Journal of the American Pomological Society 68(1): 24-32 2014

Mechanical Blossom Thinning of 'GoldRush' / M.9 Apple Trees with Two String Types and Two Timings

James R. Schupp[1] and Thomas M. Kon

Additional index words: crop load management, fruit quality, fruit set, fruit size, *Malus x domestica,* return bloom, spur leaf injury, yield

Abstract

'GoldRush' / M. 9 NAKBT337 apple trees [*Malus x domestica* (Borkh.) Mansf] were mechanically blossom thinned at either pink or full bloom bud stages, using a Darwin mechanical thinner with either of two different string attachments. Thinning treatments removed entire blossom clusters, reduced flower number on remaining spurs, removed 15-29% of the spur leaf area of persisting spurs, and reduced initial fruit set when compared to the hand thinned control. Mechanical blossom thinning treatments reduced hand thinning time, crop load and yield per tree, but had no effect on mean fruit weight at harvest. Fruit size distribution was unaffected by thinning treatment. Fruit firmness from mechanically thinned trees increased when compared to the control. No differences were observed in soluble solids concentration or acidity between fruit from hand thinned control and mechanically blossom thinned trees. Thinning at pink increased 2013 return bloom when compared to the hand-thinned control and to treatments applied at full bloom. String type and timing were not significant factors to explain the differences in efficacy that have been observed in our previous trials.

The Darwin string thinner (Darwin 300; Fruit-Tec, Deggenhausertal, Germany) was developed as a mechanical blossom thinner for apple. Several authors have observed beneficial results on fruit size from mechanical blossom thinning (Damerow et al., 2007; Dorigoni et al., 2008; Schupp et al., 2008; Sinatsch et al., 2010). Pennsylvania State University researchers have conducted several mechanical blossom thinning efficacy trials on apple since 2007, but mechanical blossom thinning produced a beneficial result in terms of fruit size in only the initial study (Schupp et al., 2008).

The initial study was conducted at king bloom (20% open blossoms) on 'GoldRush', and utilized the original string type supplied with the Darwin blossom thinner. Subsequent experiments showed that mechanical string blossom thinning was effective in removing blossoms and reducing fruit set, but several negative consequences were observed, including: reduced spur leaf area, sub-optimal yield, reduced fruit calcium, and no influence on return bloom (Kon et al., 2013). In the two year study, the largest increase in fruit weight was 28 g, and was observed in the most severe blossom thinning treatment which reduced yield by more than 50%. These studies were conducted on 'Gala' and 'Pink Lady' at 80% to full bloom, utilizing the heavier injection-molded string type that the Darwin is presently equipped with. Thus it was plausible that differences in cultivar response, timing of treatment relative to bloom stage, or string type could explain the differences in outcomes between our previous studies. The present study was undertaken to compare treatment protocol and experimental parameters by which the previous studies were conducted to determine if any of these factors could help us to obtain a beneficial increase in fruit size from blossom thinning apple with a mechanical string thinner.

[1] Corresponding author: Department of Plant Science, Fruit Research and Extension Center, Pennsylvania State University, Biglerville, PA 17307

Materials and Methods

Experiments were initiated in the spring of 2012 at the Pennsylvania State University's Fruit Research and Extension Center in Biglerville, PA on 5-year-old 'GoldRush'/M.9 apple trees at 1.2 x 3.7 m spacing. The trees were trained to tall spindle (Robinson et al. 2006), pruned to maintain a 3 m tall, 1.2 m narrow canopy architecture, and supported by a 4-wire vertical trellis. The orchard was maintained using organic practices, with a mowed sod groundcover. String thinning treatments were applied at pink or at full bloom with a Darwin 300 equipped with 108 strings of either the original plastic style, or the newer type injection-molded style. Both styles of string were 50 cm long and were mounted on a 3m-tall spindle in two columns, to replicate the string pattern used in the initial study. The original strings were 3.0 – 3.1 mm thick throughout their length. The new style injection molded strings were 8 mm thick at the base and tapered to 3.6 mm at the tip. The speed of the clockwise rotating spindle was set at 210 rpm, and the forward tractor speed was 4.8 $km \cdot h^{-1}$ for all mechanical thinning treatments. The height and angle of the frame was adjusted to conform to the vertical inclination of the tree canopy.

A total of 20 five-tree plots were selected and flagged. Treatments were randomly assigned to five-tree plots, and data were collected on two trees in the middle of the plot. Treatments were applied as follows: 1) control, 2) mechanically thinned at pink, with the original strings, 3) mechanically thinned at pink, with the new style strings, 4) mechanically thinned at full bloom, with the original strings, and 5) mechanically thinned at full bloom, with the new style strings. Blossom cluster counts were recorded before and after mechanical thinning treatment on two or three representative limbs per tree.

After primary spur leaves were fully expanded, 10 spurs per plot were excised for evaluation. The remaining tree in the middle of the plot was assigned for spur evaluation. To ensure that the selection of spurs for destructive analysis was unbiased, spurs were selected as follows: limbs selected were near horizontal in position, the investigator utilized the junction of the primary limb and the trunk as a reference point, the 3^{rd}, 5^{th}, 7^{th}, and 9^{th} flowering spurs that the investigator observed were excised and placed in a labeled polyethylene bag. This process was repeated on multiple limbs until a total of 10 flowering spurs were collected. Lateral bloom was not selected. Samples were refrigerated at 3°C until measurements were taken, and processing was completed within 2 days. The number of blossoms and leaves per spur were counted and recorded. When counting the number of leaves per spur and determining leaf area, floral bracts, petioles, and unexpanded leaves were discarded. Leaves that were damaged by the mechanical blossom thinner were counted under the condition that a portion of the lamina was still intact. A leaf area meter (LI-COR 3100; LI-COR, Lincoln, NE) was used to determine leaf area per spur.

Initial and final fruit set, and time required for follow-up hand thinning were evaluated. Fruit were counted on the selected limbs after petal fall and after June Drop to determine initial and final fruit set, respectively. Circumference was measured on selected limbs to express fruit set per unit cm^2 limb cross-sectional area (LCSA). All trees were subjected to hand thinning after final fruit set was counted, as all treatments still had supra-optimal crop load at the time fruit set was evaluated (Table 1).

The number of fruit, yield, individual fruit weight, and fruit size distribution of the two data trees were determined with an electronic weight sizer (Durand Wayland, Lagrange, Georgia). Twenty fruit of uniform size were sub-sampled from each plot for fruit quality analysis. Fruit firmness (MDT-2; Mohr Test and Measurement LLC, Richland, WA) was evaluated from two punctures per fruit. Soluble solids concentration (model PR-32 α digital refractometer, Atago, Bellevue,

Table 1. Effect of string type and timing of mechanical thinning treatment on blossom cluster removal, blossoms per spur, leaf number, spur leaf area, and fruit set of 'GoldRush' apple in 2012.[z]

String type	Timing	Clusters removed	Blossom no.	Leaf no.	Leaf area per spur	Fruit set		
						Initial	Final	Final
		(no./cm^2 LCSA)[y]	(no./ spur)[x]	(no./ spur)[x]	(cm^2)[x]	(fruit/cm^2)[w]	(fruit/cm^2)	(%)
Control	---	0.0	5.0	9.8	54.1	39.7	13.0	54.8
Old	Pink	1.8	4.5	8.6	40.1	26.5	11.2	55.2
New	Pink	2.6	4.1	8.3	38.1	22.5	10.5	49.5
Old	Full Bloom	1.6	4.2	9.1	46.1	25.6	8.5	35.7
New	Full Bloom	1.7	4.0	8.6	41.8	22.7	8.2	42.5
Significance								
	Control vs. All	0.0057[v]	0.0026	0.0395	0.0256	0.0120	0.0741	0.4231
	Pink vs. Full Bloom	0.3230	0.5098	0.4087	0.3031	0.9450	0.1296	0.1986
	Old vs. New	0.4610	0.1784	0.3507	0.4998	0.4880	0.7507	0.9546
	Timing x String Type	0.5515	0.5887	0.7808	0.8094	0.9029	0.8891	0.5362

[z] Means of seven observations. Thinning treatments were applied at pink or at full bloom with a Darwin 300 (Fruit-Tec, Deggenhausertal, Germany), equipped with 108 of either the original plastic strings, or the newer style injection-molded strings. Spindle speed was 210 rpm and forward tractor speed was 4.8 km•h^{-1} for all mechanical thinning treatments.

[y] LCSA = limb cross-sectional area

[x] Means of 40 harvested spurs per treament (n = 4)

[w] Initial fruit set was recorded after petal fall. Final fruit set was recorded after June drop.

[v] P(F). A one-way ANOVA was performed with the GLM procedure, and single degree of freedom contrasts were used to compare treatment groups of interest.

WA) and titratable acidity (malic acid equivalents; Model HI-84432 digital titrator; Hanna Instruments, Woonsocket, RI) were measured from a composite sample of juice extracted from slices of all 20 apples. Trunk diameters were measured to calculate trunk cross-sectional area (TCSA) in December 2012, after seasonal growth was complete. In the spring of 2013, return bloom was estimated by counting blossom clusters on three representative limbs of two trees in each plot. Blossom density was expressed as number of blossom clusters/cm^2 LCSA.

The experiment was a 2 x 2 augmented factorial with four replications. A one-way ANOVA was performed with the GLM procedure, and single degree of freedom contrasts were used to compare treatment groups of interest.

Results and Discussion

A frost occurred on March 27, 2012, with overnight low temperature of -1.1°C when the bloom stage was at pink. Visual evaluation of all flowers on 10 randomly selected limbs showed that this cold event resulted in 49% blossom mortality to 'GoldRush' in this block. Blossom density was heavy, so we also evaluated flower survival on these limbs and determined that sufficient blossoms survived the frost to produce 655% of an optimal crop, based on a target crop density of 6 fruit per cm^2 LCSA (Kon and Schupp, 2013). Viable blossom density was therefore deemed adequate to conduct the experiment. Liquid lime sulfur at 25 $ml \cdot L^{-1}$ was mistakenly applied once to all trees at petal fall, and may have contributed to some additional fruit thinning (McArtney et al., 2006).

Mechanical blossom thinning treatments had some significant effects compared to untreated controls, but there were few differences or interactions between the two timings and two string types. Thinning treatments removed entire blossom clusters, reduced blossom number of persisting spurs by 10-20%, reduced spur leaf number by 7-15%, removed 15-29% of the spur leaf area of persisting spurs, and reduced initial fruit set 33-43% when compared to the control (Table 1). Reduced leaf area per spur resulted from both the removal of entire leaves and of portions of remaining leaves. Bourse shoots had not elongated at the time of treatment, thus bourse shoot leaves were unaffected.

Spindle rotational speeds and forward tractor speed were selected based on previous work. Kon et al. (2013) observed similar reductions in blossom number (17%), leaf number (15%), and spur leaf area (15%) in the first year of a mechanical blossom thinning experiment with identical spindle and tractor speeds (210 rpm and 4.8 $km \cdot h^{-1}$, respectively). Despite use of a different cultivar, string number, and method of selecting spurs for analysis, the mechanical string thinner had consistent results in regard to blossom and leaf removal when compared to previous trials. Several authors claim that the damage to spur leaf tissue incurred during mechanical blossom thinning is minimal (8-10% damage) and of little consequence (Damerow et al., 2007; Kong et al., 2009; Veal et al., 2011). Kon et al. (2013) and Sauerteig (2012) quantified spur leaf injury with use of a leaf area meter. Both studies suggested that significant injury to spur leaves occurred, and implied that this injury may have negative consequences. No incidence of mechanical damage to the fruits was observed in this study.

Mechanical blossom thinning treatments reduced hand thinning time, crop density, and yield per tree, but had no effect on mean fruit weight at harvest (Table 2). Mechanical blossom thinning treatments reduced hand thinning time by 27-33% when compared to the control. Reduced hand thinning time of mechanically thinned trees accords with the findings of Schupp et al. (2008), and this likely corresponds to the reduction in the number of blossoms and blossom clusters. Crop densities of all treatments were very low, as the control treatment had a crop density of 3.5 fruit per cm^2 TCSA. The minor variation in crop density across treatments observed may be explained by hand-thinning. All trees were thinned uniformly, as only disease infected or insect damaged fruit, small fruit, or clustered fruit were removed. When compared to the control, yields of mechanically thinned trees were reduced by 28-40%. Considering this significant yield reduction, it would be expected that early blossom thinning would have improved fruit size and quality as compared to the control. Several authors observed increased fruit size when comparing mechanical blossom thinning treatments to a control (Damerow et al., 2007; Dorigoni et al., 2008; Dorigoni et al., 2010; Hehnen et al., 2012; Kong et al., 2009; Schupp et al., 2008; Solomakhin and Blanke, 2010; Strimmer et al., 1997; Veal et al., 2011), and many of these reports included follow-up hand-thinning as part of the treatment. Damage to spur leaves early in the season can reduce fruit set and fruit growth rate (Ferree and Palmer, 1982; Yuan and Greene, 2000). Aside from the reduction in yield observed in all trees subjected to mechanical thinning treatments, fruit size distribution was unaffected by thinning treatment (Fig. 1).

Table 2. Effects of string type and timing on hand thinning time, crop load, yield, and fruit weight of mechanically thinned 'GoldRush' apple in 2012.[z]

String type	Timing	Hand thinning time (s/tree)	Crop density (no. fruit/cm^2 TCSA)[y]	Yield per tree (kg)	Fruit weight (g)
Control	---	174	3.5	15.6	218
Old	Pink	117	2.8	11.3	223
New	Pink	118	2.3	10.8	219
Old	Full Bloom	126	2.4	11.2	221
New	Full Bloom	127	1.3	9.4	240
Significance					
	Control vs. All	0.0082[x]	0.0175	0.0003	0.2825
	Pink vs. Full Bloom	0.5581	0.1209	0.4085	0.1864
	Old vs. New	0.9417	0.0821	0.2309	0.2547
	Timing x String Type	0.9845	0.4390	0.4914	0.0871

[z] Means of four observations. Thinning treatments were applied at pink or at full bloom with a Darwin 300 (Fruit-Tec, Deggenhausertal, Germany), equipped with 108 of either the original plastic strings, or the newer style injection-molded strings. Spindle speed was 210 rpm and forward tractor speed was 4.8 km•h^{-1} for all mechanical thinning treatments.

[y] TCSA = trunk cross-sectional area

[x] P(F). A one-way ANOVA was performed with the GLM procedure, and single degree of freedom contrasts were used to compare treatment groups of interest.

Fruit firmness was slightly higher in mechanically thinned trees, which accords with Kon et al., 2013 (Table 3). String type and the interaction of string type x timing affected titratable acidity, however the differences were small. Soluble solids concentration was not affected by thinning treatment. Thinning at pink increased 2013 return bloom over that of the hand-thinned control and when contrasted with thinning at full bloom. Use of the mechanical thinner at earlier bloom stages may improve the potential for annual bearing.

In our previous experiment in which the desired results of increased fruit size and quality were attained, treatments were applied at early bloom timing to 'GoldRush'/M.26 apple trees, using the original round plastic strings (Schupp et al., 2008). Subsequent apple trials were conducted on other cultivars ('Gala' and 'Pink Lady'), in the range of 80 – 100% full bloom, and utilized heavier injection molded strings that are presently supplied with the Darwin machine. Since all mechanical thinning treatments in this study were effective in removing flowers, but resulted in similar outcomes pertaining to leaf damage, yield, fruit size and quality, we conclude that string type and timing are not significant factors in explaining the differences in efficacy between our previous trials. String thinning is used to adjust apple crop load in Europe, and this technology has been successfully adapted to blossom thinning peaches and nectarines in the U.S. (Baugher et al., 2010, 2011; Schupp and Baugher, 2011). The damage to spur leaves, subsequent lack of increase in fruit size, and

Table 3. Effects of string type and timing on fruit quality indices of mechanically thinned 'GoldRush' apple in 2012, and return bloom in 2013.[yz]

String type	Timing	Fruit firmness (N)	Soluble solids (%)	Titratable acidity (%)[x]	Return bloom (no. flower buds/cm²)
Control	---	79.6	15.9	0.99	10.2
Old	Pink	82.6	16.9	1.02	17.8
New	Pink	85.3	17.5	1.18	15.2
Old	Full Bloom	82.0	16.9	1.06	11.3
New	Full Bloom	81.8	16.3	1.06	10.2
Significance					
	Control vs. All	0.0332[w]	0.7660	0.0593	0.1583
	Pink vs. Full Bloom	0.1280	0.2527	0.3625	0.0130
	Old vs. New	0.3412	1.0000	0.0446	0.3876
	Timing x String Type	0.2476	0.2163	0.0446	0.7106
	Pink vs. Control	--	--	--	0.0242

[z] Means of four observations. Thinning treatments were applied at pink or at full bloom with a Darwin 300 (Fruit-Tec, Deggenhausertal, Germany), equipped with 108 of either the original plastic strings, or the newer style injection-molded strings. Spindle speed was 210 rpm and forward tractor speed was 4.8 km•h^{-1} for all mechanical thinning treatments.
[y] Sample size of 20 fruit per plot (n = 4). All fruit selected for postharvest analyses were of a uniform size.
[x] Percent malic acid was selected for analysis because it is the most abundant acid in apple.
[w] P(F). A one-way ANOVA was performed with the GLM procedure, and single degree of freedom contrasts were used to compare treatment groups of interest.

concerns over the spread of fire blight (Ngugi and Schupp, 2009) are disincentives to its use on apple in temperate growing regions of the U.S.

Acknowledgements

The authors would like to thank H. Edwin Winzeler and Melanie A. Schupp for technical assistance. We also thank Richard P. Marini for his advice on statistical analysis.

Literature Cited

Baugher, T. A., J. Schupp, K. Ellis, E. Winzeler, J. Remcheck, K. Lesser, and K. Reichard. 2010. Mechanical string thinner reduces crop load at variable stages of bloom development of peach and nectarine trees. HortScience 45:1327-1331.

Baugher, T. A., J. Schupp, K. Ellis, J. Remcheck, E. Winzeler, R. Duncan, S. Johnson, K. Lewis, G. Reighard, G. Henderson, M. Norton, A. Dhaddey, and P. Heinemann. 2010. String blossom thinner designed for variable tree forms increases crop load management efficiency in trials in four peach growing regions. HortTechnology 20:409-413.

Damerow, L., A. Kunz, and M. Blanke. 2007. Regulation of fruit set by mechanical thinning. Erwerbs-Obstbau 49:1-9.

Dorigoni, A., N. Dallabetta, and P. Lezzer. 2008. Le alternative al carbaryl per il diradamento del melo. L'nformatore Agrario 9:52-54.

Dorigoni, A., P. Lezzer, F. Micheli, N. Dallabetta, and J. Pasqualini. 2010. Diradare il melo a macchina:

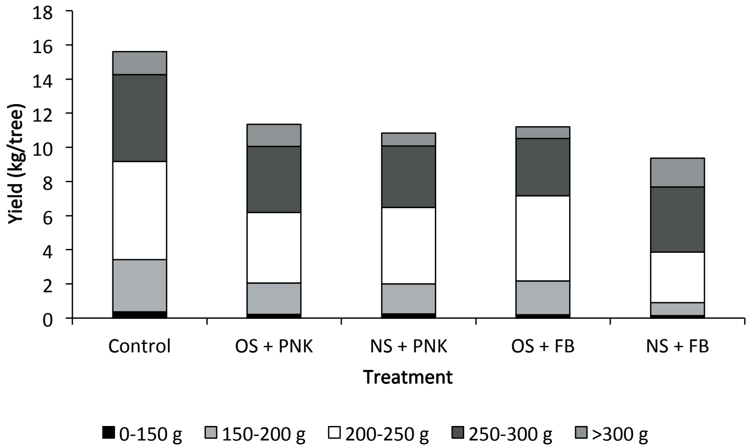

Fig. 1. Effects of two string types and two timings on fruit size distribution and yield of mechanically thinned 'GoldRush' in 2012 (OS = old strings; NS = new strings; PNK = pink bud stage; FB = full bloom bud stage). String thinning treatments were applied at pink or at full bloom with a Darwin 300 (Fruit-Tech, Deggenhausertal, Germany), equipped with 108 of either the original plastic strings, or the newer style injection-molded strings. Both styles of string were 50 cm long and were mounted on a 3m-tall spindle in two columns. The original strings were 3.0 - 3.1 mm thick throughout their length. The new style injection molded strings were 8 mm thick at the base and tapered to 3.6 mm at the tip. Speed of the clockwise rotating spindle was 210 rpm, and forward tractor speed was 4.8 km•h^{-1} for all mechanical thinning treatments.

cosa sapere per farlo bene. L'nformatore Agrario 22:63-67.

Ferree, D.C. and J.W. Palmer. 1982. Effect of spur defoliation and ringing during bloom on fruiting, mineral level, and net photosynthesis of 'Golden Delicious' apple. J. Amer. Soc. Hort. Sci. 107:1182-1186.

Hehnen, D., I. Hanrahan, K. Lewis, J. McFerson, and M. Blanke. 2012. Mechanical flower thinning improves fruit quality of apple and promotes consistent bearing. Sci. Hort. 134:241-244.

Kon, T.M. and J.R. Schupp. 2013. Thinning tall spindle apple based on estimations made with a hand-thinning gauge. HortTechnology 23 (in press.)

Kon, T.M., J.R. Schupp, H.E. Winzeler, and R.P. Marini. 2013. Influence of mechanical string thinning treatments on vegetative and reproductive tissues, fruit set, yield and fruit quality of apple. HortScience 48:40-46.

Kong, T., L. Damerow, and M.M. Blanke. 2009. Effect of mechanical thinning on ethylene efflux, yield, and fruit quality in apple. Erwerbs-Obstbau 51:39-52.

McArtney, S., J. Palmer, S. Davies, and S. Seymour. 2006. Effects of lime sulfur and fish oil on pollen tube growth, leaf photosynthesis and fruit set in apple. HortScience 41:357-360.

Ngugi, H., and J.R. Schupp. 2009. Evaluation of the risk of spreading fire blight in apple orchards with a mechanical string blossom thinner. HortScience 44:862-865.

Robinson, T.L., S.A. Hoying and G.H. Reginato. 2006. The tall spindle apple production system. N. Y. Fruit Qtrly. 14:21-28.

Sauerteig, K.A. 2012. Response of apple, peach, and sweet cherry to mechanical blossom thinning. The Univ. of Guelph, Guelph. M.S. Thesis.

Schupp, J.R., and T.A. Baugher. 2011. Peach blossom string thinner performance improved with selective pruning. HortScience 46:1486-1492.

Schupp, J.R., T.A. Baugher, S.S. Miller, R.M. Harsh, and K.M. Lesser. 2008. Mechanical thinning of peach and apple trees reduces labor inputs and increases fruit size. HortTechnology 18:660-670.

Sinatsch, S., B. Pfeiffer, I. Toups, J. Zimmer, and B. Benduhn. 2010. Comparison of different thinning measures for organic grown apples. 14th Intl. Conf. on Organic Fruit Growing 14:200-205.

Solomakhin, A.A., and M.M. Blanke. 2010. Mechanical flower thinning improves fruit quality of apples. J. Sci. Food Agric. 90:735-741.

Strimmer, M., M. Kelderer, and K. Pieber. 1997. Neue auduennungsmethoden im biologischen apfelbau. Erwerbs Obstbau 39:130-136.

Veal, D., L. Damerow, and M.M. Blanke. 2011. Selective mechanical thinning to regulate fruit set, improve quality and overcome alternate bearing in fruit crops. Acta Hort. 903:775-82.

Yuan, R. and D.W. Greene. 2000. Benzyladenine as a chemical thinner for 'McIntosh' apples. II. Effects of benzyladenine, bourse shoot tip removal and leaf number on fruit retention. J. Amer. Soc. Hort. Sci. 125:177-182.

❖ ❖ ❖ ❖

Long-term leaf mineral nutrition in 'Pacific Gala' apple (*Malus Xdomestica* Borkh.) as affected by rootstock type and irrigation system during six stages of tree development.

Abstract:
Use of an efficient rootstock and irrigation system are essential to establish a high-density orchard with a high production potential. High production becomes more important as World population increases and the availability of usable agricultural land and irrigation water decrease. Rootstock vigour and irrigation method are among the most important factors that affect the uptake of mineral nutrients and thus tree growth, fruit yield, and fruit quality attributes in apple (*Malus* X *domestica*Borkh.). The effects of four rootstocks and two irrigation systems on leaf size and mineral nutrition, and on the interaction between leaf nutrient concentrations, growth, and fruit quality attributes were studied over 4 years in 'Pacific Gala' apple. Evapotranspiration (ET_c)-based irrigation scheduling, adjusted for the percentage of ground shading, was used for both the sprinkler and drip irrigation systems. Leaf calcium (Ca) concentrations decreased, but leaf potassium (K) concentrations increased with increasing rootstock vigour, resulting in the highest leaf Ca, but the lowest leaf K concentrations in trees on 'Budagovsky 9' (B.9) dwarfing rootstock. On average, trees supplied by drip irrigation had larger fruit and higher leaf magnesium (Mg) and manganese (Mn), but lower leaf Ca, K, zinc (Zn), and copper (Cu) concentrations than those irrigated using the sprinkler system. A significantly lower volume of water was applied to trees using drip irrigation than by sprinkler irrigation. Highly-negative correlations were found between leaf K concentrations and leaf dry weight percentages (DW%), between starch degradation pattern (SDP) and fruit firmness, between leaf K and leaf Mg concentrations, and between leaf K and leaf Mn concentrations. Highly-positive correlations existed between leaf N and leaf Fe concentrations, between fruit yields and leaf N concentrations, and among the concentrations of most leaf micro-nutrients.

From: Esmaeil Fallahi, Kazem Arzani, and Bahar Fallahi; The Journal of Horticultural Science & Biotechnology (2013) 88(6):685-692.