High Density Pear Production: An Opportunity for NY Growers

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Pear production in the North America is characterized by low density orchards (150-200 trees/acre) planted on seedling rootstocks which have low early production and low mature yields. Most fruit growers consider pears as a long-term investment and a low profitability crop. In contrast pear production in Europe is characterized by very high planting densities, higher yields and greater profitability. European growers use quince as a rootstock for pear trees. There are more than 10 quince varieties used as rootstocks in Europe with some more dwarfing than others. In North America, quince rootstocks have not been used due to concern over their lack of cold hardiness and susceptibility to pear decline and fire blight. Recently several more hardy quinces have been identified which may allow their use in the Northeast in the future. Nevertheless, without access to fully dwarfing quince or pear rootstocks, few have been willing to try high density pear orchards for fear that they will be unmanageable. This if further complicated by the lack of growth regulating chemicals or established cultural practices to manage tree growth.

> **"Similar to apples, pears can be planted at high tree densities to improve early yields and profitability during the first 5 or 10 years. Our high density pear experiment at Geneva has shown very high yields of good quality fruit are possible when high planting densities are used. Although we don't have the perfect dwarfing rootstocks for pears, by using the concepts of limb bending and limb renewal pruning developed in apples, we can successfully manage very high planting densities using semi-dwarfing pear rootstocks and thereby achieve much higher yields than common in NY State."**

In the last 10 years several semi-dwarfing pear rootstocks with improved precocity have become available and techniques for managing tree growth have been developed in apple which has given us the opportunity to evaluate high density pear orchards that could be managed similarly to high density apple orchards. We theorized that if high early production could be achieved, pears would be an attractive alternative fruit crop for fruit growers. Although fire blight and pear psylla continue to be critical challenges in pear production, if high density plantings produced high yields similar to apple, fruit growers could profitably plant new pear orchards to diversify their operations. The purpose of this study was to evaluate several new rootstock at a broad range of densities to determine if high early and sustained yields could be achieved.

Materials And Methods

In 2003, a 2 ha replicated field trial was planted at Geneva, NY where we compared 4 orchard training systems, Central Leader (242 trees/acre), Vertical Axis (519 trees/acre), Tall Spindle (908 trees/acre) and Super Spindle (2,180 trees/acre) on 6 rootstocks (seedling, OHF97, OHF87, Pyrodwarf, Pyro2-33 and Quince A) with 3 varieties ('Bartlett', 'Bosc' and 'Taylor's Gold Comice') was planted at Geneva, New York, USA. Tree densities and spacings are given in Table 1. The plot was set up as a replicated experiment with 4 replications. Within each replication, plots consisted of 4 rows (130 ft. long) with each variety planted in one row. Along the row each 25 ft section had a separate rootstock. The trees were unirrigated and received 60 lb N/acre and 120 lb K_2O/acre each year. Foliar boron and nitrogen were applied at white bud and petal fall, respectively each year.

The central leader system was developed by heading the leader at 36 inches at planting and removing any feather larger than 2/3 diameter of leader. During the second through the fourth years, the leader was headed by 1/3 each year and a strong vertical shoot arising near the heading cut was trained as the leader. The central leader was supported by a steel tube tree stake. At the end of the second year, a lower tier of 4 scaffold branches was selected and tied to 30° above horizontal . Competing shoots were removed annually and each scaffold branch was pruned to a single axis.

The vertical axis system was developed by heading the leader at 48 inches at planting and removing any feather larger than 2/3 diameter of leader. Strong shoots which competed with the leader were suppressed each spring by pinching 2-3 times. During the second through the fourth years, the leader was not headed. The central leader was supported by a 3m steel tube tree stake and a single wire trellis 2.5m high. At the end of the second year, a lower tier of 4 scaffold branches was selected and tied to 15° below horizontal. Competing shoots were removed annually and each scaffold branch was pruned to a single axis.

Table 1. Orchard training systems and rootstocks evaluated at Geneva, NY, USA.

System	Spacing (ft)	Planting Density (tree/acre)	Rootstocks
Central Leader	10 x 18	242	Seedling, OHF97, OHF87, Pyrodwarf
Vertical Axis	6 x 14	519	OHF97, OHF87, Pyrodwarf, Pyro2-33, Quince A
Tall Spindle	4 x 12	908	OHF97, OHF87, Pyrodwarf, Pyro2-33, Quince A
Super Spindle	2 x 10	2,178	OHF97, OHF87, Pyrodwarf, Pyro2-33, Quince A

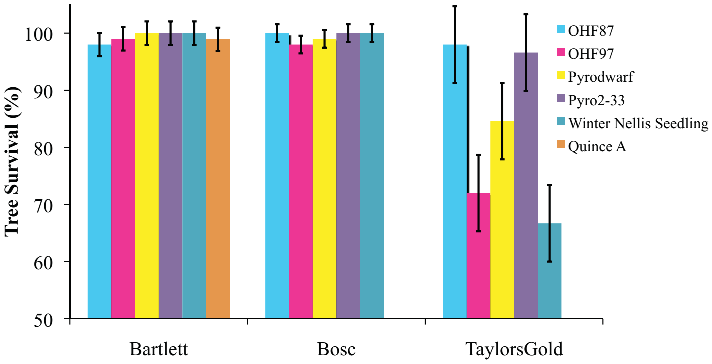

Figure 1. Effect of rootstock on pear tree survival after 8 years with 3 scion cultivars at Geneva, NY, USA.

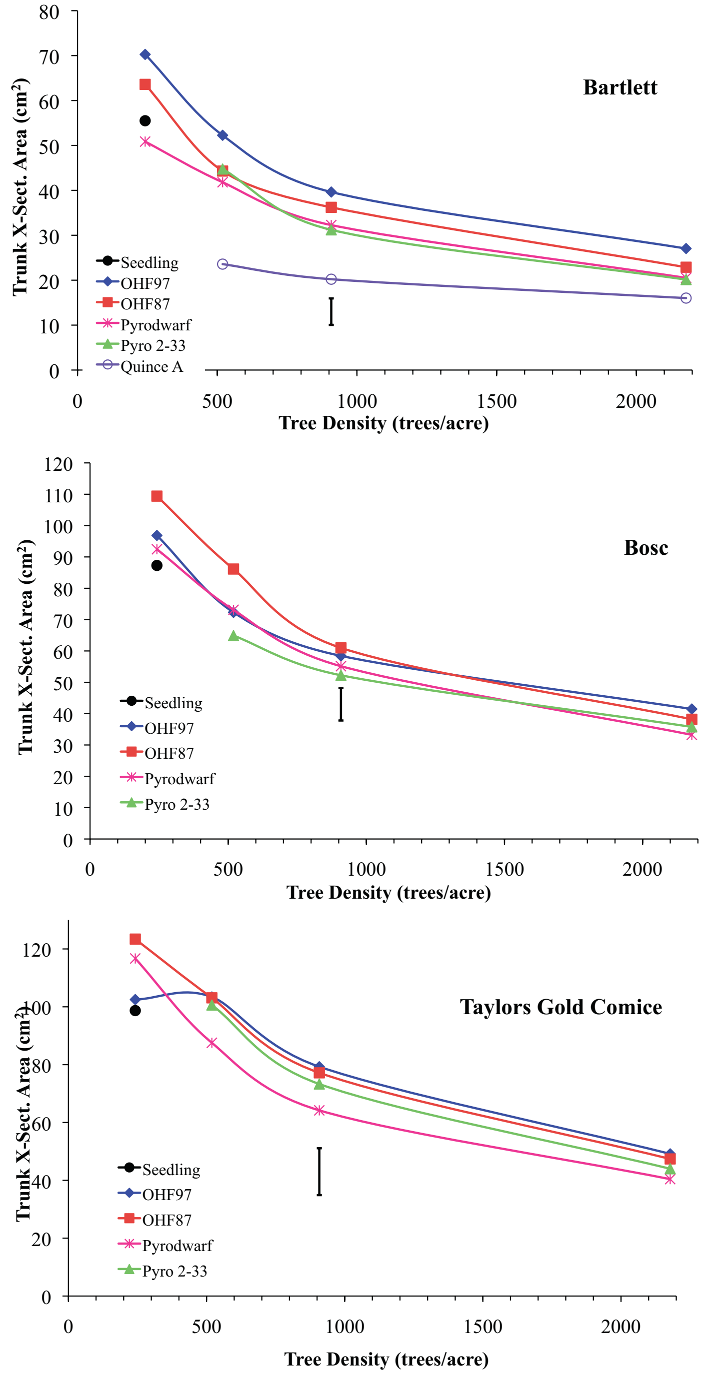

Figure. 2. Effect of rootstock and tree planting density (trees/acre) on tree size (cm2 of TCA) of 'Bartlett', 'Bosc' and 'Taylor's Gold Comice' pear trees after 8 years at Geneva, NY, USA.

The tall spindle system was developed in a manner similar to the vertical axis system except the leader was left unheaded at planting (60 inches tall) and the lower tier of scaffold branches were tied to 45° below horizontal in the second year.

The super spindle system was developed by leaving the leader un-headed at planting (60 inches tall). The central leader was supported by a 4 wire trellis with the top wire at 8 feet. Strong shoots which competed with the leader were suppressed each spring by pinching and any shoot larger than 1 inch diameter was removed each spring back to the trunk with an angled cut. Branches near each wire were bent below the horizontal and tied to the wire at the end of the second year. Horizontal branches that were longer than 24 inches were shortened to a lateral spur at the start of the 4th year.

Yield and fruit number were recorded each year. Canopy light interception of 'Bartlett' trees in each system on two rootstocks (Pyrodwarf and OHF97) was measured in year 6 at harvest using a Ceptometer light meter (Decagon Devices, USA). Tree survival and trunk circumference were recorded at the end of 8 years. Data were analyzed using SAS Proc Mixed (SAS Institute, Cary NC).

Results

Tree Survival and Growth Tree survival of all rootstocks with 'Bartlett' and 'Bosc' was good but with 'Taylor's Gold' there was significant tree damage and death following a winter freeze event in 2004/2005 (Fig. 1). Trees on Winter Nellis seedling rootstock and OHF97 suffered the worst death (35 and 30%, respectively) while trees on Pyrodwarf had 18% tree death and those on OHF87 and Pyro2-33 had little damage or tree death.

After eight years, there were large differences in tree size (measured as trunk cross-sectional area) that were related to tree planting density (Fig. 2). Tree density had a much stronger effect on tree size than rootstock genotype. There was a strong reduction in tree size as tree density was increased. The high density super spindle trees had a trunk cross-sectional area that was ~60% the size of the low density central leader trees. Among rootstocks, the largest trees were on OHF97, OHF87 and seedling while trees on Pyrodwarf and Pyro2-33 were intermediate and trees on Quince A were the smallest. Trees on Pyrodwarf had many rootsuckers (data not presented).

Tree light interception in the 6th year was positively related to tree planting density with only small differences related to rootstock (Fig. 3). Canopy light interception level is an indication of total canopy size per acre and is a good indication of yield potential. Optimum light interception level with apple and pear is about 70-75% of total light. In our pear planting the lowest planting density, interception was 50% for trees on Pyrodwarf and 58% for trees on OHF97. At the highest density light interception was 75% for trees on Pyrodwarf and 79% for trees on OHF97.

Yield. None of the trees on any rootstock, system or variety were precocious since none produced any yield in the second year (2004). The 'Bartlett' and 'Bosc' trees had a small crop in the third year and a large crop in the fourth year achieving 1,000 bu/acre at the highest tree density while the 'Taylor's Gold Comice' trees had only a small crop in the fourth year achieving only 100

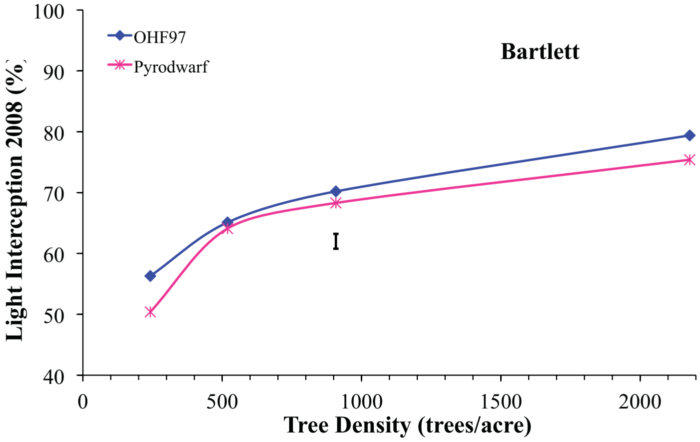

Figure 3. Effect of rootstock and tree planting density (trees/acre) on canopy light interception at harvest (Aug. 25) in the 6th year (2008) of 'Bartlett' pear trees at Geneva, NY, USA.

bu/acre. The greatest yield per tree in the early years was with the Vertical Axis and Tall Spindle trees but in later years (7-8) the trees in the Central Leader system grew larger and had the greatest yield. Over the first 8 years the Central Leader and the Vertical Axis systems had similar cumulative yields/tree while at greater tree densities cumulative yield/tree decreased (data not shown).

In contrast, cumulative yield/acre over 8 years was strongly and positively related to tree density (Fig. 4). The relationship was curvilinear and was steepest between the low density Central Leader (242 trees/acre) and the Vertical Axis (519 trees/acre). With 'Bartlett' the slope was positive across the entire density range we tested but with 'Bosc' the curve was almost flat above 519 trees/acre. With 'Bartlett' the high density super spindle system on OHF87 and 97 had a cumulative yield over 8 years of 5,780 bu/acre while with 'Bosc', the super spindle system on OHF87 had a cumulative yield of 3,900 bu/acre and with 'Taylor's Gold' a cumulative yield of only 1480 bu/acre. In contrast, the low density central leader system had cumulative yields of only 1,760, 1,950 and 315 bu/acre for 'Bartlett', 'Bosc' and 'Taylor's Gold', respectively. Among rootstocks, OHF87 and OHF97 had the highest yields/acre with 'Bartlett' and Quince A had the lowest yield/acre, regardless of the system (Fig 4). Pyro2-33 and Pyrodwarf were intermediate. However, with 'Bosc', Pyrodwarf and OHF87 had the highest yield/acre while OHF97 had significantly lower yields. Pyro2-33 was again intermediate. With 'Taylor's Gold', Pyro2-33 had significantly higher yields except with the super spindle system where Pyrodwarf had the highest yield.

Yield Efficiency. Cumulative yield efficiency was greatest for 'Bartlett' trees, intermediate for 'Bosc' and lowest for 'Taylor's Gold'. With 'Bartlett' and 'Bosc' the relationship between tree density and yield efficiency was quadratic with the highest efficiency with the Vertical Axis system (Fig. 5). With 'Bartlett' the central leader system had the lowest yield efficiency while with 'Bosc' the high density super spindle system had the lowest yield efficiency. There was little difference in yield efficiency among rootstocks. With 'Bartlett', OHF87 tended to be slightly more efficient and Pyrodwarf and OHF97 less efficient. With 'Bosc' and 'Taylor's Gold Comice', Pyro2-33 and Pyrodwarf tended to be the most efficient.

Fruit Size. Average fruit size over 6 cropping seasons

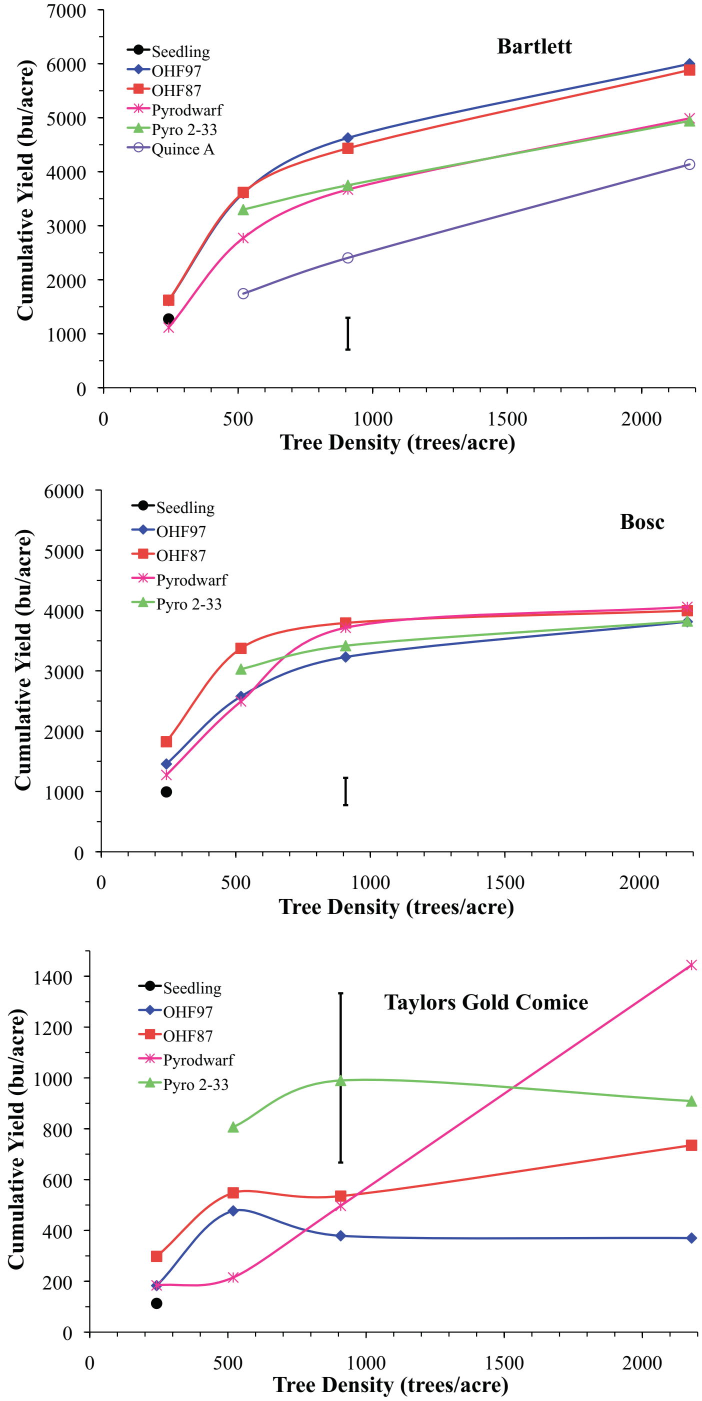

Figure. 4. Effect of rootstock and tree planting density (trees/acre) on cumulative yield (bu/acre) of 'Bartlett', 'Bosc' and 'Taylor's Gold Comice' pear trees after 8 years at Geneva, NY, USA.

(2005-2010) was negatively correlated to tree planting density (Fig. 6). The lowest planting density (Central Leader) had the largest fruit size while the highest planting density (Super Spindle) had the smallest fruit size. Some of the negative effect of high planting densities on fruit size was due to increased cropload with the higher density systems. However when fruit size was adjusted for cropload, the adjusted fruit size was still negatively related to planting density (data not shown). This means that there is an inherent negative effect of planting density on fruit size. Among rootstocks, Quince A had the largest fruit size at all planting densities with 'Bartlett' while Pyrodwarf and seedling rootstocks had the smallest fruit

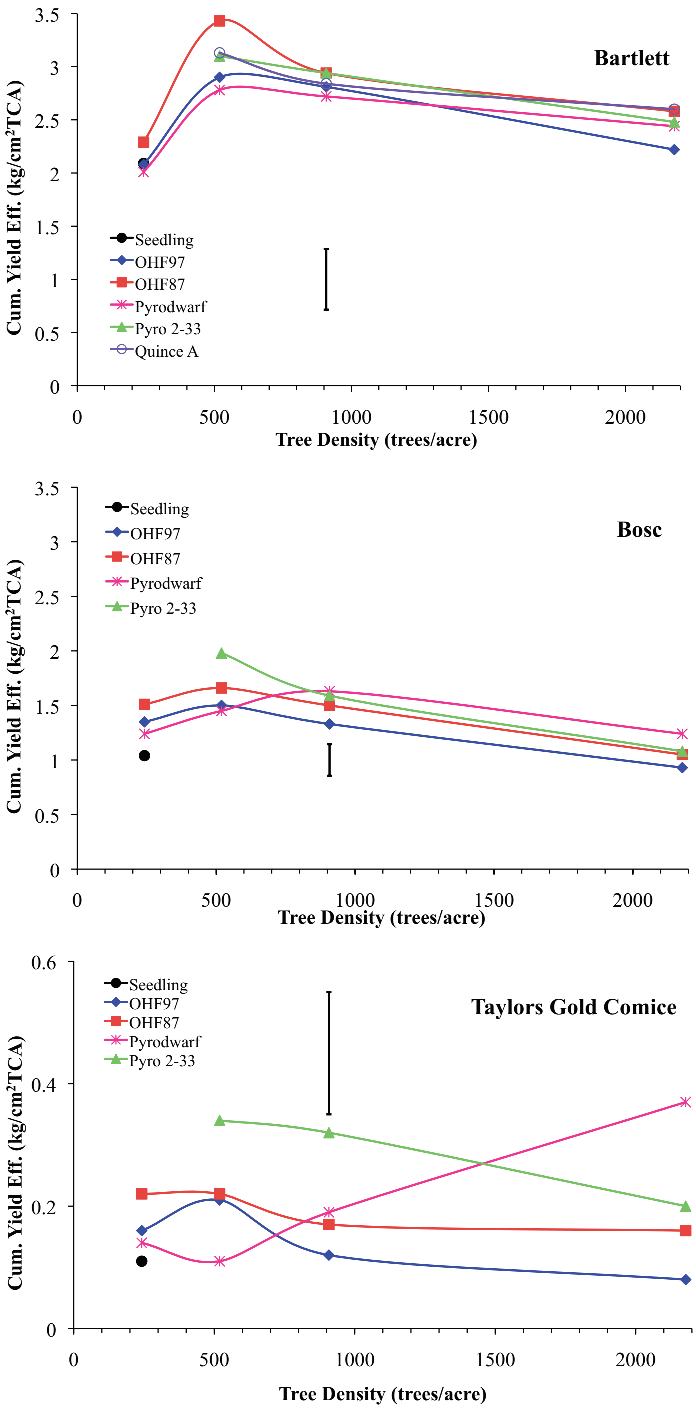

Figure. 5. Effect of rootstock and tree planting density (trees/acre) on cumulative yield efficiency (kg/cm2 TCA) of 'Bartlett', 'Bosc' and 'Taylor's Gold Comice' pear trees after 8 years at Geneva, NY, USA.

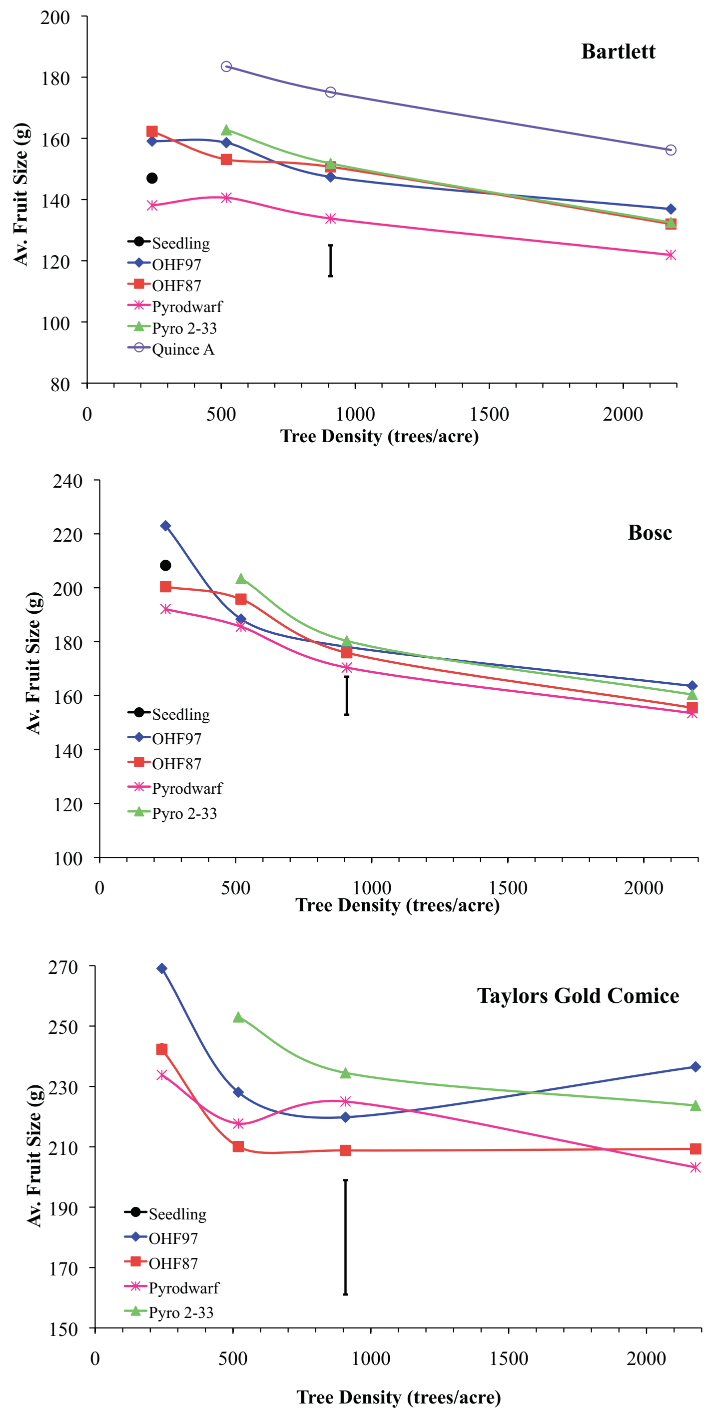

Figure. 6. Effect of rootstock and tree planting density (trees/acre) on fruit size (g) of 'Bartlett', 'Bosc' and 'Taylor's Gold Comice' pear trees after 8 years at Geneva, NY, USA.

size. OHF87, 97 and Pyro2-33 had intermediate fruit size. With 'Bosc', there were no large differences in fruit size among rootstocks except at the lowest planting density where OHF97 had the largest fruit size and Pyrodwarf had the smallest fruit size. With 'Taylor's Gold', OHF97 and Pyro2-33 had the largest fruit size while OHF87 had the smallest fruit size. When fruit size was adjusted for cropload, there were no significant differences among rootstocks in fruit size with 'Bosc' or 'Taylor's Gold'. However, with 'Bartlett', Quince A had significantly larger adjusted fruit size than seedling and Pyrodwarf.

Discussion

Our results show that very high tree planting densities with *Pyrus communis* rootstocks can be managed and are much more productive than low density systems. The strong positive relationship between tree density and cumulative yield/acre at the end of year 8 indicates that for New York conditions there is great benefit to using high tree planting densities in new pear orchards. The curvilinear shape of the relationship of yield and tree density indicates that the optimum planting density depends on the influence of economic factors and the law of diminishing returns (Robinson, et al., 2007, White and DeMarree, 1992).

Although we have not yet conducted and economic analysis, it is unlikely that the highest planting density (2100 trees/acre) will have the highest profitability since there was no yield in the second year and only a small crop in the third year. Such high planting densities depend on yield in the second and third year to pay for the high initial investment to plant the super spindle (Robinson, 2007). Our work with apple indicates that densities of 900-1100 trees/acre (Tall Spindle) give the maximum profitability and it is likely that there will be a similar result with pears.

A second important result of this research is that at wide plant spacings pear trees grow larger trees after 8 years than when the same rootstock is planted at closer plant spacings regardless of rootstock. This is similar to results on apple (Robinson, 2007), peach (Robinson et al., 2006) and cherry (Robinson et al., 2008). The strong effect of tree planting density on tree growth was likely due to 2 factors: 1) inter-tree root competition for water and nutrients at the high planting densities, and 2) more intensive canopy management and cropping at the higher tree densities. With the Tall Spindle and the Super Spindle systems, the lower tier lateral branches were tied down below horizontal in year 2 and large diameter limbs were removed annually each year to limit the size of the canopy to the allotted space. When removal of large limbs is repeated over several years, the size of the canopy remains smaller and presumably root system size is also limited. From a practical viewpoint this result indicates that there is a large range of tree densities that are manageable with semi-dwarfing rootstocks. This result means that semi-dwarfing rootstocks such as OHF87 and Pyro2-33 can be planted at relatively high planting densities and will be manageable for many year. Our experiment is only 8 years old and the long-term manageability of the very high density Super Spindle with semi-dwarfing rootstocks such as OHF 97 is questionable, however, the appearance of the trees after 8 years leads us to believe that there will be no problem managing the Tall Spindle system at 900-1100 trees/acre for the life of the planting. We also have the option of using growth inhibiting chemicals, root pruning and/or ringing to help control growth if needed.

Our results among rootstocks show that OHF87 and OHF97 rootstocks are more vigorous than Quince A (Westwood et al., 1976). Similarly our data confirm that Pyrodwarf and Pyro2-33 rootstocks appear to be intermediate in vigor between Quince A and OHF87 or 97 (Wertheim,1998). Pyro2-33 was classified by Wertheim (1998) as more vigorous than Pyrodwarf but in our study the two stocks were similar with 'Bartlett' and while with 'Bosc', Pyro2-33 was smaller than Pyrodwarf. With 'Taylor's Gold', Pyrodwarf was smaller than Pyro2-33. The two OHF rootstocks, and the two Pyro stocks had significantly greater yield per acre with 'Bartlett' than did Quince A regardless of the planting density. Even when yield of 'Bartlett' was normalized by trunk cross-sectional area (yield efficiency), Quince did not have better yield efficiency than the *Pyrus communis* stocks. These results are different than an early report of this experiment in which Quince A was more yield efficient than *Pyrus communis* stocks in the early years (Robinson, 2009). From a practical perspective, OHF87 appears to be an excellent choice for NY pear orchards since it was winter hardy in the 2004/2005 freeze, it is somewhat dwarfing, highly yield efficient and very productive. An interesting alternative is Pyro 2-33 which is a little more dwarfing than OHF87 and just as efficient. Pyrodwarf is not recommended since it had some tree losses in the winter of 2004/2005, is not as yield efficient as OHF87 and produces large numbers of root suckers which have large thorns.

The only serious concern with the performance of high density pears was the reduction in fruit size associated with high tree planting densities. Although some of the effect was related to higher crop loads and could be corrected with better thinning of the high density systems, it is troubling that even after adjusting for the differences in crop load there was still a significant reduction in fruit size associated with the higher tree densities. To fix this problem, will require improved cultural management techniques. It must be noted that this experiment was not irrigated and it is possible that irrigation may help overcome the negative effect of density on fruit size.

Conclusions

The results of this study show that increasing tree planting density results in much higher yields than previously imagined in NY pear orchards. The extremely high planting density of the Super Spindle achieved a yield of 1,000 bu/acre in the 4th year and has continued to be productive indicating good long term profitability of such high planting densities with semi-dwarfing *Pyrus communis* rootstocks. However the more moderate planting densities of the Tall Spindle which also had high yields but with lower initial investment cost may have may have greater economic profitability. The yields reported here are similar to apple orchard yields in the first 8 years and should cause NY fruit growers to take a serious look at high density pear plantings. Many of the successful strategies employed in our study were borrowed from the Tall Spindle apple system. They include: 1) Not heading the tree at planting. 2) Tying down limbs in the first year if using feathered trees or in the second year if using whips, and 3) Using limb renewal pruning strategies to manage high density systems. However, one of the most important components of the apple Tall Spindle, a fully dwarfing precocious rootstock like M.9, is not available for pear. Nevertheless we have shown that semi-dwarfing rootstocks such as OHF87 and Pyro2-33 can be successfully used at densities of ~1000 trees/acre in the Northeastern USA. Although fire blight and pear psylla still remain problems which complicate pear production, we believe that good management of these two problems can lead to very successful high density pear orchards in NY State. Furthermore, the adoption of new fire blight resistant pear varieties may provide new marketing alternatives and less problems with fire blight.

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Acknowledgements

We thank the NY Pear Growers Association led by Francis Delamano for the initial funding of this project.

Terence Robinson is a research and extension professor in the Dept. of Horticulture at the Geneva Experiment Station who leads Cornell's program in orchard management systems.