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Canopy Development and Yield Efficiency of 'Golden Delicious' Apple Trees in Four Orchard Management Systems[1]

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Additional index words. trellis, hedgerow, interstem, slender spindle, *Malus domestica*

Abstract. **The canopy development and yield efficiency of 'Golden Delicious' apple trees (*Malus domestica* Borkh.) were measured during the sixth growing season for slender spindle (2151 trees/ha), trellis (1121 trees/ha), interstem hedgerow (795 trees/ha), and pyramid hedgerow (425 tree/ha) management systems. Pyramid hedgerow trees had the greatest trunk circumference, height, spread, and canopy volume/tree, but had a lower canopy volume/ha than the slender spindle or trellis. About 20% of the canopy of all 4 systems was present at bloom in May, 90% in June, and the maximum in July. Spur leaves followed the development pattern of the whole canopy but shoot leaf area did not reach its maximum until August. Interstem hedgerow trees had the most open canopy with the lowest amount of leaf area/unit of canopy height and the greatest amount of light penetration in the canopy. The pyramid hedgerow had a higher LAI than other systems and the increase in light in the upper third of the tree was not as great as the other systems. Trellis trees had the greatest number of fruit/100 cm^2 area of both spur and shoot leaves and also the highest yield/unit trunk cross section of the 4 systems. The upper third of the canopy of all systems had the largest number of flowers and fruit, greatest amount of fruit/100 cm^2 of leaf area and more light than the mid- and lower-thirds. Cumulative yield/ha and canopy volume/ha were closely related to number of trees/ha but the trellis and interstem system had a greater density of fruit/m^2 of canopy than the slender spindle or pyramid hedgerow systems.**

Increased production costs and land values coupled with dwindling labor supplies have encouraged fruit growers to improve efficiency and to increase production on existing land. Yields/unit land of apple orchards can be increased by closer spacing (3, 15, 20). Small, closely-spaced trees in modern orchards have efficient light utilization (9, 10) and are dwarfed by rootstocks which favor flowering, fruit set and partitioning of photosynthate into fruit vs. vegetative growth (16, 17). Training method also influences yield/unit of land (6), dry matter accumulation (4), and pruning and harvesting efficiency (13). As tree density increases, the amount of capital invested and management also increases (13). Past studies generally focused on a single phase of management. The fruit grower, however, is concerned with the summation of the effects of all phases in the evaluation of productive efficiency.

Canopy development and yield efficiency of 6-year-old 'Golden Delicious' trees grown in 4 orchard management systems are compared in this study. Each system consists of a combination of rootstocks, spacing, training, and pruning designed to achieve orchard efficiency, and it is the management systems as a whole that must be considered when comparisons are made.

Materials and Methods

Trees of 'Golden Delicious' were established in 1973 in 4 orchard management systems on a deep, fertile silt loam soil near Wooster, Ohio. The most intensive system was the slender spindle on Malling (M) 9 rootstock planted 1.52 × 3.05 m (2151 trees/ha) with each tree supported by a post (1.83 m protruding) and trained using the techniques described by Wertheim (19). Trees on the trellis system were on M 9 rootstock planted 2.44 × 3.66 m (1121 trees/ha) and fastened to a 4-wire trellis (top wire 1.83 m). Trellis trees were trained as oblique palmettes by annually tying branches to the wire maintaining 45° to 60° angle with the main trunk. Six to 8 main scaffolds/tree were maintained while additional branches growing into the row were removed. The interstem hedgerow consisted of trees with a 15.2 cm interstem of M 9 on Malling Merton (MM) 106 rootstock and planted 2.74 × 4.21 m (795 trees/ha) with the lower union of the interstem above ground level. The pyramid hedgerow trees were on MM 106 and were planted 4.27 × 5.49 m (425 trees/ha). The last 2 systems were free-standing and trained as central leaders using wooden clothespins the first season and wooden spreaders in subsequent years to establish strong, wide crotch angles and maintain the dominance of the central leader. Trees in all systems received minimal annual pruning with only necessary training cuts being made. Rows had a N-S orientation and trees received standard herbicide and pesticide schedules and uniform fertilization on a per ha basis. Chemical thinning was used as needed with all trees receiving the same treatment. The systems were arranged as randomized complete blocks with 4 replications of 17 m rows.

Tree height, spread, and trunk circumference and length of 5 terminal shoots per tree were measured each year. The weight of fruit/tree was determined in 1975-1978. In addition, in 1977 and 1978 the fruit from each tree was graded on an FMC weight-sizer and the numbers of fruit in each of the following size classes was counted: *Size 1,* 8.0 cm diameter and larger (box size 80-88s); *Size 2,* 8.0-7.3 cm (100-113s); *Size 3,* 7.3-5.7 cm (125-138s). The fruit was graded according to commercial standards and culled fruit removed and counted.

In 1978, a frame creating a 30 × 30 cm column was located in the row midway between the trunk and branch tip on the south side of 10 single tree replicates of each system (Fig. 1). The height of the column extended from the soil line to highest foliage and was divided into 3 equal parts and leaves, flowers and fruit counted on May 27, June 12, July 11, and August 24. Light in the column was determined on a bright cloud-free day in September with LiCor 190 S quantum sensor. The columns were removed from the trees after each measurement with the base left in place so that the same volume and location were sampled on each date. In addition, all the leaves on 4 trees of each system were counted and leaf area determined by removing

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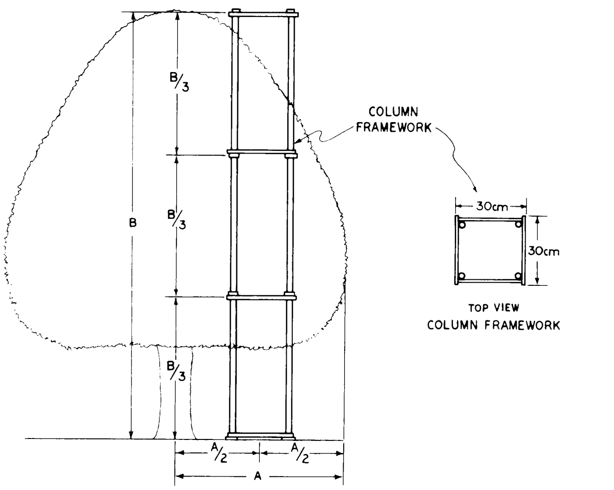

Fig. 1. Location of the frame defining a 30 × 30 cm column midway between the trunk and canopy edge (A) with height determined by the highest foliage (B) and divided into 3 equal parts.

every 50th leaf and determining the average leaf area on all the removed leaves with a LiCor leaf area meter. Total tree leaf area was then calculated by multiplying the total number of leaves/tree by the average leaf area.

Results and Discussion

After 6 years in the orchard, pyramid hedgerow trees had the greatest trunk circumference, height, spread, and canopy volume/tree, but had a lower canopy volume/ha than the slender spindle or trellis systems (Table 1). Trees in this system continued to be the most vigorous as evidenced by the greatest terminal shoot length. The trellis and slender spindle trees were similar in trunk circumference and height and all cultural operations could easily be accomplished without ladders. The trellis trees had a greater in-row spread and smaller across row spread because the branches growing into the row middle on trellis trees were tied to the wire. Trellis trees had a greater canopy volume/tree but did not differ from the slender spindle in volume/acre. The slender spindle required some containment pruning at the 1.52 m spacing and this stimulated more vigorous terminal shoot growth than found on either the trellis or interstem trees. The interstem trees were generally larger than the trellis trees, but had a smaller canopy volume/ha. The interstem on MM 106 produced significantly more root suckers than did MM 106 in the pyramid hedgerow or M 9 in the other systems. Earlier findings (1, 3) that the volume of fruiting canopy during the early developmental years of the orchard can be increased by planting more trees/unit area was confirmed.

About 20% of the canopy of all 4 systems was present at bloom in May, 90% present in June, and maximum in July with a decline in August in the sample location. If spur and shoot leaf areas were compared, spur leaves followed the trend of the whole canopy but shoot leaf area/unit canopy height did not reach its maximum until August (Table 2). The maximum canopy of both spur and shoot leaves developed later in the season than predicted by the model of Cain (2). The model indicated that spur canopy was complete at the completion of petal fall, but in this study it was only 90% present in mid-June, 10-14 days after the completion of petal fall.

During the time of bloom in May, when most of the canopy consists of spur leaves, the interstem hedgerow trees had the lowest amount of leaf area/unit of canopy height with the other 3 systems being similar (Table 2). Spur leaf area/unit canopy height in June and July did not differ among the systems, but spur area in the slender spindle and interstem were lower in August than in the trellis and pyramid hedgerow. Although some of this difference could have been due to natural leaf drop of the older spur leaves, it is suggested that the greatest cause of the reduction was the shift in limb position due to the increasing crop weight. This shift would tend to move spur leaf area out of the sample area. Since the branches on the trellis were partially supported and on the pyramid hedgerow were larger and had a smaller fruit weight/unit limb cross section, the shift in position was not as great in these systems.

The leaf area index (LAI) in the sample area of pyramid hedgerow was generally higher than in trees of the other systems. This reflects the greater height and leaf density of these trees (Table 2). Heinicke (8) found that the greatest vertical concentration of foliage was half-way between the center and outside of the tree. This was the location of the sample in this study. He reported that a LAI of 4 to 5 was the maximum that would allow sufficient light to strike all foliage for the maximum photosynthetic rate. Only the interstem trees had an LAI in the most dense area of the canopy that would allow for maximum photosynthesis. However, calculation of the LAI for whole trees based on a total leaf count of 4 trees of each system gives the following LAI values: pyramid 4.12, interstem 3.20, trellis 3.11, and slender spindle 3.26. These values indicate that a desirable canopy density was achieved in trees of all systems. Although the trellis and slender spindle trees had very different shapes, the LAI of trees in these systems were similar throughout the season.

Total leaf area data (Table 2) indicates that the most intensive system (2151 trees/ha) had the greatest total leaf area followed closely by the least intensive system (425 trees/ha).

Table 1. Tree size, vegetative growth, and canopy volume of 6-year-old 'Golden Delicious' apple trees grown in 4 orchard management systems.

Management systems	Trunk cross section (cm^2)	Height (m)	Inrow spread (m)	Across row spread (m)	Average shoot length (cm)	Number of root suckers/ tree	Canopy[z] volume/tree (m^3)	Canopy volume/ha (m^3)
1. Slender spindle	38cc[y]	2.4c	2.0c	2.4c	37b	4.9b	10.4c	22420a
2. Trellis	41bc	2.2c	3.1b	1.8d	24d	4.0bc	17.5b	19639a
3. Interstem hedgerow	50b	2.9b	3.0b	3.1b	32c	11.4a	19.8b	15768b
4. Pyramid hedgerow	101a	4.1a	3.8a	3.5a	43a	1.7c	33.5a	14244bb

[z]Volume of trees in system 1, 3, 4 calculated as: $V = 2/3\ \pi r^3 + \pi r^2 h$, (r = spread ÷ 2, h = height); System 2 = (inrow spread (IS) × (cross row spread (CS) × 4.5 + ((h-4.5) × (IS) (CS) ÷ 2.

[y]Mean separation within columns by Duncan's multiple range test, 5% level.

Table 2. Leaf area/unit canopy and leaf area index of a mid-canopy sample[z] of 6-year-old 'Golden Delicious' apple trees grown in 4 orchard management systems.

Management system	Leaf area (cm^2)/cm canopy height							Leaf area index (LAI)				Leaf[y] area/ha (m^2)
	May	June		July		August						
		Spur	Shoot	Spur	Shoot	Spur	Shoot	May	June	July	August	
Slender spindle	9.7a[x]	16.4a	18.5a	25.7a	11.3b	6.3b	25.5a	1.7b	6.2b	6.4b	5.5a	27,738
Trellis	8.0a	19.8a	13.9ab	20.1a	17.8a	11.3a	22.3ab	1.3b	5.6b	6.4b	5.6a	19,128
Interstem hedgerow	4.8b	13.1a	11.4b	19.6a	10.4b	5.1b	17.3b	0.8c	4.1c	5.0b	3.7b	18,834
Pyramid hedgerow	8.4a	18.5a	14.7ab	20.1a	15.7a	10.1a	18.3b	2.1a	8.3a	9.1a	7.1a	23,371

[z]Data from a 30 x 30 cm column located at the mid-point of the branch spread in the tree row.

[y]Calculated from entire tree leaf counts of 4 trees of each system.

[x]Mean separation within columns by Duncan's multiple range test, 5% level.

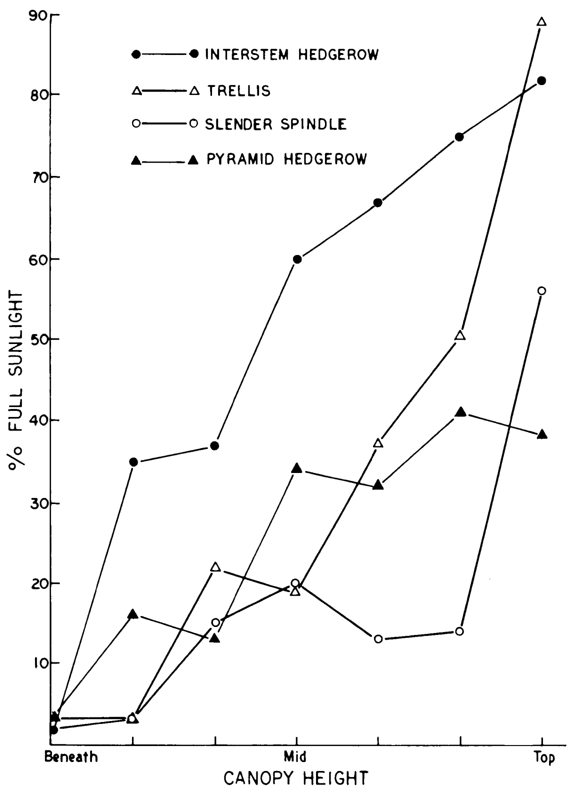

Fig. 2. Light levels at various heights in the canopies of 'Golden Delicious' apple trees in 4 management systems measured on September 26, 1978.

The trellis and interstem systems had similar lower total leaf areas. These data present a different picture than canopy volume/ha data which generally increased as tree density increased. The greater density (leaf area cm^2/cm canopy height) of leaves in the pyramid and lower density in the interstem hedgerow trees probably accounted for most of the divergence.

A determination at various heights in the sample area of the photosynthetically active radiation (PAR) expressed as percent full sun indicates that the interstem trees with lower leaf densities had significantly more light in the lower and mid-canopy areas than the other systems (Fig. 2). The leaf density of the pyramid hedgerow trees prevented the sharp upward trend of light penetration in the upper canopy observed in the other systems, As expected, light increased from the lower canopy toward the upper canopy in trees of all management systems. Light exceeded the 30% full sunlight level reported by several workers (1, 7, 8) as necessary for flower initiation in the upper third of trees in all systems and in the upper 2/3 of the interstem trees. Since the sample area was taken in the most dense part of the canopy and flowers were observed throughout the canopy of trees in all systems, it is suggested that light regime in these young trees was satisfactory and the single light measurement at the end of the season did not adequately reflect the entire season light regime.

The trellis trees had a greater number of flowers and fruit born terminally in the sample area than either the interstem or pyramid hedgerow trees with no difference among systems in lateral flowers (Table 3). Pyramid hedgerow trees had a greater leaf area/flower than trees in the other systems. Trellis trees had the greatest number of fruit/100 cm^2 area of both spur and shoot leaves. Although there was a tendency for fruit set to be higher on trellis trees, the differences among systems were not significant. Magness and Overley (11) found that a minimum

Table 3. Flower and fruit distribution and their relationship to leaf area[z] of 6-year-old 'Golden Delicious' apple trees grown in 4 orchard management systems.

Management system	May 25, 1978			July 11, 1978					
	No. of flowers		Leaf area/ flower (cm^2)	No. of fruit		Fruit/ 100 cm^2 leaf		Set (%)	
	Terminal	Lateral		Terminal	Lateral	Spur	Shoot	Terminal	Lateral
Slender spindle	57ab[y]	29	6.4b	1.3b	.6	.22bc	.02b	2.0	1.8
Trellis	69a	30	5.7b	3.4a	1.3	.45a	.14a	5.5	4.2
Interstem hedgerow	40b	22	5.5b	1.7b	.8	.27b	.08b	4.5a	3.1
Pyramid hedgerow	42b	17	14.7a	1.4b	.8	.11c	.04b	2.5	2.9
		NS			NS			NS	NS

[z]Data taken from a 30 x 30 cm column located at the mid-point of branch spread in the tree row.

[y]Mean separation within columns by Duncan's multiple range test, 5% level.

Table 4. Leaf, flower, and fruit distribution[z] at various canopy levels of 6-year-old 'Golden Delicious' apple trees.

Canopy level	Leaf area (cm^2)/cm canopy height							No. of flowers		Leaf area/flw. (cm^2)	No. of fruit		Fruit/ 100 cm^2 leaf area
	May	June		July		August							
		Spur	Shoot	Spur	Shoot	Spur	Shoot	Term	Lat		Term.	Lat.	
Lower	3.8b[y]	10.0c	6.3c	8.1c	7.6c	6.8b	9.9c	20c	5c	8.2a	.5c	.1b	.06b
Mid	9.4a	23.1a	13.2b	17.7b	18.7a	10.2a	18.8b	57b	22b	9.6a	1.5b	.6b	.10b
Upper	10.1a	17.9b	24.4a	38.4a	15.1b	7.6b	33.9a	79a	46a	6.4a	3.8a	1.8a	.21a

[z]Data from a 30 × 30 cm column located at the mid-point of the branch spread in the tree row.
[y]Mean separation within columns by Duncan's multiple range test, 5% level.

Table 5. Yield and fruit size distribution of 6-year-old 'Golden Delicious' grown in 4 orchard management systems planted in 1973.

Management system	Yield (kg/tree)				Cumulative yield (ton/ha)	Fruit size[z] distribution 1978 (kg)				No. fruit/ tree	Fruit/ m^3 canopy	Yield/ trunk area (kg/cm^2)
	1975	1976	1977	1978		1	2	3	culls			
Slender spindle	6.0c[y]	11.0c	9.9b	19.8c	101.1a	6.2a	8.1c	4.0c	1.5c	118c	8.5ab	.59b
Trellis	9.5b	14.6b	19.5a	30.9b	77.7b	5.0a	13.0b	9.3b	3.6ab	195b	10.3a	.90a
Interstem hedgerow	7.3c	9.9c	14.5ab	32.1b	50.9c	6.4a	13.2b	9.1b	3.3b	200b	10.5a	.66b
Pyramid hedgerow	11.7a	20.8a	18.7a	42.3a	41.7c	6.8a	17.4a	13.7a	4.3a	268a	8.0b	.38c

[z]Size 1 = 8.0 cm and larger dia (80-88s); Size 2 = 8.0-7.3 cm (100-113s); Size 3 = 7.3-5.7 cm (125-138s).
[y]Mean separation within columns by Duncan's multiple range test, 5% level.

of 30-40 leaves were required to maintain the proper balance between fruit size and yield of standard trees. Calculations based on the numbers of leaves and fruit of whole trees in this study show the following number of leaves/fruit in 1978: pyramid, 89, interstem, 57; trellis, 50; and slender spindle, 58. These figures indicate that ample foliage was present to maintain fruit size and yield in all systems and that chemical thinning may have been excessive.

The lower third of the sample volume in all systems had the smallest leaf density throughout the season and made the smallest contribution in number of flowers or fruit (Table 4). There was no difference in leaf area/flower in the various canopy heights at time of bloom. In the mid-third of the sample column, spur leaf density reached its maximum in June and decreased through the remainder of the season. The decrease probably reflected drop of many small spur leaves that developed early and became shaded as the upper canopy developed. In the upper level spur leaf density did not reach its maximum until July with a decline in August likely due to fruit weight moving spur leaf area out of the sample column. The upper third of the canopy sample produced the greatest number of flowers and fruit both terminal and lateral and had the highest efficiency evaluated by number of fruit/100 cm^2 of leaf area. The greater productivity and optimum light regime of the upper third of the canopy in all the systems emphasize the importance of designing trees and systems that maximize exposure of the canopy surface area to light.

Relatively large trees on the pyramid hedgerow had the highest yield/tree and lowest density of fruit/m^3 of canopy (Table 5). However when a severe frost in 1977 at bloom significantly reduced yield of all trees, the large tree size was not an advantage. Of the 2 most intensive systems, the trellis trees consistently yielded more than the slender spindle on a per tree basis. Early yields of the slender spindle trees were probably reduced by injury resulting from the preservative in the supporting posts (5), but growth during the last 3 years appeared normal. The trellis and interstem trees had similar canopy volumes (Table 1) and similar yields/tree, fruit size distribution and fruit/m^3 of canopy. Cumulative yield was closely related to tree density during the first 6 years as has been shown in a number of other studies (14, 15). Fruit size distribution was not greatly altered by the treatments but trees grown as slender spindles tended to have a higher percentage of their fruit in the large size classes than other systems. The density of fruit in the whole canopy had a similar trend to the total fruit/100 cm^2 leaf area in the sample column (Table 3). Tukey (18) used the number of fruits per linear unit of row distance as an indicator of bearing intensity. Using this indicator the systems in 1978 had the following number of fruit/meter of row:slender spindle, 75; trellis, 82; interstem, 72; pyramid, 62. Efficiency as measured by the yield/unit trunk cross section indicated that the trellis trees were most efficient, followed by the interstem and slender spindle with trees on the pyramid hedgerow being least efficient.

'Golden Delicious' trees trained and managed as a trellis appear to have the greatest physiological efficiency of the 4 systems in this study. Trellis trees had a high leaf area/unit of canopy height coupled with the largest number of fruit/100 cm^2 of leaf area and the greatest yield/trunk cross sectional area. The efficiency of the trellis trees was probably a combination of the precocity of the M 9 rootstock coupled with a training system and spacing that required little pruning and tying positioned the branches and leaves for a favorable light relationship. Although slender spindle, the other supported system, had a higher cumulative yield/ha, it had a lower physiological efficiency as indicated by the above measurements due in part to the amount of pruning required to contain the trees to the space allotted.

Of the free standing systems, the interstem trees were more efficient having a higher number of fruit/100 cm^2 leaf area, higher yield/trunk cross sectional area, and cumulative yield. The openness of the canopy of the interstem trees and optimum light penetration that resulted is probably due mostly to the influence of the rootstock-interstem combination on the growth habit of the scion coupled with limb spreading and central leader training. The pyramid hedgerow was the least efficient system in the study having the lowest yield/trunk cross section, fruit/100 cm^2 leaf area and cumulative yield. The upright vigorous growth habit of these trees imparted by the rootstock was not sufficiently counteracted by limb spreading and minimum pruning to improve efficiency and early fruiting in relation to the other systems.

Data gathered during the first 6 years of this study indicate that dwarfing precocious rootstocks such as M 9 or interstems such as M 9/MM 106 that produce open spreading canopy impart significant physiological efficiency to an orchard management system. Since the advantages gained are permanent and require little economic input, the selection of the correct rootstock or interstem is preeminent in achieving efficiency in any management system. Coupled closely with this choice must be a training system and spacing that allows for minimum pruning and optimum light penetration during the early years.

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The Behavior of Peach and Pear Trees under Extreme Drought Stress[1]

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Abstract. **Trees of peach (*Prunus persica* (L.) Batsch) and pear (*Pyrus communis* L.) were grown without irrigation and received only 86-mm rainfall during the growing season. Many peach trees died after experiencing leaf water potentials below −30 bars in July and August. Defoliation began in July, fruit growth was arrested, flavor was astringent, and flower buds failed to differentiate. Pear trees survived under similar conditions although tops died back or grew poorly and flowering was reduced. Regrowth came from trunks and lower scaffolds. Heavy pruning ("dehorning") delayed the appearance of drought symptoms until very late in the season and resulted in 100% survival of both peach and pear trees. Heavy thinning of peaches in early June did not affect current season's symptoms but apparently reduced dieback and death of trees.**

Orchards with many trees per acre on relatively shallow soils have been planted in the Yakima Valley. These orchards depend almost totally on irrigation. Thus, official announcements in the spring of 1977 that some of these orchards would receive no water stimulated interest in the response of trees to severe drought. Horticultural literature has not dealt with such extreme events.

The exhaustion of readily available moisture causes wilting or curling of the leaves, partial defoliation, and decreased fruit growth (2, 4). This may be followed by failure of flower buds to differentiate (1, 3) dieback of the top or the loss of scaffold limbs.

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