THE INFLUENCE OF ORCHARD SYSTEM AND PRUNING SEVERITY ON YIELD, LIGHT INTERCEPTION, CONVERSION EFFICIENCY, PARTITIONING INDEX AND LEAF AREA INDEX

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Abstract

An orchard systems trial comparing slender spindle/M.9, Y-trellis/M.26, central leader/M.9/MM.111 and central leader/M.7 'Empire' apple trees was previously reported to have large differences in yield over the first 10 years. As the orchard matured, the Y/M.26 system continued to yield more than any other system by an average of 38% from year 11 to 14. Yields for the SS/M.9 system were second while the CL/9/111 and CL/M.7 systems had the lowest yield. Light interception was stable for each system since the 9th year. The Y/M.26 system intercepted an average of 69% PAR while the other three systems intercepted from 45-50% PAR. A large portion of the differences in yield between systems could be explained by light interception. Leaf area index was also well correlated with light interception and yield. The efficiency of converting light energy into fruit was greatest for the Y/M.26 system. The CL/M.7 system had the lowest efficiency at year 10 but by year 14 had a similar conversion efficiency as the SS/M.9 and CL/9/111 systems which were intermediate. Partitioning index (yield/unit increase in trunk cross-sectional area) generally matched rootstock efficiency. The systems using M.9 (SS/M.9 and CL/9/111) had the highest partitioning index while the CL/M.7's had the lowest partitioning index. Conversion efficiencies were generally correlated to partitioning index except with the Y/M.26 system which had the highest conversion efficiency but only an intermediate partitioning index. This was likely the result of a highly efficient training system but only a moderately efficient rootstock. The efficiency of the Y/M.26 system was reduced when pruning severity was increased by removing from 0 to 4 large limbs. As pruning severity increased yield was reduced and shoot growth was increased. Most of the variation in yield between systems (84%) was accounted for by differences in light interception while only 13% of the yield variation was attributable to differences in conversion efficiency.

1. Introduction

The most important measure of the performance of an orchard system is yield. Yield is determined by both orchard configuration factors (spacing, tree height:clear alley width ratio, tree shape, and rectangularity of planting) and tree physiological factors (scion, rootstock, tree form, canopy density and pruning practices). Orchard configuration factors such as tree spacing and tree height:clear alley width ratio primarily affect total light interception and can best be optimized by measuring or modeling orchard light interception (Jackson, 1981; Palmer, 1981). However, to separate the effects of orchard configuration factors from the tree physiological factors, requires an estimate of the fruit producing efficiency of the tree. The most common of these efficiency measurements is the ratio of yield of fruit per unit of trunk cross-sectional area (TCA). However, a more fundamental estimate of tree efficiency is the efficiency of converting light energy into fruit (yield of fruit per unit of light energy intercepted) (Palmer, 1988). This index provides a method to compare different growing systems independent of orchard configuration factors which allows extension of the results of a field trial beyond the particular set of spacings used in the study.

Our objectives in this study were to apply these principles to a long-term orchard systems trial in New York to explain the differences in yield performance between systems and to evaluate the relative importance of orchard configuration factors and tree physiological factors in explaining yield variation among the systems.

2. Materials and Methods

A replicated field trial of 'Empire' apple trees trained to four orchard management systems was planted in 1978 in Geneva, NY. The 4 systems were: 1) slender spindle on M.9 rootstock (SS/M.9) at 1957 trees/ha; 2) Y-trellis on M.26 rootstock (Y/M.26) at 1283 trees/ha; 3) central leader on an M.9 interstem and MM.111 understock (CL/9/111) at 961 trees/ha; and 4) central leader on M.7a rootstock (CL/M.7) at 450 trees/ha. A more complete description of this trial is given by Robinson et al. (1991).

In years 7-14, yield, TCA, canopy height, canopy width and light interception were measured. Light interception over the entire area allotted per tree was measured at full canopy in September by hemispherical photography (Robinson and Lakso, 1991). Total light energy intercepted over the growing season was estimated from the single measurement in September of each year. From measurements of cumulative yield and cumulative light energy intercepted, the ratio of fruit fresh weight per unit of light energy intercepted was calculated and termed conversion efficiency. An index of partitioning of dry matter between fruit and vegetative tree growth was calculated as the ratio of fruit yield per unit of increase in TCA. In year 14, leaf area index was measured by separately counting spurs, short shoots and long shoots and measuring leaf area on representative shoots of each type. In years 12-14, pruning treatments of differing severity were imposed on the Y-trellis/M.26 trees. Trees were pruned by removing from 0-4 branches. The severity of the pruning was quantified as the ratio of cumulative fresh weight of prunings per unit of final TCA.

3. Results and Discussion

Cumulative yield over 14 years was higher for all of the high-density systems than for the CL/M.7 system (Table 1). During the first 5 years the S.S/M.9 system had the highest yield. Since year 6 the Y-trellis/M.26 system had the highest yield followed in order by the S.S./M.9, CL/9/111 and CL/M.7 systems. There was a consistent positive linear relationship between annual yield and tree density for the 3 pyramid shaped systems that persisted through year 11. By year 12 the CL/M.7 system had equaled the yield of the CL/9/111 system and by year 14 all three pyramid shaped systems had similar yields. Cumulative yield after 14 years was highly correlated to tree density for the 3 pyramid shaped systems. This indicates that an important way to increase cumulative yield, not only in the early years of the life of an orchard but also over most of its productive life, is to increase tree planting density. The Y-trellis/M.26 was an anomaly to this relationship since it had a greater yield than was predicted from its tree density.

The differences in yield between the four orchard systems could be due to any one of three factors: 1) pruning and training strategy, 2) rootstock, or 3) spacing. Since each system has a unique combination of the 3 factors it is not possible to determine with traditional statistical analysis the independent effects of each factor. This illustrates an inherent limitation of orchard systems trials like this one. However, in an attempt to explain the yield variation in this experiment, we evaluated our results in terms of both orchard configuration factors and tree physiological factors. To determine the effects of orchard configuration factors (spacing and tree height:alley ratio) we measured light interception for each system and to determine the tree physiological efficiency of each system we measured light conversion efficiency.

Average light interception from 1984-1991 was highest for the Y-trellis and lowest for the two CL systems (Table 2). Light interception was well correlated with yield, leaf area index and TCA per hectare(Tables 1 and 2). Canopy volume per hectare was not correlated to light interception. Light interception since year 7 was relatively stable for all systems except the CL/M.7 system which continued to increase in light interception from 35% at year 7 to about 50% by year 14. The greater light interception of the Y-trellis was the result of the canopy architecture which allowed the tree canopy to grow over the tractor alleys. This allowed less light to fall on the alleys between rows. The other three systems which are all vertically stacked, pyramid-shaped trees, intercepted a small percentage of the light falling on the alleys. In this study the Y-trellis intercepted about 70% of available PAR at maturity while the slender spindle system intercepted only 50% of PAR in spite of 30% greater tree density. This illustrates the problem of short stature trees planted in single rows where mature light interception is relatively low due to a low tree height:clear alley ratio.

The highest conversion efficiency in our study was with the Y-trellis/M.26 system followed in order by the S.S./M.9, CL/9/111 and C.L./M.7 systems (Table 2). The efficiency of converting light energy into fruit is a measure of the efficiency of the tree system to both produce carbohydrates from intercepted light (assimilation efficiency) and to partition the carbon to the fruit (partitioning efficiency). When measured over several years, conversion efficiency index incorporates the effects of light on shoot development, return bloom, fruit set, fruit size and photosynthetic efficiency. This index allows comparisons of the physiological efficiency of the systems independent of orchard configuration factors. On this basis, it can be predicted that the less efficient systems would still have lower yield than the more efficient systems even if they were configured to intercept the same amount of light.

An estimate of how well the tree partitions its resources into fruit.(partitioning efficiency) can be calculated from the ratio of annual fruit produced to annual amount of vegetative growth produced. It is difficult to measure directly the annual amount of vegetative growth; however, the annual increase in trunk cross sectional area (TCA) is a measure of this growth. Thus, the ratio of yield to the increase in TCA is an estimate of partitioning between fruit and vegetative growth. In our study the S.S./M.9 system had the highest partitioning index followed in order by the Y-trellis/M.26, CL/9/111 and CL/M7 systems (Table 2). The ranking of partitioning indices in our study was the same as the commonly reported rankings of rootstock efficiencies with M.9 being more efficient than M.26 which in turn is more efficient than M.7 (NC-140, 1991).

Conversion efficiency and partitioning index were generally well correlated indicating that differences in conversion efficiency were primarily due to differences in partitioning. An exception to this correlation was the Y-trellis/M.26 system which had the highest conversion efficiency but an intermediate partitioning index. An explanation for this anomaly is that the Y-trellis is a highly efficient tree form but M.26 is only a moderately efficient rootstock. Thus, the high yield of the Y-trellis /M.26 system was the result of: 1) high light interception, 2) a highly efficient tree form and 3) a moderately efficient rootstock. The efficiency of the Y tree form is likely due to the good light exposure of the spur leaves with minimal shoot growth (Sansavini and Corelli, 1992). The relatively high yield of the SS/M.9 system was the result of moderately high light interception, moderately high conversion efficiency and a high partitioning of carbon into fruit due to a highly efficient rootstock. With the CL/M.7 the poor yield was the result of both low light interception and poor conversion efficiency through the first 10 years due to an inefficient rootstock.

Although rootstock is known to influence partitioning and hence conversion efficiency, pruning severity can also modify the efficiency of a system. The influence of pruning severity on system efficiency was studied by differentially pruning the Y-trellis/M.26 system from years 12-14. As the severity of pruning was increased there was a linear reduction in yield and a linear increase in shoot growth. Increasing pruning severity by removing from 0 of 4 scaffold branches reduced yield by 16% and increased vegetative shoot growth by 54%. Conversion efficiency and partitioning index were both reduced in a linear manner as the severity of pruning increased (Figure 1). This illustrates that the efficiency of a system can be manipulated by pruning severity and when comparing orchard systems pruning differences should be minimized

4. Conclusions

The differences in light interception among the systems accounted for 84% of the yield variation. Conversion efficiency differences accounted for a relatively small portion (13 %) of the yield variation among systems. Only 3% of the variation in yield among orchard systems could not be explained by these two variables. The high level of variation accounted for by light interception indicates that much of the difference in performance among the systems was due to orchard configuration factors alone. In the New York state there is now a strong trend to smaller trees to allow all orchard management operations to be done from the ground. In many cases, the decrease in tree size has not been accompanied by an adequate reduction in tractor alley width. As a consequence, many dwarf orchards in New York have relatively low light interception and relatively low yields. This has resulted in height to clear alley width ratios of 1 or less. Cain (1972) indicated that for optimum light interception the ratio should be 2. [An alternative formula for calculating tree height for optimum light interception is: (row spacing+2)+1m.]. Using this last formula, those who desire a 2m. tall tree should expect to reduce between-row spacing to 2m. Failures of high density orchards to produce expected yields can usually be traced to inadequate light interception.

It is clear that in our experiment the differences in yield between systems were largely the result of the differences in light interception and orchard configuration. Nevertheless differences in conversion efficiency were significant and indicate that orchard systems differ in their efficiency of light utilization. To optimize orchard performance requires both high conversion efficiency and high light interception.

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Table 1. Trunk cross-sectional area, canopy volume, leaf area index and yield of 'Empire' apple trees grown in four orchard management systems for 14 years.

System	Tree Density (trees/ha)	Final TCA (m^2/ ha)	Final Canopy volume (m^3/ ha)	Final Leaf area index	Cum. yield (Mt/ha)
Slender Sp./M.9	1957	6.20 b[z]	4.53 b	2.65 b	397 b
Y-trellis/M.26	1283	10.03 a	5.96 b	3.65 a	541 a
C.L./M.9/M.111	961	5.90 bc	5.69 b	2.28 bc	289 c
C.L./M.7	450	5.66 c	7.86 a	1.82 c	220 d

[z] Means followed by the same letter are not significantly different (P=0.05 n=4).

Table 2. Light interception, yield, conversion efficiency and partitioning index of 'Empire' apple trees grown in four orchard management systems.

System[z]	Average light interception '84-'91 (%)	Cum. yield 84-'91 (Mt/ha)	Conversion efficiency '84-'91 (g fruit/MJ PAR)	Partitioning index '84-'91 (kg fruit/cm^2 increase in TCA)
Slender Spindle/M.9	50 b[y]	324 b	6.1 a	11.1 a
Y-trellis/M.26	69 a	477 a	6.5 a	8.5 b
C.L/M.9/MM.111	45 c	253 c	5.3 b	7.8 b
C.L./M.7	47 bc	198 d	4.0 c	5.4 c

[z] The orchard was planted in 1978.

[y] Means followed by the same letter are not significantly different (P=0.05 n=4).

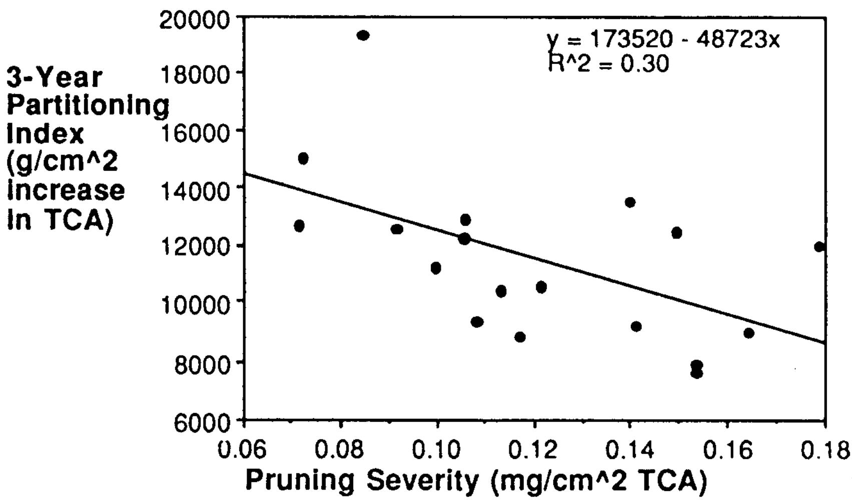

Figure 1. Effect of pruning severity on partitioning index of 'Empire/M.26' apple trees grown under the Y-trellis management systems.