High-density Apple Orchard Performance on an Orchard Replant Site: An 11-year Summary

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ADDITIONAL INDEX WORDS. slender spindle training, irrigation, fumigation, ridomil, fruit size, yield, *Malus domestica*

SUMMARY. High-density apple (*Malus domestica*) orchard management techniques and productivity were evaluated on an old orchard replant site in North Carolina. Trees were planted at 5 × 10 ft (1.5 × 3.0 m), giving a tree density of 871 trees/acre (2152 trees/ha). Well-branched 'Smoothee Golden Delicious' trees on 'Mark' rootstock were planted in 1990. Orchard-management factors which increased cumulative yield were supplemental irrigation (+21%), slender spindle training (+19%), preplant tree-hole fumigation (+11%), and fumigation + postplant mefenoxam (Ridomil) collar drench (+17%). Collectively, these factors increased cumulative yield by 55%. Supplemental irrigation was the only treatment to significantly impact fruit quality, increasing average fruit size by 20% over the 11-year study.

Dwarf, high-density orchards are the production systems of the future (Barritt, 1991; Williams and Barritt, 1991; Marini et al., 2001a). Dwarfing rootstocks that are productive are the key to high-density orchard success (Barden and Marini, 1999; Barritt et al., 1995; Ferree, 1995; Marini et al., 2000), but performance differences across climates needs to be taken into account during orchard planning. Fernandez et al. (1997), documented the sensitivity of 'Mark' rootstocks to drought stress but across sites Mark has been one of the highest yielding rootstocks for 'Gala' (Marini et al., 2001a, 2001b). Irrigation is an important component in intensive orchard management (Drake and Evans, 1997).

Most high-density apple orchards will likely be planted in replant sites. Replant difficulties such as retarded growth, permanent tree stunting, delayed fruiting, reduced fruit production potential and/or reduced tree survival have been reported (Yadava and Doud, 1980; Traquair, 1984). These replant site problems have been attributed to many different factors (Slykhuis, 1990; Traquair, 1984) with equal diversity in treatments to overcome them. Preplant soil disinfection with biocides such as formalin (Covey et al., 1984) and methyl bromide (Koch et al., 1980) have resulted in improved tree growth. Monoammonium phosphate fertilizer has improved growth of apple seedlings in replant problem soils in northwestern U.S. (Neilsen et al., 1991; Slykhuis and Li, 1985). Preliminary tests in North Carolina indicated that preplant tree hole fumigation with methyl bromide alone or in combination with post plant, twice yearly soil drenches with mefenoxam, (Ridmil 91-97 formulation; Novartis, Greensboro, N.C.) greatly improved tree growth and fruiting in an old orchard replant site (Unrath et al., 1991).

Tree-training systems have become a focal point for optimizing early production and total performance of dwarf high-density orchards. Systems that have generated most interest include Central Leader (Heinicke, 1975); Vertical Axis (Granger and Philion, 1988; Lespinasse and Delort, 1986); Slender Spindle (Perry, 1990; Oberhofer, 1987; Wertheim, 1978) and many versions of the Spindle Systems (i.e., traditional, multirow, V-spindle and Y-spindle) (Robinson et al., 1991; Williams and Barritt, 1991). Training system and associated tree density can be strongly related to yield, but also depend on cultivar (Robinson et al., 1991).

The objective of this study was to evaluate which orchard management techniques contribute to enhance productivity of high-density orchards in old orchard sites.

Methods and materials

ORCHARD ESTABLISHMENT. In September 1989, immediately after harvest, a 20-year-old orchard was removed from a site at the Mountain Horticultural Crops Research Station at Fletcher, N.C. The site was cleared of stumps and visible roots, leveled and seeded with tall fescue (*Festuca elatior*) ground cover. Soon after, while soil temperatures were still warm, the exact tree hole location of a dwarf high-density orchard was laid out on the site.

TRAINING SYSTEMS. Well branched, nursery trees of 'Smoothee Golden Delicious' on 'Mark' rootstock were planted 5 × 10 ft, 871 trees/acre in a randomized complete block design. Treatments included two tree-training systems: a mini-central leader (MCL), similar to that described by Heinicke (1975) except with limb whorls closer together and slender spindle (SS) (Oberhofer, 1987; Wertheim, 1978). To encourage ample branching along the leader on SS-trained trees, the previous year's leader growth was tied to a horizontal position before dormant budbreak of the second leaf growth (1991). Leaders were tied horizontally in the other direction for another 3 weeks to encourage uniform budbreak on all sides of the leader. In subsequent years (mainly the third and forth growing seasons), a polyethylene plastic sleeve was used to enclose the previous seasons leader growth (6 weeks before budbreak). Clothespins were used to seal the sleeve at top and bottom to create a mini-greenhouse effect and encourage lateral budbreak. This procedure was repeated, until branched leader growth reached the top of the 8-ft (2.4-m) support posts.

PREPLANT SOIL TREATMENTS. Tree holes assigned to the fumigation treatment were augured to a depth of 30 inches (76.2 cm). A 1-lb (0.45-kg) can of methyl bromide, frozen to –20 °F (–28.9 °C) to depressurize it, was placed in the bottom of each hole, punctured, and the hole immediately refilled with the excavated soil in Fall 1989. In Spring 1990, all tree holes were augured and the planting established. Another preplant treatment incorporated 1 lb of monoammonium phosphate uniformly into the excavated soil as the trees were planted.

SOIL TREATMENTS. Four soil amendment (SA) treatments were used to address the old orchard site replant factor: Untreated control (Ck); preplant tree hole fumigation (F); Preplant fumiga-

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tion plus postplant soil drenches, twice yearly, using 950 mL (32.1 fl oz) of a 0.25% mefemoxam (Ridomil 2E) solution per tree as a collar drench (F+R); and monoammonium phosphate (MAP).

EXPERIMENTAL DESIGN. Overhead sprinkler irrigation was used on all plots to provide spring frost/freeze protection. A split plot design was used to evaluate supplemental over-tree irrigation, with half receiving only natural rainfall and the other receiving supplemental irrigation (SI) to achieve a minimum total application of 1 inch (2.54 cm) per week during the postfrost/freeze growing season. The two training systems and the four SA treatments were used as a 2 × 4 factorial design within each of the irrigation plots. Each plot consisted of eight trees and a 'Snowdrift' crabapple pollinizer separated each plot. Plots were replicated four times within each of the irrigation plots.

At harvest a 25-fruit random sample per plot was taken to evaluate quality. Total yield per plot was collected and used to calculate yield (all trees were defruited in the first two growing seasons). Yield data were analyzed using a split plot analysis with SI as the main plot factor and each of the eight factorial treatments as subplots (Proc ANOVA; SAS Inst. Inc., Cary, N.C.). Mean separations were by Fisher's least significant difference of SAS.

All plots were chemically thinned annually with NAA and followed with touch up hand thinning, as needed. In 1999 there was a severe negative interaction between the chemical thinner and a pesticide cover spray containing a paraffin spray oil. This interaction resulted in thinning that was typically appropriate in terms of number of fruit/tree, but resulted in drastically stunted fruit size and reducing total yield in the experiment (from 30+ bins of normal sized fruit down to five bins of golf-ball-sized fruit). To adjust for the impact of this interaction that we judged not to be attributable to the experimental research treatment effects, we estimated the yield in 1999 by multiplying the number of fruit per plot harvested in 1999 by the average fruit size per plot for 1996, 1997, 1998 and 2000.

Results and discussion

All three management factors (irrigation, tree training and soil amendment treatments) significantly influenced orchard productivity (Table 1). SI significantly increased cumulative yield every year except the third leaf. Following the 2000 harvest, cumulative yield from SI was increased 21%, 6979 bushels (bu)/acre (1 bu = 42.0 lb) for SI versus 5751 bu/acre for CK (328.1 $t \cdot ha^{-1}$ versus 270.3 $t \cdot ha^{-1}$). When yield was examined by individual year SI was significant in 1993-96, and 1998 (data not shown), but this early yield impacted cumulative yield throughout the length of the study. Training system had a significant effect on cumulative yield throughout the entire study (Table 1). At the end of the study (2000) the SS training had out produced the MCL training by 19%, 6916 bu/acre versus 5814 bu/acre (325.1 $t \cdot ha^{-1}$ versus 273.3 $t \cdot ha^{-1}$). Individual annual yield was significant for training treatment in 1992-94, and 1998-99, (data not shown).

The SA factors designed to ameliorate the replant disorder also had a significant impact on cumulative yield (Table 1). At the end of the study (2000), F enhanced yield by 11% (7022 bu/acre (330.0 $t \cdot ha^{-1}$)), F+R by 17% (7384 bu/acre (347.0 $t \cdot ha^{-1}$)) and MAP reduced yield by 25% (4734 bu/acre (222.5 $t \cdot ha^{-1}$)); over the Ck treatment, which had 6320 bu/acre (297.0 $t \cdot ha^{-1}$). The only significant two-way interaction was irrigation (SI) × training (T). The early years of the study (1992–95) were those of significant interaction (data not shown), but were sufficient to impact cumulative yield throughout the test. The significant SI × T interaction shows that only with SI was the SS training able to develop its full (greatest) production potential. The SI × soil amendment (SA) interaction was only significant for individual

Table 1. Cumulative yield of 'Smoothee Golden Delicious' in response to irrigation, training system and soil amendment treatments growing on a replant site through eleventh leaf.

Soil amendments	Yield (bushels/acre)[z]			
	Mini central leader		Slender spindle	
	Supplemental irrigation	No irrigation	Supplemental irrigation	No irrigation
Check	5847[y]	5804	8651	4977
Fumigation	6783	6270	8556	6480
Fumigation + mefenoxam	7236	6074	9008	7216
Monoammonium phosphate	4038	4463	5712	4721

[z]1 bushel/acre = 0.047 $t \cdot ha^{-1}$.

[y]Significance: irrigation and training were significant at 5%, preplant treatment and the interaction of irrigation × training were significant at 1% and other two-way and the three-way interactions were not significant.

Table 2. Fruit size of 'Smoothee Golden Delicious' in response to supplemental irrigation in a replant site.

Irrigation	Fruit size (g[z])									
	Year									
	1992	1993	1994	1995	1996	1997	1998	1999	2000	
	Growing season									
	3rd	4th	5th	6th	7th	8th	9th	10th	11th	Avg
Nonirrigated	156	149	161	140	161	121	122	140	167	146
Supplemental irrigation	178	201	197	155	161	123	205	164	194	175
Significance	**	**	**	*	NS	NS	**	**	**	**

[z]1 g = 0.04 oz.

NS,*,**Nonsignificant or significant means at $P = 0.05$ or 0.01.

year yields in 1993, 1996, and 1998 and for cumulative yield in 1993–94 (data not shown), and did not persist to the end of the study (Table 1). The T × SA interaction was only significant in 1992, which had no impact on cumulative yield at the end of the study (Table 1). The three way interaction of SI × T × SA was nonsignificant for all individual years yield, but was significant for cumulative yield in 1993, 1995 and 1996 (data not shown), however it was not significant at the end of the study (Table 1).

Collectively, the effect of SI, SS training and F+R soil amendment improved cumulative yield by 55% over the nonirrigated, mini-central leader, non preplant treated, considered to be the control (Table 1), 9008 versus 5804 bu/acre (423.4 versus 272.8 $t \cdot ha^{-1}$), at the end of the study.

The only fruit quality index that was significantly affected by treatment was fruit size associated with the SI main effect (Table 2). In every year except 1996 and 1997, fruit size was significantly increased with supplemental irrigation. Over the life of the study, average fruit size was increased by 20%, [175 versus 146 g/fruit (6.2 versus 5.1 oz/fruit)]. The irrigation main effect increase in cumulative yield is 21%. Thus irrigation's impact on yield was almost entirely from fruit size increase. By contrast, preplant SA treatments increased tree size and slender spindle training produced more branches, both of which increased only the number of fruit produced since no fruit size increases were associated with the SA and T data (data not shown).

When the cumulative productivity of this dwarf, high density orchard (1990–2000) was compared with a previous planting consisting of semi-dwarf, central leader trees of the same cultivar on the same orchard site (1970–89), the early production in this high density, slender spindle orchard over the central leader orchard was clearly demonstrated. In the third and fourth leaf, cumulative production was over 11 times greater (1,462 versus 97 bu/acre (68.7 versus 4.6 $t \cdot ha^{-1}$)) in the higher-density orchard. Through the seventh leaf cumulative yield was 3.7 times larger (data not shown). Through the eleventh leaf, the dwarf high density, irrigated, slender spindle orchard has produced a cumulative yield of over 8651 bu/acre (406.8 $t \cdot ha^{-1}$). In contrast, the semi-dwarf, central leader orchard required production through the seventeenth leaf to achieve a similar cumulative yield.

These data confirm the conclusion that irrigation is an essential management tool for optimizing intensive orchard management (Drake and Evans, 1997) and strongly agrees with the findings of Fernandez et al. (1997), that documented the sensitivity of 'Mark' rootstock to drought stress. Our soil amendment treatment results support the soil disinfection benefits of methyl bromide reported by Koch et al. (1980) and our preliminary findings with soil fumigation (Unrath et al. 1991) but disagree with the beneficial findings of MAP reported by Neilson et al. (1991) and Skykhuis and Li (1985). While they reported improved apple seedling growth with MAP in replant problem soils, our results with MAP showed a dramatic decrease in fruit production in our replant orchard site. These data collected in a high-density orchard setting support the suggestion of Robinson et al. (1991), that training system is strongly related to yield. Our results suggest that this association is related to both increased early production potential and to improved longevity of production.

These data demonstrate that dwarf, high-density apple orchards can be very productive in the climatic conditions of the southeastern U.S. Growers who will commit to providing the necessary orchard management (including preplant soil amendments, such as fumigation, to overcome soil replant problems, intensive tree training for optimal branch development and commit resources and close attention to the irrigation needs for dwarfing rootstocks can expect high, early and sustained production potential from these orchards. Such plantings should generate sufficient return to justify the high cost of orchard establishment (soil amendments, high tree numbers and tree support system costs).

Optimally productive, profitable dwarf high-density orchards will have to integrate appropriate rootstock size successfully for a specific training system into an acceptable orchard spacing, which will likely vary with cultivar vigor, as well as soil fertility and replant site considerations.

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Amendment of Muskmelon and Watermelon Transplant Media with Plant Growth-Promoting Rhizobacteria: Effects on Seedling Quality, Disease, and Nematode Resistance

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SUMMARY. **Greenhouse and field trials were performed on muskmelon (*Cucumis melo*) and watermelon (*Citrullus lanatus*) to evaluate the effects of six formulations of plant growth-promoting rhizobacteria (PGPR) that have previously been shown to increase seedling growth and induce disease resistance on other transplanted vegetables. Formulations of Gram-positive bacterial strains were added to a soilless, peat-based transplant medium before seeding. Several PGPR treatments significantly increased shoot weight, shoot length, and stem diameter of muskmelon and watermelon seedlings and transplants. Root weight of muskmelon seedlings was also increased by PGPR treatment. On watermelon, four PGPR treatments reduced angular leaf spot lesions caused by *Pseudomonas syringae* pv. *lachrymans*, and gummy stem blight, caused by *Didymella bryoniae*, compared to the nontreated and formulation carrier controls. One PGPR treatment reduced angular leaf spot lesions on muskmelon compared to the nontreated and carrier controls. On muskmelon in the field, one PGPR treatment reduced root-knot nematode (*Meloidogyne incognita*) disease severity compared to all control treatments.**

In the state of Florida, over 13,659 ha (33,750 acres) of watermelons and 2,833 ha (7,000 acres) of muskmelons were grown in 1997–98 season (Florida Department of Agriculture, 1998). Florida growers currently faced with environmental concerns, regulatory constraints, and competition from Mexico, will soon have to face the loss of methyl bromide, the soil fumigant used to control many soilborne pathogens, nematodes, insects, and weeds. The Food Quality Protection Act (FQPA) also has accelerated the removal of other chemicals used in vegetable production from the market as industry declines to reregister older pesticides. This has resulted in research efforts focused on the development of agricultural systems based on reduced chemical inputs and an increased incorporation of biological control tactics.

Plant growth-promoting rhizobacteria have been shown to enhance plant growth and protect roots from pathogens on many crops (Weller, 1988). One of these PGPR formulations, Kodiak (Gustafson LLC, Plano, Texas), is a biological seed/hopper box treatment for use in agronomic crops. Kodiak contains *Bacillus subtilis* (strain GB03) that has been shown to promote plant growth and increase yield in peanut (*Arachis hypogaea*) (Turner and Backman, 1991) and cotton (*Gossypium hirsutum*) (Brannen and Backman, 1993, 1994).

Soilless transplant growth mixes are an ideal medium for delivery of PGPR in transplanted crops. This ap-

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