Iran Agricultural Research, Vol. 32, No. 2, 2013
Printed in the Islamic Republic of Iran
Shiraz University

The Effect of Chemical Thinning on Seasonal Changes of Mineral Nutrient Concentrations in Leaves and Fruits of 'Soltani' Apple Trees

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Received 14 October 2013, Accepted 5 February 2014, Available Online 1 June, 2014

ABSTRACT- The purpose of this study was to elucidate the effects of chemical thinning on seasonal variations of leaf and fruit mineral compositions of 'Soltani' apple trees. Treatments, including unthinned control, naphthalene acetic acid (NAA) at 5 and 10 mg L^{-1}, naphthaeneacetamide (NAD) at 25 and 50 mg L^{-1}, benzyladenine (BA) at 50 and 100 mg L^{-1} and carbaryl at 500 and 1000 mg L^{-1} were applied when fruit diameters were about 8 to10 mm. The results showed that leaf nitrogen (N), phosphorus (P) and potassium (K) concentrations decreased, whereas calcium (Ca) and magnesium (Mg) increased during the season. Fruit mineral concentration changed with the age of the fruits. All nutrients decreased with fruit maturation. Most chemical thinners affected leaf concentrations of N and K but not P, Ca and Mg. Chemical thinning increased the fruits' P, K and Mg concentrations. It is concluded that fruit chemical thinning may affect the accumulation of some nutrients, especially P and K in apple fruits and could improve fruit quality as well.

Keywords: Apple, Chemical thinning, Mineral nutrients

INTRODUCTION

Crop removal by chemical thinners is one of the most important operations in apple orchard management, and its effects on crop productivity are well documented (25). The severity, method and timing of flower or fruitlet thinning can influence crop load, fruit size, and return bloom (17). It is also possible that such thinning practices affect leaf and fruit mineral compositions' however, this has been much less studied.

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Concentrations of mineral elements such as calcium (Ca), magnesium (Mg), potassium (K) and nitrogen (N) in apple fruits at harvest time can influence postharvest fruit quality in storage (13, 16). Thinning of flowers or fruitlets usually decreases Ca and increases K concentrations in the fruit (7, 10). However, in some cases Ca concentrations have either increased or not been affected when applying flower and fruitlet removal (20). Szot (23) showed that fruits from apple trees subjected to flower thinning had the highest P and K content, but tended to have the smallest Ca content and the biggest K/Ca ratio. High K and low Ca in fruits may have an adverse relationship with storage, but higher P in fruits from trees subjected to thinning is likely to reduce their susceptibility to low temperature injury. Baninasab et al. (1) also reported that macronutrient contents were affected by crop load in pistachio trees. They found that N and phosphorous (P) concentrations in many organs of pistachio trees from ON trees were the lowest as compared to that of OFF trees. In contrast to N and P, Ca and Mg of most organs were greater in heavily cropping trees than in lighter cropping trees. It is unclear whether changes in mineral composition in response to thinning are simply due to the effects of fruit size or other factors associated with crop load (1, 8, 27). Moreover, information on the effect of chemical thinning on nutrient concentrations of different organs of apple trees is limited.

The objective of this study was to quantify the effect of chemical thinning on seasonal patterns of nutrient (N, P, K, Ca and Mg) concentrations of leaves and fruits of "Soltani" apples.

MATERIALS AND METHODS

Trees

In 2009 and 2010 growing seasons, orchard experiments were carried out on a block of 13-year old apple trees (*Malus domestica* Borkh. cv. Soltani) grown on seedling rootstock in a commercial orchard in Semirom (31° 25′ N and 51° 34′ E), Iran. Trees in the orchard were spaced 4 and 5 m apart within and between the rows respectively. Standard commercial culture practices were followed during the experiment. Physical and chemical characteristics of the orchard soil were as follows: loam texture; pH = 7.4; electrical conductivity (EC) = 1.05 dS m^{-1}; available N= 1.2%, P and K 11.3 and 69 mg kg^{-1} soil, respectively.

Treatments

Immediately before full bloom, 27 trees with good health and similar flower densities were selected from the orchard block. The following fruitlet chemical thinning treatments were applied to individual trees when fruit diameter was about 8 to10 mm on May 24, 2009 [14 days after full bloom (DAFB)], and May 1, 2010 (17 DAFB) :

1- Unthinned control
2- Naphthalene acetic acid (NAA) at 5 and 10 mg L^{-1}
3- Naphthaeneacetamide (NAD) at 25 and 50 mg L^{-1}
4- Benzyladenine (BA) at 50 and 100 mg L^{-1}
5- Carbaryl (Sevin 50 WP) at 500 and 1000 mg L^{-1}

Sampling

Samples (leaves and fruits) for chemical analysis were taken from trees between 800 and 1000 h on each date to minimize diurnal effects. Leaves and fruits were sampled every 30 d (except for harvest time) from 45 DAFB to fruit maturation on June 24, 2009 and May 29, 2010 (45 DAFB), July 24, 2009 and June 28, 2010 (75 DAFB), August 23, 2009 and July 27, 2010 (105 DAFB) and September 15, 2009 and August 19, 2010 (128 DAFB = harvest time). Thirty leaves per tree were randomly sampled from the middle of the current season shoots as well as ten average size fruits from each tree. All samples were placed in plastic bags and kept in a large ice box until they were brought to the laboratory. Samples were then washed in a weak detergent solution, rinsed in tap water several times, given a final rinse in distilled water, dried at 70 °C for 48 h in a forced-air oven, and ground to pass a 40-mesh screen for nutrient analyses.

Chemical Analysis

All samples were analyzed for N, P, K, Ca, and Mg. Total N in samples was measured using a Kjeltec 2300 Analyzer unit (Foss Tecator, Sweden). To determine other elements, samples (1.0 g) were ashed in a muffle furnace at 550 °C for 5 h; the obtained ash was dissolved in 10 mL of 2 N HCl, which later increased up to 100 mL with distilled water. The amount of P was determined colorimetrically using the blue phosphomolybdate complex at 660 nm and the ammonium molybdate and stannus chloride procedure (17). Atomic absorption spectrometry (Perkin-Elmer 3030) was used to determine Ca and Mg. Potassium was determined using a flame photometer (Jenway, PFP7). Mineral element concentrations were expressed on a dry weight basis.

Experimental Design

The experiment was designed as a randomized complete block with three replications. The data were analyzed using a two-way ANOVA, with one factor being sampling time and the other being the fruits' chemical thinning. Statistical analysis was performed using MSTATC (Michigan State University, East Lansing, MI) and the means were compared using the least significant difference (LSD) test at P=0.05. Since no significant differences were found between the two years, data from both years were pooled together and presented (21).

RESULTS AND DISCUSSION

Sampling time had a significant effect on the N concentration in leaves (Table 1). As seen in Table 2, all measured N exhibited a decrease with sampling time. On the last sampling date, N concentration in the leaves was 17.63 % less than the first sampling time (15.84 vs. 19.23 mg g^{-1}). Also, chemical thinning of the trees was found to have affected the N concentration of leaves. All treatments, except for the 25 mg L^{-1} NAD and 100 mg L^{-1} BA, significantly increased the N concentration of leaves compared with the unthinned control trees, with the largest increase being the 10 mg L^{-1} NAA (18.53 mg g^{-1}) (Table 2). A significant interaction was found between sampling time and chemical thinning; an increase was observed in leaf N when using 10 mg L^{-1} NAA at 42 DAFB (21.59 mg g^{-1}) (Table 1, Fig. 1).

Table 1. Analysis of variance (ANOVA) of sampling time (S), chemical thinning (C), and their interaction (S×C) for the concentrations of nitrogen (N), phosphorous (P), potassium (K), calcium (Ca) and magnesium (Mg) in leaves and fruits of 'Soltani' apples

Source of variance	d.f.	*p*-Values									
		N		P		K		Ca		Mg	
		Leaf	Fruit	Leaf	Fruit	Leaf	Fruit	Leaf	Fruit	Leaf	Fruit
S	3	0.0001	0.0001	0.0001	0.0001	0.007	0.0001	0.0001	0.0001	0.0001	0.0001
C	8	0.0001	ns*	0.0001	0.0004	0.003	0.029	0.002	0.01	ns	0.008
S×C	24	0.008	ns	ns	0.032	ns	0.008	ns	ns	ns	ns
Error	70	-	-	-	-	-	-	-	-	-	-

*ns, non-significant

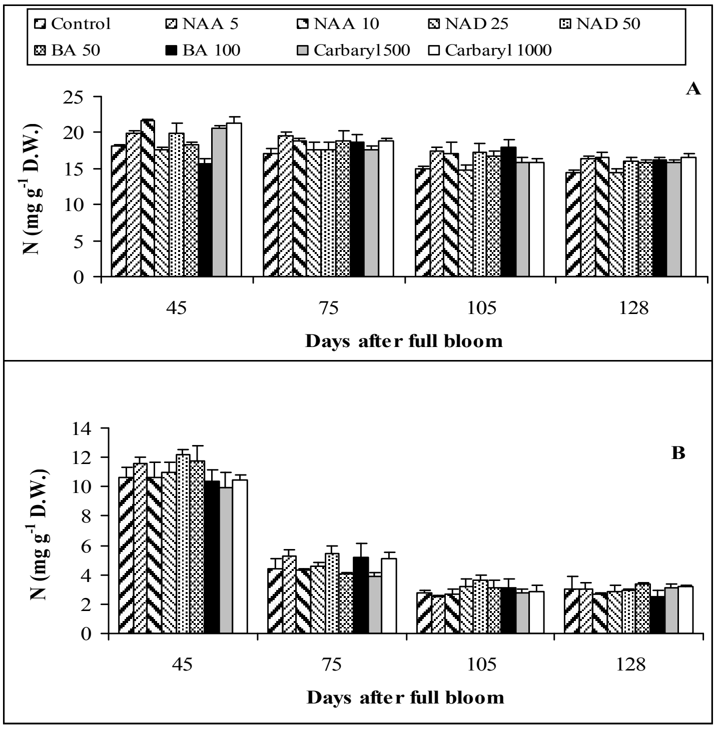

Fig. 1. Seasonal variation in the concentration of N in leaves (A) and fruits (B) as affected by chemical thinning for 'Soltani' apples. Data are means ± SE

Nitrogen concentration in apple fruits was significantly affected by sampling time (Table 1). Nitrogen concentration in the fruits sharply decreased from 45 to 75 DAFB but remained constant thereafter, without any significant differences between thinned and unthinned control trees (Table 2). There was no interaction between sampling time and fruit chemical thinning (Table1). However, in the last sampling time, N concentration was relatively similar in fruits of all treatments (Fig. 1). The direction of seasonal changes in both leaf and fruit N concentrations are in agreement with those reported for other tree species. In deciduous fruit trees, leaf and fruit N concentrations decreased during the growing season (24). Nachtigall and Dechen (15) showed that N concentration in leaves and fruits decreased significantly along the growth season in apple trees. Tissues of young leaves usually have lower water content and higher N concentration (14). Therefore, N concentration decrease observed in apple leaves along the growing season can be related to a dilution effect occurring with leaf growth. In the present study, we observed that chemical thinners increased leaf N in apples. Greater leaf N concentration in trees with less fruit was also observed by Brown et al. (4), Baninasab et al. (1) (for pistachio trees) and Fernandez-Escobar et al. (for olive leaves) (9).

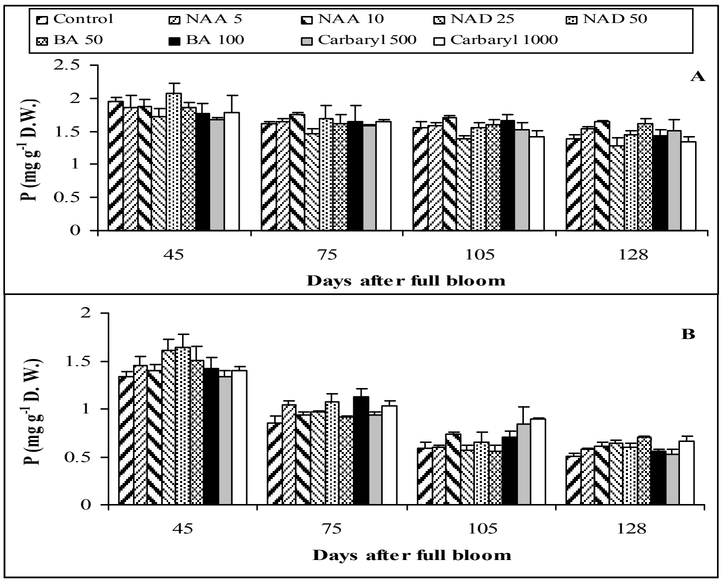

Fig. 2. Seasonal variation in the concentration of P in leaves (A) and fruits (B) as affected by chemical thinning for 'Soltani' apples. Data are means ± SE

The concentration of P in the leaves was significantly affected by sampling time (Table 1). Leaf P concentration was higher in younger leaves, decreased with leaf maturation and reached 1.63 mg g^{-1} on the last sampling date (Table 2). The seasonal changes found in leaf P concentration were generally in agreement with those reported for other fruit tree species such as walnuts (6) and olives (9), in which leaf P concentration decreased throughout the growing season. The application of chemical thinners had no effect on leaf P compared with non-treated trees in the control. The only treatment that significantly increased leaf P concentration was NAA at 10 mg L^{-1} and NAD at 50 mg L^{-1} (Table 2). Previous studies have also shown that leaf P concentration in peach trees was not affected by crop load (2). In this study, there was no interaction between sampling time and fruit chemical thinning (Table 1). However, on the last sampling date, leaf samples obtained from 5 mg L^{-1} NAA had 25.40 % (1.85 vs. 1.38 mg g^{-1}) higher P compared with the non-treated trees in the control (Fig. 2).

Sampling time and chemical thinning significantly affected fruit P concentration (Table 1), which was at its maximum at 45 DAFB, decreasing significantly with fruit maturation. However, on the last sampling date, P concentration in the fruits was 59.18% less than the first sampling time (0.60 vs. 1.47 mg g^{-1}) (Table 2). This result is in agreement with Nachtigall and Dechen (14) who found that fruit P content was high in the initial fruit development, and systematically decreased with fruit growth in three cultivars of apple ('Gala', 'Golden Delicious' and 'Fuji'). All chemical thinners increased fruit P content compared with the non-treated control trees. The greatest increase was found when NAD at 50 mg L^{-1} and carbaryl at 1000 mg L^{-1} was applied (Table 2). The increases in fruit P content were similar to those reported for 'Cox's Orange Pippin' apples by Johnson (10). There was a significant interaction between sampling time and chemical thinning; and an increase in fruit P was observed when using 50 mg L^{-1} NAD at 42 DAFB (1.64 mg g^{-1}) (Table 1, Fig. 2).

Sampling time and the application, but not interaction, of chemical thinners significantly affected leaf K content (Table 1). Potassium in the leaves sharply decreased from 45 to 75 DAFB and increased at 105 DAFB but remained relatively constant thereafter (Table 2). Low leaf K concentration during the growth flush of spring may be partially attributed to a dilution effect resulting from leaf expansion and the increase in leaf mass rather than an actual decrease in leaf K content (1). Conversely, an increase in the K concentration of the leaves during fruit development indicated that K accumulates as the season progresses and the rate of K accumulation exceeds the rate of dry matter accumulation in leaves (19, 27). All chemical thinners, except for the 25 mg L^{-1} NAD and 500 mg L^{-1} carbaryl, significantly increased the K concentration of leaves compared with the non-treated control trees, the largest increase being observed in treatment 5 mg L^{-1} NAA (14.37 mg g^{-1}) (Table 2). On the last sampling date, the K concentration of leaves from NAA at 5 mg L^{-1} was 27.0 % greater than that of the non-treated control trees (14.45 vs. 10.33 mg g^{-1}) (Fig. 3). Higher K concentration in the trees with less fruit was also observed by Baninasab et al. (1) in pistachio trees.

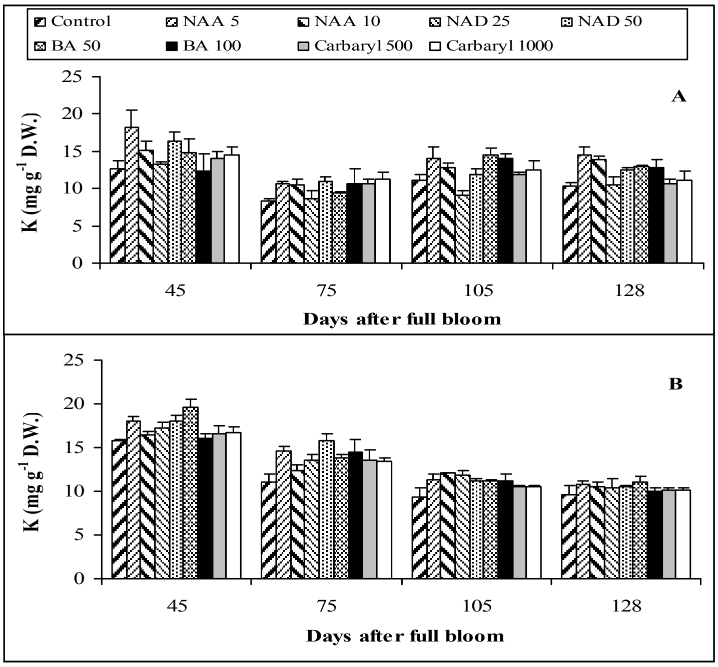

Fig. 3. Seasonal variation in the concentration of K in leaves (A) and fruits (B) as affected by chemical thinning for 'Soltani' apples. Data are means ± SE

The fruits' Potassium was significantly affected by sampling time (Table 1). The concentration of K in the fruits showed the same pattern as that of P (Table 2). This was similar to the results of Himelrick and Walker (11), who reported that the concentration of K in 'Delicious' apple fruits generally decreased over the season. Fruit K concentration was also, significantly affected by chemical thinning (Table 1). Fruits of thinned trees exhibited significantly higher K than the non-treated control trees (Table 2). However, compared with the control, the greatest increase was found when BA at 50 mg L^{-1} (13.89 mg g^{-1}) was applied (Table 2). A significant interaction was found between sampling time and chemical thinning, an increase in fruit K content being observed when using 50 mg L^{-1} BA at 42 DAFB (19.55 mg g^{-1}) (Table 1, Fig. 3). Volz and Ferguson (24) reported similar findings with 'Braeburn' apple trees. They concluded that fruit K concentrations were greater in thinned trees than unthinned trees.

Leaf Ca was significantly affected by sampling time, but not by chemical thinning or the interaction between the two (Table 1). The concentration of Ca in leaves showed a minimum value at 45 DAFB and increased significantly until the last sampling time (Table 2), a tendency which is typical for this element (9, 24). The increase in leaf Ca concentrations throughout the season can be explained by Ca immobility in plant tissues and its lack of redistribution to other plant organs (15).

Sampling time significantly affected fruit Ca (Table 1). Calcium in the fruits sharply decreased from 45 to 105 DAFB and remained relatively constant thereafter (Table 2). The seasonal changes in fruit Ca concentration were in agreement with those reported for apples (15) and navel oranges (26). There were no significant effects of thinning treatments on the fruits' Ca concentration (Table 1). This result is in agreement with those reported by Johnson (11) who found that in 'Cox's Orange Pippin' apples, late thinning (19 DAFB) had little or no effect on fruit Ca concentrations. Also, there was no interaction between sampling time and fruit chemical thinning (Table 1). However, the greatest concentration of Ca was obtained on the last sampling time from trees treated with 25 mg L^{-1} NAD (Fig. 4).

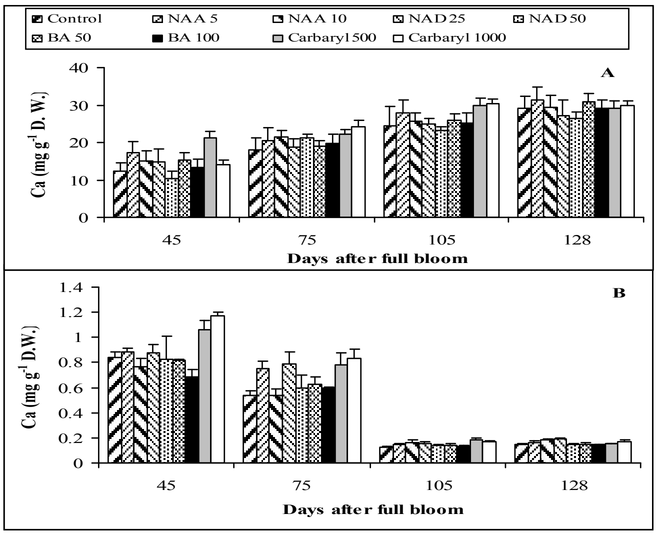

Fig. 4. Seasonal variation in the concentration of Ca in leaves (A) and fruits (B) as affected by chemical thinning for 'Soltani' apples. Data are means ± SE

Sampling time significantly affected the leaves' Mg (Table 1). Mg Concentration in leaves showed a minimum value at 45 DAFB (1.84 mg g^{-1}) and increased significantly until 105 DAFB (4.11 mg g^{-1}), remaining relatively constant thereafter (Table 2). The direction of seasonal changes in leaf Mg concentration is in agreement with the results reported on pistachios (1, 19) and Figs (3). In these species, leaf Mg values increased throughout the season; however, the contrary was found to be true for Japanese pears (5). These results indicate that the relationship between leaf Mg and leaf age varies widely among species. Leaf Mg increases are probably a consequence of lower K competition, since leaf K decreased along the growth cycle (15). The application of most of the chemicals had no effect on leaf Mg compared with the non-treated control trees (Table 2). Blanco et al. (2) also reported that crop load did not affect leaf Mg concentration in peaches. No interaction between was found to exist between sampling time and fruit chemical thinning (Table 1). However, on the last sampling date, Mg concentration of leaves treated with 1000 mg L^{-1} carbaryl was 9.53 % greater (4.72 vs. 4.27 mg g^{-1}) than the control (Fig. 5).

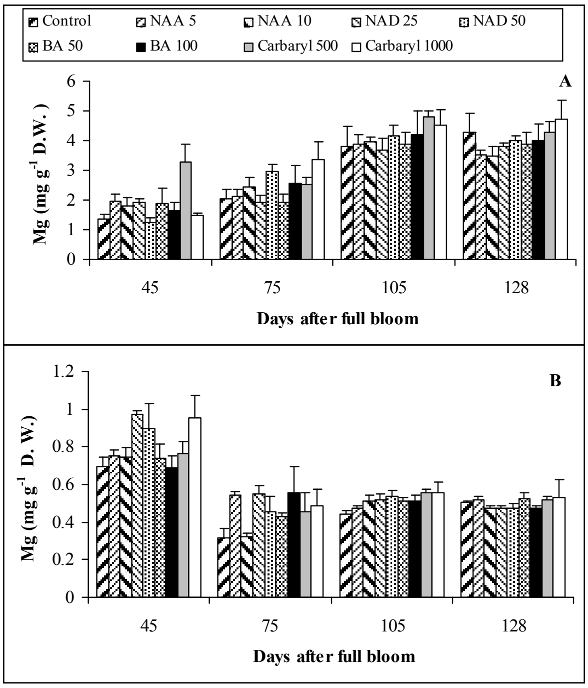

Fig. 5. Seasonal variation in the concentration of Mg in leaves (A) and fruits (B) as affected by chemical thinning for 'Soltani' apples. Data are means ± SE

Magnesium concentration in the fruits was significantly affected by sampling time (Table 1). Concentration of Mg in fruits, after an initial significant decrease during the second sampling date, exhibited a gradual increase to 105 DAFB and remained constant afterwards (Table 2). The seasonal changes of the fruits' Mg concentration was generally in agreement with reports on pistachios (1) and oranges (26). Also, fruit Mg concentration was found to be significantly affected by chemical thinning (Table 1). All treatments, except for the 10 mg L^{-1} NAA, 50 and 100 mg L^{-1} BA, significantly increased the Mg concentration of fruits compared with the control, with the highest increase being observed when 1000 mg L^{-1} carbaryl (0.63 mg g^{-1}) was used (Table 2). This is similar to the results of Volz and Ferguson (24), who reported that cluster thinning significantly increased 'Braeburn' apple fruits' Mg concentration compared with non-treated control trees. No interaction was found between sampling time and fruit chemical thinning (Table 1). However, on the last sampling time, the greatest concentration of Mg was obtained from trees treated with 1000 mg L^{-1} carbaryl (Fig. 5).

CONCLUSION

In this study, we evaluated the effect of chemical thinning on seasonal patterns of nutrient concentrations of leaves and fruits of apple trees. Our results showed that all mineral concentrations in fruits decreased during fruit maturation. Concentrations of N, P and K decreased in the leaves, whereas Ca and Mg concentrations increased during the season. In leaf tissues, the concentration of all minerals increased in response to thinning. Chemical thinning at the fruits' 8 to10 mm diameter stage caused increases in some minerals, especially P and K, and influenced fruit quality in cv. Soltani apples.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support of the Isfahan University of Technology. The authors thank R. Mohammadi and D. Bahram for their valuable help with this study.

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اثر تنک شیمیایی بر تغییرات فصلی عناصر معدنی برگ و میوه سیب "سلطانی"

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چکیده- هدف از این پژوهش بررسی اثرات تنک شیمیایی بر تغییرات فصلی عناصر معدنی در برگ و میوه درختان سیب رقم سلطانی بود. تیمارهای آزمایش شامل شاهد (تنک نشده)، اسید نفتالن استیک در غلظت های ۵ و ۱۰ میلی گرم در لیتر، نفتالن استامید در غلظت های ۲۵ و ۵۰ میلی گرم در لیتر، بنزیل آدنین در غلظت های ۵۰ و ۱۰۰ میلی گرم در لیتر و کارباریل در غلظت های ۵۰۰ و ۱۰۰۰ میلی گرم در لیتر بود که در زمانی که میوه ها قطری حدود ۸ تا ۱۰ میلی متر داشتند، روی درختان محلول پاشی شد. نتایج نشان داد در طول فصل رشد غلظت نیتروژن، فسفر و پتاسیم برگ کاهش در حالی که کلسیم و منیزیم افزایش یافت. غلظت ترکیبات معدنی میوه نیز با افزایش سن میوه ها تغییر یافت به گونه ایی که با بلوغ میوه ها غلظت عناصر فوق کاهش یافت. بسیاری از ترکیبات شیمیایی تنک کننده کاربردی سبب تغییر در غلظت نیتروژن و پتاسیم برگ شد در حالیکه بر غلظت فسفر، کلسیم و منیزیم برگ اثری نداشت. تنک شیمیایی سبب افزایش غلظت فسفر، پتاسیم و منیزیم میوه ها شد. بر اساس نتایج این تحقیق تنک شیمیایی با اثر بر تجمع برخی عناصر غذایی در میوه سیب به خصوص فسفر و پتاسیم قادر است سبب بهبود کیفیت میوه ها شود.

واژه های کلیدی: سیب، تنک شیمیایی، عناصر معدنی

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**مکاتبه کننده