The apple tree is a very efficient plant. It produces leaves very early in the season, and it can keep those leaves functional over a long season. It can also put a very high percentage of its yearly energy production into the crop. Several studies have shown that modern dwarf apple trees with excellent crops can put 60-80% of all their productivity into the crop. This is significantly higher than most crops. Yet similar orchards may produce well or poorly. Why is that and how can we control that? We will review the key bases of productivity in apples to try to answer those questions.

The apple grower, at the most basic level, is a farmer of sunlight. The sun provides the energy that is converted from light to sugars and dry matter by photosynthesis of leaves. This dry matter is then distributed to grow the tree, grow the crop and burn by respiration to support all the growth.

Apple trees are also perennial plants that live many years and live through the dormant winter by storing away energy in the form of carbohydrate and nutrient reserves. These reserves, from last year’s sunlight stored as starch, can then be used in the spring to support growth of the young shoots and roots when there are no or few leaves yet. Studies have shown that the reserves are critical before bloom, but they are used only until about bloom. After bloom, the reserves are replenished even though there is also active growth of the tree and crop.

Since the reserves are no longer important after bloom, this means that the development of the crop (1) is supported by the photosynthesis of the current season’s leaves and (2) will be very dependent on the current weather.

We and other researchers have studied over many years how the apple orchard captures sunlight, how the apple tree responds to weather, and what controls fruit growth and drop. It is helpful to consider the steps of farming the sun and what factors affect them (Table 1).

Some factors are not easily managed while others are function of decisions a grower makes. Clearly, for any given location the energy available to the orchard depends on the general latitude and the climate (sunny versus cloudy, and long versus short season). For NY growers this is a real limit as we have a relatively cloudy climate with fairly short season. So we have to make the most of the other things we can control.

Consequently, we have focused a great deal of our research effort on understanding how the grower can affect the sunlight intercepted by the orchard and how they can then distribute it optimally for balancing yield, fruit quality and return cropping.

Yield Potential is Limited by Sunlight Interception

Many studies have shown a clear positive relationship between apple orchard light interception and yield (Figure 1). A

Table 1. Sunlight Energy Availability and Utilization.

<table>
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<th>Sunlight Energy</th>
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<tr>
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Figure 1. The relationship of apple orchard yields to percent sunlight interception from many studies. The dashed line approximates the maximum yield possible for any orchard light interception while the vertical arrow indicates the reduced yields that result from poor light distribution within the trees.
key point is that to have a high yield potential requires a high percent of the available light to be intercepted by the orchard. Of course the conversion of sunlight energy into useable sugars depends on the health of the leaves and the supply of water and nutrients. So maintaining good tree health via pest, water and nutrient management is important to ensure that the sunlight that is intercepted is effectively used to support growth.

A second key point is that a high light interception is no guarantee of high yield; that depends on light distribution within the tree as will be discussed below.

The production of small crops even with high light interception is a long-standing problem that is normally due to poor pruning and training (assuming the trees are otherwise healthy). Our physiological studies have found that it is critical to have good sunlight exposure of apple spurs for (1) setting fruit after bloom, (2) producing good fruit size and quality, and (3) obtaining good return bloom. It turns out that except for fruit coloration, the critical time for good spur exposure is the first month or so after bloom. This is the time when the fruit are dropping or staying on, growing cell numbers for size potential, and the spurs are developing flower buds for next year. Thus a particularly important time to check trees for good light penetration is around and just after thinning.

Factors Affecting Crop Development versus Tree Growth

Why is it so important to get sunlight to the spurs and fruit? To answer that question, we have studied how fruit is supported and found that:

- In the first weeks after bloom, fruit are supported by spur leaves, including non-fruiting spurs, but are not supported much by extension shoots. After thinning time the extension shoots are long enough to begin to support fruit growth.
- Active extension shoots support their own growth first, and do not support fruit until they have at least 12 expanded leaves if in full sun. If shoots are shaded, they may require 20 leaves to support themselves before helping the fruit.
- This means that we should focus on getting good exposure of the spur leaves which support the early development of the fruit.

From these studies it seemed that productive orchards were ones that intercepted more light with the spurs and less with long shoots. Working with Jens Wunsche, we tested this idea by estimating spur versus long shoot light interception in orchards with different light interception and different canopy densities. We found that yields were directly related to how much total light could be intercepted by the spurs (Figure 3). Except in young orchards, the more light the long shoots intercepted the lower the yields.

Thus, the yield of an orchard is directly related to the total amount of sunlight intercepted by the spurs during the first 3-4 weeks or so after bloom. The more sunlight intercepted by shoots and less by spurs, the lower the yields.

Thus during the critical period of cell division and fruit drop, the spurs are the primary source of support for the fruit. This has several implications for growers.

Trees will be more productive if:

- they have a good balance of mostly spurs with some extension shoots to ensure high light interception by the spur canopy. This is often attained by using thinning cuts instead of heavy heading cuts that reduce spur numbers and increase shade from more vigorous shoots on the outside of the tree.
- the pruning and training of trees maintains excellent light exposure of the spurs at least until about a month after bloom.

![Figure 2. At this critical stage of fruit development the fruit is being supported only by the spur leaves, so having excellent exposure of the spurs is important for fruit set and good fruit size potential.](image)

![Figure 3. The relationship of apple orchard yields to total sunlight intercepted by the spurs or by the extension shoots. The best yields came from orchards with a high total light interception, but primarily by spurs.](image)
Thinning time is a great time to examine the trees for good light penetration. In central leaders it may even require a few large thinning cuts at that time if the winter pruning did not open large enough windows. Alternatively, for older trees the Palmette Leader form may be helpful as the large gaps on the east and west sides guarantee good light penetration for several weeks after bloom.

- trees have good but not excessive vigor. Good nutrition and water will help produce spurs with large leaf area which supports good fruit development and return bloom. Vigor is also needed to develop good branches for replacement pruning when other branches are thinned out. However, too much vigor will cause excessive extension shoot growth and spur shading.

**Reaching the Crop Potential**

Once the crop potential has been set early in the season with good light interception and good light distribution to the spurs, then it is important to adjust fruit number per tree through thinning to balance the tree’s photosynthetic capacity with crop load to properly size and ripen the fruits.

This of course requires a healthy tree with good nutrition and adequate water supply. We have also found that excessive summer pruning of dense canopies due to poor winter pruning can markedly reduce the tree’s photosynthesis ability and limit final fruit sizing. This is due to a loss of function of the remaining leaves that were in the shade most of the season. So, better winter pruning to keep an open canopy will help early spur exposure to get better set and size potential, but will also help by requiring less summer pruning and better tree function.

Finally, good pest management is important to reduce direct loss from fruit damage, but also to maintain tree function for full ripening. In our studies of European Red Mite effects, we found that the effects of mite infestations on the fruit were due to reducing the leaf photosynthetic ability, which reduced the ability of the tree to ripen the crop. It also reduced next year’s crop potential as it inhibited fruit bud development.

**Summary**

An apple orchard is a very efficient system that can have a high yield potential since it can have a long season with leaves, high light energy interception and a high percentage of the productivity being fruit. However, proper training and pruning to expose the spurs to good sunlight in the first month bloom is critical to both this year’s and next year’s crop.

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