11. KenKnight, G. and J. H. Crow. 1967. Observations on susceptibility of pecan varieties to certain diseases at the Crow farm in DeSoto Parish, Louisiana. Proc. Southeastern Pecan Growers Assn. 60:48-57.
12. Littrell, R. H. and R. E. Worley. 1975. Relative susceptibility of pecan cultivars to fungal scorch and relationship to mineral composition of foliage. Phytopathology 65(6):717-718.
13. Madden, G. D. and E. J. Brown. 1975. Budbreak, blossom dates, nut maturity and length of growing season of the major varieties grown in the west. Pecan South 2(3):96, 97, 112, 113.
14. Mizel, R. F. and D. E. Schiffhauer. 1986. Larval infestations levels of pecan bud moth, *Gretchena boilinana* (Lepidoptera: Tortricidae), in relation to cultivar and position on the tree. Environ. Entomol. 15:436-438.
15. Sanderlin, R. S. 1987. Evaluation of pecan cultivars and USDA selections for scab disease susceptibility. Res. Rpt. Pecan Res-Ext. Sta. Louisiana Agr. Expt. Sta., Shreveport, La.
16. Sherman, W. B. and N. Gammon. 1977. Performance of pecan cultivars in north central Florida. Pecan South 4(1):38-40.
17. Sharpe, R. H., G. H. Blackmon, and N. Gammon, Jr. 1952. Relation of potash and phosphate fertilization to cold injury of Moore pecans. Proc. Southeastern Pecan Growers Assn. 45:81-85.
18. Smith, C. L. and L. D. Romberg. 1948. Pecan varieties and pecan breeding. Proc. Texas Pecan Growers Assn. 27:18-26.
19. Sparks, D. 1976. Nitrogen scorch and the pecan. Pecan South 3:500-501.
20. Sparks, D. 1992. Abnormal flowering in pecan associated with freezing temperature. HortScience. 27:801-803.
21. Sparks, D. 1992. Pecan cultivars—the orchard's foundation. Pecan Production Innovations. Watkinsville, Ga.
22. Sparks, D. and G. D. Madden. 1985. Pistillate flower and fruit abortion in pecan as a function of cultivar, time, and pollination. J. Amer. Soc. Hort. Sci. 110:219-223.
23. Sparks, D. and J. A. Payne. 1977. Freeze injury susceptibility of non-juvenile trunks in pecan. HortScience 12:497-498.
24. Sparks, D. and J. A. Payne. 1978. Winter injury in pecans—A review. Pecan South. 5(2):56-60, 82-88.
25. Sparks, D. and I. Yates. 1990. Pecan cultivar susceptibility to sooty mold related to leaf surface morphology. J. Amer. Soc. Hort. Sci. 116(1):6-9.
26. Woodroof, J. G. and E. K. Heaton. 1961. Pecans for processing. Georgia Agr. Expt. Sta. Bul. 80.
27. Worley, R. E., O. J. Woodard, and B. Mullinix. 1983. Pecan cultivar performance at the Coastal Plain Experiment Station. Univ. Georgia Agr. Expt. Sta. Res. Bul. 295.

Fruit Varieties Journal 51(1):7-12 1997

Irrigation Management Influence on Fruit Quality and Storage Life of 'Redspur' and 'Golden Delicious' Apples

S. R. DRAKE[1] AND R. G. EVANS[2]

Abstract

During three crop seasons 'Redspur Delicious' apps (*Malus domestica*, Borkh) from furrow irrigated plots had more red color and lower soluble solids content (SSC) than trickle irrigated apples. 'Golden Delicious' from furrow irrigated plots were larger, softer and had lower SSC than apples from trickle irrigated plots. No carbohydrate or mineral differences were evident for 'Redspur' or 'Golden Delicious' from furrow or trickle irrigation treatments. No other fruit quality differences were apparent between trickle or deficit-trickle irrigation treatments. Fruit quality losses occurred with both cultivars during storage, but losses were not related to irrigation type. Good quality fruit was produced with all irrigation procedures, even under limited water.

Introduction

Fruit grown in semi-arid regions of the world generally require supplemental irrigation to supply water needs. Water supplies in these regions can vary greatly from year to year and insufficient supplies are not uncommon. Restricted supplies require care-

[1]Research Horticulturist, USDA, ARS, TFRL, 1104 N. Western Ave., Wenatchee, WA 98801.
[2]Agriculture Engineer, WA State Univ., IAREC, 24106 N. Bunn Rd., Prosser, WA 93350.

ful water management to produce quality fruit.

Fruit quality can be manipulated with water management. Mild water stress can reduce fruit size, increase soluble solids and color development, and advance physiological maturity of the fruit (2, 3, 4, 5, 6, 7, 8, 10, 12). Reports of differences in fruit firmness and titratable acidity as a result of water management provide conflicting results. Some reports (1, 8, 9) suggest that firmness is decreased with restrictive levels of irrigation, but others (2, 13) suggested that irrigation level had no effect on firmness. Acid content of apples can either be increased or decreased with the use of deficit irrigation (2, 8, 9, 13), as is the case for storage quality (8, 9).

This conflicting information requires development of better understanding of the effect of water management on apple quality and storage life. Water management is now one of the critical issues in apple production, and water shortages will increase in importance in the future. The objective of this study was intended to help define the influence of ample vs. deficit water management on apple quality and storage life in relation to time of harvest.

Materials and Methods

This study was conducted over 3 crop seasons using 'Redspur Delicious' on MM.106 rootstock and 'Golden Delicious' on M.26 rootstocks grown at the Washington State University, Irrigated Agriculture Research and Extension Center, Prosser, WA. Trees were planted in 1976 at a spacing of 5.5 x 5.5 m in a Warden fine sandy loam that averaged 1.1 m in depth. Field capacity (FC) was 28% by volume, and permanent wilting point was 8.4% by volume. Irrigation treatments superimposed over the block were: 40 trees of furrow irrigation (F), 36 trees of trickle irrigation (T) and 42 trees of deficit trickle irrigation (DT). Average annual precipitation in this region is 190 mm, of which 50 mm falls May through September.

The furrow irrigation (F) treatment consisted of 2 rows of trees in the block that were irrigated every 2 weeks for 24 hrs via furrows 45 cm apart (~800 mm/yr). At each irrigation, the entire soil surface from the bottom of the furrow to the top of the crown between furrows was wetted. The remaining rows of the block were divided into 2 trickle irrigation treatments with 4 emitters per tree spaced 1 m apart in a box configuration.

Both trickle irrigation treatments were scheduled using a U.S.W.B. class "A" evaporation pan (0.80 pan coefficient). One irrigation treatment (T) was irrigated at 100% E all season each year (~450 mm/yr). In the second treatment (DT), irrigation was withheld until mid-July or August each year and then restored by trickle irrigation at 100% E (~400 mm/yr). Each trickle irrigation treatment consisted of 3 groups (replication) of 3 trees each per cultivar.

Fruit were harvested at recommended commercial harvest (16) and 10 days later for the three crop seasons. Samples from the (F) irrigation treatment were taken from three selected trees in a row of uniform size and crop load. The middle tree in each three tree irrigation group (T and DT) was selected for sampling. At each of two harvest, 40 uniform fruit from each cultivar, irrigation treatment and replication were taken. Twenty fruit were used for each evaluation, at harvest (0 days), and after 120 days in regular atmosphere storage at 1° C. At harvest, fruit quality was determined immediately on 10 fruits, and 10 fruits were evaluated for shelf life after 7 days at 20° C. After storage for 120 days 10 fruit were evaluated immediately and 10 fruit after 7 days at 20°. Fruit flesh was analyzed for minerals, carbohydrates, firmness, soluble solids content (SSC), titratable acidity and external fruit color, as described previ-

ously (3). We performed analysis of variance (ANOVA) using SAS (SAS Institute, Cary, NC) as a factorial design. Irrigation treatments (3 levels), harvest time (2 levels), storage time (2 levels) as the subplots and years (3) were used as replication (this was done using the means of 3 trees per treatment group each of 3 years). Based on significant F tests, means were separated by the Waller-Duncan range test.

Results and Discussion

Irrigation influenced the color of 'Delicious' apples (Table 1). 'Delicious' grown with (F) irrigation had lower Hunter L and b values and higher a values than apples grown with (T) irrigation, and (DT) irrigated apples had intermediate color values. Hue values indicated that (F) and (DT) fruit had more red color than (T) fruit (13% and 23% respectively).

It seems contradictory that apples grown with the most (~800 mm/yr) and least (~400 mm/yr) water had the best red color, as indicated by the hue values. An earlier study (13) suggested that trickle irrigation produced redder apples than sprinkle irrigated apples when water was applied at a rate equal to 100% evaporation (E) for both types of irrigation. In this study, the extremes (F) and (DT), one with excessive water use and the other with minimal water use, produced apples with better red color than (T) irrigation applied at 100% (E). It should be noted that in this study, water was applied at ground level and not overhead where the cooling effect of water has been shown to influence red color development. Harvest timing or cold storage had no influence on the color of 'Delicious' apples, and no interactions between treatments were observed.

When removed from refrigerated storage and held for 7 days at 20° C (ripening time), the Hunter a and b values of 'Delicious' apples were reduced regardless of the type of irrigation used. However, there was no change in either Hunter L or hue values.

Irrigation and harvest date had no influence on the color of 'Golden Delicious' apples (Table 1). During 120

Table 1. Color during three crop seasons in Washington State of 'Delicious' and 'Golden Delicious' apples as influenced by irrigation type, harvest, storage and ripening time.

Variable	Hunter Color							
	L	a	b	hue	L	a	b	hue
	'Delicious'				'Golden Delicious'			
Irrigation								
Trickle	43.9 a[z]	19.9 b	13.3 a	34.2 a	72.7 a	-5.0 a	34.8 a	98.6 a
Deficit-Trickle	41.3 ab	21.2 ab	12.2 ab	30.2 b	73.3 a	-5.2 a	35.05 a	98.8 a
Furrow	40.4 b	21.8 a	11.5 b	27.9 b	73.4 a	-5.3 a	34.7 a	98.9 a
Harvest								
I	42.7 a	21.5 a	12.7 a	32.3 a	73.7 a	-5.0 a	35.0 a	99.0 a
II	41.0 a	20.4 a	12.0 a	29.2 a	72.6 a	-5.3 a	34.6 a	98.4 a
Storage (days)								
0	42.1 a	21.6 a	12.4 a	31.6 a	73.8 a	-7.1 b	33.9 b	102.1 a
120	41.6 a	20.3 a	12.2 a	29.8 a	72.5 a	-3.2 a	35.8 a	95.3 b
Ripe (days)								
0	42.3 a	21.6 a	13.1 a	31.4 a	74.7 a	-7.0 a	33.2 a	102.0 a
7	41.4 a	20.3 b	11.6 b	30.3 a	71.5 b	-3.2 b	36.4 b	95.5 b

[z]Means in a column within irrigation, harvest, storage period or ripening time not followed by a common letter are significantly different ($P \geq 0.05$).

days storage and 7 days of ripening, 'Golden Delicious' became less green (smaller "a" values) with pronounced increase in yellow color (higher b values). Considering hue values, there was a distinct shift from green to yellow color. Depending on the market, there is a distinct preference for green or yellow 'Golden Delicious,' and this market preference should be considered for best return.

Irrigation had no influence on the firmness of 'Delicious,' but there was a difference in the firmness of 'Golden Delicious' due to irrigation (Table 2). 'Golden Delicious' apples grown under (T) or (DT) irrigation were 10 to 13% firmer than apples grown under (F) irrigation. Larger apples are generally considered to be less firm than smaller apples of the same maturity. Apples grown under (F) irrigation in this study were larger than those grown under (T) or (DT) irrigation (187 g as compared to 131 g and 163 g respectively for 'Golden Delicious,' and 214 g as compared to 162 g and 204 g for 'Delicious'). Historically larger apples demand a higher price than smaller apples, but smaller apples grown under low soil moisture have better keeping quality (8). Harvest date had no effect on the firmness of 'Delicious' but 'Golden Delicious' firmness was reduced 8% with a 10 day delay in harvest.

Firmness of both 'Delicious' and 'Golden Delicious' was lost during storage and ripening. This loss of firmness in storage for 'Delicious' would not be considered serious. After 120 days of storage, firmness values for 'Delicious' were well in excess of the minimum firmness requirement (54N) for apples (15). During 120 days of storage 'Delicious' lost 7.5% of their original firmness; whereas 'Golden Delicious' lost 36%. Storage for 120 days resulted in a major loss in firmness for 'Golden Delicious' regardless of irrigation treatment. Firmness loss of this magnitude would seriously reduce consumer acceptance of apples in this condition. During ripening, firmness loss for 'Delicious' was accelerated, but 'Golden Delicious' lost very little of their firmness during 7 days of ripening.

Table 2. Firmness, soluble solids content, and titratable acidity during three crop years in Washington State of 'Delicious' and 'Golden Delicious apples as influenced by irrigation type, harvest, storage and ripening time.

	Firmness (N)		Soluble Solids Content (%)		Titratable Acidity (@% Malic)	
Variable	Del	GD	Del	GD	Del	GD
Irrigation						
Trickle	64.1 a	68.0 a	13.6 a[z]	14.6 a	0.18 NS	0.34 NS
Deficit-Trickle	62.7 a	66.5 a	13.5 a	14.5 a	0.19	0.34
Furrow	62.9 a	60.5 b	12.7 b	13.1 b	0.19	0.37
Harvest						
I	64.1 a	67.6 a	13.4 a	14.3 a	0.19 a	0.37 a
II	62.4 a	62.3 b	13.1 a	13.9 a	0.18 a	0.34 b
Storage (days)						
1	65.5 a	74.9 a	13.9 a	14.1 a	0.20 a	0.44 a
120	60.9 b	55.0 b	12.6 b	14.0 a	0.17 b	0.26 b
Ripe (days)						
0	68.2 a	67.3 a	13.8 a	14.4 a	0.20 a	0.38 a
7	58.2 b	62.7 b	12.8 b	13.8 a	0.18 b	0.32 b

[z]Means in a column within irrigation, harvest, storage or ripening time not followed by a common letter are significantly different ($P \geq 0.05$).

Table 3. Carbohydrate content during three crop years in Washington State of 'Delicious' and 'Golden Delicious apples as influenced by irrigation type, harvest, storage.

	Carbohydrates (g/100 mls)							
	Sucrose		Glucose		Fructose		Sorbitol	
Variable	Del	GD	Del	GD	Del	GD	Del	GD
Irrigation								
Trickle	2.0 ab[z]	2.8 a	1.9 a	2.2 a	5.2 a	2.6 a	0.34 ab	0.48 a
Deficit-Trickle	1.7 b	2.7 a	2.0 a	2.0 ab	5.1 a	2.6 a	0.30 b	0.49 a
Furrow	2.1 a	2.9 a	2.0 a	1.8 b	5.2 a	2.7 a	0.35 a	0.43 a
Harvest								
I	2.3 a	3.3 a	2.2 a	2.3 a	5.6 a	3.1 a	0.37 a	0.56 a
II	1.6 b	2.2 a	1.8 a	1.7 b	4.8 b	2.1 b	0.29 b	0.37 b
Storage								
0	2.3 a	3.2 a	2.1 a	2.4 a	5.4 a	3.0 a	0.36 a	0.58 a
120	1.6 b	2.4 a	1.9 a	1.7 b	4.9 b	2.2 b	0.30 b	0.35 b

[z]Means in a column within irrigation, harvest, or storage not followed by a common letter are significantly different ($P \geq 0.05$).

Both 'Delicious' and 'Golden Delicious' apples grown under (T) or (DT) irrigation had higher SSC than apples grown under (F) irrigation, with differences of as much as 6.3% for 'Delicious' and 10.6% for 'Golden Delicious.' Previous reports showing that fruit grown under moisture deficit have higher SSC (1, 2, 11) agree with our study. The higher the SSC the more valuable the fruit becomes. Time of harvest had no influence on the SSC of either cultivar. There was a distinct drop in SSC for 'Delicious' during storage and ripening, but no differences were apparent for 'Golden Delicious.'

Irrigation did not influence titratable acidity in either cultivar. Later harvest caused a loss of titratable acidity for 'Golden Delicious,' but not 'Delicious.' Both cultivars lost acid content during storage and after ripening.

'Delicious' apples grown under (F) irrigation had a higher sucrose and sorbitol content than apples grown under (DT) irrigation (Table 3). Other researchers (12) have reported increased sorbitol in apples grown under water deficit. 'Delicious' grown under (T) irrigation was intermediate in sucrose and sorbitol content between apples (F) or (DT) irrigation. Irrigation had little influence on carbohydrates in 'Golden Delicious.'

There was a reduction in sucrose, fructose and sorbitol in 'Delicious' apples and glucose, fructose and sorbitol in 'Golden Delicious' apples with later harvest and storage time. No change in the sucrose content of 'Golden Delicious,' or glucose content of 'Delicious' due to harvest or storage time was evident. The values for total carbohydrates in this study do not agree with the values for SSC (Table 2), a difference not entirely unexpected. The individual sugars were determined using non-enzyme treated juice, and their total would be 5 to 15% lower in value than SSC. SSC includes values for oligosaccharide and starch that cannot be determined on non-enzyme treated juice.

Irrigation had no influence on the flesh Ca, Mg, P, K or N content of either 'Delicious' or 'Golden Delicious' (data not shown). Even though there was no difference in Ca content between apples from the 3 irrigation treatments, visual symptoms of bitter pit were much more frequent in the apples from the (F) irrigation treat-

ments. This could possibly be due to fruit size which tended to be large in the (F) treatment than in other treatments. A more likely reason may be water variability as a result of furrow irrigation or alternate wetting and drying of the soil (14). Increased Ca has been reported (12) in apples grown under water deficit.

Mineral content of 'Delicious' apples remained constant during storage with no apparent loss (data not shown). 'Golden Delicious' had less Mg and N after 120 storage than at harvest but had no other mineral content differences due to storage.

Conclusions

Good quality fruit can be produced using considerably less water than commonly used. Color, particularly of 'Delicious' apples, can be changed by irrigation management. 'Delicious' apples grown under (F) and (DT) irrigation were redder than apples grown under (T). This difference in color was significant and could be used as a marketing technique and would be recognized by the consumer. This color difference could result in a higher grade for 'Delicious' apples grown under (F) and (DT) irrigation than if grown under (T). Color of 'Golden Delicious' was not affected by irrigation type. Both, 'Delicious' and 'Golden Delicious' grown with either (T) or (DT) irrigation had higher SSC which would increase their consumer acceptance. It should be noted that fruit from trees on rootstocks more sensitive to dry soils than MM.106 may react differently than in this study.

Although quality differences were evident for apples grown under different irrigation treatments or amounts of water, quality fruit can be produced even with procedures using considerably less water than is currently practical. Time of harvest, storage and ripening influence apple quality to a much greater degree than any irrigation method used in this study.

Literature Cited

1. Assaf R., I. Levin and B. Bravado. 1975. Effect of irrigation regimes on trunk and fruit growth rates, quality and yield of apple trees. J. Hort. Sci. 50:481-493.
2. Drake, S. R., E. L. Proebsting, Jr., M. O. Mohan and J. B. Thompson. 1981. Influence of trickle and sprinkle irrigation on 'Golden Delicious' apple quality. J. Amer. Soc. Hort. Sci. 106:255-258.
3. Drake, S. R., F. E. Larsen, J. K. Fellman and S. S. Higgins. 1988. Maturity, storage quality, carbohydrates and mineral content of 'Goldspur' apples as influenced by rootstock. J. Amer. Soc. Hort. Sci. 113:949-952.
4. Ebel, R. C. 1985. Postharvest physiology of 'Delicious' apples grown under deficit irrigation. Master's thesis, Washington State Univ., Pullman, WA.
5. Ebel, R. C. 1991. Apple tree and fruit response to drought stress. Ph.D. Thesis, Washington State Univ., Pullman, WA.
6. Ebel, R. C., E. L. Proebsting and R. G. Evans. 1995. Deficit irrigation to control vegetative growth in apple and monitoring fruit growth to schedule irrigation. HortSci. 30:1229-1231.
7. Evans, R. G., E. L. Proebsting, S. R. Drake and M. O. Mahan. Water deficit effects on apple quality and maturity. Amer. Soc. Agric. Eng. paper no. 85-2601.
8. Gueltat-Reich, S., R. Assof, B. A. Broudo and I. Levin. 1974. The keeping quality of apples in storage as affected by different irrigation regimes. J. Hort. Sci. 49:217-225.
9. Haller, M. H. and P. L. Harding. 1937. Relation of soil moisture to firmness and storage quality of apples. Proc. Amer. Soc. Hort Sci. 35:205-211.
10. Landsberg, J. J. and H. G. Jones. 1981. Apple orchards, p. 419-469. In: Water deficits and plant growth. T.T. Kozlowski (ed.) Vol. VI. Academic Press, New York.
11. Middleton, J. E., E. L. Proebsting and S. Roberts. 1979. Apple orchard irrigation by trickle and sprinkle. Trans. Amer. Soc. Agr. Eng. 22:582-584.
12. Mills, T. M., M. H. Behboudian, P. Y. Tan and B. E. Clothier. 1994. Plant water status and fruit quality in apples. Hortsci. 29:1274-1278.
13. Proebsting, E. L., S. R. Drake and R. G. Evans. 1984. Irrigation management, fruit quality and storage life of apple. J. Amer. Soc. Hort. Sci. 109:229-232.
14. Raese J. T. 1995. Personnal communication. USDA, ARS, Tree Fruit Research Lab., Wenatchee, WA 98801.
15. Washington Agriculture code 16-690-015. Fruit Storage 31 March 1989.
16. Washington Apple Maturity Handbook 1993. Washington apple maturity program, Wenatchee, WA 98801.