53% the succeeding year, but there was no significant correlation between crop and current-season’s shoot growth.

The fall and spring maxima of starch and the winter maximum in sugar concentration found in wood of pistachio are in agreement with data reported for various deciduous trees (8). Additional fluctuations in carbohydrates have been associated with their utilization in fruit development. For example, the declines in carbohydrate levels during June in the sour cherry (1) and during June and August in the fig (4) were brought about by their respective fruit crops. In pistachio, the low levels particularly of sugars but also of starch in August occurred at the time fats have been shown to rapidly accumulate in the nuts. In fact, it appears that the demand for carbohydrates for fat synthesis and storage in the kernels in August is second in intensity only to that for new shoot growth in April and May. This is indicated by the low sugar and starch levels in August in all samples analyzed, even those from halves of trees that were nonbearing. It seems likely that nonbearing portions of the trees supplied carbohydrates to bearing portions. Davis (5) reported a similar response in deflorated branches of the ‘Sugar’ prune, Prunus domestica L., and suggested that the tree may behave as a unit when a large fruit crop matures.

Since no consistent differences in total nitrogen were found between bark or wood of bearing and nonbearing branches, a relationship between it and shoot growth and/or nut production was not indicated. Accumulation of nitrogen in October in all fractions analyzed is attributed primarily to its translocation from the leaves prior to leaf abscission. This phenomenon has been well established in several other studies (9).

Literature Cited


Fruit Numbers, Fruit Size, and Yield Relationships in ‘McIntosh’ Apples

C. G. Forshey
Hudson Valley Laboratory, Highland, NY 12528
D. C. Elfving
Cornell University, Ithaca, NY 14853

Additional index words. fruit thinning, fruit growth, Malus domestica

Abstract. In 3 ‘McIntosh’ apple (Malus domestica Borkh.) orchards, yield was positively related to fruit numbers, but negatively related to fruit size. Increases in fruit size from thinning were proportionately less than decreases in fruit numbers. Fruit thinning increased the percentage of larger fruits, but reductions in yield were such that the actual number of large fruits was either unchanged or reduced.

1Received for publication November 26, 1976.
2Professor.
3Assistant Professor.
quered for crop prediction, multiple variables are involved.

In 1932, Fletcher (10) reported significant increases in size and color of hand-thinned 'Jonathan' apples. These improvements in fruit quality were associated with substantial reductions in yield. Since then, fruit thinning of apples, both hand and chemical thinning, has been intensively studied. The accumulated data, though voluminous, shed little light on fruit numbers—fruit size—yield relationships. In some instances, the data were limited to fruit set and neither yield nor fruit size at harvest were reported (4, 8, 15, 23). Differences in yield sometimes appeared to be unrelated to differences in fruit set (17, 22, 23). In very few cases were the actual number of fruits/tree reported (21, 25).

While most thinning studies did include effects on fruit size, quantitative evaluations of treatment effects were not always possible. Fruit size has been reported, with and without yields, as % of various size classes with size based on diameter (7, 10, 13, 14, 25, 26); as weight or bushels of fruit in various size classes (21, 25); as mean fruit weight (25, 26); as the number of fruits/bu (5, 6, 20, 23); as average diameter in inches (17, 22); as mean fruit volume in cc (20); and as % of check with the size basis undefined (2).

Reported effects of fruit thinning on yield have been contradictory. Batjer (2), in a summary of 19 year's experiments, indicated that chemically thinned 'Delicious', 'Golden Delicious', and 'Winesap' trees yielded 89-102% of the unthinned checks, but the check trees were hand-thinned after fruit set counts were made. Where the results were not complicated by such thinning of the checks, some investigators reported negligible effects of thinning on yield (7, 13, 17) while others found that thinning reduced yield substantially (6, 10, 14, 16, 18, 21, 23). In accounts summarizing several thinning experiments, there was no reduction in yield in some tests and significant reductions in others (22, 25, 26).

Batjer (2) suggested that the increase in fruit size was roughly proportional to the degree of thinning. However, in several studies, the increase in fruit size was proportionately less than the reduction in fruit set (5, 6, 20, 23, 26) or in the number of fruits/tree (21, 25). The generalizations, omissions, and contradictions in the literature indicate that the quantitative relationships among fruit numbers—fruit size—yield in apples have not been adequately explored. This study was conducted in an effort to clarify these relationships in the 'McIntosh' cultivar.

Materials and Methods

Data were collected from one ‘McIntosh’ orchard in 1975 and from 2 orchards in 1976. The orchards are described in Table 1. In 1975, 3 chemical thinning treatments (unthinned, NAA 5 ppm, and NAA 10 ppm) were applied to whole trees, at random, with 5 replicates of each NAA treatment and 4 unthinned trees. The sprays were applied 14 days after full bloom. In 1976, whole trees at Peru were hand-thinned, at random, to 3 levels of crop (unthinned, 1 fruit/spur, and fruits spaced 10-15 cm apart), with 4 replicates of each treatment. In hand thinning, which was completed 28 days after full bloom, an effort was made to remove the smaller fruits and retain the larger ones (2, 16). The Ithaca trees were unthinned.

Table 1. Description of 3 experimental 'McIntosh' apple orchards.

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Tree age</th>
<th>Rootstock</th>
<th>No. of trees</th>
<th>Range in trunk circum. (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walden, N.Y.</td>
<td>1975</td>
<td>16</td>
<td>Seedling</td>
<td>14</td>
<td>59.8—85.2</td>
</tr>
<tr>
<td>Peru, N.Y.</td>
<td>1976</td>
<td>10</td>
<td>MM 106</td>
<td>12</td>
<td>36.7—54.0</td>
</tr>
<tr>
<td>Ithaca, N.Y.</td>
<td>1976</td>
<td>16</td>
<td>M 2</td>
<td>14</td>
<td>28.6—57.8</td>
</tr>
</tbody>
</table>

Table 2. Fruit numbers, fruit size, and yield of 3 'McIntosh' apple orchards.

<table>
<thead>
<tr>
<th>Location</th>
<th>Yield (kg/tree)</th>
<th>No. fruits/tree</th>
<th>Fruit size (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>Walden, 1975</td>
<td>203.8</td>
<td>94.9—312.9</td>
<td>1781</td>
</tr>
<tr>
<td>Peru, 1976</td>
<td>140.8</td>
<td>89.2—214.6</td>
<td>1158</td>
</tr>
<tr>
<td>Ithaca, 1976</td>
<td>117.6</td>
<td>57.4—213.6</td>
<td>1079</td>
</tr>
</tbody>
</table>

The fruits were counted as they were harvested and the yield of each tree was determined in kg. Drops were included in the 1975 data, but not in 1976 because preharvest fruit drop was negligible in both orchards. In the Peru orchard, 2 branches of 10-15 cm circumference were sampled on each tree for individual fruit weights. These samples were used to estimate fruit size distribution.

Results

The thinning treatments, in combination with natural tree variability and differences in location, season, and tree size and age, produced a wide range in fruit numbers, fruit size, and yield (Table 2). The larger trees at Walden produced the highest yields and the widest range in fruit size. The Peru orchard yielded more than the Ithaca orchard, and had the largest fruit of the 3 locations. Predictably, the unthinned Ithaca orchard had the smallest fruit. The total range in fruit size (97.4—136.5 g) represents differences in %<6.4 cm (2½ inches) of approximately 48.2—2.0% (11). The greater variability in trunk size in the Ithaca orchard was reflected in ranges in fruit numbers and yield that were proportionately greater than in the other 2 orchards.

Yield was so closely related to fruit numbers that a single regression line accurately described the relationship for all 3 orchards (Fig. 1). Evaluations of the relationships between fruit size and fruit numbers were complicated by differences in tree size. Both the yield and the number of fruits/tree associated with optimum fruit size would obviously vary directly with tree size. To eliminate this variable, yield and fruit numbers were expressed on the basis of trunk cross-sectional area for comparisons with fruit size. The correlation of fruit size with yield was negative (r = −0.24 to −0.63) as was that with fruit numbers (r = −0.54 to −0.74). These relationships were significantly different.
Fig. 2. Relationship between fruit size and yield/tree in 3 'McIntosh' orchards.

For the 3 locations and in neither case could the relationships be described by a single regression line (Fig. 2 & 3).

When the data from the Walden and Peru orchards are summarized by thinning treatments, the effectiveness of the treatments in reducing fruit numbers is evident (Table 3). In both cases, the net effect was 2 levels of thinning that would be considered moderate and heavy. Both hand and chemical thinning increased fruit size, but differences in fruit size between moderate and heavy thinning were not statistically significant.

Fruit size distribution was significantly altered by moderate thinning, but there was no further change with additional thinning (Fig. 4). The branch samples averaged 9.1% of the total crop with a range of 7.4–13.3%. The coefficient of variability between mean fruit size of the branch samples and mean fruit size of the entire tree was ±4.5 g, or 3.7% of mean fruit size for the orchard. This indicates that the branch samples provided a valid basis for estimating fruit size distribution for the entire tree.

Discussion

The close relationship between fruit numbers and yield, regardless of tree size, clearly indicates that this is the dominant factor in yield. The relationship between fruit size and yield was less precise, consistently negative, and specific for each orchard. The negative correlation between fruit size and fruit numbers was predictable because a major objective of fruit thinning is an increase in fruit size.

In agreement with previous results with this and other cultivars (5, 6, 20, 21, 25, 26), increases in fruit size were proportionately less than reductions in fruit numbers (Table 3, Fig. 3). This is not surprising because the developing fruits compete with the shoots and a reduction in fruit numbers is associated with increased shoot growth (1, 9, 18). When fruit numbers are reduced by thinning, the leaf/fruit ratio is improved, but a portion of any resultant increase in the supply of metabolites is diverted into vegetative growth.

Since the increase in fruit size did not compensate for reductions in fruit numbers, effective fruit thinning was associated with significant reductions in yield. Reducing fruit numbers from 1555/tree to 1109/tree increased the percentage of 120's but reduced yield to such an extent that there was no difference in the number of fruits in that size class (Fig. 4). Further thinning to 810 fruits/tree did not significantly alter fruit size distribution, but did reduce yield, and the number of 120's, by an...
additional 24.7%. Admittedly, fruit size was not a serious problem in this orchard and a greater response to thinning could be expected in other situations. However, in other studies in which the fruit size response was greater (10, 14, 18, 23), percentages of larger fruits were misleading and thinning beyond a moderate level was counter-productive. Failure to substantially increase the number of larger fruits, regardless of percentage, indicates that the primary effect of fruit thinning on fruit size is more often a reduction in the number of smaller fruits than a dramatic increase in the size of the remaining fruits.

The effects of factors other than fruit numbers on fruit size is emphasized in Fig. 3. The distinctly different fruit numbers-fruit size relationships in the 3 orchards are manifestations of differences in tree vigor and growing conditions, and perhaps in conditions the previous growing season (1). The potential size of a given pome fruit is determined early in the season and growth proceeds at a relatively uniform rate thereafter. This uniform growth rate permits the accurate prediction of the harvest size of the fruit as early as mid-summer (3, 11, 19, 24, 27). The growth rate, once established, is not easily altered, and fruit numbers is only one of several factors involved. Economically feasible changes in fruit numbers, therefore, can affect fruit size only within rather definite limits, and maximum effectiveness requires adjustment in fruit numbers relatively early in the season. As stated by Tukey (24), thinning does not change a potentially small fruit into a large fruit, but rather ensures that a potentially large fruit will size properly.

These results have important implications, for 'McIntosh' at least, as follows:

1. In apple crop prediction, the emphasis should be on estimating fruit numbers rather than fruit size.
2. Fruit thinning can quickly reach the point of diminishing returns. Rather than a high percentage of large fruits, the objectives of thinning should be the elimination of the smallest fruits, improved fruit quality, and annual production.
3. Optimum fruit size requires optimum vigor and growing conditions as well as adequate thinning. Attempting to compensate for deficiencies in either of the other 2 areas with excessive thinning is likely to be ineffective and costly.
4. In high density plantings, where vegetative growth must be carefully controlled, heavy production is essential. Fruit thinning should be limited to the minimum that ensures acceptable fruit quality and adequate repeat bloom for a full crop. Large fruits should not be the primary objective because they may be attainable only through over-thinning that stimulates unnecessary and undesirable vegetative growth.

Literature Cited