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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Additional index words. leaf water potential, soil moisture, pruning, thinning, flower bud differentiation, *Prunus persica, Pyrus communis*

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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In this experiment peach and pear trees were not irrigated in 1977, and the sequence of events leading to death or injury was monitored. The effects of severe pruning and heavy fruit thinning were tested to determine whether they could modify the physiological consequences of extreme drought.

Materials and Methods

This research was conducted in the WSU orchards at Prosser in small blocks of 30-year-old 'Elberta' peaches and 20-year-old 'Bartlett' pears with 'D'Anjou' pollinators.

The 'Elberta' block of seven 22-tree rows was in Shano very fine sandy loam that averaged 1.2 m in depth underlaid by a relatively uniform basalt rock surface. The field-holding capacity (FHC) was 18% and the permanent wilting percentage (PWP) was 6%.

Two rows were furrow irrigated (Fig. 1). The remaining

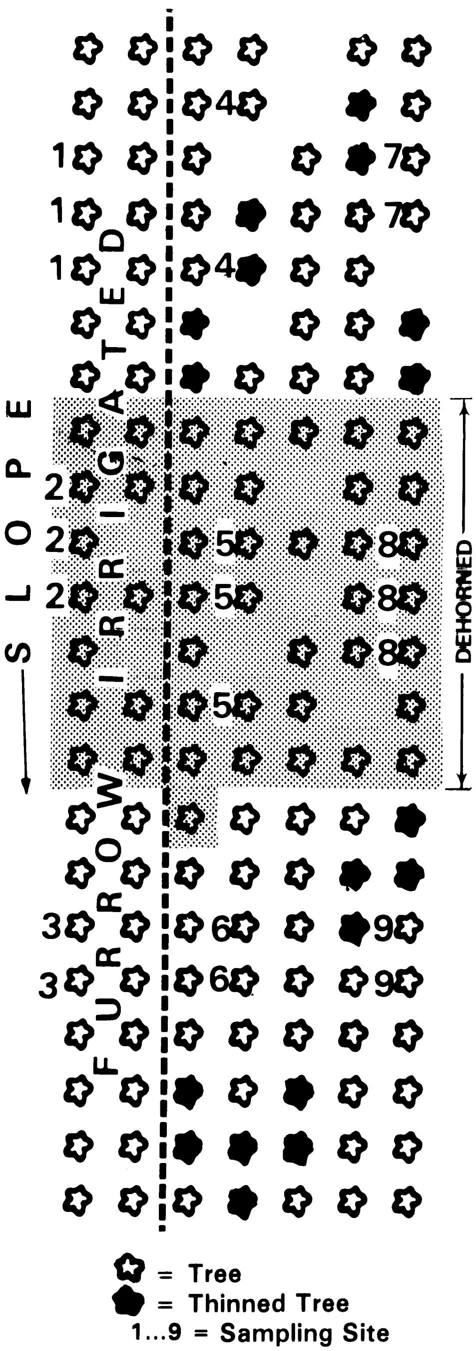

Fig. 1. Plot map, 'Elberta' peaches, with area irrigated, area "dehorned", location of thinned trees, and sampling sites.

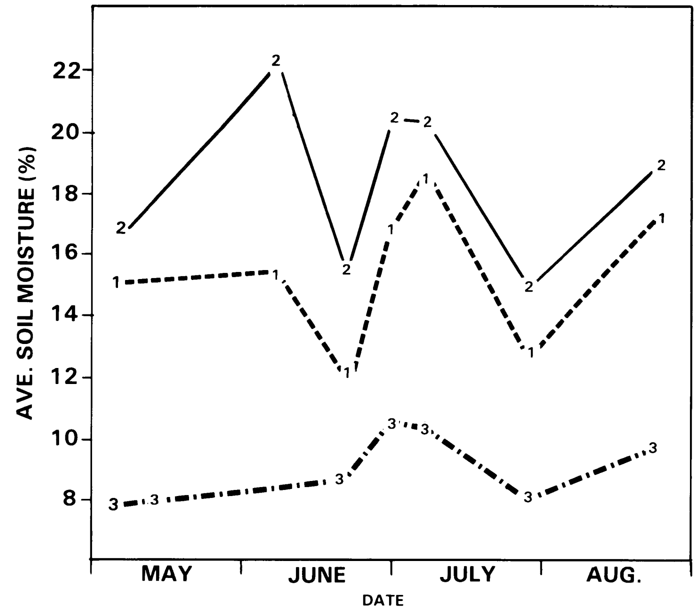

Fig. 2. Seasonal changes in average soil moisture to bedrock, furrow-irrigated peach trees. Numbers represent sampling sites (See Fig. 1); PWP=6%, FHC=18%.

trees were not irrigated. The 7 trees at the upper and the 8 trees at the lower end of the block received a light pruning during dormancy. The 7 central trees on all rows were "dehorned" on April 25 (all the scaffold limbs were removed at about 1.5 m above the ground).

Within the non-irrigated, normally pruned block, 18 trees were very heavily thinned about the time pit hardening was initiated. The thinning treatments were randomized within the non-irrigated, normally pruned block. Soil samples for gravimetric moisture analysis were collected from the same trees at 9 sites (Fig. 1) at irregular intervals from May 5 to August

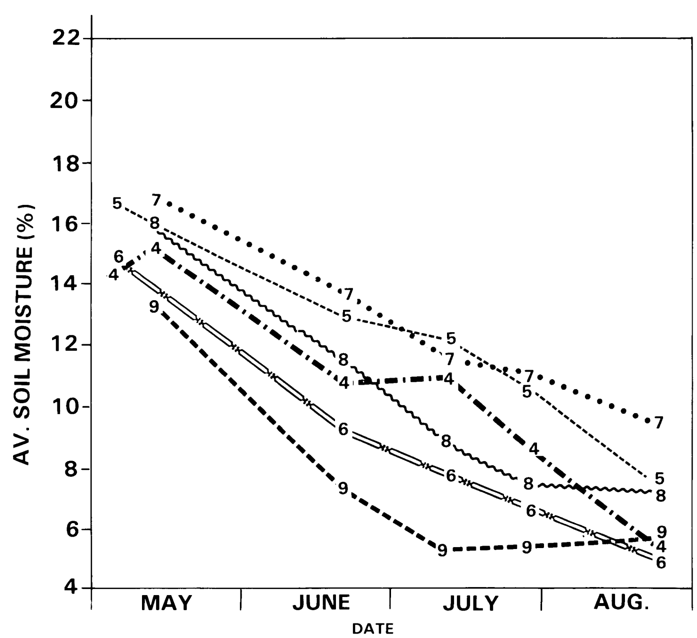

Fig. 3. Seasonal changes in average soil moisture to bedrock non-irrigated peach trees. Numbers represent sampling sites (See Fig. 1); PWP=6%, FHC=18%.

Table 1. Rainfall and pan evaporation by months, 1976-77, Roza Unit, Irrigated Agriculture Research and Extension Center (WSU), Prosser, Washington.

Year	Month	Rainfall (mm)	Evaporation (mm)
1976	Sept.	1	160
	Oct.	4	88
	Nov.	T	--
	Dec.	4	--
1977	Jan.	3	--
	Feb.	10	--
	Mar.	12	--
	Apr.	1	181
	May	18	168
	June	7	253
	July	3	250
	Aug.	39	258
	Sept.	19	113
	Oct.	3	74

28. Soil was taken from 3 holes per tree in 30-cm increments to bedrock. Leaf water potential (Ψ_W) was measured every 2 weeks at the soil sampling sites using the Scholander pressure bomb (5). Ψ_W was determined on 4 shaded leaves per tree collected in the afternoon near the time of minimum values, and read immediately. Defoliation was rated on August 6, September 10, October 8, and October 17. The amount of defoliation was rated from 0, leaves still green, to 10, complete defoliation. Fruit samples collected August 31 were weighed and rated for skin color. During dormancy the length of shoots and number of flower buds per shoot was determined. In 1978 bloom density and tree recovery were rated on a scale of 0 to 5 where 5 was normal, and 0 had no bloom or was dead.

The block of 40 'Bartlett' pear trees with 6 'D'Anjou' pollenizers planted 6 x 6 m was not irrigated in 1977. The soil was Hezel loamy fine sand and Warden very fine sandy loam at least 1.5 m deep with PWP of 5% and FHC of 13%. A plot of 18 trees in the middle of the block was "dehorned".

Soil moisture and leaf water potential were measured as previously described.

Results and Discussion

1. Peaches

a. Soil moisture. The average soil moisture in 1.2 m of soil remained near or slightly below FHC most of the year at sites 1 and 2 in the furrow-irrigated rows (Fig. 2). It was maintained only a little above PWP at site 3.

The non-irrigated rows started the season with different amounts of water in the soil (Fig. 3). Water was removed at different rates in the different areas. It only took 35 days for soil moisture percentage to drop by 6% at site 9, 50 to 55 days at sites 6 and 8 and 70 to 80 days at sites 4, 5 and 7. Perhaps sites 4, 5 and 7 had access to ground water reserves.

Site 9 was below 7% average moisture by late June, site 6 in late July and site 4 in mid August. Site 5 was projected to go below 7% about September 1 and site 8 approached 7% about August 1. Site 7 had only reached 9% by August 23.

Rainfall was very light during the time of this experiment (Table 1). Evaporation was normal for the area.

b. Leaf water potential. Leaf water potentials were similar on all 3 irrigated sites in spite of the low soil moisture at site 3 (Fig. 4). The leaf water potential of non-irrigated trees at site 9 went below −25 bars about July 1, site 6 a few days later with site 8 reaching −32 bars in late August while the remaining non-irrigated sites stayed at −26 bars or above (Fig. 5).

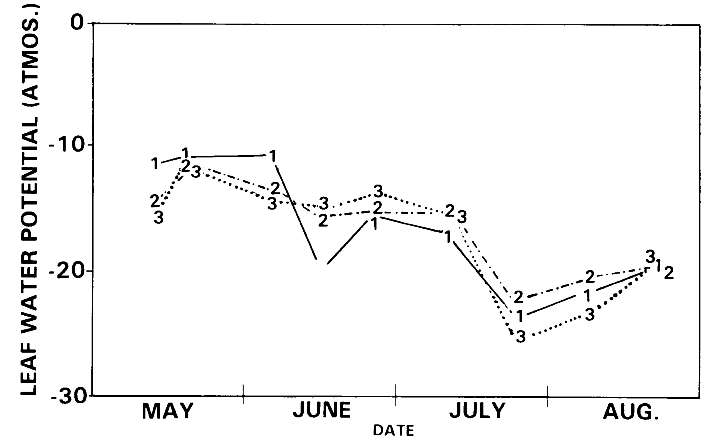

Fig. 4. Seasonal changes in leaf water potential, furrow-irrigated peach trees. Numbers represent sampling site (See Fig. 1).

c. Plant symptoms. Most of the leaves at site 9 had turned yellow as of August 6 and leaves were yellowing at site 6. Trees at these sites were about half defoliated by September 10 (Table 2). On October 8 normal leaf color change had begun on all plots while sites 6 and 9 still retained some leaves, which were changing color. By October 17 all the dry plots were well into leaf fall but the irrigated trees were just beginning to defoliate.

Fruit on trees at sites 6 and 9 stopped growing and shrivelled in early August. The irrigated trees produced a full crop of peaches that were normal sized for a non-thinned crop. Fruit on the irrigated "dehorned" trees (site 2) were very large but there were very few fruits per tree. Among non-irrigated trees, site 5 produced a few normal-sized fruits but the fruit failed to grow normally at all other sites. Even where size was acceptable the fruit were astringent, and the skin lacked red pigment.

Average shoot growth was 32-34 cm on irrigated trees, 21-24 cm on non-irrigated trees and as little as 12 cm at site 9, where trees became stressed the earliest (Fig. 5). Shoot

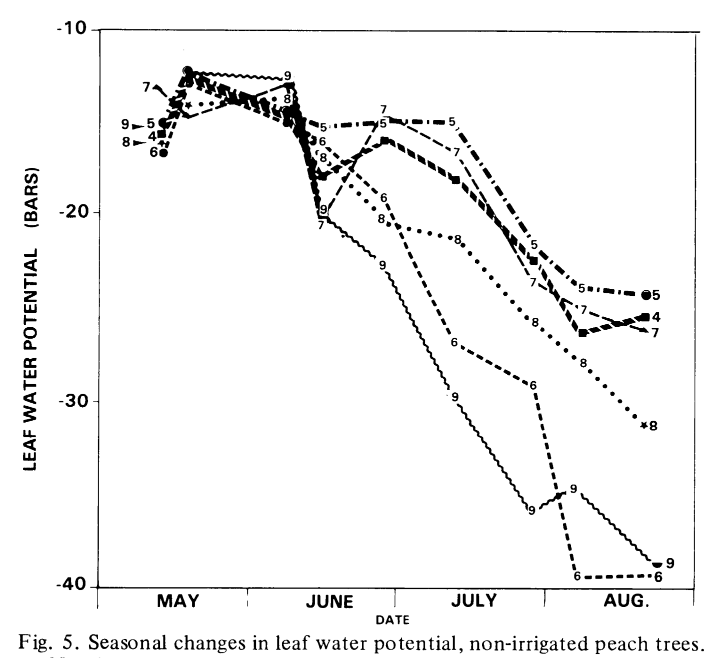

Fig. 5. Seasonal changes in leaf water potential, non-irrigated peach trees. Numbers represent sampling sites (See Fig. 1).

Table 2. Summary of soil moisture, leaf water potential, defoliation, fruit size, growth, flowering, yield and tree recovery at nine sampling sites, 'Elberta' peaches, 1977 and 1978.

Characteristic	Sampling site (*See* Fig. 1)								
	Irrigated			Non-irrigated					
	1	2	3	4	5	6	7	8	9
Soil and tree water status									
Avg soil moisture (%), July 28	12.5 b[z]	14.8 a	8.1 de	8.5 d	10.6 c	6.4 fg	10.1 c	7.3 ef	5.5 g
Leaf water potential (atmos), Aug. 8	−14.5 a	−20.6 ab	−23.6 ab	−26.4 abc	−24.3 abc	−39.0 d	−25.7 bc	−28.6 bcd	−34.6 cd
Tree condition									
Defoliation rating, Sept. 10	.5 b	0 b	0 b	0 b	0 b	6.7 a	1.0 b	0 b	7.5 a
Date defoliation started	Oct. 14 b	Oct. 20 b	Oct. 18 b	Oct. 12 b	Oct. 14 b	Aug. 30 a	Oct. 1 b	Oct. 10 b	Aug. 6 a
Fruit weight (g), 1977	141 bc	226 a	127 c	77 d	135 b	28 e	102 c	100 c	26 e
Avg shoot length (cm), 1977	32 a	––	34 a	23 b	––	21 b	24 b	––	12 b
Fruit buds/cm, 1977-78	.49 a	––	.55 a	.48 a	––	0 b	.26 a	––	0 b
1978 recovery									
Bloom density rating[x], 1978	5 a	5 a	5 a	4 a	4 a	0 b	4.5 a	0 b	0 b
Tree recovery rating[w], 1978	5 a	5 a	5 a	5 a	5 a	1.7 b	5 a	5 a	2.0 b
Yield (kg/tree), 1978	102 ab	70 b	143 a	87 ab	29 bc	0 c	72 b	0 c	0 c

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

[y]0=all green, 1=few yellow, 3=mod yellow, 5=all yellow, 6=20% defoliated, 8=60% defoliated, 10=100% defoliated, 5=normal bloom, 0=no bloom.

[x]5=normal bloom, 0=no bloom.

[w]5=normal tree, 0=dead tree.

growth was not measured on the "dehorned" trees but under irrigation was well over a meter long and many-branched. Without irrigation "dehorned" trees had less shoot growth than with irrigation but were still vigorous and branched. Fruit buds failed to develop at sites 6, 8 and 9.

In 1978, with full irrigation, the trees recovered and grew normally; however, in the area surrounding sites 6 and 9, many trees died. Because of the lack of bloom the surviving trees in areas 6, 8 and 9 bore no fruit. The "dehorned" trees all survived and grew well in 1978.

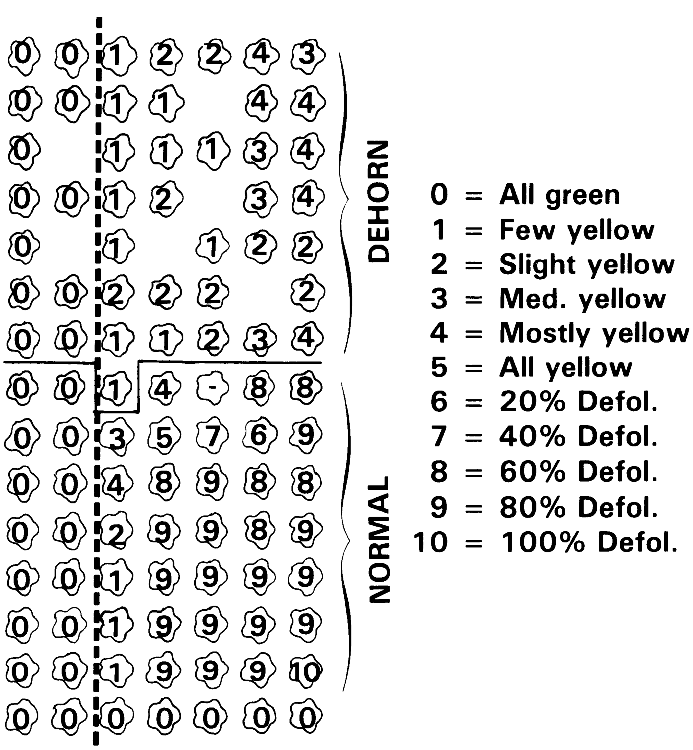

Fig. 6. Defoliation ratings, October 8, 1977, "dehorned" and lower dry plots, peaches.

2. Cultural practices

a. Pruning. "Dehorning" reduced the diameter of the tree canopy from about 5 m to about 2 m and the height from 4 m

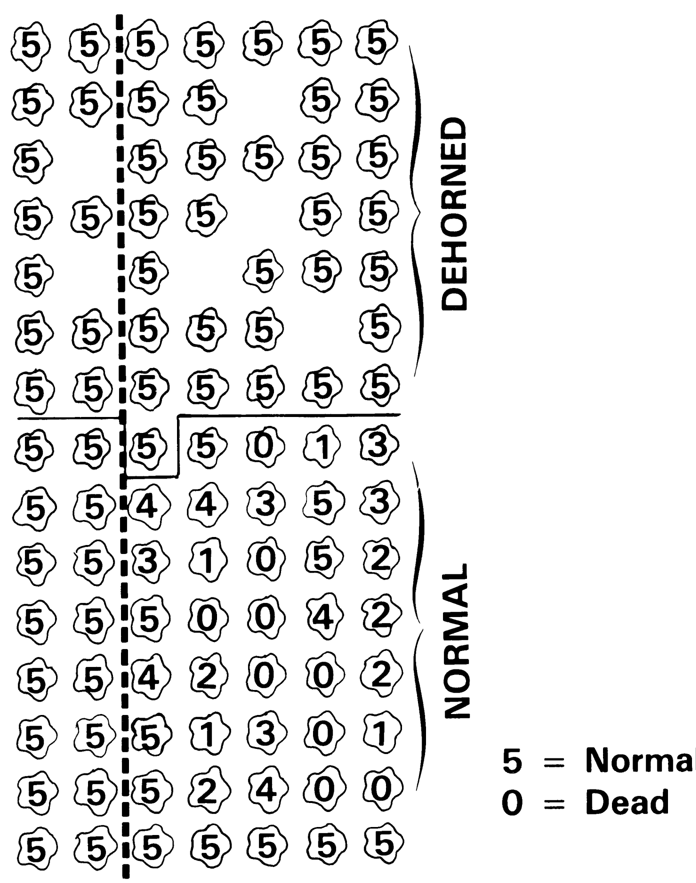

Fig. 7. Peach tree recovery rating, June 28, 1978, "dehorned" and lower dry plot.

Table 3. Effect of thinning non-irrigated peach trees on fruit size, defoliation, shoot length, fruitfulness, tree recovery and yield in the following year.

Characteristic	Treatment	
	Check	Thinned
Weight/fruit (g)	64	85*
Shoot length (cm)	17.0	17.2
Defoliation rating[z], Sept. 10	3.2	2.6
No. fruit buds/cm shoot	.19	.30*
Tree recovery rating[y]	3.4	4.4*
1978 yield (kg/tree)	38	68*

[z]Rating 2=slight yellow; 3=moderate yellowing of leaves.

[y]Rating 5=normal tree; 0=dead tree.

*Value differs from check at 5% level of significance.

to 1.5 m. Soil moisture was significantly higher in the "dehorned" plots (sites 2, 5, 8) than in the lower check plots (sites 3, 6, 9) but was not different from the upper check plots (sites 1, 4, 7) (Table 2; Fig. 2, 3).

Furthermore, the vigorous growth induced by "dehorning" appeared to resist drought injury. There was an abrupt discontinuity in defoliation on October 8 at the boundary between the "dehorned" block and the lower normally pruned block (Fig. 6). Fruit on these "dehorned" trees were of moderate size, late maturing, had little or no red pigment, and were

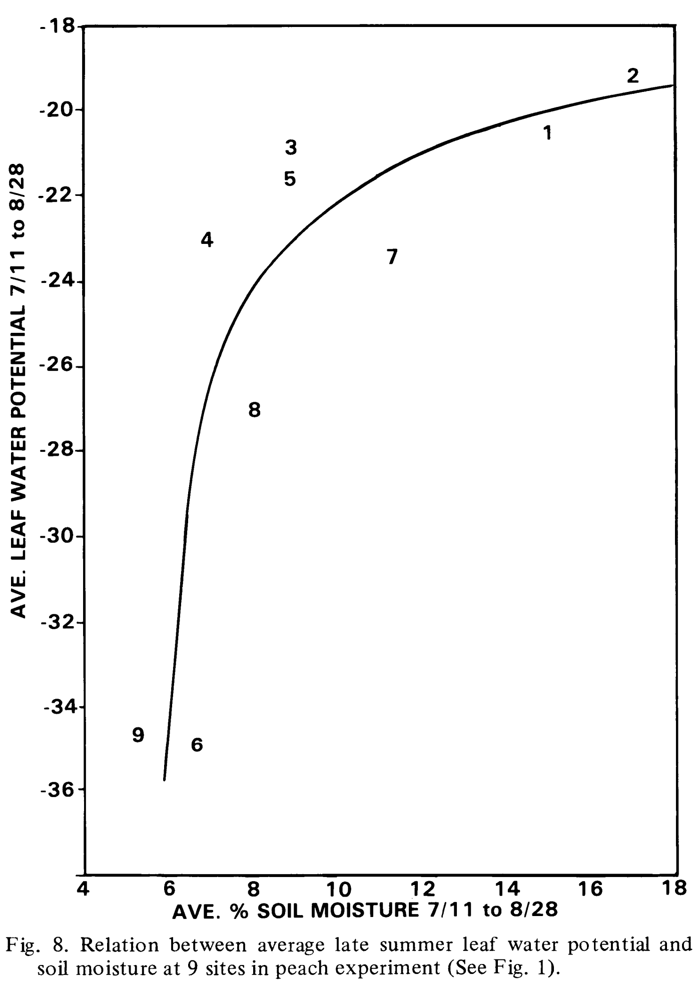

Fig. 8. Relation between average late summer leaf water potential and soil moisture at 9 sites in peach experiment (See Fig. 1).

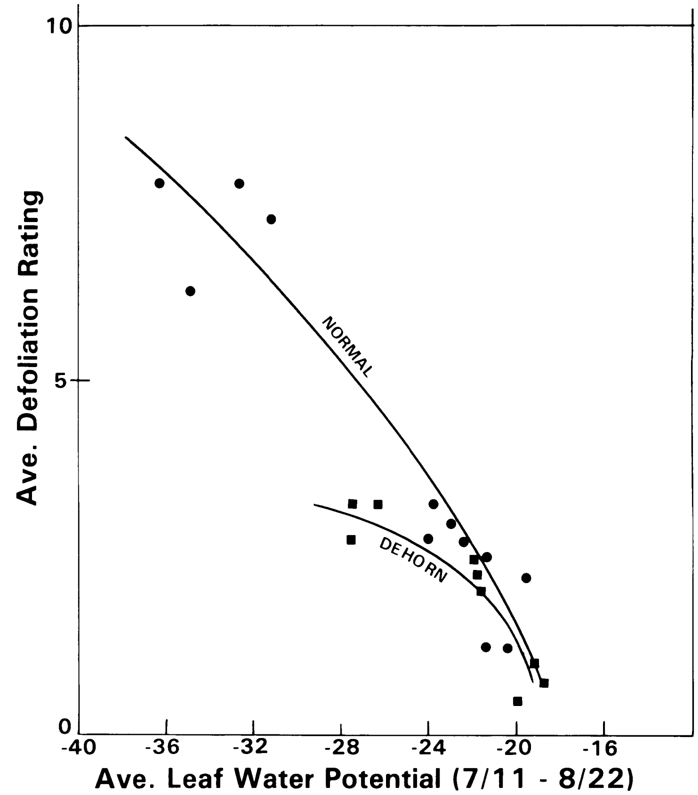

Fig. 9. Relation between leaf water potential and defoliation of peach trees as affected by pruning. Circles represent normally pruned trees, squares represent "dehorned" trees.

astringent. Some of these trees failed to produce blossom buds.

In June, 1978, all "dehorned" trees were in good condition and growing well. Most trees which had been pruned normally were damaged and many died (Fig. 7).

b. Thinning. Very heavy fruit thinning increased the size of drought-affected fruit (Table 3). Shoot length and defoliation were not affected. Heavy thinning of fruit apparently promoted tree survival. Fruitfulness and yield in 1978 were increased by fruit thinning.

3. Relationship among soil moisture, leaf water potential, and symptoms

The sequence of symptoms leading to death from drought began at about the time the entire rooting volume had nearly reached PWP. Leaf Ψ_w were between −25 and −27 bars and interior leaves began to turn yellow, wilt, and fall from the tree. At site 9 this occurred in late June and July, at site 6 in August. The trees that died were around sites 6 and 9, and most of the remaining trees in this area did not blossom in 1978.

Trees on which visible leaf senescence was delayed until early September all survived and bore a crop in 1978. Soil moisture at these sites reached PWP in late August or thereafter. Ψ_w remained above −27 bars.

In the "dehorned" trees soil moisture at site 8 approached PWP by August 1 and remained at that level throughout August. At site 5 the PWP was reached by September 1. Soil moisture declined steadily at both sites, reaching values of −32 and −25 bars respectively. Dehorned trees grew rapidly early in the season and, except trees near site 8, retained green leaves nearly until the normal time for defoliation. Trees near site 8, turned color in mid-September, 2 to 3 weeks earlier than normal.

Table 4. Defoliation and fruit condition in 1977 and cropping in 1978 of pear trees as affected by heavy pruning, with associated soil and plant water status.

Characteristic	Sampling		
	Check A	"Dehorn"	Check B
Soil and plant water status			
Avg. soil moisture (%) June 14 to Aug. 27	3.9 a[y]	5.2 b	4.3 a
Avg. leaf water potential (bars) May 24 to Aug. 15	−30.4 a	−21.8 b	−31.9 a
Plant condition			
Avg. defol. rating[z] Aug. 6	7.4 a	0 b	7.3 a
Sept. 10	8.6 a	0 b	8.4 a
Oct. 17	9.5 a	5.7 b	9.0 a
Mature fruit condition	Shrivelled	Normal	Shrivelled
Marketable yield	None	Slight	None
1978 cropping			
Yield (kg/tree)	46 a	41 a	78 a
Avg. fruit weight (g)	132 a	144 a	111 a

[z]0=green; 5=all leaves yellow; 6=20% defol.; 10=100% defol.
[y]Mean separation by Duncan's multiple range test, 5% level.

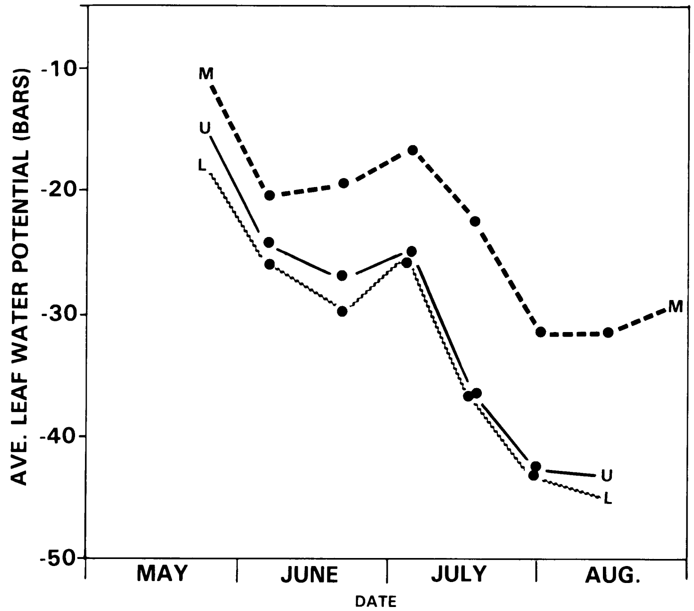

Fig. 10. Seasonal changes in leaf water potential, non-irrigated pear trees. U and L represent the upper and lower, normally pruned blocks; M represents the middle, "dehorned" block.

Leaf water potential decreased most rapidly when most of the available soil water had been depleted (Fig. 8). Defoliation of normally pruned trees during the period from July 11 to August 22 was highly correlated (r=.95) with Ψ_w (Fig. 9). Leaf water potentials of dehorned trees were typically lower than those of normally pruned trees at a defoliation rating of 3. This observation suggests that the vigorous growth induced by dehorning was more resistant to drought stress than was the less vigorous growth from normal pruning.

4. Pears

The pear trees responded to drought in a manner similar to the peaches. The sandy soil reached PWP by mid-June. Average soil moisture did not change significantly from June 14 to Aug. 27. Average soil moisture remained significantly higher in the "dehorned" block than in the two normally pruned check blocks (Table 4), and although leaf water potential decreased from May to August (Fig. 10), "dehorned" trees maintained significantly higher leaf water potential (Table 4). "Dehorning" apparently delayed development of injurious drought stress. This was reflected in a two-month delay in defoliation (Table 4). Very few pears were produced on "dehorned" trees because most of the fruitful wood was removed, but those that were produced matured normally whereas fruit on the check trees shrivelled and were not useable.

"Dehorned" 'Bartletts' produced flowers on 1-year-old wood in 1978; 'D'Anjou' did not. Trees that partially defoliated in the previous July bloomed erratically. On the trees that defoliated earliest bloom was reduced and delayed. Development of individual florets was retarded and bloom straggled. A partial crop was set and matured. Trees with the most severe drought symptoms in 1977 did not set a crop. "Dehorned" trees set very well but their bearing surface was much smaller than normally pruned trees.

Vegetative growth in 1978 was weak on the periphery of drought-injured trees. If vigorous growth occurred, it came from the trunk and lower portion of the main scaffolds. Such vigorous growth usually appeared on trees that were summer pruned or that had died back.

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