Crop Load Management of New High-Density Apple Orchards

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New orchard training systems like the Tall Spindle, which use highly feathered trees with minimal pruning at planting can have significant yield in the second year. Our research results show that over the first five years the yield potential in NY State with the Tall Spindle is double or triple what most growers expect. However, over cropping in the second or third year can result in biennial bearing and can also result in decreased vegetative growth resulting in stunted trees. Many new orchards have insufficient growth in the first two years making proper crop load management essential to obtaining adequate tree growth for future high yields. In addition, many varieties, which are biennial, like Honeycrisp or Fuji, can be induced into a biennial cycle by over cropping in the second or third year. Because of these problems, some question the value of any production in the second year. It has also long been assumed that production in the third year will result in greater cumulative production than waiting until the fourth year to begin production. Despite these questions we have maintained that with proper crop load management, trees can produce impressive crops in the second and third years while producing sufficient growth to ensure high crops in the fourth to sixth years. Our recent trials with several dwarfing rootstocks has provided some objective research data on which to base the optimum crop loads of young trees.

"The second year yield potential of a highly feathered, unpruned apple tree is much higher than previously envisioned by most growers. However, fruit production comes at the expense of tree growth in the second year and the induction of biennial bearing. Our research indicates that high-density orchards in the Tall Spindle system should be cropped in the second year at a crop load of 4-6 fruits/cm^2 TCA depending on variety. Lower density orchards should not be cropped in the second year but managed with a 3rd and 4th year crop load of 4-6 fruits/cm^2 TCA depending on variety. With highly feathered nursery trees planted at 1300 trees/acre and carrying a crop load of six, it is possible to produce 400 bushels per acre in the second year."

Tree Growth vs. Cropping Trial

In 2003 we planted a field trial at Geneva using Golden Delicious as the scion and several dwarfing rootstocks (M.9T337, M.9Pajam2, M.26, G.16, G.41, and G.935). In years three, four and five a range of crop loads were imposed on the trees and tree growth and fruit size were measured. Crop load was calculated in the traditional way as the number of fruits per unit of trunk cross-sectional area with units of fruits/cm^2 TCA. Tree growth was measured as the increase in TCA measured in cm^2. Tree growth data in years three to five with different crop loads was used to calculate the relationship between crop load and tree size each year. This data was used to calculate theoretical curves of production under different cropping scenarios in years two to six.

The results of our study show that in years three to five there was a significant negative relationship across all rootstocks between crop load and tree growth as measured by increase in trunk cross-sectional area (Figure 1). The relationship was steepest for the third year and flatter for the fifth. The fifth year (2007) was a very dry year, which

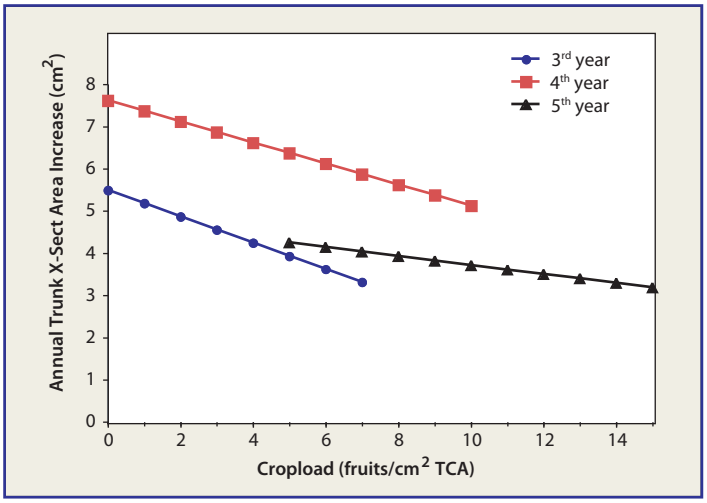

Figure 1. The effect of increasing crop load of young dwarf Golden Delicious apple trees on tree growth in years 3-5.

resulted in a smaller increase in TCA, regardless of crop load, than in the previous year (2006). If 2007 had had normal rainfall we predict that the TCA increase for each crop load would have been more than 2006 thus giving a trend of increasing growth increment over the years three to five.

The slopes of the lines in Figure 1 were plotted as the percentage reduction in growth per unit of crop load for each of the years three to five (Figure 2). This gave a decreasing line from year three to year five indicating that the impact of crop load on tree growth diminishes as the trees get older. We projected the impact of crop load on growth in year two by extending the line from years three and four back to year two. This data indicates that for each unit of crop load imposed on trees in the second year, tree growth would be reduced by 8.1%, while a similar crop load in year five would only decrease growth by 2.25%. This means that a crop load of 5 fruits/cm^2 TCA in year two would reduce tree growth by 40% while a crop load of 10 would reduce tree growth by 80%. In contrast, a crop load of 5 in year five would only reduce growth by 11% and a crop load of 10 in year five would reduce growth by only 22%.

The calculated reduction in growth for each year was used to construct theoretical tree growth curves with a crop load of either 5 or 10 for each year (Figure 3). If production was begun in year two as is recommended with the tall spindle system tree growth was reduced 40% by a crop load of 5 and 80% by a crop load of 10. If those crop loads were also imposed on the trees in years three to five the final tree size was reduced by 18% when a crop load of 5 was carried by the trees beginning in year two through year five, while tree size was reduced by 36% when a crop load of 10 was carried by the trees beginning in year two through year five. Similar calculated tree growth curves were developed if cropping was delayed until year three or if cropping was delayed until year four. When cropping was delayed until year three, the negative impact on tree size was less than if cropping was begun in year two. If cropping was delayed until year four, the impact of cropping on tree size was small.

Theoretical annual fruit production curves were calculated from the tree growth curves in Figure 3 for crop loads of either 5 or 10 fruits/cm^2 TCA (Figure 4). If production was begun in the second year production in that year was greatest but the reduction in tree growth during years two to five resulted in fewer fruits/tree in years three, four and five. If production was delayed until the 3rd or 4th year then fruit number/tree in year two was less but was greater in year five since the trees were larger and could carry more fruit at a similar crop load.

These production curves in Figure 4 allowed the calculation of different cropping scenarios to determine the best cropping strategy for growers (Figure 5). Three scenarios were evaluated: either begin production in the second year and suffer the penalty of reduced tree growth or wait until the third or fourth years and allow the trees to grow before cropping. Much to our surprise the results showed little

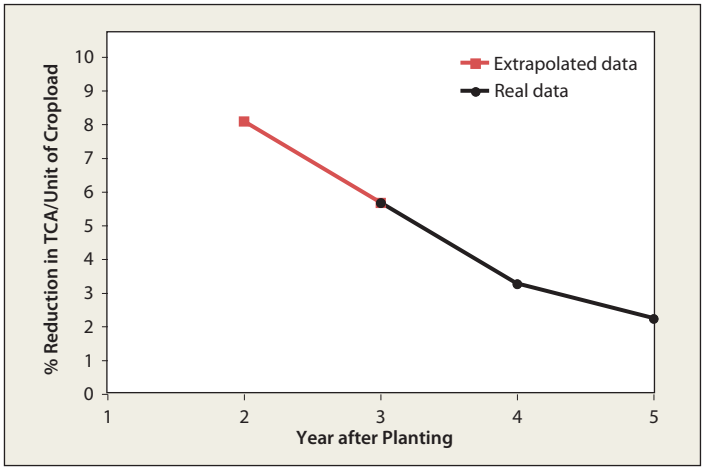

Figure 2. The reduction in tree growth of young dwarf Golden Delicious apple trees due to cropping in years 3-5 and the extrapolated reduction in tree growth for year 2.

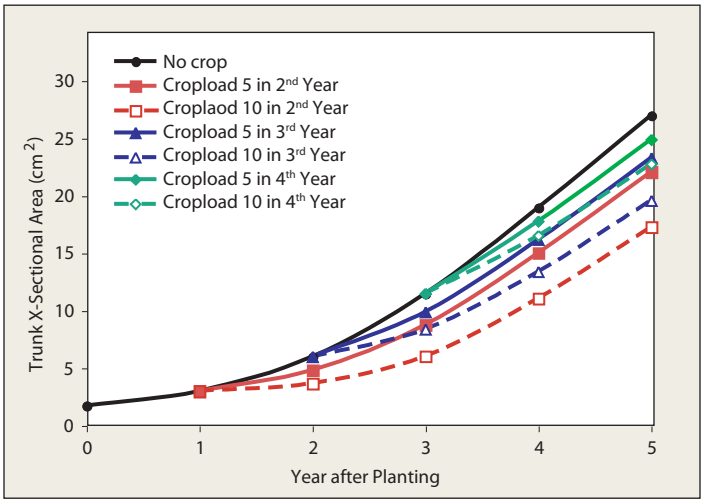

Figure 3. Theoretical tree growth of young dwarf Golden Delicious apple trees with crop loads of either 5 or 10 fruits per cm² TCA beginning in years 2, 3, or 4.

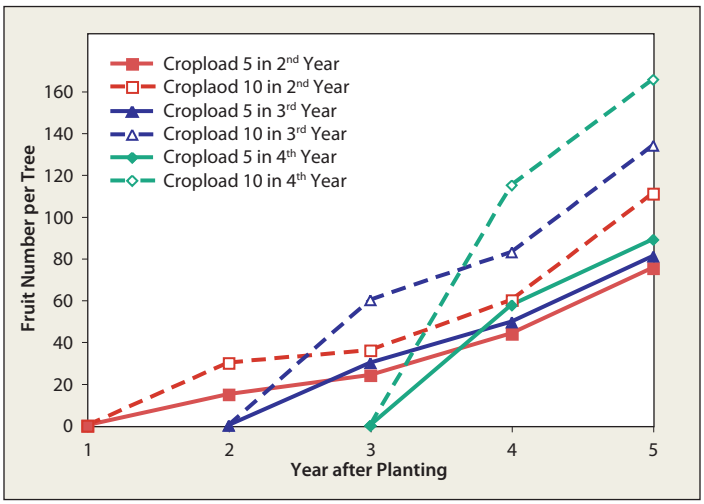

Figure 4. Theoretical annual fruit production of young dwarf Golden Delicious apple trees with crop loads of either 5 or 10 fruits per cm² TCA beginning in years 2, 3, or 4.

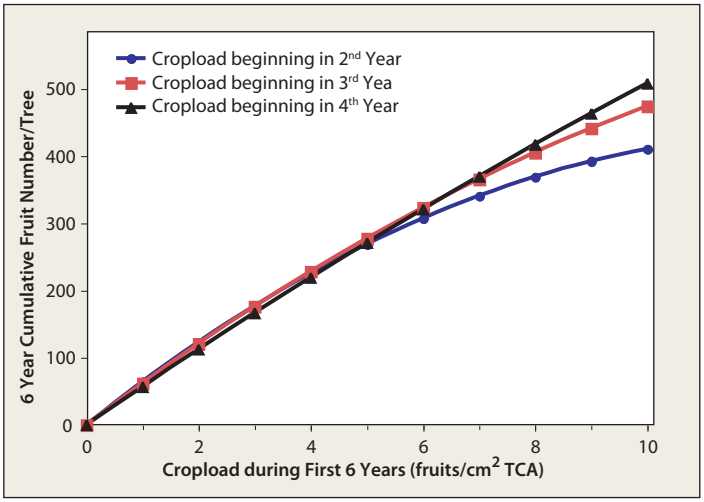

Figure 5. Theoretical cumulative fruit production over 6 years of young dwarf Golden Delicious apple trees with crop loads ranging from 1 to 10 fruits per cm² TCA beginning in years 2, 3, or 4.

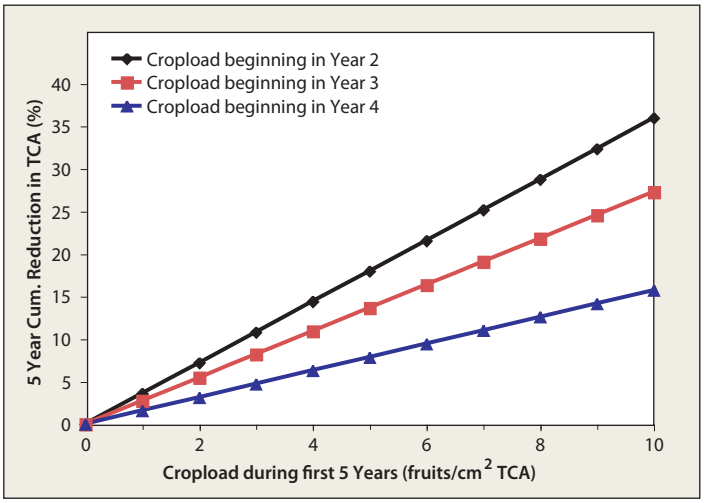

Figure 6. Theoretical reduction in growth of young dwarf Golden Delicious apple trees with crop loads from 1 to 10 fruits per cm² TCA beginning in years 2, 3, or 4.

difference in the cumulative yield over six years regardless of the when cropping was begun (Figure 5). If crop load was less than 5 the cumulative production was essentially the same whether cropping was begun in the second year or third or fourth year. However, if crop load was higher than 5 there was greater cumulative production if cropping was delayed until the third or fourth year. We have generally recommended that growers limit crop load on young trees to 5 fruits/cm² TCA which would limit the impact of early cropping on early tree growth. However, by beginning cropping earlier, fruit production can begin to pay back the investment in the new orchard sooner. Thus, the best strategy for growers is to begin production in the second year but to strictly limit crop load to 5 fruits/cm² TCA or less.

Regardless of the similar impacts of early cropping on fruit production there is always a negative impact of cropping on tree growth. We calculated theoretical five year cumulative growth reduction curves as a function of crop load for the 3 cropping scenarios (Figure 6). If cropping was begun in year two, cumulative tree growth would be reduced more at each crop load than if cropping was delayed until year three or year four. Thus, after five years the early cropping strategy would result in smaller trees than with the later cropping scenarios. This result has three practical implications: 1) For high density systems (>1000 trees/acre) like the Tall Spindle or super spindle systems containing tree size is an important objective and the early cropping scenario can be used to reduce tree size by 18-30% depending on the crop load allowed during years two to five. This reduction in tree size should help long-term management of the trees. In addition, tree spacing is so small and tree density is so high with these systems that larger trees would probably not be more productive since aggressive pruning would be required to contain tree size. 2) For medium density orchard systems (400-800 trees/acre) like the Vertical Axis, where significant tree growth after planting is needed, the data clearly show that the best strategy is to prevent any production in the second year and to strictly limit production in the third year to no more than 5 fruits/cm² TCA. This will ensure larger trees which fill their space earlier and larger crops in years five to ten. 3) For low-density systems (<400 trees/acre) cropping should be avoided until year four to ensure near maximum tree growth during the first five years. Cropping in year four has a small impact on tree growth and thus will not dramatically change tree size after six years. Although this strategy maximizes tree growth and cropping at low tree planting densities, the lack of production in years two and three is a serious economic disadvantage for low-density systems and is the primary reason they are not recommended for either fresh or processing orchards in NY State.

Recommended Crop Loads

The cumulative fruit production curves in Figure 5 and the tree growth reduction curves in Figure 6 indicate that with crop loads of 4 to 6 the counter balancing effects of growth reduction and production are optimized. At higher crop loads during the early years, growth would be reduced

too much and fruit size would also be smaller while at crop loads lower than 4 the lack of production in the early years would result in little payback of the investment to plant the orchard. Within this range the varietal characteristics must be considered. Varieties differ in their biennial bearing tendency and this must be incorporated into the crop loads allowed on young trees. For annual cropping varieties like Gala, we recommend crop loads of 6 fruits/cm^2 trunk cross-sectional area (20-25 apples/tree in the second year, 30-50 apples/tree in the third year, and 80-100 apples/tree in the fourth year). For slow growing and biennial bearing varieties like Honeycrisp, we recommend crop loads of 4 fruits/cm^2 trunk cross-sectional area (12-18 apples/tree in the second year, 20-35 apples/tree in the third year, and 40-70 apples per tree in the fourth year). Within each year, the low end of the range should be used for low vigor trees and the high end of the range for high vigor trees. For other biennial bearing varieties, which are vigorous such as Fuji, Jonagold, Mutsu, Spy and Fortune we recommend 5 fruits/cm^2 trunk cross-sectional area (16-20 apples/tree in the second year, 25-40 apples/tree in the third year, and 65-80 apples per tree in the fourth year).

Figure 8. Second year Gala/M.9 apple tree planted in the Tall Spindle System which was highly feathered at planting and minimally pruned and hand thinned to 6 fruits/cm2 TCA in early June of the second year resulting in 35 fruits/tree of box size 113 which was 410 bushels/acre .

Many apple growers try to follow these general recommendations, but at harvest discover that the crop load on young trees is often higher than optimum resulting in reduced growth and biennial bearing. A more precise method is for growers to measure TCA in early June and

Table 1. Crop load recommendations for young apple trees based on trunk diameter

Trunk diameter (inches)[z]	TCA (cm^2)	Recommended Number of Fruits/Tree[y]		
		Weak Growing, Biennial, Varieties (Honeycrisp)	Strong Growing, Biennial Varieties (Fortune, Fuji, Golden Delicious, Jonagold, Mutsu, Spy)	Annual Varieties (Gala, Empire Mac, Rome, Idared) Idared)
0.25	0.3	1	2	2
0.5	1.3	5	6	8
0.75	2.9	11	14	17
1	5.1	20	25	30
1.25	7.9	32	40	48
1.5	11.4	46	57	68
1.75	15.5	62	78	93
2	20.3	81	101	122
2.25	25.7	103	128	154
2.5	31.7	127	158	190
2.75	38.3	153	192	230
3	45.6	182	228	274
3.25	53.5	214	268	321
3.5	62.1	248	310	372
3.75	71.3	285	356	428
4	81.1	324	405	486
4.25	91.5	366	458	549
4.5	102.6	410	513	616
4.75	114.3	457	572	686
5	126.7	507	633	760

z Trunk cross-sectional area=3.1416 X radius^2 Trunk diameter in inches = 2.54 * diameter in cm. Cross sectional area {cm^2} = ((diameter {inches} times 2.54) divided by 2)^2 times 3.1416.

y For Honeycrisp the recommended crop load = 4 fruits/cm^2 TCA. For other biennial bearing varieties the recommended crop load = 5 fruits/cm^2 TCA. For annual varieties the recommended crop load = 6 fruits/cm^2 TCA.

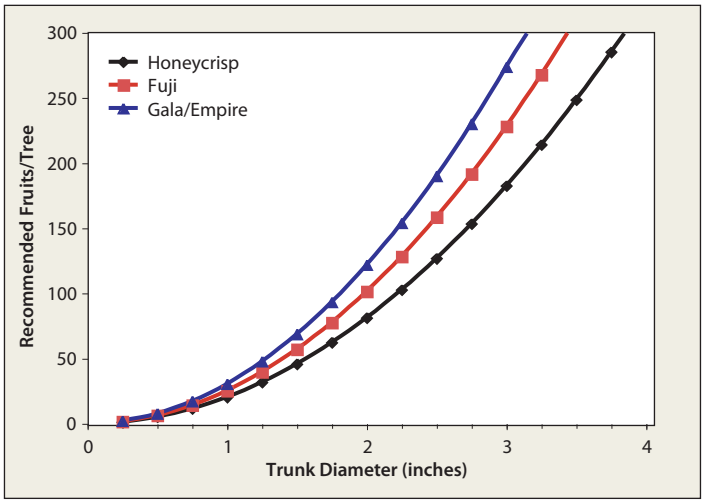

Figure 7. Crop load recommendations for young apple trees based on trunk diameter. For Honeycrisp the recommended crop load = 4 fruits/cm^2 TCA. For other biennial bearing varieties the recommended crop load = 5 fruits/cm^2 TCA. For annual varieties the recommended crop load = 6 fruits/cm^2 TCA.

use the data in Table 1 or Figure 7 to determine the recommended fruit number per tree to optimize early cropping and tree growth. If young trees are then hand thinned by mid-June to the precise crop load targets excellent crops can be achieved without sacrificing tree growth or inducing biennial bearing. An example of a Gala/M.9 tree in its second year planted in the Tall Spindle system (3'x11'=1320 trees/acre) is shown in Figure 8. This tree is from our Wayne County orchard systems trial at Vanderwalles orchard and was highly feathered at planting with minimal pruning. The proper level of crop load was imposed by hand thinning in early June of the second year to the target level of 6 fruits/cm^2 TCA, which resulted in 400 bushels per acre of good size Gala's in the second year.

Conclusions

The yield potential over the first five years in NY State is much higher than previously envisioned by most growers. As growers plant more high-density Tall Spindle orchards it is important that they avoid the common mistake of excessive crop loads in years two to four which leads to too little tree growth. Growers should try to obtain 18-24 inches of leader shoot growth in the first year, and 30-36 inches of leader shoot growth in the second and third years and 18" of leader shoot growth in the fourth year. A number of management factors including planting high quality trees, managing limb angle by tying feathers down, and applying fertigation soon after planting are important to achieve this level of growth. However, proper management of crop load is essential if the right balance of growth and fruit production is to be achieved. Especially with the Tall Spindle system, significant production can and should be obtained in the second-fourth years, which will limit vegetative growth in future years resulting in a "calm" tree. If crop loads are strictly limited to 4, 5 or 6 fruits/cm^2 TCA, depending on variety, by the middle of June, biennial bearing can also be avoided.

Terence Robinson is a research and extension professor at Cornell's Geneva Experiment Station who leads Cornell's program in high-density orchard systems.