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Yield and Production Efficiency of Four Apple Cultivars in Selected Orchard Management Systems

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Abstract. **Trees of 'Golden Delicious', 'Topred Delicious', 'Millersturdeespur Delicious', and 'Sundale Golden Delicious' apple (*Malus domestica* Borkh.) were grown in two or more of the following orchard management systems established in 1973: slender spindle (SS), 2151 trees/ha, 'Golden Delicious' and 'Sundale Golden Delicious'; trellis (TR), 1121 trees/ha, all cultivars; interstem hedgerow (IH), 795 trees/ha, all cultivars; and pyramid hedgerow (PH), 425 trees/ha, 'Golden Delicious' and 'Topred Delicious'. Yields of 'Golden Delicious' in the SS and TR were similar during the first 7 years and these systems generally produced higher yields than the less-intensive systems (IH and PH) during this period. Except for a drop in yield in the TR system in year 10, 'Golden Delicious' trees ≥8 years old in all systems produced >50 t·ha^{-1}. 'Topred' in the TR system outyielded IH and PH every year, while IH had higher yields than PH in three out of the eight cropping years. The spur-type cultivars Sundale and Millersturdeespur had lower yields per hectare than the standard-habit cultivars because they were spaced too widely. Yields of the systems with 'Sundale' generally followed plant density, with the SS being highest, IH lowest, and TR in between and often not significantly different from the other two systems. Orchard management systems had no consistent effects on fruit size. The cumulative yield per hectare of 'Golden Delicious' over 11 years grown as SS outproduced the IH and PH systems, with the TR yields intermediate. 'Sundale' managed as SS outproduced both the TR and IH systems. 'Topred' in the TR had higher cumulative yields per hectare than the PH system. An economic comparison of the 'Golden Delicious' systems indicated that PH provided the highest rate of return and the SS the lowest, with the IH and TR systems intermediate.**

Numerous studies have shown the advantages that increasing tree density has on early yields of apple orchards (Ferree, 1980; Granger et al., 1986; Jackson, 1980; Thompson and Rogers, 1981; Jackson et al., 1987; Wertheim et al., 1986). Relatively few studies are available that present yield data from these plantings over an extended period so that consistency of production can be evaluated. As tree density is increased, it becomes necessary to alter tree training, orchard management, and possible rootstock selection to accommodate the new orchard management system. Currently, many unconventional training systems are being evaluated experimentally around the world, and in limited grower trials in an attempt to improve long-term orchard efficiency and productivity (Blizzard et al., 1988; Dunn and Stolp, 1987; Van den Ende et al., 1987; Jackson et al., 1987; Wertheim et al., 1986). However, most published results are only for the early producing years.

The present study presents results over 11 years from a study established to evaluate production of four cultivars in two or more orchard management systems that differ more widely in tree size and shape than the European studies. Each system consists of a combination of rootstocks, spacing, training, and pruning designed to maximize orchard efficiency, and it is the management systems as a whole that must be considered when production and economic comparisons are made.

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Materials and Methods

Trees of 'Golden Delicious' were established in 1973 in four orchard management systems on a deep, fertile silt loam soil near Wooster, Ohio. The following cultivars were included in the experimental design, but were not compared on all systems: 'Topred Delicious', a standard-habit form in three systems; 'Millersturdeespur Delicious', a spur-habit form in two systems; and 'Sundale Golden Delicious', a spur-habit form in three systems. The most intensive system was the slender spindle (SS) on M.9 rootstocks planted 1.5 × 3.0 m (2151 trees/ha) with each tree supported by a post (1.8 m protruding) and trained using techniques described by Wertheim (1968). Trees on the trellis (TR) system were on M.9 rootstock planted 2.4 × 3.6 m (1121 trees/ha) and fastened to a four-wire trellis (top wire 1.8 m). Trellis trees were trained as oblique palmettes by annually tying branches to the wire maintaining 45° to 60° angle with the main trunk. In the early years, nearly all branches were retained and tied into the row. After the trellis was covered, limbs were thinned over several years, retaining six to eight permanent scaffold branches with a spacing of 50 to 80 cm between limbs. The interstem hedgerow (IH) consisted of trees with a 15-cm interstem of M.9 on MM.106 rootstock and planted 2.7 × 4.2 m (795 trees/ha), with the lower union of the interstem above ground level. The pyramid hedgerow (PH) trees were on MM.106 and were planted 4.3 × 5.5 m (425 trees/ha). The last two systems were free-standing and trained as central leaders using wooden clothespins the first season and wooden spreaders in subsequent years to establish strong permanent scaffolds with wide crotch angles to maintain the dominance of the central leader. Permanent scaffold limbs were developed in tiers with 60 to 90 cm between tiers and four to six limbs per tier.

Trees in all systems received minimal annual pruning, with only necessary training cuts in early years and thinning-out cuts when the trees had filled their allotted space. Rows had a north–

south orientation and trees received standard herbicide and pesticide treatments and uniform fertilization on a per-hectare basis. Chemical thinning was used as needed, with all trees of a cultivar receiving the same treatment. The systems were arranged as randomized complete blocks with four replications of 17-m rows.

In the third growing season, the trees of 'Golden Delicious' produced their first fruit; whereas 'Delicious' began production in the fourth season. In addition to the weight of fruit per tree from the 5th year onward, the fruit were graded on an FMC weight-sizer and the number of fruit in each of the following size classes was counted: ≥8.0 cm in diameter (box size 80–88); 8.0–7.3 cm (100–113); 7.3–5.7 cm (125–138). The fruit was graded according to commercial standards and culled fruit removed and counted. Trunk circumference was determined annually.

Results and Discussion

'Golden Delicious' trees in SS had filled their allotted space the fourth growing season, while those in TR had it filled in year 6, with the IH and PH trees having lower branches intermingling slightly in the row and having reached their desired height of 3.0 and 4.5 m, respectively, in year 7. Yields of 'Golden Delicious' in the two most-intensive systems (SS and TR) were not different during the first 7 years and these two systems had consistently higher yields than the less-intensive systems during this period (Fig. 1). In another study comparing the SS and TR systems, there was no difference in production of four cultivars over the first 4 years (Ferree, 1982), which illustrates the efficiency of the TR system with 48% fewer trees to promote early yields. From the 8th year onward, the TR and IH tended to decline in yield, while the PH and SS tended to increase, but the differences were not always significant. Except for the drop of yield in the TR system in year 10, trees 8 years or older in all systems produced >50 $t \cdot ha^{-1}$.

'Topred Delicious' trees filled their allotted space in TR in the 5th year, but in IH and PH did not fill until the 7th year. Frost at bloom eliminated the crop in year 5 and decreased it in year 7, while other seasons were frost-free during bloom. The TR system out-produced the others every year, while IH had higher yields than the PH in 3 out of the 8 cropping years (Fig. 2).

Generally the spur-type cultivars (Sundale Golden Delicious and Millersturdeespur) never filled their allotted space in any of the systems. Their overall lower yields per hectare (Figs. 3 and 4) compared to the standard-habit cultivars reflect the improper spacing that was used for these cultivars. In a review on light interception by orchards, Jackson (1980) emphasized the advantages of hedgerow orchards and the importance of adequate foliage to intercept light if orchard yields are to be optimized. When our study was initiated, it was decided for consistency of comparison to maintain uniform spacing for all cultivars within a system. To avoid the mistake of putting a cultivar at a disadvantage that cannot be overcome, future trials should either compare each cultivar at several spacings within each system or have the spacing adjusted for each cultivar so allotted space will be filled. It is estimated that if the trees had been spaced 30% to 40% closer, which has been shown (Ferree and Lich, 1978; Ferree et al., 1975; Autio and Southwick, 1986) to be the approximate reduction in tree size due to the spur-type strains used in this study, yields would have approximated those of the standard-habit cultivars.

The yields of systems with 'Sundale' generally followed planting density, with the SS being highest, IH lowest, and TR in between (Fig. 3). Although this trend appeared consistent, there was often not a statistical separation between the TR and the other two systems, with the SS having significantly higher

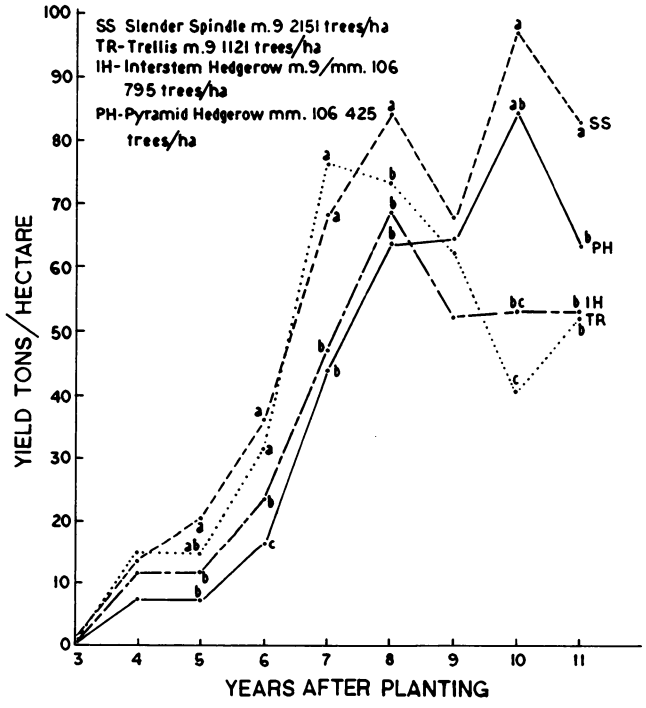

Fig. 1. Yield of 'Golden Delicious' in four orchard management systems through 11 years. Mean separation within years by Duncan's multiple range test, $P = 0.05$. Data for systems are means of the following number of observations: SS, 44; TR, 28; IH, 24; PH, 32.

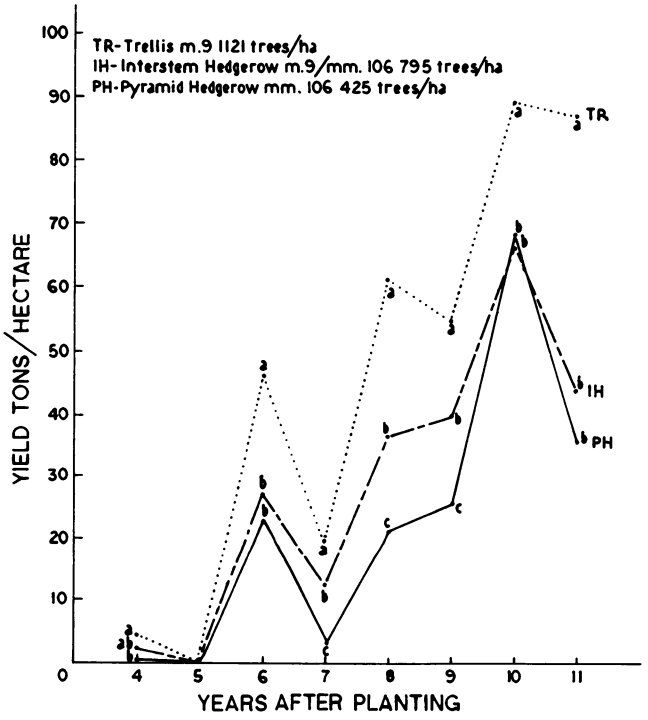

Fig. 2. Yield of 'Topred Delicious' in three orchard management systems through 11 years. Mean separation within years by Duncan's multiple range test, $P = 0.05$. Data for systems are means of the following number of observations: TR, 28; IH, 24; PH, 32.

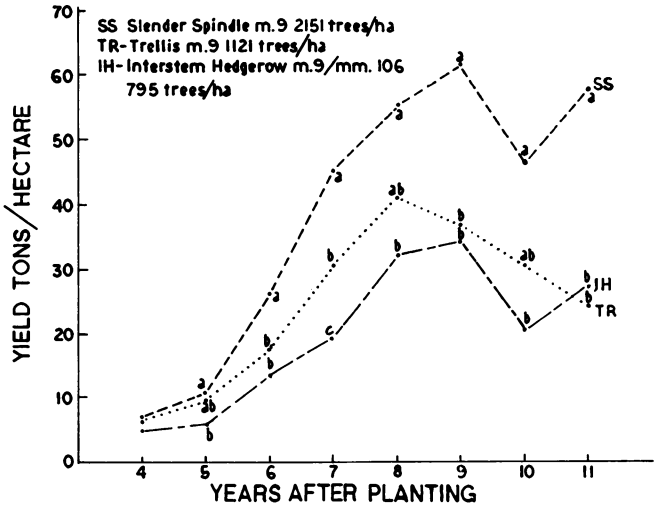

Fig. 3. Yield of 'Sundale Golden Delicious' in three orchard management systems through 11 years. Mean separation within years by Duncan's multiple range test, 5% level. Data for systems are means of the following number of observations: SS, 44; TR, 28; IH, 24.

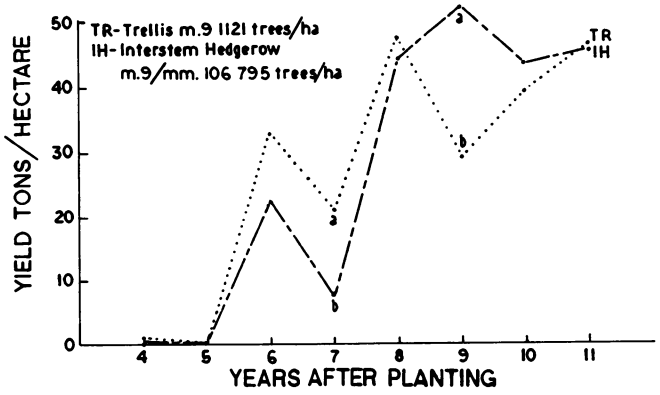

Fig. 4. Yield of 'Millersturdeespur Delicious' in two orchard management systems through 11 years. Mean separation within years by Duncan's multiple range test, $P = 0.05$. Data for systems are means of the following number of observations: TR, 28; IH, 24.

yields than the other systems in 3 of the 8 years. The yield of "Millersturdeespur Delicious' was not greatly different between the two orchard management systems studied (Fig. 4). It is of interest that the TR system out-produced the taller IH trees in year 7, when a frost at bloom reduced yields of 'Delicious'.

Although orchard management systems resulted in differences in fruit size distribution in a particular year, a trend for one system to produce larger fruit than another was not apparent and thus data from only the last 4 years, which were free of frost and had relative high yields, are presented (Fig. 5). In most years, 'Topred' and 'Millersturdeespur' had a greater proportion of their crop in the largest two size classes than either 'Golden Delicious' or 'Sundale'. Generally, 'Sundale' had a higher percentage of cull fruit than 'Golden Delicious'. This difference was largely due to the degree of russeting, a result that agrees with previous findings that spur-habit 'Golden Delicious' strains had more russet and greener fruit than standard strains (Ferree and Lich, 1978). The expected reduction in fruit size associated with higher crop loads was not clearly evident. For example, SS trees of 'Golden Delicious' in year 10 had a significantly larger yield than TR trees (Fig. 1), but little difference in the percentage of crop in the two largest size classes. The higher yields of the TR trees on 'Topred' generally resulted in a smaller percentage in the larger size classes, while IH trees of 'Topred' tended to have larger fruit size in most years (Fig. 5). Great variations appeared from year to year in the effect of management systems on fruit size of 'Millersturdeespur' and 'Sundale', with no consistent trend evident.

After 11 growing seasons, trunk cross-sectional area of trees on SS or TR management systems on M.9 rootstocks did not differ (Table 1). 'Golden Delicious' trees, as expected, were nearly 28% larger than 'Sundale' trees in both systems. IH trees on M.9/MM.106 were larger than TR trees of 'Golden Delicious' or 'Millersturdeespur Delicious', but tree sizes were not different with the other cultivars. Cumulative yield per tree was closely associated with tree size of 'Golden Delicious' and 'Millersturdeespur'. The relatively poor yields of the large 'Topred'/MM.106 trees in the PH system resulted in no difference in cumulative yield per tree on 'Topred' among the three systems. 'Sundale' trees did not differ in trunk cross-sectional area, but IH trees had higher cumulative yields than SS trees.

When orchard production was evaluated by cumulative yield per hectare, 'Golden Delcious' grown at SS out produced the IH and PH systems, with the TR not different from either extreme (Table 1). 'Sundale' managed as SS out-produced both the TR and IH systems. 'Topred' on the TR had higher cumulative yields per hectare than the PH system. When efficiency of the trees was evaluated by comparing the cumulative yield produced per unit of trunk cross-sectional area ($kg \cdot cm^{-2}$), it is clear that spur-habit cultivars were more efficient than the standard-habit cultivars. Similar findings have previously been reported for 'Delicious' (Ferree et al., 1975), but previous work with 'Golden Delicious' has not shown spur forms to be more efficient (Ferree and Lich, 1978; Ferree et al., 1980). 'Golden Delicious' TR trees were more efficient than SS trees, which agrees with previous work (Ferree, 1980; Blizzard et al., 1988; Crassweller and Ferree, 1984; Granger et al., 1986), and IH trees were more efficient than PH trees with both 'Golden Delicious' and 'Topred Delicious'. With 'Millersturdeespur' and 'Golden Delicious' TR trees were more efficient than IH trees, but there were no differences in efficiency between these systems with either 'Sundale' or 'Topred'.

Thompson and Rogers (1981) suggested that a production of 47 $t \cdot ha^{-1}$ on a sustained basis is an achievable goal sought by American apple growers. From year 7 onward, all systems with 'Golden Delicious' achieved this goal. However, with 'Topred', only the TR system achieved this goal from the 8th year onward. When the spur-habit cultivars were evaluated under this criterion, 'Sundale' on SS from year 8 was the only combination to sustain this level of production. The time required to achieve these yields was later in this study than has been achieved in other studies with greater planting densities (Thompson and Rogers, 1981; Jackson et al., 1987), other management systems (Thompson and Rogers, 1981; Dunn and Stolp, 1987; Jackson et al., 1987), or more desirable climates (Dunn and Stolp, 1987; Jackson et al., 1987). However, early yields are comparable to or exceed the results obtained in studies with similar densities and similar (Blizzard et al., 1988; Granger et al., 1986) or different training systems (Blizzard et al., 1988; Van den Ende et al., 1987).

We ran a regression of yield per hectare and fruit size over the most productive 6 years for 'Topred' and 'Golden Delicious'. Although the variability was large with 'Topred', a trend appeared for very little difference in fruit size at high yields per

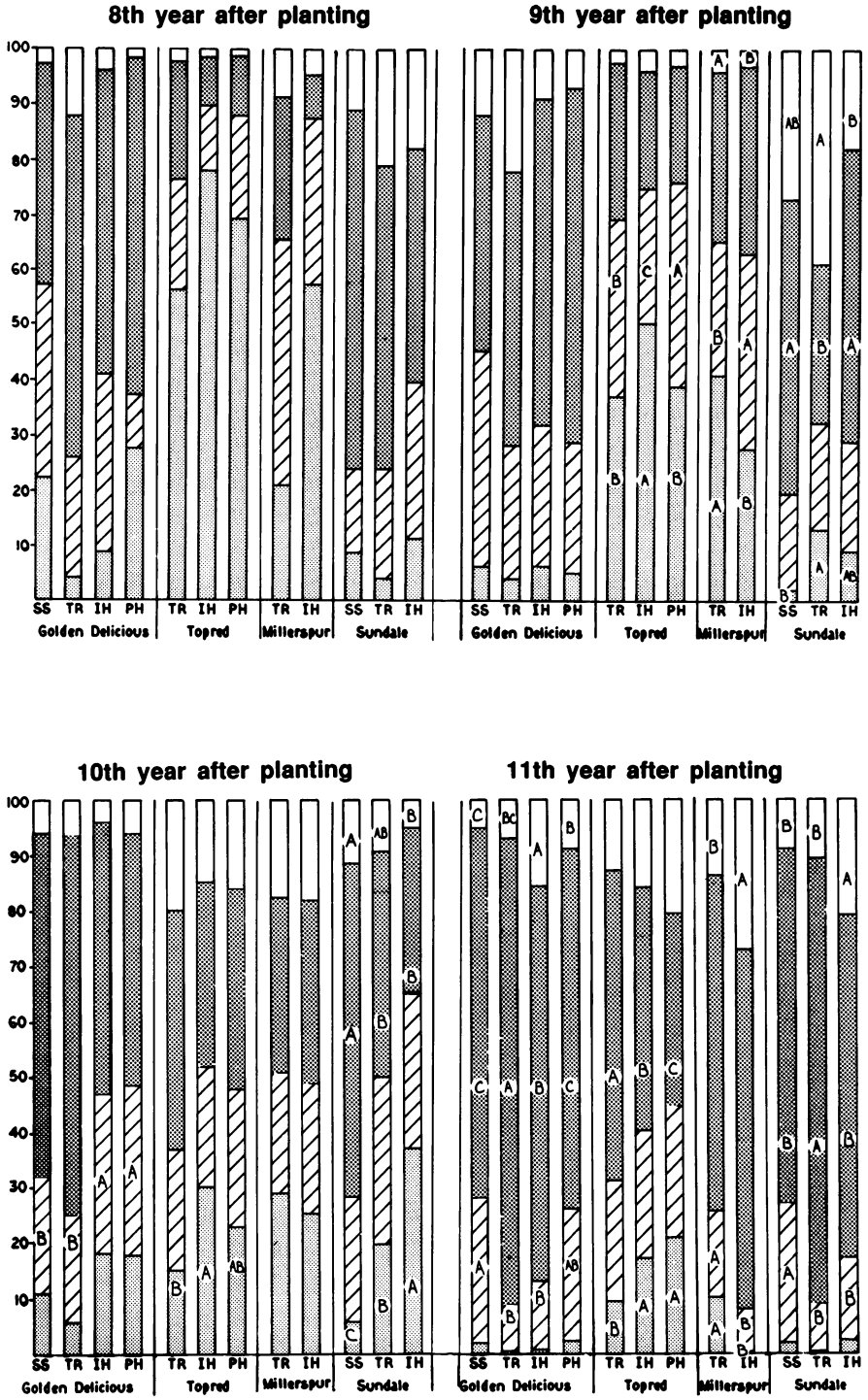

Fig. 5. Fruit size distribution years 8 to 11 of four cultivars grown in two or more of the following orchard systems: SS = slender spindle M.9, 2151 trees/ha; TR = trellis M.9, 1121 trees/ha; IH = interstem hedgerow M.9/MM.106, 795 trees/ha; PH = pyramid hedgerow MM.106, 425 trees/ha. Fruit size (cm diameter) (▨) > 8.0; (▨) 7.9 to 7.3; (▨) 7.2 to 5.7; and (□) culls and <5.7 cm. Data for systems are means of the following number of observations: SS, 44; TR, 28; IH, 24, PH 32. Letters indicate mean separation by Duncan's multiple range test, $P = 0.05$; 5% level; lack of letters = not significant.

hectare. However, when yields per hectare were lower, the TR system tended to produce larger fruit than the IH, with the PH producing the smallest fruit. If an arbitrary limit were established to have only 20% of the fruit 7.3 cm (125s or smaller) in diameter or smaller, it appears yields on the TR should not exceed 50.4 $t \cdot ha^{-1}$, IH 33.6 $t \cdot ha^{-1}$, and PH 16.8 $t \cdot ha^{-1}$. Canopy light distribution and spur quality demonstrate the same general trend, being relatively high in the TR and IH systems and very low in the PH system (Ferree, 1989). When the same comparisons between yield per hectare and fruit size are evaluated for 'Golden Delicious', no clear trend was evident for one system being superior to another. This could possibly be due to the much higher yields of 'Golden Delicious' than for 'Topred'.

The frosts that occurred in years 5 and 7 during bloom may

Table 1. Influence of orchard management system on tree size and cumulative yield over 11 years of four apple cultivars.[z]

Management systems	Trunk cross-sectional area (cm^2)	Cumulative yield		
		kg/tree	$t \cdot ha^{-1}$	$kg \cdot cm^{-2}$
Golden Delicious				
Slender spindle	52.7 c	160.7 c	473.9 a	3.56 c
Trellis	50.9 c	268.4 bc	364.7 ab	5.37 a
Interstem hedge row	90.2 b	336.8 b	320.6 b	4.90 b
Pyramid hedge row	200.0 a	556.2 a	352.9 b	2.81 d
Topred Delicious				
Slender spindle	---	---	---	---
Trellis	68.5 b	213.6	363.8 a	3.11 a
Interstem hedge row	85.7 b	220.0	228.0 ab	3.12 a
Pyramid hedge row	230.6 a	295.6	117.1 b	1.31 b
Sundale Golden Delicious				
Slender spindle	37.2	105.2 b	311.7 a	7.01 b
Trellis	36.7	147.1 ab	198.0 b	9.06 ab
Interstem hedge row	36.2	162.0 a	156.9 b	10.24 a
Pyramid hedge row	---	---	---	---
Millersturdeespur Delicious				
Slender spindle	---	---	---	---
Trellis	29.1 b	141.2 b	220.5	11.82 a
Interstem hedge row	61.1 a	204.3 a	217.5	7.81 b
Pyramid hedge row	---	---	---	---

[z]Mean separation by Duncan's multiple range test, $P = 0.05$. Data for systems are means of the following number of observations each year: SS, 44; TR, 28; IH, 24; PH, 32.

have negated the normal yield advantages expected with increasing planting densities (Jackson, 1980; Jackson et al., 1987; Wertheim et al., 1986). Yields in this study may also have been inflated because of the use in calculation of a full hectare based only on living trees. Wertheim et al. (1986) calculated yields based on 0.9 ha to allow for turning and farm roadways. The following tree losses over 11 years occurred in this study: SS, 17%; TR, 25%; IH, 19%; PH, 6%. These rather large losses would have lowered the yields reported if they had been included in the calculations. Funt et al. (1987), in a recent economic analysis based on the yields from this study, found that management systems were affected equally by tree loss no matter if it occurred in the 3rd or 6th year of the planting. However, tree losses exceeding 40% in the 3rd year resulted in an economic loss and replanting would only be profitable for the SS system.

Very little containment pruning was required to hold 'Golden Delicious' to its allotted space in the TR and IH systems, while significant containment pruning had been required after the fourth year with the SS. 'Golden Delicious' trees in PH required more and more containment pruning as the trees became older. The decline in yield noted in the TR and IH trees (Fig. 1) in years 9 and 10 may have been due to the lack of adequate extension growth resulting from heavy cropping and lack of pruning. Numerous heading back cuts and removal of old spur complexes have been successful in returning a balance of shoot to spur leaves and improved fruit size of spur-bound 'Delicious' (Ferree and Forshey, 1988). Shading studies (Rom and Ferree, 1986) and shoot removal (Myers and Ferree, 1983) have demonstrated the importance of shoot leaves in close proximity to the fruit for adequate fruit size.

Economic analyses using data from this planting and actual costs indicate that the high establishment and labor requirement of the SS system resulted in the lowest internal rate of return among these systems (Table 2; Funt et al., 1983, 1984). Conversely, the PH system had the highest internal rate of return, primarily due to it low establishment cost and low labor requirement in the early years. In Europe (Goedegebure, 1980), the SS system is considered very viable economically, but they generally have lower costs of trees, support systems, and have mechanized the planting and post-driving operations to significantly lower production costs. In Europe, only feathered trees are recommended for planting in the SS system; however, in the present study, nonfeathered trees were used. Ferree and Rhodus (1987) have shown a 30% increase in yield from feathered trees of 'Golden Delicious' over the first 3 production years, compared to nonfeathered trees. The economic analysis was recalculated using some reasonable alterations in inputs to determine the impact on the interal rate of return of the SS system. If post and tree costs are reduced 30% and planting machine costs and time were reduced 50%, to compare to those reported in Europe, an internal rate of return of 13.4% for SS would be achieved, which equals the return of the IH and TR systems, Increasing yield during the first 3 years by 30% would result in a 15.3% rate of return. Combining all these factors results in a 6.9% improvement in internal rate of return, which is slightly above the IH and TR systems, but still below the PH system. In an earlier study, Funt (1979) estimated similar rates of return for SS, but lower rates of return for a medium-density orchard that would be similar to PH in this study. Although all these improvements are feasible with current technology, the increases in management expertise necessary to make intensive orchard systems economically viable become evident with this analysis.

In summary, intensification with 'Golden Delicious' by planting either as TR or SS improved yields in the early years and the most intensive SS system generally maintained a production advantage in years 8 through 11. 'Topred Delicious', which is a relatively low-yielding standard habit strain, performed much better on the TR system than either of the free-standing systems. Although 'Sundale Golden Delicious' would not be recommended because of its greener and more russeted fruit, its small size was most suited to the SS system. The two orchard management systems tested with 'Millersturdeespur Delicious' had little effect on its productivity. The results clearly demonstrate that spacing must be adjusted to the ultimate size of the scion and failure to do this results in rather low yields, as evidenced by the results from the two spur-type cultivars.

Intensive plantings of apple have high initial investments. Growers with limited land and ample capital may be willing to

Table 2. Internal rates of return for 'Golden Delicious' in four orchard management systems.[z]

Year	Internal rates of return (%)					
	PH	IH	TR	SS	SS[y]	SS[x]
10	17.8	13.2	13.2	8.4	13.4	15.3
9	14.0	10.7	11.4	4.9	10.2	12.4
8	10.3	8.8	9.6	2.8	8.4	10.7
7	1.7	0.4	3.9	−3.4	1.9	4.8

[z]Basic economic inputs were: Labor, $6.00/hr; tree cost, $4.50; post cost, $2.60; Tractor and auger, $23.34/hr; Fruit value/kg, $0.2475.
[y]Using a 30% reduced cost for post and trees, a 50% reduced equipment usage and less labor at planting.
[x]Using cost reductions plus a 30% increase in yield.

risk a 15% rate of return on an investment twice as large compared to an 18% return on a smaller investment. High early yields and efficient management practices are required for high returns. Therefore, intensive plantings are preferred when land is limited and ample capital and management skills are available. Less intensive plantings are favorable when ample land and capital are available and management is less skilled.

Literature Cited

Autio, W.R. and F.W. Southwick. 1986. The effects of rootstock and root-interstem combination on the growth, productivity and anchorage of a spur and standard strain of Delicious apple tree. Fruit Var. J. 40:128–133.

Blizzard, S.H., S. Singha, T.A. Baugher, and B.D. Cayton. 1988. Yield and fruit quality of apple trees under three high density management systems. Fruit Var. J. 42(2):67–72.

Crassweller, R.M. and M.E. Ferree. 1984. Influence of rootstocks and support systems on yield, tree size and cork spot on spur and non-spur Delicious apple trees. Fruit Var. J. 38:145–149.

Dunn, J.S. and M. Stolp. 1987. Apples on the Lincoln canopy-mechanized management. HortScience 22:568–572.

Ferree, D.C. 1980. Canopy development and yield efficiency of 'Golden Delicious' apple trees in four orchard management systems. J. Amer. Soc. Hort. Sci. 105:376–380.

Ferree, D.C. 1982. Tree performance and yield efficiency of several apple cultivars on M.9 and M.9 interstems. Fruit crops 1982: A summary of research. Ohio Agr. Res. Dev. Cent. Res. Circ. 272:7–11.

Ferree, D.C. 1989. Influence of orchard management systems on spur quality, light, and fruit within the canopy of 'Golden Delicious' apple trees. J. Amer. Soc. Hort. Sci. 114:869–875.

Ferree, D.C. and C.G. Forshey. 1988. Influence of pruning and urea sprays on spurbound 'Delicious' apple trees. J. Amer. Soc. Hort. Sci. 113(5):699–703.

Ferree, D.C., C.A. Morrison, and L.C. Shew. 1975. Red Delicious apples....which strain is best? Ohio Agr. Res. Dev. Cent., Ohio Rpt. 60:19–22.

Ferree, D.C., D.A. Chandler, and J.C. Schmid. 1980. Performance of selected apple cultivars on semi-standard rootstocks in southern Ohio. Fruit crops 1980: A summary of research. Ohio Agr. Res. Dev. Cent. Res. Circ. 259:1–3.

Ferree, D.C. and R. Lich, III. 1978. The search for a russet-free strain of 'Golden Delicious'. Ohio Agr. Res. Dev. Cent., Ohio Rpt. 63:51–53.

Ferree, D.C. and W.T. Rhodus. 1987. Early performance and economic value of feathered apple trees on semi-standard rootstocks. J. Amer. Soc. Hort. Sci. 112:906–909.

Funt, R.C., A.E. Lines, and D.C. Ferree. 1984. Economics of producing, packing, storing and transporting Golden Delicious apples in Ohio, 1982. Ohio State Univ. Coop. Ext. Serv. HT 84-2.

Funt, R.C., D.C. Ferree, and A.E. Lines. 1983. Rates of return of four apple production systems. Acta Hort. 135:177–184.

Funt, R.C., D.C. Ferree, and M.A. Ellis. 1987. Influence of tree loss on rate of return of different apple production systems. Acta Hort. 203:101–106.

Funt, R.C., E.J. Partenheimer, and L.D. Tukey. 1979. Internal rates of return for difference 'Golden Delicious' apple orchard systems in Pennsylvania. J. Amer. Soc. Hort. Sci. 104(2):154–159.

Goedegebure, J. 1980. Economic aspects of high density plantings in apple-growing in the Netherlands. Acta Hort. 114:338–398.

Granger, R.L., G.L. Rosselle, A. Charland. 1986. Effect of planting densities, rootstocks and training systems on the Spartan apple cultivar. Acta Hort. 160:105–114.

Jackson, J.E. 1980. Light interception and utilization by orchard systems. Hort. Rev. 2:208–267.

Jackson, J.E., J.W. Palmer, S.J. Wertheim, G. Bunneman, F. Winter, J.V. Christensen, S. Sansarini, and A. Mika. 1987. The international planting systems trial. HortScience 22:550–551.

Myers, S.C. and D.C. Ferree. 1983. Influence of time of summer pruning and limb orientation on yield, fruit size, and quality of vigorous 'Delicious' apple trees. J. Amer. Soc. Hort. Sci. 108:630–633.

Rom, C.R. and D.C. Ferree. 1986. The influence of fruiting and shading of spurs and shoots on spur performance. J. Amer. Soc. Hort. Sci. 111:352–356.

Stephens, C.P. and J.A.H. Nicholson. 1978. The economics of intensive orchards in the United Kingdom. Acta Hort. 65:31–39.

Thompson, A.H. and B.L. Rogers. 1981. Performance of four apple cultivars on Malling 26 rootstocks grown in intensive culture with summer shearing. Fruit Var. J. 35:126–130.

Van den Ende, B., D.J. Chalmers, and P.H. Jerie. 1987. Latest developments in training and management of fruit crops on Tatura trellis. HortScience 22:561–568.

Wertheim, S.J. 1968. The training of the slender spindle. Proefstation Voor De Fruitteelt Wilheminadorp. Publ. 7.

Wertheim, S.J., A. de Jager and M.J.J.P. Duyzens. 1986. Comparison of single row and multi-row planting systems with apple, with regard to productivity, fruit size and colour, and light conditions. Acta Hort. 160:243–258.