somewhat affected by rootstock, tree vigor, and crop load.

The interaction of the above factors produces an array of soil moisture situations in Hudson Valley orchard soils (figure 3, table 6). These data, taken from irrigation experiment sites and from sites where regular soil moisture determinations were made for other studies, are from rather widely separated orchards. As such, they represent markedly different soil and rainfall situations, but have in common the fact that none is located on deep soil of the most desirable texture. In figure 3
Irrigation of Apples in the Hudson Valley

Figure 3.—Available soil moisture, at a depth of 18 inches, in 3 McIntosh apple orchards during the 1964 growing season (#1—Nassau slate loam, #2—Cossayuna gravelly loam, #3—Dutchess gravelly loam).

The principal difference between the orchard on Dutchess soil and the other two was in rainfall, but the major difference between the orchards on Nassau and Cossayuna soils was in soil depth. In spite of a higher initial moisture content, the Nassau soil reached 25 percent ASM more than 2 weeks before the deeper Cossayuna. In the 3 years covered in table 6, soil moisture was a much more consistent problem in the Nassau than in the deeper soils. In 1962, with comparable rainfall, the number of days below the desired minimum soil moisture level in this very shallow soil was twice that in the deep-phase Cossayuna.

The differences in soil moisture relationships between orchard locations and soil types are translated directly into differences in irrigation requirements. Obviously, more frequent replenishment would be re-
Table 6. Duration of soil moisture deficits in 6 McIntosh apple orchards — 1962-64

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil type</th>
<th>Soil depth</th>
<th>Days below 25% ASM *</th>
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<tr>
<td></td>
<td></td>
<td>inches</td>
<td>1962</td>
</tr>
<tr>
<td>Marlboro</td>
<td>Nassau slate loam</td>
<td>18</td>
<td>79</td>
</tr>
<tr>
<td>Milton</td>
<td>Cossayuna gravelly loam (shallow phase)</td>
<td>24-30</td>
<td>55</td>
</tr>
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<td>New Paltz</td>
<td>Cossayuna gravelly loam (deep phase)</td>
<td>36-48</td>
<td>38</td>
</tr>
<tr>
<td>Salt Point</td>
<td>Cossayuna gravelly loam (shallow phase)</td>
<td>24-30</td>
<td>43</td>
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<tr>
<td>Pleasant Valley</td>
<td>Albia silt loam</td>
<td>24-30</td>
<td>33</td>
</tr>
<tr>
<td>LaGrangeville</td>
<td>Dutchess gravelly loam</td>
<td>24-30</td>
<td>61</td>
</tr>
</tbody>
</table>

* Available soil moisture at 18-inch depth, at the drip line of the branches, from May 1 to Sept. 20, average harvest date for the variety.
† Orchard abandoned.

required to maintain 25 percent ASM in the Nassau than in the deep-phase Cossayuna soil. But regardless of the soil type involved, the problems of irrigating apples are different from those associated with irrigation of shallow-rooted crops and some adjustments in technique are required. Since root development is extensive to a depth of 2 feet (provided the soil is at least 2 feet deep), each application of water should be sufficient to penetrate at least to that depth.

In determining the amount of water necessary to wet to this depth, it is well to remember that the only possible change, other than complete saturation, is an increase to the field capacity. Half enough water to raise a given soil to the field capacity will not raise all the soil halfway to field capacity, but will raise half the soil to that level without affecting the other half. The depth to which an application of water penetrates varies with soil type and with the water content at the time of irrigation. A given amount of water will penetrate to greater depths in a light-textured than in a heavier soil. In the same manner, a given amount of water will penetrate to greater depths in a soil of high initial water content than in the same soil at a lower moisture level.

This particular point is well illustrated by work in 1957 on Hoosic gravelly loam, a relatively coarse soil with good to excessive internal drainage. In this study, some water was applied when available soil moisture was less than 25 percent at the 18-inch depth. Applications of 3 inches of water, when the moisture content was 25 percent ASM or more at a depth of 18 inches, always resulted in penetration to a depth of 24 inches, but not in penetration to this depth when the initial content was less than 25 percent ASM. In the soils that have been irrigated in this study (Cossayuna, Hoosic, Nassau), applications of 3
inches of water have consistently penetrated to 24 inches if the initial moisture level was 25 percent ASM or more at a depth of 18 inches. On these soils, 3 inches of water generally maintained soil moisture above 25 percent ASM for 3 weeks without rain. This appears to be an efficient amount to apply to these soils, but on soils of different texture or depth, more water might be required and the interval between irrigations might be quite different.

**Fruit Growth Responses to Irrigation**

In 2 of the 10 years covered by this study, available soil moisture in experimental orchards remained above 25 percent throughout the entire growing season, but some irrigation was necessary to maintain the desired level in each of the other 8 years. The results of these experiments are summarized in table 7.

The major purpose of irrigating apple trees is to increase the rate of fruit growth, and the effects of irrigation are usually assessed in terms of fruit size. Since apples are sold on the basis of diameter in inches, the common criterion for comparison is diameter. All too frequently, fruit growers have been disappointed in rather modest increases. However, diameter is a 1-dimensional measurement and fruit growth is 3-dimensional; consequently, volume provides a much better basis for comparing fruit size and growth. The relationship between diameter and volume is illustrated in figure 4. In this graph, the growth of the same fruits is presented on the basis of increases in both diameter and volume, with the scales adjusted to make the curves comparable during the early part of the period. However, as size increased, the curves diverged appreciably. The volume curve approaches a straight line over most of its length, but the diameter curve is typically sigmoid. This is due to the fact that, as the size of a spheroid increases, progressively more volume is required to add a given increment to the diameter. With Delicious, an increase in diameter from 2.25 to 2.50 inches is associated with an increase in volume of 2.16 cubic inches. However, a similar increase from 2.50 to 2.75 inches requires a volume increase of 2.64 cubic inches. The increase from 2.50 to 2.75 represents a 10 percent increase in diameter, but a 33 percent increase in volume.

In spite of the inadequacy of diameter as an expression of fruit growth, it is the routine measurement commonly used. There is no practical method for measuring volume directly in the field, and it is usually calculated from diameter measurements. In these calculations, variety is a very important consideration. The diameter of fruits of both Delicious and Golden Delicious is greater in the longitudinal than in the transverse plane. Volume of these varieties, as measured by immersion, closely approaches that of a sphere of the same diameter as that of the cheek of the apple. In contrast, the stem-calyx axis of
<table>
<thead>
<tr>
<th>Year</th>
<th>Variety</th>
<th>Soil type</th>
<th>Rainfall</th>
<th>Days below 25% ASM</th>
<th>Inches of water to maintain 25% ASM</th>
<th>Response to irrigation — increase in Fruit size</th>
<th>2.5 in. &amp; up</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1955</td>
<td>Cortland</td>
<td>Pittsfield-Wassaic gravelly loam</td>
<td>19.64</td>
<td>26</td>
<td>6</td>
<td>ns [†]</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>1956</td>
<td>Golden Delicious</td>
<td>Pittsfield-Wassaic gravelly loam</td>
<td>16.84</td>
<td>0</td>
<td>0</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>1957</td>
<td>Golden Delicious</td>
<td>Hoosic gravelly loam</td>
<td>9.95</td>
<td>110</td>
<td>12</td>
<td>0.22</td>
<td>15.6</td>
<td>129</td>
</tr>
<tr>
<td>1958</td>
<td>Golden Delicious</td>
<td>Hoosic gravelly loam</td>
<td>14.86</td>
<td>53</td>
<td>6</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>1959</td>
<td>Golden Delicious</td>
<td>Hoosic gravelly loam</td>
<td>18.45</td>
<td>16</td>
<td>3</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Delicious</td>
<td>&quot; &quot; &quot;</td>
<td>&quot; &quot;</td>
<td>16</td>
<td>3</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>McIntosh</td>
<td>&quot; &quot; &quot;</td>
<td>&quot; &quot;</td>
<td>16</td>
<td>3</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>1960</td>
<td>Golden Delicious</td>
<td>Cossayuna gravelly loam</td>
<td>28.87</td>
<td>0</td>
<td>0</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Delicious</td>
<td>&quot; &quot; &quot;</td>
<td>&quot; &quot;</td>
<td>0</td>
<td>0</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>1961</td>
<td>Golden Delicious</td>
<td>Cossayuna gravelly loam</td>
<td>19.55</td>
<td>41</td>
<td>6</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Delicious</td>
<td>&quot; &quot; &quot;</td>
<td>&quot; &quot;</td>
<td>41</td>
<td>6</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>McIntosh</td>
<td>&quot; &quot; &quot;</td>
<td>&quot; &quot;</td>
<td>41</td>
<td>6</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>1962</td>
<td>Delicious</td>
<td>Nassau slate loam</td>
<td>13.39</td>
<td>37</td>
<td>6</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>McIntosh</td>
<td>Nassau slate loam</td>
<td>11.57</td>
<td>86</td>
<td>12</td>
<td>0.15</td>
<td>22.2</td>
<td>68</td>
</tr>
<tr>
<td>1963</td>
<td>McIntosh</td>
<td>Nassau slate loam</td>
<td>11.10</td>
<td>79</td>
<td>12</td>
<td>0.12</td>
<td>24.2</td>
<td>55</td>
</tr>
<tr>
<td>1964</td>
<td>Milton</td>
<td>Cossayuna gravelly loam</td>
<td>14.77</td>
<td>37</td>
<td>6</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

* Inches — May through September at irrigation orchard sites.  
† Available soil moisture at 18-inch depth at the drip line of the branches. Period is from May 1 to average harvest date for the variety.  
‡ Diameter in inches.  
§ Percent.  
‖ Bushels per acre.  
†† Difference between irrigated and unirrigated not statistically significant at 5% level.
McIntosh is short relative to the diameter at the cheek and erroneous measurements would be made if volume were assumed to be that of a sphere of the same diameter. Measurements of fruit volume by immersion, and comparison of these values with the volume of a sphere of the same diameter, indicate that a McIntosh fruit is only 0.85 of the volume of such a sphere. These varietal relationships are illustrated in figure 5.

As indicated earlier, fruit growth curves based on volume will approach a straight line throughout most of a typical growing season because apple fruit increases in volume slowly but more or less regularly (25). There are no periods of sharply accelerated or decelerated growth as with the stone fruits. Under near-optimum conditions, the rate of fruit growth is so consistent that harvest size has been predicted.
as early as 35 days after bloom (3). An interruption in growth, whether due to a soil moisture deficit or to some other factor, causes a loss that cannot be corrected later. Maximum fruit size in apples can be attained only by maintaining optimum conditions throughout the growing season. Optimum soil moisture conditions, at least in the soils investigated in this study, would require a moisture level of 25 percent ASM, at a depth of 18 inches at the drip line of the branches, from bloom to harvest.

![Figure 5](image_url)

*Figure 5.—Relationship between transverse and longitudinal diameters in 3 apple varieties.*

The effects of prolonged periods of lower soil moisture are illustrated in figure 6. Irrigation was necessary in this orchard in June, and there was already a difference in rate of fruit growth when the first measurements were made. In response to rain in late July (fig. 2), the rate of fruit growth in the unirrigated treatment increased. For a time, the 2 growth curves were parallel, with the unirrigated about 10 days behind the irrigated because of growth losses before the late July rains. However, by mid-August a second soil moisture deficit had developed and the mid-July to mid-August growth rate could no longer be maintained. The curves were markedly divergent thereafter.

From the marketing standpoint, fruit size is best described by size distribution data because these provide an estimate of the proportion of the crop that is within the most desirable size range. Relatively small increases in diameter are often associated with substantial improvement in size distribution and proportionate increases in the market value of the fruit. Data for the years of positive response to irrigation are presented in table 8.
Figure 6.—Fruit growth of irrigated and unirrigated Golden Delicious —1957 (Solid line—irrigated; broken line—unirrigated).

Table 8. Effects of irrigation on fruit size distribution

<table>
<thead>
<tr>
<th>Variety and year</th>
<th>Diameter at harvest</th>
<th>Proportion measuring:</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>inches</td>
<td>&lt;21/2 in.</td>
<td>21/2-3 in.</td>
<td>3 in. &amp; up</td>
</tr>
<tr>
<td>Golden Delicious — 1957</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigated</td>
<td>2.76</td>
<td>3.6</td>
<td>62.3</td>
<td>34.1</td>
<td></td>
</tr>
<tr>
<td>Unirrigated</td>
<td>2.54</td>
<td>16.6</td>
<td>76.2</td>
<td>7.2</td>
<td></td>
</tr>
<tr>
<td>Delicious — 1962</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigated</td>
<td>2.69</td>
<td>17.8</td>
<td>76.9</td>
<td>5.3</td>
<td></td>
</tr>
<tr>
<td>Unirrigated</td>
<td>2.54</td>
<td>33.4</td>
<td>66.2</td>
<td>.4</td>
<td></td>
</tr>
<tr>
<td>McIntosh — 1962</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigated</td>
<td>2.68</td>
<td>16.9</td>
<td>79.4</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Unirrigated</td>
<td>2.56</td>
<td>33.1</td>
<td>65.7</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>
An increase in average fruit size is, of course, reflected in an increase in the total yield. The yield increases in this study have not been large (table 7), but they have been consistent with the increases in fruit size. Theoretically, an increase in average fruit diameter from 2.54 to 2.69 inches, as was obtained with Delicious in 1962, would be associated with an increase in volume of 18.8 percent. The observed yield increase closely approached this figure and the same was true of McIntosh in 1962. In contrast, the increase in yield of Golden Delicious in 1957 was more than twice the calculated increase in volume. However, in this study there was not only an increase in fruit size, but also an increase in the number of fruits per tree. Irrigation was necessary in early June and apparently the application of water at that time significantly reduced June drop. Severe soil moisture deficits in early June are most unusual in the Hudson Valley and frequent response of this type could not be expected.

**Other Effects of Irrigation**

The principal response of bearing apple trees to irrigation is an increase in fruit size, but there may be other benefits. Unfortunately, most of these are more difficult to evaluate than the more obvious effects on fruit growth.

Numerous investigators have reported reduced availability of essential elements when soil moisture was deficient (9, 13, 27). Severe deficiencies of both potassium and boron have consistently been associated with dry weather and, in fact, boron deficiency symptoms have been prevented by irrigation (8). Because it is important in soil nitrogen relationships, soil moisture is a matter of serious concern with varieties such as McIntosh which, at least under Hudson Valley conditions, require rather careful regulation of nitrogen for best quality. In these studies there were sometimes statistically significant differences in foliage levels of essential elements, but none were reduced to the deficiency level. However, in soils with a past history of potassium or boron deficiency, the effects of irrigation on availability could be highly beneficial.

Prolonged periods of drought may also adversely affect carbohydrate metabolism. When soil moisture is deficient, the starch content of woody tissues of unirrigated trees may be substantially less than that of irrigated trees (16, 17). While the practical importance of this might not be immediately obvious, a low level of reserve carbohydrates could be detrimental in 3 readily apparent ways. First, cold tolerance would be reduced and such trees could be seriously damaged if the following winter were unusually severe. Also a lack of carbohydrates might reduce either early growth the following spring or fruit set for the suc-
ceeding crop. Flowering however, would not be adversely affected,— in fact, a soil moisture deficit may actually increase flowering (11, 17).

One rather subtle influence of irrigation is the effect on utilization of rain. As pointed out earlier, the depth to which a given amount of water will penetrate depends on the initial water content of the soil. Occasionally, the higher water content of irrigated soil will enable an otherwise ineffective rain to penetrate well into the root zone. This point is illustrated in table 9. These data clearly show deeper penetration of the 1.35 inch rain in the soil of higher initial moisture content.

<table>
<thead>
<tr>
<th>Table 9. Effect of soil moisture on depth of penetration of rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Table Content" /></td>
</tr>
</tbody>
</table>

*1.35 inches on 6/12.
† Available soil moisture — average of 8 readings per treatment.
‡ Number of blocks from a total of 8 per treatment.

Factors Affecting Response to Irrigation

Of all the elements that combine to determine the success or failure of irrigation, the most decisive one is the moisture status of the soil. This is, of course, largely the product of the interaction of rainfall and soil type. If there are no prolonged periods of moisture deficiency, there can be no positive response to irrigation. In table 5 it was pointed out that the rate of fruit growth was significantly reduced when available soil moisture at 18 inches was less than 25 percent. Obviously, the indicated growth rates below this point could not be maintained indefinitely, and growth would cease entirely when all or nearly all of the soil in the root zone reached the PWP. Factors other than soil moisture also affect fruit growth and the exact growth rate varies somewhat from year to year, and from orchard to orchard in a given year, because of differences in tree age, vigor, crop load, and certain weather effects.

The reduction in rate of fruit growth that inevitably follows a soil moisture deficit also varies somewhat with these factors. However, if the difference between growth rates below and above 25 percent ASM, as indicated in table 5, is considered to be the average loss in fruit growth when soil moisture is the limiting factor, it should be possible to calculate the minimum number of days of deficient soil moisture
necessary for measurable response to irrigation. Variation in fruit size is such that a difference in diameter of 0.06 to 0.08 inch at harvest is usually necessary for statistical significance. If 2.75 inches is considered to be the optimum average fruit diameter at harvest, 30 to 50 days below 25 percent ASM, depending on location, would be required for a measurable reduction in diameter or for a statistically significant response to irrigation.

Soil depth, because of its influence on root distribution, is a dominant factor in both the duration and the severity of soil moisture deficits. Soil moisture problems were more frequent and more persistent in the very shallow Nassau than in either the Dutchess or Cossayuna soils. The shallower soils may also have a larger part of the root zone, proportionately, at the PWP when soil moisture at 18 inches is less than 25 percent ASM, thus increasing the severity of the moisture deficit. With McIntosh on Nassau slate loam, the rate of fruit growth was reduced by 33 percent when available soil moisture at 18 inches was less than 25 percent. The reductions in rate of fruit growth for the same variety on Dutchess and Cossayuna soils were 21 and 22 percent respectively. Soil depth is the one factor that contributes most to the differences between orchards cited here. There is an additional factor to be considered, however, in a comparison of the two Golden Delicious orchards. The orchard used in 1957-59 was only 9 years old in the first year of treatment, while the other was approximately 40 years old. Age may have been as much a factor in root distribution as soil depth.

The need for irrigation, and consequently the response to it, is determined to some extent by variety. As mentioned earlier, at least 30 days below the desired minimum soil moisture level are necessary for a measurable difference in fruit diameter. In the Hudson Valley, soil moisture deficits frequently develop in late July or in early August. If soil moisture first becomes the limiting factor in mid-July, the effect on fruit size of varieties harvested before September 1 will be negligible. Unless the soil is extremely shallow (18 inches or less), the fruit of such varieties will not be subjected to periods of deficient moisture that are long enough to significantly reduce fruit size. The longer the growing season required to mature a variety, the greater the potential benefits from irrigation. Where positive response has been obtained, the variety benefitting most was Golden Delicious. McIntosh was least responsive and Delicious was intermediate between them. In this area, McIntosh is normally harvested 15-20 days before Delicious and 30 days before Golden Delicious. The difference in varietal response is undoubtedly due to the fact that the interval between harvest of McIntosh and the later varieties extended to a period of soil moisture deficiency. It is interesting to note that in neither 1957 nor 1962 was the maximum potential response obtained. In 1957 the period of soil moisture defi-
ciency was interrupted for 3 weeks by heavy rain, and in 1962 there were 2 such interruptions.

On the basis of the data from 1957 and 1962, it is apparent that 1964 was a year in which response to irrigation could be expected even though there was no response in the experimental orchard. If the variety in the 1964 experiment had been Delicious instead of Milton, the later harvest date of Delicious would have extended the moisture-deficient period from 17 to 71 days. With a soil moisture deficit of this duration, response to irrigation is almost certain. Rainfall, both the total for the year and for the growing season (table 2), and soil moisture determinations at other sites (table 6) also indicate that some locations suffered soil moisture deficits serious enough to adversely affect fruit size. Substantial response to irrigation was possible in some Hudson Valley orchards in 1964.

The effects of a soil moisture deficit may be moderated somewhat by accompanying weather. A lack of water is much less damaging in a relatively cool and humid season than in one that is hot and dry. In this respect, 1957 and 1962 represent markedly different situations. These years were comparable in number of days with soil moisture below 25 percent ASM, but temperatures were higher and humidity lower in the earlier year. Response to irrigation was notably greater in 1957 and, while differences in variety account for some of the difference in response, it is doubtful if it is entirely varietal.

Some of the factors other than soil moisture that affect fruit size may also affect response to irrigation. One such factor is crop load. In the 1962 experiment with Delicious, fruit thinning treatments were combined with irrigation. Chemical thinning reduced fruit set from 43 fruits/100 blossom clusters, a definite over-set, to 26. Fruit growth data from this study are presented in figure 7. The irrigated—unthinned and the thinned—unirrigated treatments were not statistically different, but both were significantly different from the other two treatments. It is obvious that fruit thinning affected fruit size as much as irrigation and that the application of water did not compensate for

| Table 10. Effect of nitrogen level on the response of McIntosh to irrigation — 1962 |
|-----------------------------------------------|-------|-------|
| Treatment          | Nitrogen * | Fruit diameter |
|                   | percent   |         |
| Low nitrogen      |           |         |
| Irrigated         | 1.63   | 2.64   |
| Unirrigated        | 1.62   | 2.54   |
| High nitrogen     |           |         |
| Irrigated         | 1.93   | 2.73   |
| Unirrigated        | 1.85   | 2.60   |
| LSD 5%            | .16    | .08    |

* Mid-August leaf analysis — percent dry weight.
inadequate thinning. Optimum fruit size was attained only where irrigation was combined with adequate thinning.

Another factor that exerts a similar influence is the nitrogen level. Differential nitrogen treatments were maintained in the McIntosh orchard in which significant response to irrigation was obtained in 1962. As indicated in table 10, the effect of nitrogen level was similar to that

![Graph showing the effect of crop load on response of Delicious to irrigation—1962 (1—Unthinned and unirrigated; 2—unthinned and irrigated; 3—thinned and unirrigated; 4—thinned and irrigated).](image)

of crop load. An increase in nitrogen improved fruit size almost as much as irrigation, and optimum size was attained only in the treatment that combined irrigation with a satisfactory nitrogen level.

To this point, all reference to fruit size has been directed toward the
average size of all fruits. However, fruits do not respond uniformly to irrigation, nor to other treatments. There is an old adage that states "once a small apple, always a small apple." This axiom is used as a guide in hand fruit-thinning in that the removal of small apples, rather than uniform spacing, is the major objective. It is this principle that permits prediction of harvest size within 35 days after bloom (3). An apple that is relatively small early in the season has less potential for growth than one that is more robust at the same time. Because of the difference in potential, individual apples will respond differently to changes that affect the rate of growth (see figure 8). In the preparation of these data, the diameters of all fruits in each treatment were averaged on the data of the first measurement. All fruits of average or

![Graph showing the response to irrigation of McIntosh apple fruits of different initial size—1962.](image-url)
above-average diameter were considered to be large while those of less than average were rated as small. It is obvious that irrigation was of much less benefit to the initially small fruits than to the larger ones. This explains why some growers assert that they have consistently obtained much greater response to irrigation than the modest increases in diameter reported here. The larger, more responsive fruits are very conspicuous and it is possible that the growers base their opinions on biased sampling.

Economics of Irrigating Apples

The physical effects of irrigation can be easily measured and, on the basis of such data, future response can be predicted with reasonable accuracy. Unfortunately, the monetary value of any benefits must be determined in the marketplace and fresh market prices for apples vary widely from year to year, making accurate price forecasts difficult. A good response to irrigation can be nullified by a sluggish market or by an untimely sale in an active market. In this section, the profitability of irrigation in individual years will be compared with profitability over a longer period of time.

The variation between orchards in such pertinent factors as soil type, varieties, equipment, and marketing acumen is such that it would be impossible to derive cost and return figures that would apply equally to all apple orchards. In this study, the calculation of costs and returns is based on certain assumptions. Appropriate adjustments must be made by the individual grower where his situation is markedly different. A set of costs and returns associated with irrigation were calculated in the following manner:

(1) **Cost basis.** Costs of irrigation were divided between fixed and variable costs. Interest on investment, and depreciation and obsolescence account for the major share of fixed costs that continue regardless of the number of acres irrigated or the number of inches of water applied. In contrast to this, variable costs include labor, gas, oil, and maintenance and vary directly with the use made of the irrigation system.

(2) **Equipment.** The exact acreage that can be covered at each setting of the pipe will vary somewhat with distance from the water supply, but the minimum acreage for efficient use of manpower, and for the capacity to cover appreciable acreages, appears to be about 3 acres per setting. The pump should be capable of supplying water to this acreage at the rate of ½ inch per hour. Less pipe or power will significantly increase costs and reduce the acreage that can be efficiently irrigated. An adequate pump, with significant pipe and fittings, would cost approximately $6000. Such a system would require a self-powered pump capable of delivering 750 gallons per minute through 2500 feet of pipe — 1000 feet of 5- or 6-inch main line and 1500 feet of 4-inch for laterals. A minimum of approximately 25 responsive acres of bearing apply orchard would be necessary to justify this amount of equipment over a period of years.

(3) **Interest and depreciation.** These fixed costs are charged on an annual basis
since they continue whether or not the system is used. Interest is charged at the rate of 6 percent on half the original cost over a 10-year period, or $180 per year. The entire system is depreciated over a 10-year period with an annual charge of $600 per year. Depreciation on the pipe could well be extended over a longer period than 10 years. It could be that obsolescence of the system might be a greater problem than actual depreciation.

(4) **Labor and operating expenses.** Averages were computed from data recorded in the conduct of irrigation experiments and from commercial orchards with several years' experience in irrigation. Operating expenses were remarkably consistent, but there were marked differences between orchards in labor requirements. Worthwhile reductions in costs could be achieved in some orchards through more efficient use of labor.

(5) **Grading of fruit.** Yields of fruit in the experimental orchards were recorded in field boxes, which usually contain about 10 percent less than a packed box. The field yields are further reduced by the removal of utilities. In these calculations, the volume of packed fruit was considered to be 75 percent of the yield in field boxes, regardless of treatment, and the value of the utilities was disregarded. Treatments were compared on the basis of fruit size only and no attempt was made to evaluate the effects of such factors as color, appearance, or condition.

(6) **Marketing of fruit.** Calculating an average price for fresh market apples in the Hudson Valley is extremely difficult. Differences between years, between periods within years, between varieties, and differences in quality and in the skill of the seller are so great that they cannot be integrated to produce an enlightening average. For these reasons, returns are based on prevailing prices for fruit of the variety and quality produced in the experimental orchards at the time the fruit was harvested.

The results with Delicious in 1962 will be used as an example of costs and returns from irrigation. In this instance, irrigation increased the yield of fruit from 501 to 569 boxes per acre and reduced the percentage of fruits of less than 2½ inches in diameter from 33 to 18. The net return, calculated in accordance with the above assumptions, is as follows:

**Returns per acre**

- **Irrigated.** 569.1 field boxes per acre less 25% for fill and utilities = 426.8 boxes of packed fruit per acre.
- 17.8% 2½-inch apples @ $2.75 = $209.00
- 82.2% 2½-inch and up apples @ $4.50 = $1,578.60

Gross return ................................................................. $1,788.00

- **Unirrigated.** 500.7 field boxes per acre less 25% for fill and utilities = 375.5 boxes of packed fruit per acre.
- 33.4% 2½-inch apples @ $2.75 = $344.85
- 66.6% 2½-inch and up apples @ $4.50 = $1,125.45

Gross return ................................................................. $1,470.00

Increase in gross return due to irrigation ...................... 318.00

**Costs**

- **Depreciation.** $6,000 depreciated over 10 years, or 600 per year on 25 acres .................................................. 24.00
- **Interest.** One-half of $6,000 @ 6% = $180, or $180 per year on 25 acres .......................................................... 7.00
Operating expenses
Labor — 1 man hour/acre in., or $1.50
Gas and oil — per acre inch 1.12
Repair and maintenance —
$100/yr., or $.34 per acre inch.
12 inches of water @ $3.00 per acre inch ............ 36.00

Added expenses because of yield increase.
Addition harvesting cost
64.8 bu. @ $.45 ........................................ 29.00
Additional handling, packing, and package cost
51.3 bu. @ $1.15 ....................................... 59.00
Total expenses ........................................... 155.00

Net return ................................................ $ 168.00

Significant response was also obtained with Golden Delicious in 1957, when the yield increase was greater than that obtained in 1962, but the price differential between sizes was somewhat less favorable. These opposing factors were offsetting, and similar handling of the 1957 data indicated a net return of $157 per acre. The lack of soil moisture during the growing season of 1964 and the reaction of the trade to the abundance of 2½-inch apples would indicate that similar returns were possible with either of these varieties in 1964.

That the returns from irrigation might be substantial in years of serious soil moisture deficits is generally conceded. However, if optimum soil moisture conditions are to be maintained at all times, some water will be applied without response. During the 10 years of this study, there were 3 years of moisture deficits of sufficient severity to adversely affect the size of apples. In 5 of the remaining 7 years, some water would have been necessary to maintain soil moisture above 25 percent ASM. These unproductive efforts would have required 27 inches of water.

Likewise, it is not difficult to demonstrate impressive profits, on a per acre basis, when dealing with relatively small plots. However, the fruit grower, while interested in unit costs and returns, is more concerned with total costs and total returns. A profit of $157 to $163 per acre is striking, but to pay for a $6000 irrigation system, a number of acres must yield profits of this magnitude. The factors that determine the number of acres required are the fixed costs, interest and depreciation, which total $780 per year. The minimum acreage required to break even is best calculated by omitting interest and depreciation from the cost estimate and dividing the adjusted net return by the fixed costs. Such calculations must cover several years.

In the 10-year period, there were 2 years in which irrigation increased the value of the crop by more than $300 per acre. Conditions were such that benefits of this magnitude also could have been expected in 1964. When the increased costs of picking, handling, packing, and packages
made necessary by this increase in yield are substracted, this sum is reduced to about $230 per acre. The potential total increase in value of the crop over the 10-year period therefore becomes $690 per acre. In each of the responsive years, 12 inches of water were required, and over the intervening years, it would have been necessary to apply 27 inches of water, making a total of 63 inches of water for the entire period. The actual operating expenses, at $3.00 per acre inch, amount to $189 per acre, reducing the net increase in value to $501 per acre. The total interest and depreciation for the 10 years ($7,800) divided by the per acre net increase in crop value equals the minimum number of acres required to pay expenses. In this case, it is 16. However, it must be emphasized that this would be applicable only when the amount and distribution of rainfall was similar to that recorded during the years 1955–1964 and the response to irrigation was similar to that in 1957 and 1962. If the dry years were less frequent — and they were abnormally close together in this period — a sizable increase in responsive acreage would be necessary to cover costs. Moreover, this figure would be markedly different for other soils, varieties, and markets.

Conclusions

The value of supplemental irrigation for apples in the Hudson Valley would appear to be dependent on the interaction of the following factors:

1. **Cultural practices.** If the bulk of the crop is to be within the most desirable size range, such factors as fertilization, fruit, thinning, and pruning must not be neglected. Additional water will not compensate for serious deficiencies in other parts of the cultural program.

2. **Rainfall.** Irrigation of apples was highly profitable in 1962, when rain during the growing season totalled 11.37 inches, but not in 1959 when the total for May through September was 13.67 inches. Seasonal distribution is as important as the total, but serious soil moisture deficits seem likely when rainfall during the growing season averages less than 2.5 inches per month.

3. **Soil type.** It is the shallow and the coarse-textured soils that are most susceptible to damaging soil moisture deficits. Apples will size surprisingly well on a good, deep loam in even the driest years, and orchards on such soils are not particularly responsive to irrigation. For maximum results, appreciable acreage must be located on such soils as Nassau slate loam, shallow phase Cossayuna gravelly loam, and Hoosic gravelly loam. As soil depth approaches 4 feet, the possibility of profitably irrigating apples in this area is greatly diminished.

4. **Water supply.** If irrigation is to be undertaken seriously there should be sufficient water to apply 12 inches to an acreage large enough to support the irrigation system. The minimum acreage that could be irrigated profitably under Hudson Valley conditions is 15, but 25 is a more realistic figure. The water supply should approach 10 million gallons and should be completely dependable in even the driest years.

5. **Equipment.** Irrigation within the cost range indicated here requires sufficient pipe to cover an average of 3 acres per setting and a pump of sufficient
capacity to apply 0.5 inches of water per hour to this acreage. Less pipe or
less power will greatly increase the cost per acre and reduce the acreage that
can be effectively irrigated. On the other hand, costs might be reduced some-
what if the equipment could be used with other crops, such as strawberries,
at times when it would not be needed for apples. This would have the effect
of reducing the fixed costs of interest and depreciation on a per-acre basis
by spreading these costs over more acres.

(6) Varieties. The influence of this factor is expressed in two ways. First, the
potential physiological response of some varieties is greater than that of
others. A significant reduction in fruit growth can be detected only after an
extended period of soil moisture deficiency. Since soil moisture deficits usually
do not develop before mid-summer, early-ripening varieties are subjected to
relatively short periods of inadequate soil moisture. The possibility of signifi-
antly improving fruit size through irrigation increases in direct proportion
to the length of growing season required for acceptable maturity. In the
Hudson Valley, worthwhile response to irrigation of summer apples would be
unlikely; for apples of the Mcintosh season, the prospects would be improved
somewhat; but the greatest opportunity for successful irrigation would be
provided by such varieties as Delicious, Golden Delicious, and Rome Beauty.

The other aspect of the variety question is related to marketing. The in-
come from irrigation was derived from two sources: an increase in yield and
an increase in the market value of the fruit as represented by changes in
size distribution of the fruit. In these studies, the increase in yield by itself
would not support this expensive practice; an increase in the sale value of
the fruit was essential for profitable irrigation. Unless there is an appreciable
price differential between sizes, returns from irrigation are likely to be dis-
appointing. This is illustrated by the 1962 Mcintosh data. Irrigation increased
fruit size of this variety almost as much as of Delicious, but the net return
for Mcintosh was not $163 per acre, but $89. As a result, the minimum
acreage for profitable irrigation of Mcintosh would be twice that for
Delicious. Irrigation is an expensive practice and $2.00 apples will not pay
for it.

(7) Market. The importance of this factor cannot be overemphasized. Signif-
icant increases in fruit size are meaningless unless they can be converted to
dollars. In years of short supply and unsatisfactory fruit size, the market
readily absorbs the costs of irrigation, but in an unfavorable market the cost
of irrigation may exceed any increase in the value of the crop. An example of
this is provided by the Delicious market in 1962 and 1963. In the former year,
irrigation was highly profitable; in the latter a larger national crop, in com-
bination with a widespread water core problem, depressed the market to such
an extent that irrigation would have been only an added expense.

The rigidity of these requirements seriously restricts the number of
Hudson Valley apple growers that could confidently expect to reap
financial rewards from irrigation. If the kind of response obtained in
1957 and 1962 could be realized on 25 acres as frequently as once in
5 years, and the fruit could be marketed as profitably as it was in those
years, irrigation equipment would pay for itself. Unfortunately, the
basic requirement for successful irrigation of apples in this area is an
appreciable acreage on shallow soil. It would be difficult to avoid shal-
low soils completely in many parts of the Hudson Valley, but the pro-
gressive growers no longer have extensive acreages on shallow soil.
Under current economic conditions, the numerous problems inherent
in shallow soil make it difficult to justify the establishment or maintain-
ence of apple plantings on sites that require irrigation. These sites may
possess other virtues, such as freedom from spring frosts, but for the
majority of them, the liabilities greatly outweigh the assets. There are
relatively few situations where appreciable acreages of shallow soil will
support profitable apple production, and irrigation of apples should
be limited to them. The practice cannot be generally recommended
to Hudson Valley apple growers.

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