FINAL PROJECT REPORT
WTFRC Project Number: AH-04-418

Project Title:	Water use, quality and growth as affected by irrigation and/or rootstock
PI:	Dr. Essie Fallahi, Professor and Research Director, Pomology,
Organization:	University of Idaho
Telephone/email:	208-722-6701 ext 225 efallahi@uidaho.edu
Address:	University of Idaho, Parma Research and Extension Center 29603 U of I Lane
City:	Parma
State/Province/Zip	Idaho 83660

Cooperators: Dr. Jim McFerson

Budget History:

Item	Year (2004)	Year 2005	Year 2006
Salaries*	6000	6000	$10,000
Benefits (45%)	2700	2700	$4,500
Wages**	2760	2760	$4600
Benefits (25%)	690	690	$1150
Equipment	450	450	$750
Supplies (Lab & Orchard) & other charges	720	720	$1200
Travel***	720	720	$1200
Miscellaneous (Land Charge)	960	960	$1600
Total	15,000	15,000	$ 25,000

* Salary is for technical assistants and FB for that is 45%; ** Wages are for various part of this project conducted by part-time helpers

*** Travel includes mileage charges for local and regional travel related to the project. We use the university motor vehicle and they charge us 42.5 cents per mile.

SIGNIFICANT FINDINGS:

Findings in 2003 and 2004 Seasons:

1) Water use was highest in July during 2004. Water usage per tree for full drips and full sprinklers were higher in 2004 than 2003. In 2004, about 1437 gallons of water per season was used by each tree with sprinkler system while each tree with full drip used 639 gallons. Trees with full sprinkler and partial zone sprinkler received greater water than those with drip systems in both 2003 and 2004. Trees with full sprinkler system received about 28 inches in 2003 and about 33 inches in 2004 while those with partial zone drip received less than 15 inches in 2003 and about 17 inches of water in 2004. At the peak of the water use (July), each full sprinkler tree received an average of 14.15 gal water per day while each tree with full drip system received an average of 5.5 gal/tree in 2004.

2) Trees with partial zone drying drip irrigation were smaller than other treatments. Tree under full drip system had the same size as those under full sprinkler in 2004. Size of 'Desert Rose Fuji' trees with double drip irrigation was not noticeably larger than those with single drip system in 2003 or 2004.

3) Trees with sprinkler irrigation had greater leaf N than those on other treatments in 2003. Total leaf value for double drip was 2.19% dwt while that of single drip was 2.16% dwt in 2003.

4) In 'Autumn Rose Fuji', yield of trees with sprinkler system was lower than those with other irrigation treatments in 2004. Fuji trees with partial sprinklers had smaller but sweeter fruits than those on other treatments in 2004.

5) Trees on Supporter 4 were larger followed by those on BUD 118, G30, RN29, and Bud 9 in 2004. In Gala, drip irrigation resulted in higher yield than sprinkler system in 2004. Fruit size of Gala on RN 29 was larger than that on other rootstocks in 2004.

6) Following soil moisture may provide a useful guide but was not very exact indicative of water needs.

Findings in 2005 Season:

1) Each tree with full micro-sprinkler (sprinkler) treatment received 1541 gallons of water (total of 35.36 inches/acre) while each tree with full drip had 908 gallons (total of 20.80 inches/acre) in 2005.

2) 'Autumn Rose Fuji' from trees with full drip had higher yield and sugar than those of sprinkler in 2005.

3) In 'Autumn Rose Fuji', partial sprinkler had lower yield and smaller fruit than many other treatments in 2005.

4) In 'Desert Rose Fuji', fruit color and percentage of sunburn were lower in trees with Double drip irrigation system as compared to Single Drip. Other yield and quality parameters were similar in Double and Single Drip irrigation systems.

5) 'Gala' Trees on RN 29 had higher yield and larger fruits than those on all other rootstocks in 2005. 'Gala' fruits from trees on Bud 9 had higher yield efficiency, fruit sugar, color, and starch degradation but lower firmness as compared to other rootstocks in 2005.

6) 'Gala' trees with drip irrigation had significantly higher yield, fruit size, and starch degradation pattern than those with sprinkler system in 2005. However 'Gala' fruits from drip irrigation had lower color, sugar, and firmness as compared to those in sprinkler system in 2005.

Findings in 2006 Season:

1) The amount of water used in each treatment in 2006 was higher than that in 2005 but the patterns of use in within treatments were similar to those in 2005 in Fuji and Gala apples.
2) Trees on B.9 had at least 79% more bourse shoots with fruit than those on other rootstocks and at least 30% more bourse shoot without fruit than Supporter 4 and G.30.
3) Gala trees on B.9 ceased its terminal growth and formed its terminal buds about one once before the trees on other vigorous rootstocks, and thus leaves from trees on B.9 can be sampled for mineral analyses about one month before the trees on more vigorous rootstocks.

4) 'Pacific Gala' fruits from trees on G.30 and B.9 rootstocks had at least 13% higher starch degradation patter (SDP) than those on RN-29 and Supporter 4 rootstocks, whereas trees on RN-29 had higher fruit weight than those on B.9 and Supporter 4. 'Pacific Gala' on G.30 had more than double the amount of fruit crack than those on any of the other rootstocks.
5) 'Pacific Gala' on B.9 had at least 8% higher shoot leaf N, than those on Supporter 4 and G.30. Trees on B.9 had 36% less shoot leaf K than those on other rootstocks. In contrast, trees on B.9 and RN-29 had at least 8% higher shoot leaf Mg and trees on B.9 had at least 24% higher shoot leaf Ca than those on the other rootstocks.

RESULTS AND DISCUSSION

Water Usage

Water usage in all irrigation systems in 'Fuji' and 'Gala' was higher in 2005 than 2004. Trees used the highest amount of water in July and August in 2004, 2005, and 2006. Trees with FS treatment received significantly greater volume of water than those with drip systems in both 2004-2006. During the entire growing season, total of 5401.2 L and 5832.7 L of water was applied to each tree with FS system while 2403.5 L and 3436.8 L was applied to each tree with full drip system in 2004 and 2005, respectively. Each tree with PRS received more water than those with any type of drip systems in 2004 and more than DD and PRD in 2005. Trees with FS treatment received 846.6 mm and 898.1 mm while those with PRD received 248.9 mm and 350.5 mm of water during the entire 2004 and 2005 growing seasons, respectively with minor or no visible damage to the trees with PRD system. 'Pacific Gala' receiving drip irrigation used about 38% less water as compared to those receiving sprinkler system (Table 12 and Figure. 6). Each tree receiving drip used 3872 liters of water whereas each tree receiving sprinkler used 6250 liters of water during 2006 growing season.

Tree Growth, Leaf Area, and Leaf Mineral Nutrient Concentrations in 'Autumn Rose Fuji'

Trees with FS and FD had similar TCSA, but both treatments had significantly greater TCSA than those of other irrigation treatments (Table 2). Fresh weight, dry weight, and leaf area tended to be higher in trees receiving FS and FD treatments than other treatments, although differences were not always significant. This difference led to a lower leaf N, Mg, and Zn concentrations in FS and FD treatments due to a dilution effect. (Table 2). Irrigation treatments did not affect percentage of dry matter (Table 2) or N content per leaf (data not shown). Leaf K concentrations (Table 2) and leaf K content and fruit K concentration (data not shown) in FS and FD treatments were significantly higher than those in other treatments. Leaf K differences in this study must be due to the difference in the volume of irrigation applied. This finding suggests that water deficiency can reduce K status and this point should be taken into account when interpreting leaf analysis data. Trees with FS and FD irrigation systems also had lower Mg concentration than other treatments due their higher K concentrations, causing an antagonistic effect between these two elements. Leaf Cu concentration in FS was higher than those in all treatments.

Yield and Fruit Quality Attributes at Harvest in 'Autumn Rose Fuji'

Trees in all drip systems had significantly higher yield and yield efficiency than those in FS (Table 3), perhaps because drip systems induce varying levels of stress on the tree, forcing them to induce higher number of fruit spurs. Fruits from trees receiving PRS and DD treatments had significantly smaller fruits. However, fruits with PRS had higher SSC than all other treatments, perhaps either due to its smaller size or due to higher level of abscissic acid (ABA) production, resulting in higher SSC. Fruit from trees receiving PRD treatment had greater starch degradation pattern but lower firmness than most other treatments. This suggests that PRD treatment advances fruit maturity. Trees with FS and FD had relatively lower sunburn due to their larger canopy, resulting in more shading and fruit protection.

Rootstock Effects on Tree Growth, Yield, and fruit Quality of 'Pacific Gala'

Results in Gala in 2004-2005: 'Pacific Gala' trees on Bud 9 were least vigorous followed by those on RN-29, G 30 and Supporter 4 (Table 4). Yield and yield (Table 4) and yield efficiency (data not shown) were higher in B9 and RN-29. 'Pacific Gala' fruit were also larger in trees on RN-29. Fruits from trees on B9 had lower firmness but higher SSC and starch degradation pattern than those on RN-29 and Supporter 4. This finding suggests that 'Pacific Gala' on this B9 rootstock matures earlier, perhaps partially due to it's smaller and more exposed canopy. Relatively smaller fruits and higher yield in the trees on B9 mandates a more aggressive thinning program on this rootstock than those on other rootstocks. Fruits from trees on G30 had better color than those on RN-29 and Supporter 4. Supporter 4 did not show over-all satisfactory performance in our evaluation. Trees on this rootstock were too vigorous and had low yield. Considering all growth, yield, and quality attributes, both RN-29 and B9 showed excellent performance. However, we strongly suggest that a fruit protection such as Surround must be applied on these trees to protect the fruits from sunburn, as canopies of these trees, particularly those on B9, are not sufficiently protected by shading.

2006 Results in Gala:

2006 Growth Analysis - *Rootstock effects* (Table 6 and Fig 1): Rootstocks influenced the scion numbers of developing spurs (DS), side shoot with fruit (SSWF), side shoot without fruit (SSWOF), bourse shoots with fruit (BSWF), and bourse shoots without fruit (BSWOF) (Table 6). For each rootstock, the numbers of scion DS, SSWF, BSWF and BSWOF in June were similar to those in August. Therefore, only values for August are reported in this report. 'Pacific Gala' on Supporter 4 and G.30 had higher numbers of DS than those on the B.9. Trees on Supporter 4 had higher number of SSWOF than those on other rootstocks. Side shoot with fruit among different rootstocks were similar. Trees on B.9 had at least 79% more BSWF than those on other rootstocks and at least 30% more BSWOF than Supporter 4 and G.30. 'Pacific Gala' Trees on B.9 always had smaller trunk cross sectional area and their terminal buds were formed and terminal growth was ceased before trees o other rootstocks (Figures 1 and 2).

2006 Growth Analysis in Gala - *Irrigation effects*

For each irrigation system, the numbers of scion DS, SSWF, BSWF and BSWOF in June were similar to those in August. Therefore, only values for August are reported in this report. Trees receiving drip irrigation had more of SSWF, SSWOF, and BSWF than trees receiving sprinkler irrigation (Table 7). However, trees with sprinkler irrigation had more BSWOF than trees receiving drip system. The number of DS was unaffected by irrigation systems.

2006 Shoot Leaf mineral analysis in Gala- *Rootstock effects*

Leaves from trees on B.9 had at least 17% less leaf area and 22% lower fresh weight, 11% less dry weight than those on other rootstocks (Table 8). 'Pacific Gala' on B.9 had at least 8% higher shoot leaf N, than those on Supporter 4 and G.30. Trees on B.9 had 36% less shoot leaf K than those on other rootstocks. In contrast, trees on B.9 and RN-29 had at least 8% higher shoot leaf Mg and trees on B.9 had at least 24% higher shoot leaf Ca than those on the other rootstocks. Trees on B.9 and Supporter 4 had 13% more P levels in their shoot leaves than those on RN-29.

2006 Fruit quality attributes at harvest in Gala- *Rootstock effects*

Rootstocks influenced the scion fruit SDP (starch degradation pattern), fruit weight, percentage of fruit crack, yield, SSC (soluble solids concentration), and fruit color (Table 9). Fruits from trees on G.30 and B.9 rootstocks had at least 13% higher SDP than those on RN-29 and Supporter 4 rootstocks, whereas trees on RN-29 had higher fruit weight than those on B.9 and Supporter 4. 'Pacific Gala' on G.30 had more than double the amount of fruit crack than those on any of the other rootstocks. Trees on RN-29 had at least 23% higher total fruit yield than those on other rootstocks, whereas trees on Supporter 4 had lower SSC than those on B.9 and G.30. Trees on B.9 had 10% more fruit color than those on Supporter 4. Fruits from G.30 had significantly lower fruit firmness.

2006 Fruit quality attributes at harvest in Gala- *Irrigation effects*

Trees receiving sprinkler irrigation had significantly 8% more fruit color than trees receiving drip irrigation (data not shown). Other fruit attributes of 'Pacific Gala' were unaffected at harvest time by irrigation systems in 2006.

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Table 1. Cumulative ET and depth of applied water and average daily and total water applied per tree in irrigation systems in 'Autumn Rose Fuji' in 2004 and 2005.

Treatment[z]	Cumulative ET values or depth of applied water (mm) in 2004						Applied in 2004 (L/tree)	Cumulative ET values or depth of applied water (mm) in 2005						Applied in 2005 (L/tree)
	June	July	Aug.	Sep.	Oct.	Cum.		June	July	Aug.	Sep.	Oct.	Cum.	
ETr	212.1	218.9	208.0	97.5	43.2	924.8		192.3	243.6	264.7	133.1	18.5	956.3	
Etc	191.5	215.6	207.3	94.7	33.8	846.6		181.9	252.0	275.1	133.1	14.6	931.2	
FS	191.5	215.6	207.3	94.7	33.8	846.6	5401.2	163.8	249.7	274.6	129.0	10.4	898.1	5832.7
PRS	95.8	107.9	103.6	47.5	16.8	455.7	3285.4	81.8	124.7	137.4	64.5	5.2	469.6	3046.9
FD	72.9	107.9	85.1	47.4	19.6	369.3	2403.5	88.9	169.2	148.6	79.5	6.4	528.3	3436.8
DD	47.2	70.1	55.1	31.2	12.8	248.9	1620.0	57.9	110.0	96.5	51.6	4.1	350.5	2282.4
PRD	47.2	70.1	55.1	31.2	12.8	248.9	1620.0	57.9	110.0	96.5	51.6	4.1	350.5	2282.4

[z] Abbreviations for irrigation treatments: FS=Full Sprinklers; PRS=Partial Root-Zone Drying Sprinklers; FD= Full Drip; DD=Deficit Drip; PRD=Partial Root-Zone Drying Drip.

Table 2. Effect of different irrigation systems on trunk cross sectional area (TCSA), leaf area, and leaf macronutrient of 'Autumn Rose Fuji' apple[z].

Irrigation[z]	TCSA (cm^2) [Y]	Fresh wt/leaf (g)	Dry wt/leaf (g)	Percent dry wt	Leaf area (cm^2/leaf)	N (% dwt)	K (% dwt)	Ca (%dwt)	Mg (% dwt)	Fe (ppm)	Zn (ppm)	Cu (ppm)	Mn (ppm)
FS	50.8 a	0.80 a	0.33 a	42.8 a	25.5 a	2.11 b	1.59 a	1.71 b	0.32 d	55 bc	14 b	8.3 a	55 ab
PRS	43.2 b	0.70 c	0.30 b	50.8 a	23.3 b	2.20 a	1.29 c	1.62 c	0.40 a	59 a	18 a	7.5 b	60 a
FD	51.6 a	0.77 ab	0.31 ab	40.7 a	23.7 b	2.10 b	1.41 b	1.63 bc	0.34 c	53 c	13 b	7.5 b	53 b
DD	44.8 b	0.72 bc	0.30 b	42.2 a	23.1 b	2.21 a	1.23 c	1.62 c	0.38 b	57 ab	17 a	7.3 b	59 a
PRD	45.2 b	0.70 c	0.30 b	41.3 a	23.5 b	2.21 a	1.28 c	1.81 a	0.39 ab	57 ab	16 a	7.4 b	60 a

[Z] Abbreviations for irrigation treatments: see footnote for Table 1. Each value is the average over 2004 and 2005. There were 5 blocks, each with 4 trees, with total of 20 trees per treatment per year. Mean separation within columns with LSD at 0.05.
[Y] TCSA= Trunk cross sectional area. %TCSA change = (TCSA in 2005-TCSA2004) /(TCSA 2004) x 100.

Table 3. Effect of different irrigation systems on fruit quality attributes in 'Autumn Rose Fuji' apple[z].

Irrigation[z]	Yield (T/ha)	Yield efficiency (kg/cm^2)	Fruit wt (g)	Fruit color (1-5)	Firmness (kg)	Sol. solids (^oBrix)	Starch pattern	Sunburn (%)	Fruit Russet (%)	Water core (%)
FS	16.7 c	0.59 b	293.7 a	3.5 ab	8.37 ab	15.4 b	3.4 b	15 bc	44 a	47 ab
PRS	17.7 bc	0.81 b	245.7 c	4.8 a	8.40 a	16.3 a	3.4 b	23 a	38 a	49 ab
FD	23.3 a	0.77 a	291.3 a	3.4 ab	8.34 ab	15.5 b	3.6 b	10 c	38 a	53 a
DD	22.6 ab	0.98 a	272.5 b	3.3 b	8.23 bc	15.5 b	3.6 b	22 ab	26 b	41 b
PRD	23.0 a	0.97 a	286.4 a	3.4 ab	8.13 c	15.3 b	3.9 a	24 a	28 b	45 ab

[z] Abbreviations for irrigation treatments: see footnote for Table 1. Each value is the average over 2004 and 2005. There were 5 blocks, each with 4 trees, with total of 20 trees per treatment per year. Mean separation within columns with LSD at 0.05.
[Y] Yield efficiency = yield per tree/TCSA.

Table 4. Effect of different rootstocks on yield and fruit quality of 'Pacific Gala' apple in 2004-2005[z].

Rootstock	TCSA (cm^2)	Yield (T/ha)	Fruit wt (g)	Fruit color (1-5)	Firmness (kg)	Sol. solids (^oBrix)	Starch pattern
Bud 9	10.4 d	13.7 ab	204.5 b	3.4 ab	8.07 c	14.5 a	4.5 a
RN 29	19.3 c	15.8 a	223.2 a	3.2 b	8.34 ab	13.9 b	4.0 b
Supporter 4	26.4 a	7.2 c	206.0 b	3.1 b	8.57 a	13.9 b	4.0 b
G 30	22.1 b	12.3 b	205.7 b	3.5 a	8.14 bc	14.1 b	4.4 a

[z] Each value is the average over 2004 and 2005. There were 5 blocks, each with 2 trees, with total of 10 trees per treatment per year. Mean separation within columns with LSD at 0.05.

Table 5. Effect of different irrigation systems on trunk cross sectional area (TCSA) , yield, and fruit quality in 'Pacific Gala' in 2004-2005[z].

Irrigation	TCSA (cm^2)	Yield (T/ha)	Fruit wt (g)	Fruit color (1-5)	Firmness (kg)	Sol. solids (^oBrix)	Starch pattern
Drip	16.1 b	14.0 a	216.7 a	3.1 b	8.07 b	14.0 a	4.3 a
Sprinkler	17.9 a	10.4 b	202.9 b	3.5 a	8.49 a	14.2 a	4.1 b

[z] Each value is the average over 2004 and 2005. Mean separation within columns with LSD at 0.05.

Table 6. Effects of rootstocks on the mean number of different types of shoots in 'Pacific Gala' apple in August, 2006.

Rootstocks	DS[z]	SSWF	SSWOF	BSWF	BSWOF
B.9	0.96 c[y]	0.09 a[x]	1.98 c	6.50 a	10.48 a
RN-29	1.88 bc	0.03 a	6.78 b	3.63 b	8.39 ab
Supporter 4	3.57 a	0.18 a	9.13 a	1.63 c	8.07 b
G.30	2.75 ab	0.08 a	7.08 b	1.53 c	7.12 b

[z]Abbreviations: DS = Developing spur, SSWF = Side shoot with fruit, SSWOF = Side shoot without fruit, BSWF = Bourse shoot with fruit, BSWOF = Bourse shoot without fruit. The values represent mean number of shoots on a segment of a limb that was 1.2 m in length in June, 2006.
[y]Means with different letters within a column are significantly different, by using protected LSD at 0.05 level. [x]Each value was the average of 5 blocks each with 4 trees (20 trees/rootstock).

Table 7. Effects of irrigation on the mean number of different types of shoots in 'Pacific Gala' apple in August, 2006.

Irrigation	DS[z]	SSWF	SSWOF	BSWF	BSWOF
Drip	2.70 a[y]	0.18 a[x]	0.18 a	0.18 a	7.59 b
Sprinkler	2.30 a	0.00 b	0.00 b	0.00 b	9.48 a

[z]Abbreviations: DS = Developing spur, SSWF = Side shoot with fruit, SSWOF = Side shoot without fruit, BSWF = Bourse shoot with fruit, BSWOF = Bourse shoot without fruit. The limb was 1.2 m in June. Each value was the average of two limbs on tree.
[y]Means with different letters within a column are significantly different, by using protected LSD at 0.05 level.
[x]Each value was the mean over 4 rootstocks with 5 blocks each with 4 trees (40 trees/irrigation treatment).

Table 8. Effects of rootstocks on the mean fresh weight, dry weight, % weight, leaf area and macronutrient concentrations in the shoot leaves of 'Pacific Gala' apple in 2006.

Rootstocks	Fresh wt (g/leaf)	Dry wtght (g/leaf)	Leaf % dry weight	Leaf area (cm^2/leaf)	N (% dwt)	P (% dwt)	K (% dwt)	Mg (% dwt)	Ca (% dwt)
B.9	0.9 b[z]	0.40 b[y]	43.06 a	33.00 b	1.97 a	0.15 a	1.00 c	0.40 a	2.00 a
RN-29	1.1 a	0.45 a	41.35 b	39.40 a	1.90 ab	0.13 b	1.25 b	0.39 a	1.61 b
Supporter 4	1.1 a	0.43 ab	39.36 c	39.80 a	1.80 b	0.15 a	1.60 a	0.32 c	1.61 b
G.30	1.1 a	0.43 ab	40.40 bc	38.90 a	1.81 b	0.14 ab	1.51 a	0.37 b	1.60 b

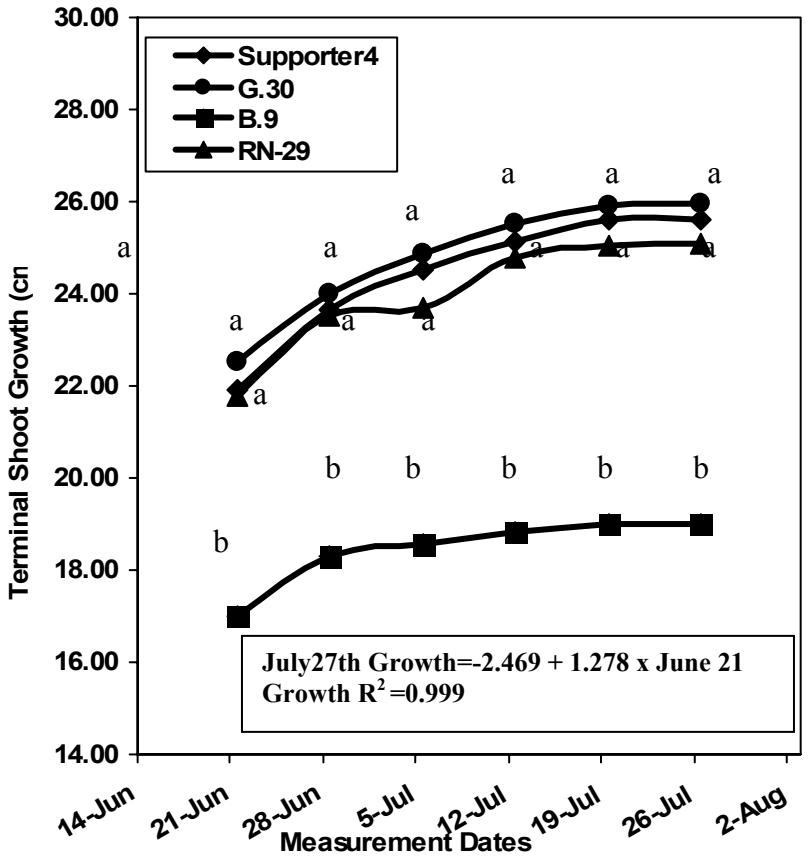
[z]Each value is the average of 5 blocks each with 4 trees (20 trees/rootstock).
[y]Means with different letters within a column are significantly different, by using protected LSD at 0.05 level.

Table 9. Effects of rootstock on the mean at-harvest fruit quality of 'Pacific Gala' apple in 2006.

Rootstocks	Avg. fruit wt (g)	Color	SSC[z] (Brix)	Firmness (Kg)	SDP	% Crack	Yield
B.9	189.2 b[y]	4.1 a[x]	14.5 a	8.8 a	4.1 a	13.4 b	19.4 b
RN-29	209.8 a	3.8 ab	14.0 ab	8.8 a	3.3 b	16.0 b	25.3 a
Supporter 4	194.0 b	3.7 b	13.8 b	9.0 a	3.2 b	20.1 b	6.1 d
G.30	201.0 ab	3.8 ab	14.4 a	8.4 b	3.8 a	45.4 a	13.2 c

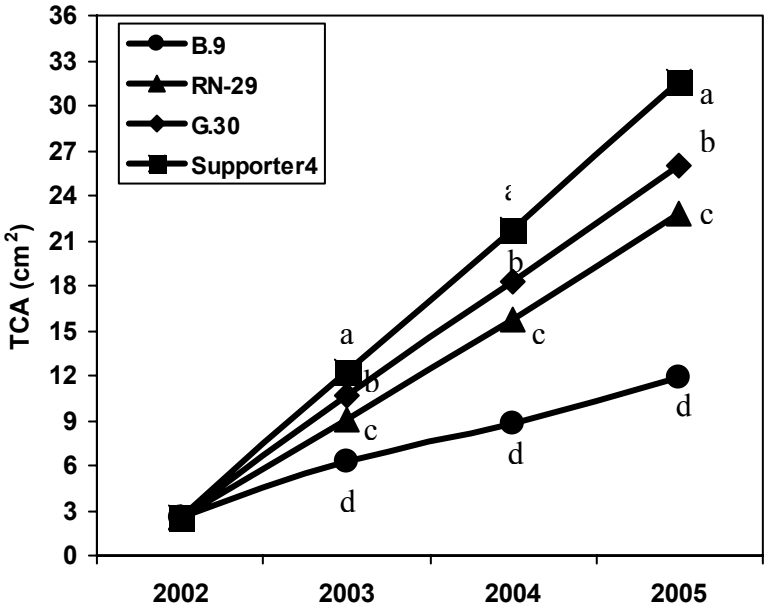
[z]SSC = Soluble solids concentration, SDP = Starch degradation pattern, Color was rated from 1 to 5 and SDP was rated from 1 to 6.
[y]Means with different letters within a column are significantly different, by using protected LSD at 0.05 level.
[x]Each value is the average of 5 blocks each with 4 trees (20 trees/rootstock).

Figure 1. Growth curves of terminal shoots on 'Pacific Gala' trees on different rootstocks during the season 2006[z].



[z]Mean separation within the sampling dates by LSD at the 5% level.

Figure 2. Mean trunk cross sectional area of 'Pacific Gala' on different rootstocks 2002-2005.[zy] .



[z]Trunk circumference was measured at 30 cm above the bud union.
[y]Mean separation within the sampling years by LSD at 5% levels.