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Long-Term Fruit Yield and Quality of Various Gala Apple Strain-Rootstock Combinations under an Evapotranspiration-Based Drip Irrigation System

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ABSTRACT

In a long-term study in 'Gala' apple (*Malus* × *domestica* Borkh) between 2004 and 2007, fruit yield and physical quality attributes (fruit weight, skin red color, and incidences of splitting and russeting) of five strains ('Pacific', 'Gale', 'Brookfield', 'Treco Red #42' and 'Buckeye') on RN29 rootstock and four strains ('Scarlet', 'Royal', 'Ultima' and 'Crimson') on Bud9 rootstock were examined under a drip irrigation system using crop evapotranspiration (ETc) adjusted by the percentage of ground shade. The strain-rootstock combinations used in this study represent the most commonly planted 'Gala' trees in the United States apple industry. 'Pacific', 'Brookfield', 'Treco' and 'Buckeye' strains (all on RN29 rootstock) had higher fruit yield in most years, resulting in significantly higher cumulative yields than 'Scarlet', 'Royal', 'Ultima' and 'Crimson' strains on Bud9 rootstock. 'Brookfield', 'Treco', 'Gale', 'Buckeye' on RN29 rootstock had similar average fruit weights and their weights were often higher than those in 'Scarlett', 'Royal', and 'Ultima' on Bud9 rootstock. 'Buckeye' and 'Gale Gala' fruits had higher visual red color ratings compared to the other strains every year. Considering all yield and quality attributes, we recommend 'Buckeye' and 'Gale' strains on RN29 rootstock under climate conditions of Intermountain west region of the USA. With a drip irrigation system, each young tree received an average of 2921 L (449 mm) and each mature tree received and average of 3996 L (614.1 mm) of water per growing season.

Keywords: drip irrigation, fruit color, fruit size, Gala strains
Abbreviations: GS, aground shading; **SSC**, soluble solids concentration

INTRODUCTION

The constant increase in world population and decrease in availability of irrigation water mandate a more efficient use of water in agriculture. Merging new orchard designs with a high-coloring strain of an apple cultivar and a more efficient irrigation system can result in production of higher yield with better fruit quality, and consumption of less water (Behboudian *et al.* 2005; Fallahi *et al.* 2007a, 2007b; Naor *et al.* 2008; Neilsen *et al.* 2010).

'Gala' apple has gained special popularity among consumers and fruit growers in the major producing or exporting areas of the world. Consumer acceptance is determined by fruit color, size, eating quality and texture (Crassweller and Hollender 1989; Fisher and Ketchie 1989; Salveit 1983; MacFie 1995; Harker 2001; Donati *et al.* 2003). Nevertheless, poor color can drastically reduce the value of apples even if they have acceptable fruit size (Crassweller and Hollender 1989; Baugher *et al.* 1990; Iglesias and Alegre 2006). Apple fruits color best in climates with clear bright days and cool nights during the preharvest period (Westwood 1993). Acceptable commercial fruit color development at harvest is often a major problem for 'Gala' apple growers in the Intermountain west region of the USA, including Washington, Idaho, Utah, Colorado and Oregon, and other regions where night-time temperatures during maturity are too high (Fallahi, pers. obs.) for suitable red color development (Iglesias and Alegre 2006). As a result, apple growers often delay harvest to attain better color. This practice, particularly under a high nitrogen regime, can lead to higher respiration and endogenous ethylene production, lower firmness, and shorter storage life (Fallahi *et al.* 1985a).

The consumer acceptability of red or bicolored apples such as 'Gala', 'Fuji', and 'Delicious' is determined mainly by their visual appearance. Formation of red color in apple is influenced by light (Tan 1980; Saure 1990; Arakawa 1991; Lancaster 1992), temperature (Blankenship 1987; Faragher 1993), cultivar (Arakawa 1988; Curry 1997; Dickinson and White 1986; Iglesias 1996; Iglesias *et al.* 1999), and strains (Iglesias *et al.* 2008). Different cultural techniques are practiced to promote anthocyanin synthesis and color improvement in 'Gala' apples, including fruit bagging (Arakawa *et al.* 1988), evaporative cooling by sprinkler irrigation to reduce fruit temperature (Williams 1993; Iglesias *et al.* 2005), and the use of the reflective film to increase the intensity of light into the tree canopy (Ju *et al.* 1999). However, the high cost of many of these practices mandates planting high-coloring strains.

Most of today's red-skinned cultivars are developed by apple-breeding programs (Sansavini *et al.* 2005), but the majority of highly colored strains are identified based on visual and/or physiological changes that occur on a limb of the original cultivar tree (limb mutations) such as 'Gala', 'Delicious' or 'Fuji'. These mutants could show some reversions as a result of a lack of stability (Lacey and Campbell 1987; White and Johnstone 1991; White *et al.* 1994). Since environmental factors such as temperature (Blankenship 1987) and cultural practices such as method of irrigation (Williams 1993; Iglesias *et al.* 2005) can affect apple fruit color, the performance of various strains of apples needs to be evaluated in each apple-growing region. Kappel *et al.* (1992) studied sensory characteristics for four strains of 'Gala' apple ('Imperial', 'Kidd's D-8', 'Regal',

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and 'Royal') under climatic conditions of Summerland, British Columbia in Canada, and found no significant difference in taste or texture. However, significant differences in visual attributes were found among the strains. In that study, 'Imperial Gala' had the greatest portion of its skin covered by red blush and Kidd's D-8 had the least (Kappel *et al.* 1992). In a similar study in Massachusetts, quantitative differences in red color among five 'Gala' strains ('Kidd's D-8', 'Royal', 'Scarlet, 'Imperial', and 'Regal') were not consistent (Greene and Autio 1993). In that study, 'Royal', 'Scarlet, and 'Regal' were more desirable and had better flavor than other strains. In an extensive study, differences in color development among eight strains of 'Gala' were studied in northeastern Spain (Iglesias *et al.* 2008). In that report, 'Royal Beaut', 'Buckeye Gala' and 'Ruby Gala' had developed the highest color, 'Brookfield' and 'Schniga' had an intermediate color, while 'Galaxy' and 'Mondial Gala' had the least color. Color development increased 2 weeks before commercial harvest and continued until after harvest.

Fruit quality attributes such as weight, titratable acidity (TA), starch degradation pattern (SDP) and soluble solids concentration (SSC) are some times measured in junction with fruit color in 'Gala' apple evaluation. Fallahi *et al.* (2007b) studied quality attributes of 'Pacific Gala' and reported that both rootstock and method of irrigation can have a major impact on fruit size, SDP, color, and SSC. In a study by Iglesias *et al.* (2008), fruit size, yield, fruit firmness, SSC, TA, and SDP were similar for the different 'Gala' strains. At Purdue University, research on a new strain of 'Gala' called 'Grand Gala' is currently underway which is believed to have 50% larger fruit size than several other strains of 'Gala' (Lehnert 2010). The unusually larger size is because a process called endoreduplication in which cells in the fruit carry out an unusual cell division, doubling the DNA in the nucleus but not dividing the cell and increasing cell numbers. The apple changes from a diploid to a polyploid in chromosome number just in the fruit, not in the leaves (Lehnert 2010).

Irrigation with a drip system uses less water than sprinkler irrigation (Proebsting 1994; Fallahi *et al.* 2007b). Research has been conducted with orchard fertigation through drip systems in British Columbia (Yao *et al.* 2001) and Poland (Żidlik and Pacholak 2001). While there has been some progress in the understanding of micro-irrigation systems (Fallahi *et al.* 2001), information on yield and fruit quality of new 'Gala' apple strains under a drip irrigation system in the Pacific Northwest is lacking.

The objective of this long-term experiment was to study the effect of the most commonly used 'strain/rootstock combinations of 'Gala' apple under an evapotranspiration-based drip irrigation system on yield, fruit physical quality attributes at harvest and water use under climatic conditions of Intermountain west USA.

MATERIALS AND METHODS

Orchard establishment

An experimental orchard was established at the University of Idaho Parma Research and Extension Center in spring and early summer of 2002. The experimental site was located at 43.8° N latitude, 116.9° W longitude, and 673 m elevation above sea level, with an annual precipitation of about 297 mm and a sandy loam soil of pH ~ 7.3. Crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.], which is a drought-tolerant grass, was planted between the herbicide strips as the orchard floor cover in all treatments. Cultural practices other than strains and drip irrigation system were similar to those recommended for commercial orchards in the Pacific Northwest (Washington State University 2009).

'Pacific', 'Gale', 'Brookfield', 'Treco Red #42' and 'Buckeye' strains, all on RN29 rootstock, and 'Scarlet', 'Royal', 'Ultima' and 'Crimson' strains all on Bud9 rootstock were planted at 1.52 m inter-tree × 4.27 m inter-row spacing with an east-west row orientation. These strain-rootstock combinations are the most commonly available 'Gala' trees in the fruit industry in the USA and were thus used for comparison in this study. The trees were obtained from the following sources: 'Pacific', 'Brookfield', 'Ultima', and 'Crimson' from the Columbia Basin Nursery, Quincy, Washington; 'Treco Red Gala #42' and 'Buckeye' from TREECO, Oregon Rootstock and Tree Co., Woodburn, Oregon; 'Gale', and 'Royal' from Van Wells Nursery, Wenatchee, Washington, and 'Scarlet' from C & O Nursery, Wenatchee, Washington. 'Manchurian crab' apple on Bud9 rootstock (C & O Nursery, Wenatchee, Washington) was planted in each row as a pollinizer between every 10 'Gala' trees, as this arrangement ensures sufficient pollination to the actual trees (Westwood 1993).

Trees were trained into a vertical axis system (Westwood 1993) during the dormant season in early March every year. Tree leaders were maintained at about 3.7 m height. Trees in all treatments were blossom-thinned at about 80% bloom with 5% lime sulfur, followed by one or two applications of post-bloom thinners. The first post-bloom thinner (when applied, depending on the crop load) was a mixture of carbaryl (44.1% by weight a.i.; Sevin XLR; 1-naphthyl *N*-methylcarbamate; Bayer Crop Science; Research Triangle Park, NC) at a rate of 0.156% of formulation and Ethephon (21.7% a.i.; Ethrel [(2-chloroethyl) phosphonic acid]; Bayer Crop Science) at a rate of 0.125 to 0.156% of formulation and was applied at petal-fall. The second post-bloom thinner (when applied, depending on the crop load) was carbaryl at 0.125 to 0.187% formulation that was applied when fruitlet diameter was about 7 mm. Fruits were subsequently hand-thinned when they were about 18 mm in diameter (around mid-June) to maintain a space of at least 12.5 to 15 cm between fruits. Kaolin (95% a.i.; Surround; Englehard; Iselin, NJ) was sprayed for sunburn protection at the rate of 56.8 kg ha^{-1} in early July, followed by three one-week interval applications, each at 28.4 kg ha^{-1} every year.

Fruit yield and quality attributes

Twenty-five fruits were randomly sampled from each tree (250 fruits per treatment) for quality analysis and the total yield per tree was recorded as the total weight of all fruits at harvest time, between August 10^{th} and 20^{th} every year during 2004-2007. For fruit quality assessment at harvest, average fruit weight was calculated and skin color was visually rated on a scale of 1 to 5, with 1 = 20% of skin surface covered with red color, progressively to 5 = 100% of skin surface covered with red color red. We did not measure the intensity of red color although we took a note if intense color was visually observed in the fruits.

Since the incidence of fruit russet on the calyx end and skin was severe only in 2007, each individual fruit was gently wiped with a damp cloth and the percentage of fruit with visible russet on the calyx end and fruit skin was calculated as: (number of fruits with the disorder/total number of sampled fruit) × 100. Also, because the stem-end cracking was more severe in 2006 and 2007, the percentage of this incidence in each of these two years was calculated with the same formula that was described for the fruit russet calculation.

Irrigation system and calculation for water application

One 16-mm drip line (Rain Bird Corp., Azusa, CA) was installed in a 10-cm deep trench (subsurface), 30 cm away from and parallel to the tree row on each of the north and south sides of each tree row. On these drip lines, pressure compensating emitters were spaced at 45 cm on each line, and each emitter delivered 2.27 L hr^{-1} of water. Trees in this system were irrigated twice a week at 100% of daily ETc (as described below), but adjusted for the ground shading area (GS). Therefore, in this treatment, liters of water applied per tree = (ETc in mm/percent drip efficiency factor) × 1.52 × 4.27 m spacing × %GS. Based on the precision in designing the irrigation systems and random checking throughout the seasons, a water-delivery efficiency factor of 100% was assumed for this drip irrigation system.

Irrigation was initiated in mid-May and terminated in mid-October every year. Shortly before the first irrigation of the year, soil moisture was measured using AquaPro sensors (Decor, CA), and trees were watered to the soil saturation point. After this general irrigation, water requirements were calculated based on ETc where ETc = ETr × Kc with ETr (Penman-Monteith reference evapotranspiration) (Allen *et al.* 1998) being calculated from the Agri-Met Parma Weather Station data and Kc being the crop coefficient. Each year starting 2002, the crop water use coefficient was calculated as: Kc = K_c base + % M × (mature K_c – K_c base). Percent canopy maturity (%M) was a measurement of tree canopy size and was calculated as: %M = 3.05 + 2.558 × (%GS) – 0.016 × $(\%GS)^2$. Kc base was the base coefficient, calculated as the percentage area between the rows that were occupied by a cover crop (crested wheatgrass). In this experiment, spacing between rows was 4.27 m and the herbicide strip extended 0.61 m on either side of the row. Thus, Kc base was [4.27-(0.61×2)]/4.27=0.71]. Percentage of ground shading (%GS) was estimated as the area of orchard shaded by the tree canopy at different times during the growing season. Ground shading reached 62% and tree maturity reached 100% in early August, 2005. Thus, Kc values for mature trees were used after August 1, 2005. Since crested wheatgrass was planted as the orchard floor cover plant, value for mature Kc for each month was adopted from the guidelines for apples, developed in Prosser, Washington (Proebsting 1994), which has similar climatic conditions of our study. In that guideline, K is 0.71 in May, 0.96 in June, 1.04 in July and August, 1.0 in September, and 0.79 in October. Rainfall during the growing seasons was generally low and when it rained, this amount was subtracted from the ETc value to calculate the actual amount of irrigation needed in each application.

Experimental design and statistics

The experiment was arranged based on a completely randomized design with 10 individual trees per strain-rootstock combination. During 2002 and 2003, we did not collect any data, as trees did not have sufficient yield yet. A majority of data in this study was collected every year during 2004 through 2007. Fruit calyx-end cracking was recorded only in 2006 and 2007 and fruit russet in 2007, as incidences of those fruit disorders were severe only during these year. The assumption of normal data distribution was checked by performing univariate analyses for all tree responses in this study. Analyses of variance were conducted using SAS (SAS Institute, Cary, NC, USA, 2007), with PROC GLM and means were separated using Fisher's Protected Least Significant Difference (LSD) at $P \leq 0.05$.

RESULTS AND DISCUSSION

Interactions between years, fruit yield and quality attributes

There was no interaction between year and strains for any of the fruit yield or quality attributes in this study. Thus, in addition to the results in each year, results of overall years from 2004 through 2007 are also reported for each of the yield and quality attributes.

Fruit yield and quality attributes

There were no significant differences in total fruit yield among 'Gala' strains in 2004, but differences began to appear in 2005 and continued through 2007 (**Table 1**). 'Pacific', 'Brookfield', 'Gale' and 'Buckeye' strains on RN29 rootstock often had higher fruit yield, resulting in significantly higher cumulative yields than 'Scarlett', 'Royal Gala', 'Ultima', and 'Crimson' strains on Bud9 rootstock (**Table 1**). Lower yield of 'Scarlett Gala', 'Royal Gala', and 'Ultima Gala' could in part be due to their rootstock effect as 'Buckeye' strain on Bud9 in a previous report also had lower yield than those on RN29 rootstock (Autio *et al.* 2008).

On average, fruits in 'Brookfield', 'Treco', 'Gale', and 'Buckeye' strains on RN29 rootstock had statistically similar weights but they were often heavier than those of 'Scarlett', 'Royal', and 'Ultima' on Bud9 rootstock (**Table 1**). Our results are consistent with two previous reports where 'Gala' strains on RN29 rootstock had heavier fruit than those on Bud9 rootstock (Autio *et al.* 2008; Fallahi *et al.* 2008). It is noteworthy that fruit weight usually has an inverse relationship with yield (Fallahi *et al.* 1985b; Fallahi and Simons 1993). However, lower yields of 'Scarlett', 'Royal', and 'Ultima' on Bud9 rootstock did not result in larger fruit size, which would suggest that the use of these strain-rootstock combinations is not advisable if fruit size is the primary goal of 'Gala' production. In our study, 'Scarlet' and 'Royal' strains on Bud9 rootstock had similar fruit weight which is consistent with the result of a previous study on M.26 rootstock by Greene and Autio (1993).

Comparing our results with three other similar studies (Greene and Autio 1993; Autio *et al.* 2008; Marini *et al.* 2008) revealed that yield per tree and fruit weights were considerably higher under conditions of Southwest Idaho than those in many locations in the eastern USA, regardless of rootstock. This could be due to the higher light intensity in Southwest Idaho as compared to the eastern United States (Fallahi, pers. obs.).

Fruits from trees of 'Buckeye' and 'Gale' strains on RN29 rootstock developed more red color than other strain-rootstock combinations every year (**Table 2**). The intensity and uniformity of red color in 'Buckeye' was higher than 'Gale' (data not shown). High red color is the most important fruit quality attributes in 'Gala' production under high desert conditions of Intermountain west region of the USA. Maturity period of 'Gala' in the region is between August 10 and August 26, when the temperature is not strongly favorable for red pigment formation. Thus, early and uniform red color development in 'Buckeye' and 'Gale' make them very suitable for the region. The intensity of red color in the 'Buckeye' fruit grown in certain regions of the eastern USA may be so intense that it could be mistaken with 'Delicious' apple by some consumer (Fallahi, communication with apple growers in New York and New England region, USA). Growers in those regions may prefer to harvest the 'Buckeye' fruit at less maturity or plant strains with less intense red color. However, under climatic conditions of Intermountain west region, 'Gala' will not develop too intense of a red color, and thus, deep red color of 'Buckeye Gala' is always a positive attribute. 'Scarlet' and 'Royal' on Bud9 rootstock had similar fruit red color, which is in agreement with the result of a similar study on M.26 by other researchers (Greene and Autio 1993). 'Treco', 'Scarlet' and 'Royal' had lower average red color than other strains over 2004-2007. Low red color of 'Royal' on Bud9 rootstock in our experiment is in agreement with the performance of this strain on a 'Fuji'/MM111 top-work study in California (Mitcham *et al.* 2005).

'Buckeye' strain on RN29 rootstock was among the combinations that had lower incidences of fruit stem-end cracking and skin russetting, resulting in a better fruit finish (**Table 2**). This suggests that 'Buckeye' on RN29 rootstock combination is a great choice, particularly for the growers who have large acreages of apple to harvest, as lower fruit splitting and more red color allow a wider harvest window. If we had used Bud9 rootstock instead of RN29 rootstock for 'Buckeye', we would have still had high color because in one of our previous reports 'Gala' fruit from trees on RN29 rootstock had similar color to those from Bud9 rootstock (Fallahi *et al.* 2008). Also, 'Buckeye Gala' on M9 in Northeastern Spain (Iglesias *et al.* 2008) and as a scion on a top-worked 'Fuji' apple orchard with MM111 rootstock in California (Mitcham *et al.* 2005) had higher color than many of the tested strains. However, since 'Gala' fruit size on Bud9 rootstock is smaller than that on RN29 (Fallahi *et al.* 2008), we suggest that fruits of trees on Bud9 be more severely thinned as compared to those on RN29 rootstock to improve fruit size.

'Scarlet' trees on Bud9 rootstock had lower calyx and skin russet than other strain-rootstock combinations. However, low yield and poor fruit color of this strain-rootstock combination makes it less suitable for planting under conditions of this experiment.

Table 1 Effect of various 'Gala' apple Strain-rootstock combinations on yield per tree and average fruit weight in 2004-2007^z.

Strain	Rootstock	Yield (kg/tree)					Fruit avg. weight (g)				
		2004	2005	2006	2007	All years*	2004	2005	2006	2007	Avg. 2004-07
Pacific	RN29	9.4 a	14.3 ab	22.3 a	50.0 a	96.0 a	221.3 a	213.1 d	218.0 abc	207.3 ab	214.9 ab
Treco	RN29	9.3 a	8.7 c	19.0 abc	44.2 a	81.2 abc	214.5 ab	242.0 a	223.0 ab	215.5 a	224.5 a
Brookfield	RN29	9.1 a	13.7 abc	22.1 a	49.2 a	94.0 a	213.3 abc	219.1 cd	228.8 a	209.9 ab	218.4 a
Gale	RN29	8.1 a	15.9 a	17.2 abc	49.1 a	90.3 a	212.0 abc	227.5 bc	231.0 a	217.3 a	222.0 a
Buckeye	RN29	9.3 a	11.2 abc	20.6 ab	46.9 a	88.0 a	199.8 bcd	235.0 ab	227.0 a	216.4 a	220.4 a
Scarlet	Bud9	8.0 a	9.5 bc	16.6 abc	27.3 b	61.6 d	209.2 abc	217.1 cd	205.6 bcd	187.4 bcd	204.5 bc
Crimson	Bud9	6.9 a	9.5 bc	12.4 c	46.9 a	75.7 bc	199.6 bcd	207.4 d	203.2 cd	195.2 abc	201.4 cd
Royal	Bud9	9.6 a	10.0 bc	15.8 abc	26.6 b	62.0 cd	196.7 cd	211.0 d	189.0 d	172.1 cd	191.9 de
Ultima	Bud9	7.5 a	10.6 abc	13.5 bc	22.1 b	53.6 d	185.6 d	206.1 d	192.5 d	169.7 d	188.7 e

^{Z} Mean separation within columns by Fisher's protected Least Significant Difference (LSD) at 0.05. For each strain-rootstock combination, every value within a year represents an average of 250 fruits (10-tree replication × 25 fruits/replication). * Cumulative for all years.

Table 2 Effect of various 'Gala' apple strain-rootstock combinations on fruit skin color rating, and percentages of fruit stem-end cracking, calyx and skin russetting^z.

Strain	Rootstock	Fruit color rating^y					Fruit crack (%)			Russet in 2007 (%)	
		2004	2005	2006	2007	all years	2006	2007	Avg. 2006-07	Calyx	Skin
Pacific	RN29	3.36 b	3.34 b	3.78 b	3.50 bc	3.49 b	21.9 ab	3.3 ab	12.6 a	66 ab	5.5 a
Treco	RN29	2.36 c	2.13 c	2.41 c	2.41 d	2.32 c	30.8 a	4.0 ab	17.4 a	67 ab	4.0 ab
Brookfield	RN29	3.39 b	3.34 b	3.79 b	3.00 c	3.34 b	23.6 ab	2.9 ab	13.3 a	63 ab	5.0 ab
Gale	RN29	4.07 a	4.09 a	4.41 a	4.00 ab	4.14 a	20.8 ab	4.8 ab	12.8 a	60 ab	2.8 ab
Buckeye	RN29	4.25 a	4.16 a	4.47 a	4.19 a	4.28 a	15.0 b	2.8 ab	8.9 b	66 ab	1.5 ab
Scarlet	Bud9	2.50 c	2.11 c	2.32 c	2.11 d	2.25 c	15.5 b	8.8 a	12.2 a	40 c	0.1 b
Crimson	Bud9	3.32 b	3.16 b	3.59 b	3.33 c	3.34 b	16.8 ab	4.5 ab	10.7 a	70 a	2.5 ab
Royal	Bud9	2.39 c	2.25 c	2.38 c	2.25 d	2.31 c	20.5 ab	2.1 b	11.3 a	49 bc	3.1 ab
Ultima	Bud9	3.96 ab	3.53 b	3.44 b	3.28 c	3.52 b	21.4 ab	2.8 ab	12.1 a	52 abc	1.5 ab

^{Z} Mean separation within columns by Fisher's protected Least Significant Difference (LSD) at 0.05. For each strain-rootstock combination, every value within a year represents an average of 250 fruits (10-tree replication × 25 fruits/replication).
^{y} Fruit color rating: 1 = 20% of skin surface covered with red color, progressively to 5 = 100% of skin surface covered with red color.

Table 3 Precipitation, evapotranspiration, depth of applied water, and total volume of applied water per tree in 'Gala' apple strains from 2004 to 2007^z.

Measurement	Year					
	2004	2005	Avg.2005-06	2006	2007	Avg. 2006-07
Precipitation (mm)	64.9	67.2	66.0	54.4	55.9	55.1
ET r (mm)	925.7	956.2	941.0	1067.9	1145.4	1106.7
ET c (mm)	846.7	930.7	888.7	1022.8	1077.7	1050.3
Water applied by drip (mm)	369.4	528.4	448.9	594.5	633.6	614.0
Applied by drip (L/tree)	2404.2	3438.0	2921.1	3872.0	4121.2	3996.0

^{z} Abbreviations:Evapotranspiration ETr = Penman Monteith evapotranspiration; ETc = Evapotranspiration Coefficient for crop (apple). Precipitation data covers the period of first irrigation (about mid-May) to last irrigation (about mid-October) in each year.

Water application

The average precipitation during the irrigation periods of 2004-2005, when trees were not yet fully mature, was 66.0 mm, and the average for 2006-2007 irrigation periods, when trees were mature, was 55.1 mm (**Table 3**). During the irrigation period in all the years, month of July usually had the lowest precipitation. As expected, trees used maximum volumes of water during July and August in all years (data not shown). On average in a drip system, young 'Gala' trees received 2921 L of water per tree (449 mm) over the 2004 and 2005 seasons, while mature trees received 3996 L of water per tree (614 mm) over the 2006 and 2007 seasons (**Table 3**). No water stress symptoms were observed in the trees with drip system. The use of a drip irrigation system in these 'Gala' strains leads to major water saving and a much preferred system of irrigation to a sprinkler system.

GENERAL COMMENTS AND CONCLUSIONS

Considering all yield and quality factors, we recommend 'Buckeye Gala' and 'Gale Gala' strains on RN29 rootstock for planting under climate conditions of Intermountain west region of USA. These two strains-rootstock combinations had higher yield and fruit weight and outstanding color than many other strains-rootstock combinations over several years. Among all strain- rootstock combinations with larger fruits, 'Buckeye Gala' on RN29 had the lowest average fruit split and skin russet. The lower incidence of these two disorders combined with a richer red color contributed to an outstanding fruit finish in 'Buckeye Gala' on RN29. The earlier red color, development in the 'Buckeye Gala' fruit would allow growers to have a wider window for harvest, before fruits split as a result of over maturity. We do not recommend planting 'Scarlett', 'Royal', 'Ultima', or 'Crimson' on Bud9 rootstock under conditions of this experiment due to their low yield, small fruit, and poor color. We believe that even if yield and fruit size could have been improved by using a stronger rootstock than Bud9, such as M9337 or RN29 (Autio *et al.* 2008; Fallahi *et al.* 2008), the fruit color would still be poor on 'Scarlett', 'Royal' or 'Crimson' strains and thus not desirable. Treco had high yield and large fruit but poor color. 'Pacific Gala' and 'Brookfield Gala' can also be recommended for planting as they both had high yield and fruit size. However, these two strains may have better fruit color when planted at higher elevations, where night-time temperatures are lower than those in our experiment (Fallahi, pers. experience) or under an overhead cooling system (Mitcham *et al.* 2005).

Application of water through a drip system, based on a full ETc rate and adjusted by percentage of ground shade can result in major water savings and result in high quality 'Gala' production.

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