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# Leaf Area Development Patterns in Young Pruned and Unpruned Apple Trees

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***Abstract.*** **Six-year-old 'Empire'/Malling 7 (M7) apple (*Malus domestica* Borkh.) trees were left unpruned or pruned moderately during dormancy, and early-season leaf area development patterns were examined. Pruning markedly shifted leaf area distribution from spur to extension shoot. Leaf area at and shortly after bloom nearly doubled in the unpruned trees due to the increased percentage of the leaf area in rapidly developing spurs; however, the final total leaf areas were not affected significantly by the pruning. Leaf area development in all trees slowed dramatically around full bloom. Yields were reduced in the pruned trees primarily due to fewer flower clusters. Leaf areas per tree correlated well with percentage of sky values from fisheye photography.**

Analysis of the bases of yield in many agricultural crops has indicated the importance of early leaf area development for growth and support of the reproductive phases (20, 26). The leaf area in apple develops quickly in the spring (4, 18) due to reserves and the preexisting tree structure; however, flowering and fruit set also occur early, prior to complete leaf area development.

Studies over many years have suggested that the presence and activity of early leaf area is important to fruit set and yield (1, 3, 9, 16, 17, 19, 23). Defoliation of spur leaves prior to fruit set caused severe reductions in fruit set while defoliation of shoot leaves had relatively little effect (6, 16), emphasizing the importance of the spur leaves. Increasing pruning severity has been shown to shift the distribution of leaf area from spurs to shoots (2) and also is recognized to be inhibitory to fruiting, especially in young trees (19).

There is little detailed data available on leaf area development despite its apparent importance prior to fruit set (4, 21), especially in relation to reproductive development and how pruning may affect it. Therefore, the objectives of this study were to compare the leaf area development in young, bearing apple trees that were unpruned (mostly spur leaves) and moderately pruned (a relative balance of spurs and extension shoots) and to determine if fisheye photography can be correlated to leaf area development.

## Materials and Methods

Twelve 6-year-old 'Empire'/M7 apple trees, spaced 4.25 × 6.0 m, were selected for uniformity of trunk size, canopy size, and general appearance. In late winter, half of the trees were pruned by heading all 1-year-old shoots longer than 25 cm, leaving about half of the previous year's growth. Additionally, about 30% of the spurs were removed. The other 6 trees were left unpruned to help establish canopy differences in which the pruned trees would eventually have a greater proportion of extension shoot leaves and fewer spur leaves than the unpruned trees. The design was a randomized block with 6 replications of the 2 treatments. Measurements of trunk circumferences at the time of pruning showed no significant differences between the 2 groups of trees.

Beginning on 28 Apr. (between tight cluster and pink on flowering spurs), 10 representatives of each of the 4 following types of growth were removed at 4- to 7-day intervals from each treatment: flowering spurs, nonflowering spurs, shoots from terminal or uppermost buds on the previous year's extension shoots, and shoots from lateral buds on the previous year's extension shoots. Leaf areas of unfolded leaves were measured with a Hayaski-Denko AAM-5 leaf area meter. As terminal and other extension shoots elongated, leaf numbers and shoot lengths were measured as was leaf area. On 26 May when growing points had differentiated clearly into extension shoots (> 5 cm), short shoots, or spurs, counts of each type of growing point were taken on each tree. These counts were multiplied by the mean leaf areas for each type of growth to estimate the leaf area per type of growth. They were then summed to estimate the total leaf area per tree on the dates of sampling. It was found that the leaf area of flowering lateral short shoots did not differ significantly from that of nonflowering lateral short shoots from previous year's growth. These data then were combined for leaf area estimates. After extension shoots had reached 10–12 cm in length (about 2 weeks after bloom), lengths of 10 representative extension shoots were measured on each tree, and the leaf area was estimated from the leaf area-shoot length regression found on shoots sampled at that time. The regression for these trees was: Leaf area $cm^2$/shoot, = 11.1 (shoot length, cm) + 17.6, $r = 0.93$. The mean extension shoot leaf area estimated from the 10 representative shoots was multiplied by the total number of extension shoots to estimate extension shoot leaf area per tree at that date.

In early July, fruit diameters were measured on the tree with a caliper for every fruit on the pruned tree and for every 3rd fruit on the unpruned trees (unpruned trees had about 3 times the fruit numbers of pruned trees). All fruit diameters and weights were measured at harvest.

Fisheye photographs were taken under each tree, 50 cm from the ground and 25 cm from the trunks on each sampling date. The images were analyzed by false color densitometry (14, 15, 24), except that only the central 140° area of the 180° photo was analyzed, to eliminate large, irregular gaps in the canopies along the horizon that were unrelated to the leaf area development of the young tree canopies in the widely spaced planting.

A very dry early season induced an abnormally early termination of all extension shoots by 19 June; thus, sampling was discontinued on that date.

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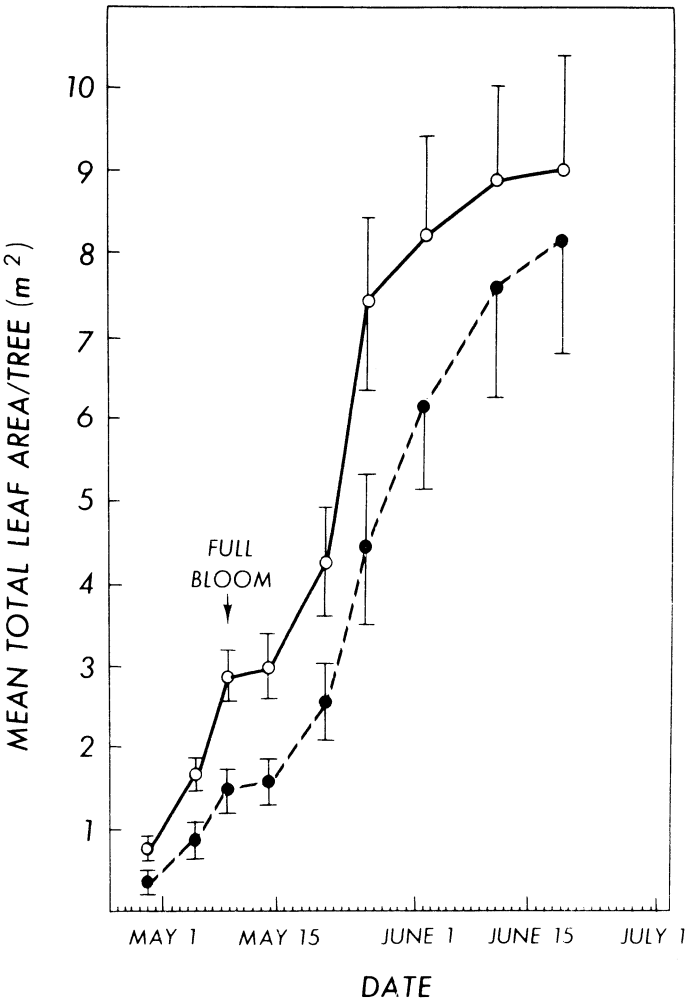


Fig. 1. Early season development of estimated mean total leaf area/tree ($m^2$) in pruned (●---●) and unpruned (○—○) 6-year-old 'Empire'/M7 apple trees. Bars at each point represent the SE (overlapping error bars omitted for clarity).

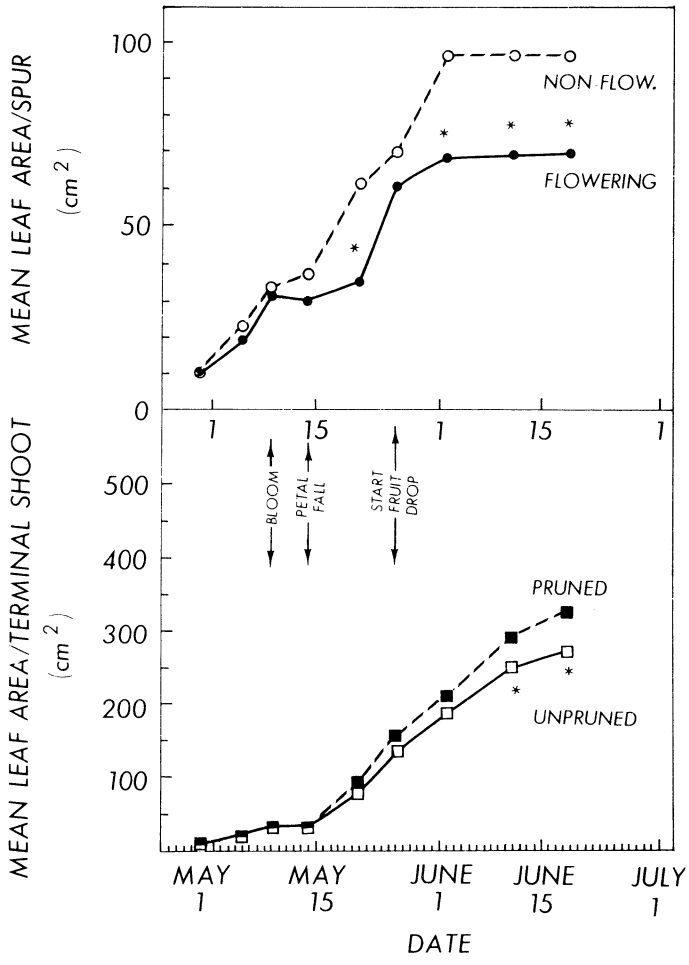


Fig. 2. Estimated leaf area development of flowering and nonflowering spurs (top) and terminal extension shoots on pruned and unpruned 'Empire'/M7 apple trees (bottom). Pruning had no effect on the observed spur development so data were pooled. The * denotes significant difference at 5% level by *t* test.

## Results and Discussion

The phenological development of the spurs and the terminal extension shoots on the measured trees did not appear to be affected by pruning, except for a slight delay at the earliest growth by the top bud on the pruned shoots. After a few days, the development was equivalent to those on unpruned trees. Important phenological dates were: one-half inch green — 15 Apr.; tight cluster — 22 Apr.; pink — 1 May; full bloom — 9 May; petal fall — 14 May; beginning of major fruit drop — 26 May; 90% extension shoots terminated growth — 19 June.

Pruning had marked effects on the distribution of types of growth by stimulating many lateral buds of 1-year-old shoots to become extension shoots rather than short shoots (Table 1). The difference between pruning treatments in the numbers of flowering spurs resulted from pruning off the spurs to establish canopy differences. Overall, the total number of growing points was reduced 50% by the pruning used. The greatest effect on the number of growing points was seen in the lateral short shoots, since pruning the previous year's shoots removed many buds. Additionally, the percentage of budbreak was reduced for the basal buds of the shoots left after pruning. The distribution toward more lateral extension shoots and accompanying leaf area in the pruned trees is similar to that reported by Barlow (2). A striking effect of pruning was that the proportion of leaf area on long extension shoots (terminal and lateral) was increased from 23% in the unpruned to 64% in the pruned.

Unpruned trees developed leaf area more quickly than pruned trees, although there was no significant difference in total leaf area on the last 2 sampling dates (11 and 19 June) (Fig. 1). The early difference in leaf area is due primarily to the difference in numbers of spurs (Table 1). In normal years with improved soil moisture, extension shoot growth on these trees would continue for several additional weeks, and then would be expected to increase final leaf area of the pruned trees more than for the unpruned trees.

From early growth until about 1 week after full bloom, unpruned trees had almost twice the leaf area of pruned trees. Unpruned and pruned trees at bloom had 32% and 18% of their final leaf area, respectively. These results are similar to those of Mika (19) who found that pruning reduced leaf area early in the season but had no effect on the final leaf areas. Ferree (5) found that the leaf area at bloom varied from 13–26% of the midsummer maximum in 4 different apple training systems with 6-year-old trees. The data of Cain (4) suggest that about 30%

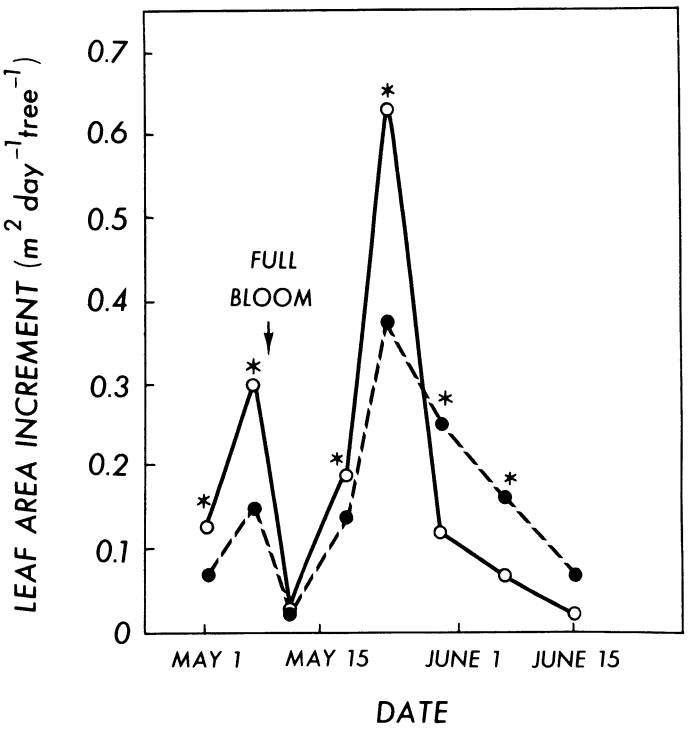


Fig. 3. Rates of total leaf area development of pruned (●—●) and unpruned (○—○) 6-year-old 'Empire'/M7 apple trees. The * denotes significant differences at 5% level between the 2 pruning treatments.

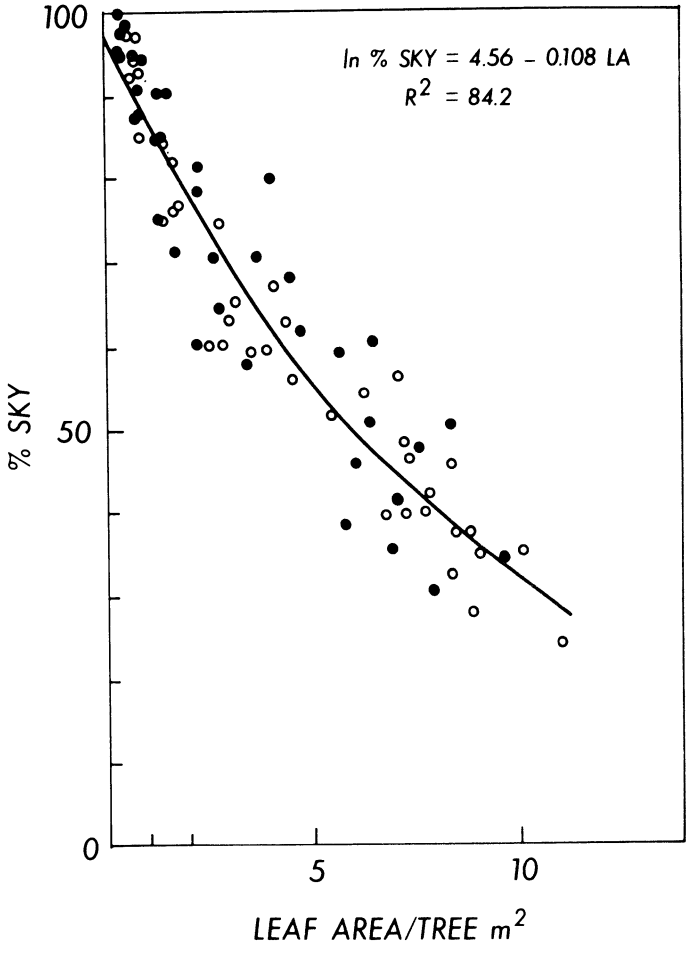


Fig. 4. The relationship of fisheye photography percentage of sky to the estimated total leaf area/tree in developing pruned (●) and unpruned (○) 6-year-old 'Empire'/M7 apple trees.

of the final leaf area was present at bloom in mature 'McIntosh' trees, while Forshey et al. (7) found 18% of the final leaf area expanded at bloom in 8-year-old 'McIntosh' trees. In 2- to 4-year-old trees, Palmer and Jackson (21) also found differences in the pattern of leaf area development dependent on relative spur/extension shoot ratios.

No differences were found between pruning treatments for spur and extension shoot development (Fig. 2), but flowering spurs showed less leaf area development after petal fall than did nonflowering spurs. This difference appeared to be due to a reduction in leaf size in flowering spurs as well as somewhat shorter bourse shoots. Pruning stimulated extension shoot growth after petal fall giving a final 19% increase in estimated leaf area compared to unpruned trees (Fig. 2).

There was an extremely small increment of growth in both spurs and shoots between full bloom and 5 days after bloom (9 and 14 May) (Fig. 2), which was reflected in a very low total leaf area increment at this time compared to periods before and after (Fig. 3). Analysis of the prevailing weather data indicated that the temperatures were average and similar to those of the previous period, so the slowed growth rate was not due to low temperature. Smith (25) found that there was rapid cell division within the developing flower/fruit before and after bloom, but there appeared to be no cell division during the period in which the flowers were fully open. Although this study was not sufficiently detailed to define precisely the timing of the growth reduction, the fact that both spurs and shoots in both treatments slowed growth concurrently suggests a coordinated pattern of growth in the whole tree.

Hansen (8) has indicated that apple trees become dependent on current photosynthates for flower, fruit, and shoot development very early, probably before bloom. Shading of trees shortly after bloom has detrimental effects on both fruit set (1, 10, 12) and return bloom the next year (1, 12). Early defoliation of spur leaves similarly reduces fruit set (6, 16). If these effects are mediated through photosynthate production, then unpruned trees should have an advantage over pruned trees due to increased leaf area for early photosynthate production.

Watson and Landsberg (27) estimated that under English growing conditions spur leaves began to export carbohydrates within 10 days of beginning growth. Under warm conditions this might be expected to begin earlier. In contrast, extension shoots do not exhibit net carbohydrate export back to the tree until they reach 12–15 unfolded leaves (13), 3–4 weeks after full bloom in this experiment (Table 1). Quinlan (22) showed that labeled carbohydrates could move basipetally from the 9th leaf below the growing shoot tip, although he did not develop a net carbon balance analysis. Since fruit drop had begun 2–3 weeks after full bloom, these observations suggest that the extension shoots do not play a significant role in supporting the carbohydrate needs of early fruit development. Whether the reserve carbohydrates and nitrogen depleted by early growth of the extension shoots is detrimental to fruit set is not clear. If early fruit development is supported primarily by carbohydrates from spur leaves, the unpruned trees, with increased spur leaf area (Table 1, Fig. 1), may have improved potential for fruit development.

Table 1. Mean number of growing points and final leaf area for each growth category per tree in pruned and unpruned 6-year-old Empire/M7 apple trees.

| Type of growth | Measurement | Unpruned | Significance[z] | Pruned |
|---|---|---|---|---|
| Terminal shoots | Number | 47 | NS | 41 |
| | Leaf area ($m^2$) | 1.27 | NS | 1.32 |
| | % total leaf area | 14 | | 16 |
| Lateral extension shoots[y] | Number | 30 | * | 120 |
| | Leaf area ($m^2$) | 0.79 | * | 3.93 |
| | % total leaf area | 9 | | 48 |
| Lateral short shoots[x] | Number | 613 | * | 133 |
| | Leaf area ($m^2$) | 3.85 | * | 0.84 |
| | % total leaf area | 43 | | 10 |
| Flowering spurs | Number | 318 | * | 160 |
| | Leaf area ($m^2$) | 2.14 | * | 1.07 |
| | % total leaf area | 24 | | 13 |
| Non-flowering spurs | Number | 93 | NS | 100 |
| | Leaf area ($m^2$) | 0.91 | NS | 0.96 |
| | % total leaf area | 10 | | 12 |
| Totals | Number | 1101 | * | 554 |
| | Leaf area ($m^2$) | 8.96 | NS | 8.12 |

[z]Denotes significance at the 5% (*) level between pruning treatments within rows by *t* test; NS, difference not statistically significant.
[y]Shoots with final length exceeding 5 cm.
[x]Includes flowering nodes on previous seasons's extension shoots.

Table 2. Fruit numbers, set, size, yield, and leaf area per fruit on pruned and unpruned Empire/M 7 apple trees.

| Measurement | Unpruned | Significance[z] | Pruned |
|---|---|---|---|
| Fruit set (No. fruit per flower cluster) | 0.28 | NS | 0.29 |
| Fruit set (excluding axillary flowers) | 0.45 | * | 0.33 |
| No. fruits | 144 | * | 52 |
| Mean fruit diam (cm) | | | |
| 7 July | 4.1 | * | 4.3 |
| 29 Sept. | 6.9 | * | 7.1 |
| Mean fruit wt (g) 29 Sept. | 133 | NS | 142 |
| Total tree yield (kg) | 19.2 | * | 7.4 |
| Tree crop lead (fruits/$cm^2$ trunk x-sect) | 5.0 | * | 1.8 |
| Final total leaf area ($cm^2$) per fruit | 622 | * | 1912 |

[z]Denotes significance at the 5% level between pruning treatments within rows by *t* test; NS, difference not statistically significant.

The yield of the pruned trees was only about 40% that of the unpruned trees, although unfortunately, the crop was not heavy for these trees (Table 2). Final yield differences were due primarily to fruit numbers since fruit weight was only increased by 5% in the pruned trees, a difference established by early July. At cropping levels of 1.8 and 5.0 fruit/$cm^2$ trunk x-sect area for the pruned and unpruned trees, fruit size would not be expected to vary greatly. Analysis of leaf-to-fruit ratios showed a 3-fold increase in leaf area per fruit in the pruned trees at the end of the season (Table 2). Several studies have shown that about 400–800 $cm^2$ of final leaf area per fruit generally is required for large fruit size (9, 17, 18). Since this requirement appeared to be met by the unpruned trees, the small increase in fruit size in the pruned trees is expected.

The final set of fruit/total flower clusters was equal (this includes axillary flowers), although there was a large difference in flower cluster numbers. If axillary flowers are excluded due to their poor development and lack of fruit set in these trees, the fruit set/established spur was significantly increased in the unpruned trees (Table 2). It should be noted that a $-5$°C frost occurred at tight cluster (22 Apr.). Yields were reduced generally in the experimental orchards, although the crop in the unpruned trees was acceptable. The effect of the frost was not clear, as little flower pistil damage was observed. Also, the previous February, March, and April temperatures were abnormally warm, a factor associated with poor cropping of apples in England (11).

Estimation of leaf area on trees by sampling and categorizing growing points, as done in this study, can be tedious. A rapid, indirect method, such as fisheye photography, can be very useful for sampling large numbers of trees. In this study, the leaf area/tree correlated to the percentage of sky in fisheye photographs (Fig. 4), suggesting that this technique could be used to obtain reasonable estimates of leaf area in experiments comparing treatments that affect (or are suspected to affect) leaf area development.

Pruning of young apple trees had no significant effects on the total leaf area developed at full canopy but had marked effects

on the rate of early development of leaf area. During bloom, the unpruned trees had almost twice the leaf area of the pruned trees due to the increased proportion of spurs and short lateral shoots.

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