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Irrigation Management, Fruit Quality, and Storage Life of Apple

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Abstract. **'Delicious' and 'Golden Delicious' apples (*Malus domestica* Borkh.) on seedling rootstock were grown with trickle and sprinkler irrigation, both operated at high frequency of irrigation (daily). Trees with trickle irrigation developed lower leaf water potentials and produced less vegetative growth than trees with sprinkler irrigation, but fruit and productivity were similar. Apples from the trickle-irrigated trees had less water content and higher soluble solids than those from sprinkler-irrigated trees. Titratable acidity tended to be lower and both red color in 'Delicious' and yellow color in 'Golden Delicious' tended to be higher in fruit from trickle-irrigated trees than from sprinkled trees; firmness at harvest was similar regardless of irrigation procedure. Storage life was not influenced consistently by irrigation. Where differences did occur, the fruit from trickle-irrigated trees was softer after storage. Changes in fruit quality similar to those observed in trickle-irrigated trees were produced by imposing, through high frequency deficit irrigation with sprinklers, similar moisture deficits on apple trees, as measured by leaf water potential.**

Research on the response of fruit trees to water supply mainly has examined the question of how dry the soil should become before it is refilled with water by irrigation. Solid set systems allow daily replacement of all (nondeficit) or some fraction (deficit) of the water used the previous day by the orchard. This capability creates the opportunity to establish steady state conditions with respect to available soil moisture that can produce different levels of moisture deficit in the tree. Pomologists now can determine how trees respond to a particular water deficit applied during a given stage of the annual cycle of development and can use this information to influence tree performance through irrigation management.

High frequency (daily) deficit irrigation through a solid set trickle system, compared with minimum deficit, sprinkler irrigation, increased the percentage of dry matter and increased the soluble solids of 'Golden Delicious' apples (3), thereby modifying their processing characteristics. Trickle-irrigated 'Delicious' apple trees were more precocious in bearing and less vegetative than sprinkler-irrigated trees (11, 13). It was suggested that these trees could have responded either to a mild water deficit imposed over most of the growing season or to a reduced active root volume resulting from drying the soil at a distance from the trickle emitter (13).

It is generally agreed that fruit maturing under a moisture deficit are smaller (4, 6, 8, 10, 12, 14, 18), have lower water content (3, 6, 7, 12, 16) and higher soluble solids (1, 3, 11, 12) than fruit receiving ample water. Fruit from trees grown under low soil moisture were reported to have keeping quality and taste superior to fruit from trees grown under higher soil moisture (5).

The study reported here was directed toward defining the effect of a moderate water deficit in apple trees, maintained through most of the growing season, on several objective fruit quality measurements in relation to time of harvest and storage life.

Materials and Methods

This study was conducted in 1979, 1980, and 1981 using 'Delicious' and 'Golden Delicious' apple trees on seedling rootstock grown at the Washington State Univ. Irrigated Agriculture Research and Extension Center, Prosser, Wash. The trees were planted in 1973 at a spacing of 3.1 × 4.6 m in a Shano silt loam soil that averages 1 m in depth. The trees were sprinkler-irrigated (SI) or trickle-irrigated (TI).

Water was applied at a rate equal to 100% evaporation (E) from a class "A" pan. Sprinkler application rates were calculated on the basis of the total area of the orchard. Trickle applications were based only on the area under the tree canopies. The tree canopies completely filled the available space by 1981.

Soil samples were collected monthly to 1.5-m depth, 0.3 and 1.5 m from the trickle emitters, from under the tree canopy and in the middle between rows of SI and TI trees. Moisture was determined gravimetrically. Leaf water potential was measured at 1- to 3-week intervals on shaded leaves of 9 'Delicious' trees/treatment by the pressure bomb method (15). Leaf water potential was used to represent the moisture status of the trees in preference to soil moisture because of irregular distribution of soil moisture with trickle irrigation.

The SI and TI blocks were adjacent but not replicated. Water was applied within the TI block at 100%, 75%, and 50% E with 3 replications. All were under a water deficit compared with the SI trees and were evaluated together as the "TI plot." Half of the SI block was irrigated daily at 100% E, the other half every 2 weeks with full replacement of the water that had been used, as determined from soil samples collected 2 days before irrigating during 1979 and 1980. In 1981, the 100% E daily SI plot was changed to 75% E and the 2-week plot was changed to 100% E daily. These were under a lesser water deficit than the TI trees and were evaluated as the "SI plot."

High frequency deficit and nondeficit regimes were established in 2 SI orchards. Three years of data were collected, 2 years from one orchard, 1 year from the other. Nondeficit irrigation maintained the soil near or above field capacity. The

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deficit irrigation was at 75% E throughout the season in one orchard, at 50% E in June and July until 2/3 of the soil moisture was used, and then 100% E until harvest in the other orchard. Deficit irrigation affected the trees similarly in both orchards so the data were combined.

Starting on 14 Aug. 1979, and 9 June 1980, and continuing through 1 Oct. and 29 Sept., respectively, weekly fruit samples were harvested from the TI and SI plots and soluble solids, titratable acidity, and water content of the fruit were determined. The final harvest was 1 Oct. 1979. Fruit were harvested on 3 dates in 1980 and 1981 to evaluate the influence of maturity on fruit quality. Skin color, firmness, soluble solids, titratable acidity, and moisture were measured immediately after each harvest. Apples were stored at 1°C after harvest. The fruit were analyzed periodically during storage at 1° for 18 to 25 weeks. Sensory analyses were performed using prescribed procedures (1). The analysis of variance consisted of irrigation methods (2 levels) as the main plot, harvest time (3 levels), and storage time (4 levels) as the subplots. Since the irrigation plots were not replicated, treatment variances were compared to within plot variances.

The color of 10 apples was determined using an Agtron model E-5W reflectance spectrophotometer. A Food Technology Corp. Texture Test System equipped with a PT1 penetration test set and a 1.11-cm probe was used to measure the firmness of 10 whole, peeled apples. Soluble solids were determined on a blended composite of wedges from 30 unpeeled apples/treatment using a digital refractometer. Titratable acidity was determined for the same composite by titrating to an end point of pH 8.2 with 0.1 N NaOH and expressed as malic acid. Moisture was determined on this same composite by the AOAC vacuum method (2). Sensory analysis were determined by the procedures outline by Larmond (9) using wedges from unpeeled apples.

Results and Discussion

During the 3 years of this experiment, the tree canopy grew to fill the available space. As a result, the amount of water applied to the 100% E TI plots was increased from half that of the 100% E SI in 1979 to equal the 100% E SI in 1981 (Table 1). In all 3 years, the water application rates that were calculated from the tree canopy area and evaporation and were applied from a single emitter per tree were insufficient to maintain leaf water potentials as high as those of SI trees. The differential in leaf water potential was greatest in 1980.

The following were associated with a lower leaf water potential in the TI than in the SI plots: 1) less vegetative growth as represented by trunk area, 2) equal or higher yields, and 3) maintenance of fruit size. The TI trees yielded much more than the SI trees in 1980, which probably influenced quality differences.

The moisture content of the fruit was higher in the SI than in the TI plots (Table 2). The difference was highly significant in 1979 and 1981 but not in 1980, especially for 'Golden Delicious'. Soluble solids were always higher in the TI plots except for 'Golden Delicious' in 1980, probably due to the heavy fruit load. The difference in soluble solids between fruit from SI and TI trees was readily detectable by taste panel.

Acidity was less in the fruit from TI than SI tree but significant only in later harvests, 155 days after full bloom or later. Skin color, whether the red of 'Delicious' or the yellow of 'Golden Delicious' was usually higher with TI than SI. The difference in color was not significant in 'Delicious'. TI 'Golden Delicious' was significantly more yellow than for SI in 1979 and 1981 but not in 1980. Fruit firmness at harvest was not affected by treatment.

There was no interaction between harvest date and storage time in relation to the irrigation effect. Moisture content of the fruit did not change during storage (Tables 2, 3). Soluble solids increased during the early part of the storage period but there was no interaction between irrigation treatment and storage time. The pattern was the same for both cultivars.

Titratable acidity was significantly higher in SI 'Delicious' apples in 1979 and 1981 after storage (Table 3). The decrease in acidity of apples during storage was about the same whether they came from TI or SI plots. Red skin color did not change during storage of 'Delicious' regardless of irrigation treatment. Softening progressed at about equal rates for both treatments. TI 'Delicious' apples were softer than sprinkled after 25 weeks of storage in 1981.

Table 1. Amount of water applied, leaf water potential, trunk area, yield, and fruit size for 'Delicious' and 'Golden Delicious' apples under trickle and sprinkler irrigation.

Parameter	Year	Delicious		Golden Delicious	
		Trickle	Sprinkle	Trickle	Sprinkle
Water applied at 100% E (ha-cm/ha)	1979	45	91	45	91
	1980	50	68	50	68
	1981	95	89	95	89
Avg. leaf water potential (mPa)	1979	−1.70**	−1.32	---	---
	1980	−1.87**	−1.24	---	---
	1981	−1.59**	−1.20	---	---
Trunk area (cm^2)	1979	99**	125	88**	110
	1980	119**	164	114**	148
	1981	155**	202	130**	170
Yield (kg/tree)	1979	23	30	44*	60
	1980	63**	38	182**	49
	1981	44	31	---	---
Fruit size (g/fruit)	1979	204	213	172	204
	1980	181**	209	234	250
	1981	236	209	226	216

*,**Pairs differ at 5% (*) or 1% (**) level of significance.

Table 2. Trickle and sprinkler irrigation effects on objective fruit quality measurements of 'Delicious' and 'Golden Delicious' apples at harvest (average of 3 harvest dates).

Parameter	Year	Delicious		Golden Delicious	
		Trickle	Sprinkle	Trickle	Sprinkle
Fruit moisture content (%)	1979	78.8**	82.6	77.0**	82.6
	1980	82.8*	84.0	82.1	82.3
	1981	83.1**	84.6	83.2**	85.6
Soluble solids (%)	1979	14.1**	11.9	15.9**	13.7
	1980	12.0**	10.5	13.5	13.1
	1981	11.9**	10.3	13.3**	11.5
Titratable acidity (% malic)	1979	0.18	0.20	0.34	0.40
	1980	0.60	0.65	0.80	0.84
	1981	0.27	0.30	0.41	0.42
Skin color (E5W)	1979	92.9**	91.9	52.4**	49.6
	1980	92.4**	89.9	48.0	48.5
	1981	92.0	91.2	51.4**	48.4
Firmness (Newtons)	1979	50.3	49.8	53.8	51.2
	1980	91.5	88.4	78.0	86.3
	1981	70.0	75.2	55.7	54.8

*,**Pairs differ at 5% (*) or 1% (**) levels of significance.

Table 3. Trickle and sprinkler irrigation effects on objective fruit quality measurements of 'Delicious' and 'Golden Delicious' apples after cold storage (average of 3 harvests).

Parameter	Weeks in storage	Year	Delicious Trickle	Delicious Sprinkle	Golden Delicious Trickle	Golden Delicious Sprinkle
Fruit moisture content (%)	22	1979	80.1**	83.5	78.6**	82.7
	18	1980	82.5**	84.8	82.0	82.4
	25	1981	83.1*	84.2	83.0**	85.4
Soluble solids (%)	22	1979	16.3**	13.8	16.3**	14.0
	18	1980	14.6**	13.1	14.7	14.4
	25	1981	13.7*	12.8	13.8*	11.9
Titratable acidity (% malic)	22	1979	0.10**	0.17	0.19	0.25
	18	1980	0.33	0.38	0.46	0.53
	25	1981	0.15	0.20	0.19	0.19
Skin color (E5W)	22	1979	94.1	93.2	53.0*	51.9
	18	1980	90.8	89.7	52.9	52.3
	25	1981	91.8	91.5	55.0**	53.5
Firmness (Newtons)	22	1979	51.6	48.0	40.5	40.0
	18	1980	58.7	59.2	51.2	51.6
	25	1981	58.7*	68.1	48.5	43.1

*,**Pairs differ at 5% (*) or 1% (**) level of significance.

The tendency of fruit from TI plots to be higher in soluble solids, perhaps lower in titratable acidity and with more skin color at harvest suggests that the water deficit may advance maturity. A series of samples collected well before maturity in 1979 showed that soluble solids was already higher and moisture content lower 108 days after full bloom in fruit from TI compared with SI trees (Fig. 1). Fruit moisture differences in 1980 were significant on 3 of 4 dates after 101 days after full bloom. Soluble solids of apples from TI plots were significantly higher by 81 days after full bloom and highly significant by 101 days. Titratable acids were always slightly lower with TI than SI though not significantly. Red color of apples was developing by 101 days after full bloom in 1980 and was several days ahead on apples from the TI trees compared with SI trees.

Significant differences in leaf water potential were established during June each year, and maintained throughout the 1979 and

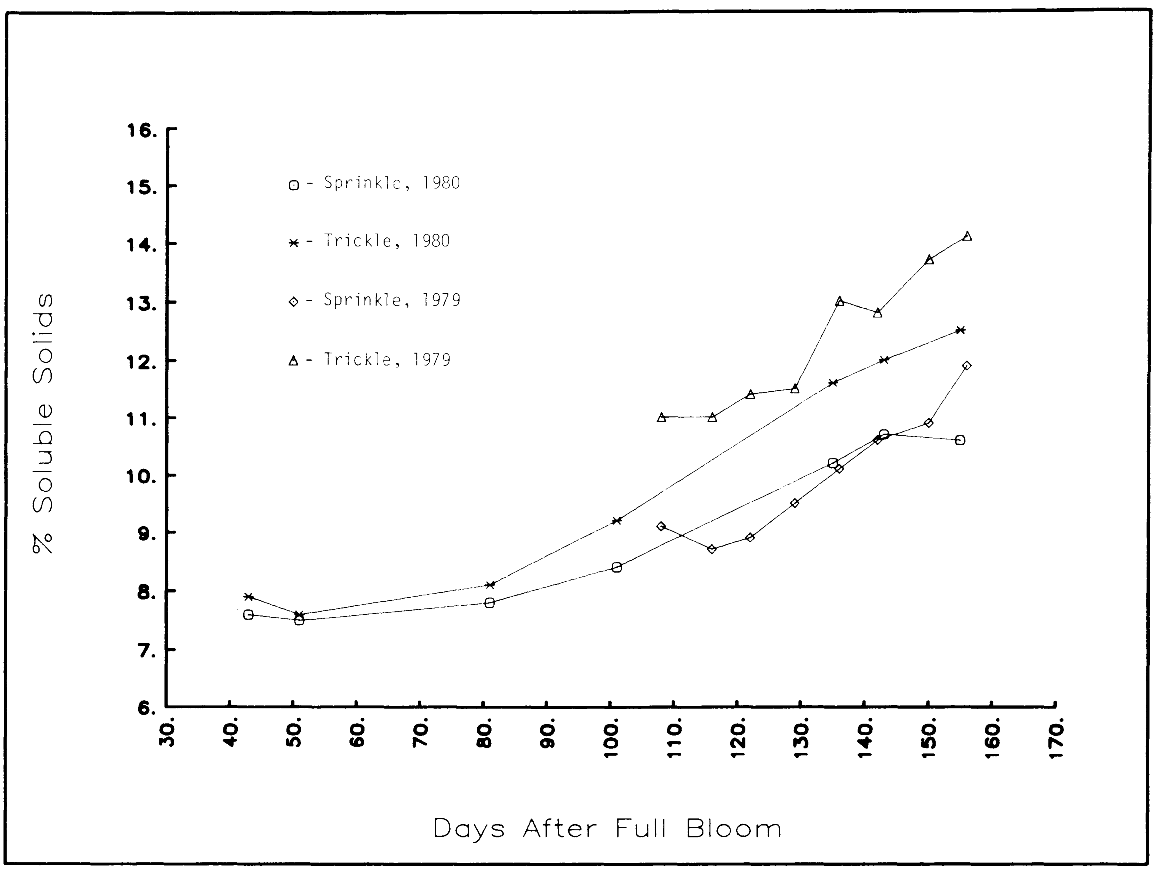

Fig. 1. Changes in soluble solids of 'Delicious' apples during maturation, as affected by water deficit in 2 years.

Table 4. Deficit and nondeficit sprinkler irrigation effects on objective fruit quality measurements of 'Delicious' and 'Golden Delicious' apples at harvest (average of 3 experiments).

Parameter	Delicious		Golden Delicious	
	Deficit	Nondeficit	Deficit	Nondeficit
Fruit moisture content (%)	82.7*	85.0	84.4*	86.0
Soluble solids (%)	12.5*	10.9	12.6*	10.8
Titratable acidity (% malic)	0.35	0.34	0.27	0.28
Skin color (E5W)	91.7	92.0	50.5	50.1
Firmness (Newtons)	84.2	86.1	50.5	50.1

*Pairs differ at 5% level of significance.

1980 seasons. Water deficits were established early enough in the season to be capable of inducing the quality differences seen in Fig. 1.

TI, as operated in this experiment, lowered leaf water potentials. Operated at deficit levels, TI also created large moisture gradients in the soil as moisture decreases to the permanent wilting percentage at a distance from the emitters and is near saturation immediately below the emitter. The dry soil may create large volumes of inactive roots on established trees, which may influence the physiology of the tree. It is difficult to separate the effects of water deficit and restricted active root zone on tree performances; therefore, water deficits were induced with SI in order to eliminate any factors associated with TI. Leaf water potential differences were established and maintained and the expected lower water content and higher soluble solids for the apples from the water deficit treatment were observed (Table 4), suggesting that the effects on fruit quality from TI trees result from water deficits.

It is clear that fruit from deficit-irrigated fruit trees, whether SI or TI, when compared with nondeficit-irrigated trees, had: 1) lower fruit moisture content, 2) higher soluble solids, 3) similar titratable acidity, color and firmness, 4) equal fruit size, and 5) equal storage life. Solid set irrigation systems operated at high frequency (daily) and at a slightly deficit level can be used to induce these fruit changes in a controlled manner.

Solid set irrigation systems open the possibility of greatly increased sophistication in irrigation of apples. High frequency deficit irrigation can be used to establish and maintain leaf water potentials within broadly defined ranges. Apple quality varies with the water status of the tree and can be controlled.

This information, taken with other data showing effects on precocity and growth control (11, 13), shows great promise for using modern irrigation technology to improve apple orchard management. Minimizing plant water deficits throughout the season, the predominant irrigation philosophy, may prove to be only one of several possible strategies for water management in apple orchards.

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