Journal of Bio-Environment Control, 21(4):445-451, (2012)

Multiple Applications of Lime Sulfur for Fruit Thinning of 'Fuji' and 'Hongro' Apple Trees

Ik-Jo Chun[1]*, Wei-Wei Zheng[1], Cheol Choi[2], Yang-Yik Song[3], In-kye Kwang[2], and Peter Hirst[4]

[1]*School of Bioresource Sciences, Andong National University, Andong 760-749, Korea*
[2]*Division of Plant Biosciences, Kyungpook National University, Daegu 702-701, Korea*
[3]*Apple Experiment Station, NIHHS, R.D.A., Gunwi 716-812, Korea*
[4]*Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, IN, USA*

Abstract. The thinning effects of lime sulfur either alone or combined with fish oil on two apple cultivars 'Fuji'/M.9 and 'Hongro'/M.9 were investigated during two consecutive seasons. Either 1% or 2% lime sulfur at full bloom decreased the amounts of both terminal and axillary fruits compared with unsprayed 'Fuji' control trees in the first year. However, 1% or 2% lime sulfur did not decrease terminal fruit set in the second year. Only, triple applications of 1% lime sulfur significantly reduced the number of terminal and axillary fruits in both years. Multiple application of 1% lime sulfur was the most effective in thinning of 'Hongro'. In the first year, double or triple applications of 1% lime sulfur was effective in thinning terminal or axillary fruit, but one time applications of 1% or 2% lime sulfur was not reduced axillary fruit in 'Hongro' apple trees. In the second season, all treatments reduced terminal or axillary fruit in 'Hongro' clusters, except single application of 1% lime sulfur. Fish oil did not always improve the thinning effects of lime sulfur in 'Fuji' or 'Hongro' apple trees. None of treatments caused significant russeting in the harvested fruits. Most of thinning treatments had little effect on 'Fuji' or 'Hongro' fruit quality in terms of fruit weight, firmness, soluble solids concentration or titratable acidity.

Key words : axillary fruit, bloom thinner, full bloom, *Malus domestica* Borkh.

Introduction

The production system of apple trees rely on intensive crop load management strategies to produce increased yields of high quality fruits. Thinning of flowers or fruitlets has been one of the most important techniques to prevent biennial bearing and improve fruit size and quality (Wertheim, 2000). In Korea, market demand is for large sized fruit (~300 g) and efficient thinning is necessary to achieve this goal. While hand thinning is a reliable method of regulating crop load, it is labor intensive as well as expensive and often difficult to availability (Bergh, 1992; Knight, 1980; Palmer et al., 1991). However, growers can only thin by hand or using approved materials in organic apple production systems (Brozozowski, 2004).

A thinning strategy to achieve a greater overall increase in fruit size is to thin preferentially fruits from axillary fruiting sites since they have a lower potential for large fruit size than fruit on 2 year-old spurs (Volz et al., 1994). Lime sulfur (calcium polysulfide), a chemical product permitted in organic apple production under EU legislation, has been shown to be an effective thinning agent on apple (Bertschinger et al., 2000; Meland, 1998; Stopar, 2004). For 'Gala', positive thinning effects were achieved spraying 3~4% lime sulfur at 85% full bloom (Guak et al., 2004). Fruit abscission of 12~40% was obtained in 'Elstar' after lime sulfur application, which is equal to that of conventional thinning agents (Bloksma and Jansonius, 2000). Similar thinning effects were also reported on 'Royal Gala' (McArtney et al., 2004). However, some negative effects have also been reported including phytotoxicity and reduced leaf size at higher concentrations (Holb et al., 2003), and fruit russeting or dimpling at lower concentrations (Williams, 1993, 1994).

'Hongro' is one of the most popular apple cultivars in Korea. It was developed at the National Institute of Horticultural and Herbal Science, Rural Development Admin-

*Corresponding author: ikjochun@andong.ac.kr
Received October 23, 2010; Revised November 2, 2010; Accepted November 22, 2010

istration (RDA), Suwon in 1980 by crossing 'Spur EarliBlaze' with 'Spur Golden Delicious' (Shin et al, 1989). 'Hongro' flowers one week earlier than 'Fuji' and produces large, sweet, and high quality fruits that mature from early to middle September in Korea (Kang, 2004). 'Hongro' flowers profusely and does not exhibit biennial bearing.

Several studies have examined the effect of chemical blossom thinners on apple and peach fruit set (Byers 1997; Byers and Carbaugh, 1991; Fallahi, 1997; Fallahi and Chun, 2004). However, the efficacies of organic bloom thinners on 'Fuji' and 'Hongro' apple cultivars have not been reported. Therefore, this study was carried out to determine the efficacies of lime sulfur as a bloom thinner on "Hongro' and 'Fuji' apples in Korea.

Materials and Methods

Experiments were carried out in an orchard of Andong Agricultural Technology Center in 2007 and 2008. Eight-year-old 'Fuji'/M.9 and 'Hongro'/M.9 apple trees with similar vigor were selected. Trees were planted 3.8 m apart within a row and spacing between rows were 1.8 m. Trees were 3 m high and 1.5 m wide and were trained as slender spindles. All selected trees were under a standard pest and disease control program for the duration of the experiments. Forty two trees were selected and arranged as a randomized complete block design. All selected trees were separated by at least one untreated guard tree. Each treatment constituted six replications. All applications were made using a hand sprayer and treatments were applied in the morning.

The treatments were as follow: 1) control: non-sprayed; 2) lime sulfur (CaS_x) 1% at full bloom (FB); 3) lime sulfur 1% at FB, and 4 days after full bloom (DAFB); 4) lime sulfur 1% at FB, 2, and 4 DAFB; 5) lime sulfur 2% at FB; 6) lime sulfur 2% at 2 DAFB; 7) lime sulfur 1% plus fish oil 2% at FB. Treatment 7 was replaced by lime sulfur 2% plus fish oil 2% at FB in the second year.

Thinning efficacy was evaluated by determining fruit set on one east-facing and one west-facing limb per tree. Fruits were harvested at commercial maturity and randomly sampled for measuring weight, and size. Fruit russeting was evaluated on all fruits per replicate on a scale from 1 (blush or russeting < 25% of fruit skin surface) to 5 (blush or russeting > 75% of skin surface). Fruit soluble solid concentration (SSC) was measured by using Atago refractometer (Atago, Japan) while fruit firmness was measured by Effegi penetrometer fitted with an 11 mm head. Titratable acidity (TA) was measured by a digital fruit acidity analyzer (Model: GMK-708, GVK, and Korea). Fruit color was measured on the reddest cheek of each fruit using a Minolta Chromameter (Minolta Corp., Japan) measuring in the Hunter L* a* b* (Hirst et al., 1990). Return bloom was assessed by counting cluster number on each tagged branch the next spring. Data were subjected to a statistical analysis using ANOVA with Duncan's multiple range tests using SAS 9.1 (SAS, Inc., Cary, NC, USA).

Results and Discussion

1. Thinning effects of lime sulfur applications

In both years, weather conditions during the treatments were similar and favorable for pollination activity and fruit set (i.e., no precipitation, wind speed < 5 mph, mean daily air temperature 13~15°C, mean relative humidity 50~60%). Either 1% or 2% lime sulfur at full bloom decreased the amounts of both terminal and axillary fruits compared with unsprayed 'Fuji' control trees in the first year. However, 1% or 2% lime sulfur did not decrease terminal fruit set in the second year. Only, triple times of 1% lime sulfur application significantly reduced the number of terminal and axillary fruits in both years (Table 1). Added fish oil did not improve the thinning effects of lime sulfur in 'Fuji' apple trees in both years.

As well as 'Fuji', multiple application of 1% lime sulfur was the most effective in thinning of 'Hongro' (Table 2). In the first year, double or triple applications of 1% lime sulfur was effective in thinning terminal or axillary fruit, but one time applications of 1% or 2% lime sulfur was not reduced axillary fruit in 'Hongro' apple trees. In the second season, all treatments reduced terminal or axillary fruit in 'Hongro' clusters, except single application of 1% lime sulfur (Table 2). The addition of fish oil in 2% lime sulfur showed the more thinning effects than the treatment of single application of 2% lime sulfur in 'Hongro' (Table 2).

Many researchers have carried out experiments on

Table 1. Final fruit number per cluster and return bloom of 'Fuji'/M.9 apples after application of thinning agents.

	Treatment	Branch diameter (cm)	Fruit number per cluster		No. of return bloom clusters/branch
			Terminal fruits	Axillary fruits	
First	Control (non-sprayed)	2.1a [z]	4.80a	3.96a	19.3a
Year	LS 1% at FB	2.2a	3.09b	3.03bc	21.4a
	LS 1% at 0, and 4 DAFB	2.1a	3.05b	2.58cd	20.6a
	LS 1% at 0, 2, and 4 DAFB	2.3a	3.04b	2.32d	20.6a
	LS 2% at FB	2.5a	2.90b	2.81bc	19.8a
	LS 2% at 2DAFB	2.3a	3.49b	3.14b	20.7a
	LS 1% + FO 2% at FB	2.6a	3.43b	3.26b	22.7a
Second	Control (non-sprayed)	1.9a	4.31a	3.16a	25.8a
Year	LS 1% at FB	2.2a	4.01a	2.70b	32.3a
	LS 1% at 0, 4 DAFB	1.9a	3.83ab	2.31cd	25.3a
	LS 1% at 0, 2, 4 DAFB	1.9a	3.43b	2.05d	32.2a
	LS 2 % at FB	2.2a	3.95a	2.48bc	38.2a
	LS 2% at 2 DAFB	2.1a	4.09a	2.53bc	29.1a
	LS 2% + FO 2% at FB	1.9a	3.90ab	2.51bc	30.6a

[z]The means within column with the same letter are not significantly different at P = 0.05 according to Duncan's multiple range tests.
*LS- lime sulfur; FO- fish oil.
*FB-full bloom; DAFB- days after full bloom.

Table 2. Final fruit number per cluster and return bloom of 'Hongro'/M.9 apples after the application of thinning agents.

	Treatment	Branch diameter (cm)	Fruit number per cluster		No. of return bloom clusters/branch
			Terminal fruit	Axillary fruit	
First	Control (non-sprayed)	1.7a[z]	4.31a	3.66a	48.4a
Year	LS 1% at FB	2.0a	4.07ab	3.51a	51.0a
	LS 1% at FB, 4DAFB	1.9a	3.14bc	2.72c	48.8a
	LS 1% at FB, 2, 4DAFB	1.8a	2.79c	2.66c	47.6a
	LS 2% at FB	2.3a	3.22bc	3.20a	50.6a
	LS 2% at 2DAFB	2.1a	3.76ab	2.92bc	50.2a
	LS 1% + FO 2% at FB	2.1a	3.89ab	3.37ab	49.3a
Second	Control (non-sprayed)	1.9a	4.28a	2.86a	25.8a
Year	LS 1% at FB	1.9a	3.75b	2.87a	32.3a
	LS 1% at FB, 4DAFB	2.1a	3.58bc	2.64b	25.3a
	LS 1% at FB, 2, 4DAFB	2.1a	3.29cd	2.18c	32.2a
	LS 2% at FB	1.9a	3.38cd	2.31c	38.2a
	LS 2% at 2DAFB	1.8a	3.11d	2.50b	23.1a
	LS 2% + FO 2% at FB	2.0a	3.07d	2.20c	30.6a

[z]The means within column with the same letter are not significantly different at P = 0.05 according to Duncan's multiple range tests.
*LS- lime sulfur; FO- fish oil.
*FB-full bloom; DAFB- days after full bloom.

chemical thinning of apple and reported that timing is a critical factor for optimum results (Bloksma and Jansonius, 2000; Guak et al., 2004; Dennis, 2000; Jones et al., 1983, 1990, 1991, 1992). Thinning at full bloom generally results in improved fruit quality and return bloom compared with later thinning (Bound et al., 1991; Byers and Carbaugh, 2002; Tromp, 2000). In our experiments, we did not see any consistent effect of application timing on thinning, however, the window of timings in these studies was small (2 days).

Robinson et al. (2003) obtained significant fruit abscission with application of 1.5% or 2.5% lime sulfur at full

Table 3. Fruit characteristics of 'Fuji'/M.9 trees after the application of thinning agents.

	Treatment	Fruit diameter (mm)	Fruit weight (g)	Russeting (%)	Hunter values			Firmness (kgf/ 0.5 cm^2)	SSC (Brix)	TA (%)
					L	a	b			
First	Control (non-sprayed)	87.6a[z]	273.2a	0.4a	48.5a	23.5a	21.0ab	3.63a	14.4a	0.25a
Year	LS 1% at FB	85.1a	251.6a	0.6a	46.9a	25.0a	19.7b	3.47a	14.6a	0.27a
	LS 1% at FB, 4DAFB	83.3a	257.2a	2.0a	48.7a	21.2a	23.6a	3.61a	14.5a	0.26a
	LS 1% at FB, 2 and 4DAFB	82.8a	256.8a	1.7a	48.1a	20.7a	21.0ab	3.78a	14.5a	0.24a
	LS 2% at FB	84.4a	253.2a	4.9a	49.8a	21.5a	22.6ab	3.60a	14.8a	0.25a
	LS 2% at 2DAFB	87.6a	277.6a	0.5a	48.4a	21.4a	20.2b	3.52a	14.3a	0.25a
	LS 1% + FO 2% at FB	85.9a	264.0a	0.8a	49.6a	23.8a	20.5b	3.63a	14.4a	0.25a
Second	Control (non-sprayed)	89.2a	300.8a	ND	45.7e	28.0a	15.3e	3.42a	13.7a	0.21a
Year	LS 1% at FB	88.2a	288.6a	ND	47.1d	26.9a	16.6d	3.48a	14.0a	0.21a
	LS 1% at FB, 4DAFB	87.9a	290.7a	ND	47.6cd	24.2cb	18.5bc	3.66a	14.0a	0.21a
	LS 1% at FB, 2 and 4DAFB	90.4a	310.1a	ND	49.9ab	21.0d	17.6c	3.45a	13.8a	0.21a
	LS 2% at FB	89.9a	305.9a	ND	48.7bc	23.6bc	18.5bc	3.44a	13.9a	0.22a
	LS 2% at 2DAFB	88.9a	304.5a	ND	49.2ab	22.9bc	19.2ab	3.64a	13.7a	0.21a
	LS 2% + FO 2% at FB	89.5a	300.5a	ND	50.2a	22.0cd	19.8a	3.55a	13.9a	0.21a

[z]The means within column with the same letter are not significantly different at P = 0.05 according to Duncan's multiple range tests.
*LS- lime sulfur; FO- fish oil.
*FB-full bloom; DAFB- days after full bloom.
*ND-Not detected.

Table 4. Fruit characteristics of 'Hongro'/M.9 trees after the application of thinning agents.

	Treatment	Fruit diameter (mm)	Fruit weight (g)	Russeting (%)	Hunter values			Firmness (kgf/ 0.5 cm^2)	SSC (Brix)	TA (%)
					L	a	b			
First	Control (non-sprayed)	83.4a[z]	246.2a	3.7a	50.7a	33.1a	19.5ab	4.04ab	14.5bc	0.17a
Year	LS 1% at FB	78.3b	250.0a	1.7a	48.1a	39.9a	16.1b	3.95ab	14.0c	0.16a
	LS 1% at FB, 4DAFB	84.8a	250.5a	1.8a	47.3a	38.0a	18.9ab	4.03ab	14.8ab	0.16a
	LS 1% at FB, 2, 4DAFB	90.7a	272.0a	1.2a	48.5a	36.7a	19.1ab	3.73b	15.4a	0.16a
	LS 2% at FB	88.3a	280.0a	1.5 a	53.8a	31.3a	20.2ab	3.82ab	15.2a	0.16a
	LS 2% at 2 DAFB	88.1a	279.7a	2.8a	53.1a	31.5a	21.8a	3.85ab	15.0ab	0.17a
	LS 1% + FO 2% at FB	83.7a	264.5a	1.2a	53.2a	31.5a	21.6ab	4.11a	14.5bc	0.18a
Second	Control (non-sprayed)	88.7a	274.3a	0.8a	54.0a	25.8d	21.6a	3.80a	13.7a	0.18a
Year	LS 1% at FB	87.2a	270.6a	1.2a	52.7b	26.7cd	19.8b	3.82a	13.4a	0.18a
	LS 1% at FB, 4DAFB	86.5a	266.2a	1.0a	51.8bc	27.9c	20.5b	3.83a	13.6a	0.18a
	LS 1% at FB, 2, 4DAFB	86.0a	256.0a	1.3a	51.7bc	29.6b	20.3b	3.83a	12.9a	0.17a
	LS 2% at FB	85.0a	255.9a	1.6a	49.8d	31.2a	18.7c	3.90a	12.9a	0.17a
	LS 2% at 2 DAFB	84.3a	255.4a	0.9a	50.8cd	30.5ab	20.0b	3.91a	13.2a	0.18a
	LS 1% + FO 2% at FB	85.1a	253.2a	1.1a	51.3c	30.3ab	20.3b	3.82a	13.3a	0.17a

[z] The means within column with the same letter are not significantly different at P = 0.05 according to Duncan's multiple range tests.
*LS- lime sulfur; FO- fish oil.
*FB-full bloom; DAFB- days after full bloom.

bloom in 'Golden Delicious'/M.9 trees, but 3% lime sulfur led to an excessive fruit removal (Stopar, 2004). In our experiments with 'Fuji' and 'Hongro', effective thinning was obtained with double or triple applications of 1% or 2% lime sulfur without russeting on the fruits (Tables 1 and 2). None of our treatments caused severe russeting in the 'Fuji' and 'Hongo' apples (Table 3 and 4). This absence of the adverse effect may be due to the

difference of cultivars, cultural practice, vigor or prevailing weather conditions during and after the treatments (Weibel et al., 2006; Wertheim, 2000; Williams, 1979).

Addition of 2% fish oil, as a wetting agent, to 2.5% lime sulfur, was found to be effective in thinning 'Bing'/Gisela5 sweet cherry, 'Enterprise'/M.9 and 'Goldrush'/M.9 apples (Robinson et al., 2003; Whiting et al., 2006). In these experiments, adding 2% fish oil to either 1% or 2% LS had no additional effect, except for slightly more thinning of axillary flowers in 'Hongro' in one year (Table 2). Based on these results, the addition of fish oil to lime sulfur application is unlikely to be used for thinning effects in 'Hongro' or 'Fuji' apple trees.

In conclusion, 1% lime sulfur applied one; two or three times were all effective in thinning axillary fruits of 'Fuji' in both years. However, the results were not consistent on 'Fuji' terminal blossoms, only triple applications of lime sulfur caused significant thinning effect (Table 1). 'Hongro' is a very vigorous cultivar, and its flowers thinned with multiple applications of 1% lime sulfur in both years (Table 2).

2. Effect of lime sulfur on fruit quality

Although treatments varied in their thinning effects, none of them had any significant effect on russeting of fruits (Table 3 and 4). All thinning treatments showed an increased L- and b-value, a decreased a-value for 'Fuji' fruits compared to the non-sprayed control trees. Lime sulfur had the opposite effect on 'Hongro' fruit color in the second year, which caused a decrease in L- and b-value, and an increase in a-value in treated fruits compared to non-sprayed controls. Application of 2% lime sulfur at full bloom proved to have the greatest effect on 'Hongro' fruit color. Most of thinning treatments had little effect on 'Fuji' or 'Hongro' fruit quality in terms of fruit weight, firmness, soluble solids concentration or titratable acidity (Tables 3 and 4). Those results should be affected by hand thinning after bloom thinning application, because orchard farmers did not want to produce low quality of fruits and biannual habit in apple trees.

Increased thinning action usually results in the stimulation of return bloom in apple (Bound et al., 1997; Byer, 1993; Guak et al., 2004; Jones et al., 1983; Veinbrants and Hutchinson, 1976), and pear (McArtney and Wells, 1995). In this experiment, the application of lime sulfur markedly reduced fruit set. However, fruit size, mean fruit weight, return bloom, SSC, firmness, and TA were unaffected by all treatments (Table 1, 2, 3, and 4), which may be due to homogeneous hand-thinning three weeks after lime sulfur spray. For both 'Fuji' and 'Hongro', most effective thinning was achieved with triple applications of lime sulfur. This treatment significantly thinned both axillary and terminal flowers. Triple applications of lime sulfur did not show significant effect on russeting of fruits, but fruit color of the two cultivars showed differences which may be the cause of their physiochemical contents.

Acknowledgements

This study was supported by 2009 Research Fund of Andong National University.

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Multiple Applications of Lime Sulfur for Fruit Thinning of ‘Fuji’ and ‘Hongro’ Apple Trees

석회유황합제의 다중처리에 따른 ‘후지’ 및 ‘홍로’ 사과의 적과 효과

전익조[1]* · 정위위[1] · 최철[2] · 송양익[3] · 강인규[2] · 피터 허스트[4]

[1]국립안동대학교 원예육종학과, [2]경북대학교 원예과학과,
[3]국립원예특작과학원 사과시험장, [4]퍼듀대학교 원예조경학과

적 요. 본 연구는 2년간 ‘홍로’/M.9 및 ‘후지’/M.9 품종의 적과를 위한 석회유황합제 및 어유와의 혼합처리 효과를 조사하기 위해 진행하였다. ‘후지’ 1년 차에 있어, 만개 시 석회유황합제 1% 또는 2% 처리는 대조구에 비해 정과 및 액과의 유과수를 감소시켰다. 하지만 2차년도에는 석회유황합제 1% 또는 2% 단용처리에서는 정과 유과수의 차이를 나타내지 않았다. 다만 석회유황합제 1%의 3회 처리에서는 1차년도와 2차년도 모두 유의적인 적과효과를 나타내었다. 석회유황합제 1%의 다중처리는 ‘홍로’에서 가장 효율적인 적과효과를 나타내었다. 1차년도의 경우, 석회유황합제 1%의 2회 또는 3회 살포가 효과적인 적과효과를 보였으며, 2차년도에서는 석회유황합제 1% 1회처리를 제외하고는 모두 유의적인 적과효과를 나타내었다. 첨가된 어유의 경우 대부분의 경우 석회유황합제의 적과효과를 강화하지 않았다. 본 시험에 사용된 모든 처리구는 과실의 동녹 형성에 악영향을 미치지 않았으며, 또한 ‘후지’ 및 ‘홍로’의 과실 중량, 경도, 가용성고형물 및 적정산도와 같은 과실품질에 영향을 미치지 않았다.

주제어 : 만개, 사과, 적화제, 측과