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1-Naphthaleneacetic acid and 6-benzyladenine thinning of a common slender spindle 'Jonagold'/M.9 apple orchard. II: Partial tree spraying

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SUMMARY

Mature slender spindle 'Jonagold'/M.9 apple (*Malus* × *domestica* Borkh.) trees were thinned using 10 mg l^{-1} 1-naphthaleneacetic acid (NAA) or 100 mg l^{-1} 6-benzyladenine (BA) and an axial fan sprayer at a spray volume of 1,500 l ha^{-1} applied to the whole canopy, or with smaller volumes, where only the upper half of each canopy was sprayed. Partial spray applications of NAA or BA (at 1,000 l ha^{-1}, 750 l ha^{-1}, or 500 l ha^{-1}) to the upper half of the trees did not cause any reduction in final fruit numbers on the upper half, or on the lower half of each tree. When the whole tree was sprayed to run-off with the same thinning agent, or at 1,500 l ha^{-1}, successful thinning on both the upper and lower parts of the canopy occurred. Good spray coverage (from 51% to 77%) was also observed on leaves at all canopy positions measured, when whole trees were sprayed at 1,500 l ha^{-1}. The development of an innovative crop load regulation strategy was an objective of the ISAFRUIT Smartfruit Project.

Spraying plant growth regulator (PGR) thinning agents such as 1-naphthaleneacetic acid (NAA) or 6-benzyladenine (BA) on apple trees reduces excessive numbers of fruitlets, and should achieve a uniform distribution of fruit within the canopy, so that all reach a marketable fruit size. Major factors influencing initial fruit set are the combination of light level in relation to canopy density, and the distribution of PGR thinner within the crown. Three days of artificial 92% shade, equivalent to a cloudy period, greatly reduced apple fruit set, while a combination of shade plus PGR thinner application induced even more fruit thinning (Byers *et al.,* 1990; 1991; Lehman *et al.,* 1987). Considering the natural shade within a canopy, the percentage of fruit that remain at harvest varied from excessive at the top, to optimal at the lower outside, to almost nil at the lower inside of the canopy (Unrath, 2002). When an axial fan sprayer was used, particularly with a low volume spray, three-to-five times more thinner was deposited in the lower quadrant of trees [i.e., the opposite of the desired distribution (Bukovac, 1986)]. Because of the greater exposure to sunlight and reduced fruit drop in the upper portion of the canopy, Unrath (2002) suggested that the top one-third of the tree should receive 80 – 90% of the spray volume, with no PGR thinner delivered to the lower part of the crown. For 6 m-high grapefruit trees, Stover *et al*. (2003) recommended that two-thirds of the total spray volume should be directed at the upper half of the crown when using an airblast sprayer with conventional radial delivery.

The aims of this study were: (i) to examine the possibility of spraying only the upper half of apple trees to reduce fruit thinning in the lower part of the canopy, while simultaneously reducing the amount of NAA or BA used; and (ii) to follow the distribution of the spray, and the resulting thinning response within the crown, when only the upper part of the canopy was sprayed. Establishing an optimal crop load through the use of PGR thinning agents is an objective of the ISAFRUIT Smartfruit Project.

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MATERIALS AND METHODS

Plant material

Partial tree thinning and spray distribution measurements were conducted in an experimental orchard at Brdo, Slovenia, in 2006 and 2007. Homogeneous mature slender spindle 'Jonagold'/M.9 apple trees, 3.0 – 3.5 m-high and 1.2 – 1.5 m-wide, planted in a single row system at a spacing of 3.0 m × 1.1 m (3,030 trees ha^{-1}) were selected according to size, vigour, and bloom density. A narrow plastic band was twisted around the trunk of the experimental trees (n = 84), 1.7 m above ground level, to separate the upper and lower parts of the canopy when flower cluster numbers and yield measurements were made. During the experiment, all trees received standard commercial pest and disease management programmes. At harvest, the fruit on each tree, from the upper and lower halves of each canopy, were counted and weighed separately.

Treatment application

Three selected trees within a 10-m row represented one spraying treatment method in each block. At least four trees were left in each row to provide a buffer zone between treatments, and three buffer rows were left between blocks. An axial fan sprayer (NI 1000 TL72; Holder, Metzingen, Germany) was used to spray both sides of the experimental trees. A distance of 10 m between two labelled stakes in a row were used for one spray treatment. NAA at 10 mg l^{-1} [Nokad; 4% (w/v) a.i.; Isagro, Cagliari, Italy] and BA at 100 mg l^{-1} [VBC 30001; 1.9% (w/v) a.i.; Valent Biosciences, Libertyville, IL, USA] were sprayed when the average fruitlet diameter was 10.2 mm or 9.7 mm, respectively. The sprayer water consumption (in l ha^{-1}) was adjusted by changing the nozzle size (pink, yellow, red, or green Albuz ATR nozzles; Agrotop, Obertraubling, Germany) and the tractor speed (3.0 or 4.5 km h^{-1}). Six single or double nozzle positions per side of the sprayer were used to deliver spray solutions to the whole canopy. When only the upper half of the canopy was to be sprayed, the top two nozzle positions (two double nozzles) on the sprayer were opened to exclude delivery to the bottom part of the crown (Figure 1). The working pressure was 10^6 Pa, and the fan capacity for all treatments was 50,000 m^3 h^{-1}. The non-thinned trees in each row represented the first controls, and a knapsack hand-sprayer was used to provide complete coverage of the foliage at approx. 1 l water per tree, to ensure run-off spraying as the second control treatment. When a tractor and axial fan sprayer were used, 1,500 l ha^{-1} was applied to the whole canopy; or 1,000 l ha^{-1} was applied to the upper half plus 500 l ha^{-1} to the lower half of the canopy; or 1,000 l ha^{-1}, 750 l ha^{-1}, or 500 l ha^{-1} were applied to the upper half of the canopy, only.

Spray deposit measurements

To estimate the distribution of the spray in each canopy, five positions were pre-selected and water-sensitive paper (26 mm × 76 mm) was fixed to the experimental trees at three heights: at the top of the crown, approx. 3 m-high (position 1); in the middle of the crown 1.8 m from the ground, internal near the trunk (position 2), or external next to the spray lane (position 3); and in the lowest part of the crown, 0.7 m from the ground, internal near the trunk (position 4), or external next to the spray lane (position 5; Figure 1). Two water-sensitive papers were fixed to a leaf at each canopy position, one to the upper (adaxial) and one to the lower (abaxial) surface of the same leaf. After a suitable drying time (approx. 1 h), all ten papers per tree were collected. The paper changed colour wherever the spray solution landed. Measurements of spray coverage areas (%) were done using an Optomax V image analyser (AMS, Saffron Walden, UK).

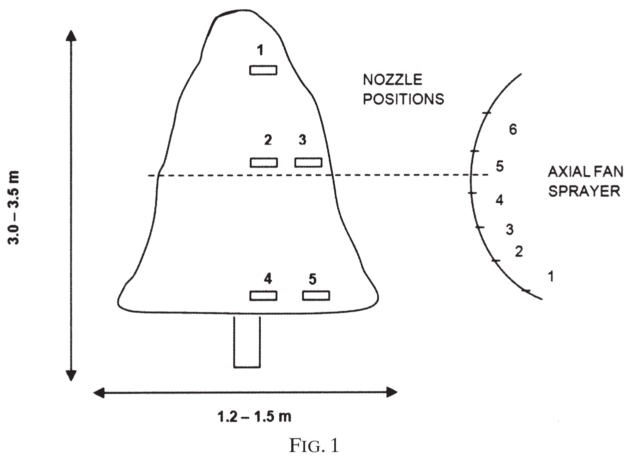

FIG. 1
The five positions of the water-sensitive papers placed on slender spindle 'Jonagold'/M.9 experimental trees, and the six relative (single/double) nozzle positions on the axial fan sprayer.

Statistics

The treatments were arranged in a randomised complete block design, with four replications. Three trees were used for each treatment in each block. In each row, four or more buffer trees were used between treatments, while, between rows, three rows were omitted from PGR thinner application in order to prevent spray drift from the other blocks. The data were subjected to statistical analysis using the Statgraphics 5.0 statistical programme (STSC, Rockville, MD, USA). Analysis of co-variance (the number of flower clusters per tree as a co-variate) was used to separate the treatment means by Duncan's multiple range test at $P = 0.05$.

RESULTS AND DISCUSSION

Previous experiments had showed that run-off application of 10 mg l^{-1} NAA or 100 mg l^{-1} BA successfully thinned 'Jonagold'/M.9 trees, an easy-to-thin apple cultivar (Stopar, 2000). Fruit from the upper half and lower half of each tree were harvested separately to measure the thinning effect of partial 10 mg l^{-1} NAA or 100 mg l^{-1} BA spraying (Table I). When trees were sprayed with 10 mg l^{-1} NAA to run-off (whole canopy), at 1,500 l ha^{-1} (whole canopy), or at 1,000 l ha^{-1} to the upper half plus 500 l ha^{-1} to the lower half, and the whole tree was estimated as one replicate, the final average fruit numbers per tree were reduced significantly to 186, 187, or 197 respectively, compared to an average of 261 fruit on a non-thinned tree (control). Application of 10 mg l^{-1} NAA at 1,000 l ha^{-1} or at 750 l ha^{-1} to the upper half of the canopy, alone did not induce significant thinning when measuring the whole tree as a unit. In the case of 500 l ha^{-1}, no thinning was noticed.

The BA thinning results were comparable to the NAA results. Spraying the whole tree with 100 mg l^{-1} BA significantly reduced the final average fruit numbers per tree (i.e., from control = 252; to run-off = 145; 1,500 l ha^{-1} = 159; and 1,000 l ha^{-1} plus 500 l ha^{-1} = 177). Spraying only the upper half of the tree with 100 mg l^{-1} BA did not reduce whole tree fruit numbers significantly (at 1,000 l ha^{-1} = 213; 750 l ha^{-1} = 198; or 500 l ha^{-1} = 198). Also, when NAA or BA fruit thinning was estimated by the number of fruits harvested per 100 flowering clusters, counted in the Spring, the results were similar to the low level of whole tree thinning estimated for 750 l ha^{-1} or 500 l ha^{-1} sprayed to only the upper part of the tree. If 1,000 l ha^{-1} of NAA or BA was sprayed on the upper half of the canopy alone, significantly lower numbers of fruit per 100 clusters were observed in the case of NAA, but not in the case of BA spray.

Separate estimates of the final crop load in the upper half of each tree gave interesting results. Applications of 10 mg l^{-1} NAA to run-off over the whole canopy, at 1,500 l ha^{-1}, or at 1,000 l ha^{-1} to the top plus 500 l ha^{-1} to the bottom of the canopy, reduced fruit numbers in the upper half of the canopy to 119, 114, or 124 respectively, compared to control trees with 158 fruit (Table I). When only the upper halves of trees were sprayed with 10 mg l^{-1} NAA at 1,000 l ha^{-1}, 750 l ha^{-1}, or 500 l ha^{-1}, the reductions in fruit numbers in the upper half were not significant.

When 100 mg l^{-1} BA was applied to the whole canopy, fruit numbers in the upper half of the canopy were

TABLE I
Yield data for the upper and lower parts of the crown of 'Jonagold'/M.9 apple trees and whole trees after the application of a PGR thinning agent in the partial tree spraying experiments in 2006 (NAA) and 2007 (BA)

	Whole tree		Upper half		Lower half	
PGR/treatment	Mean fruit number/tree	Fruit number/ 100 clusters	Mean fruit number/tree	Mean fruit weight (g)	Mean fruit number/tree	Mean fruit weight (g)
NAA (10 mg l^{-1})						
Control, (no thinning)	261 c*	141 c	158 b	115 a	106 b	121 ab
To run-off	186 a	95 a	119 a	157 e	75 a	161 d
1,500 l ha^{-1} (whole tree)	187 a	94 a	114 a	148 de	78 a	153 cd
1,000 l ha^{-1} + 500 l ha^{-1}	197 ab	102 ab	124 a	137 bcd	73 a	142 bcd
1,000 l ha^{-1} (top)	227 abc	110 ab	135 ab	127 abc	95 ab	124 ab
750 l ha^{-1} (top)	237 bc	125 bc	140 ab	139 cde	98 ab	134 abc
500 l ha^{-1} (top)	263 c	139 c	127 ab	119 ab	137 c	113 a
BA (100 mg l^{-1})						
Control, (no thinning)	252 c	96 c	102 b	157 a	150 c	145 a
To run-off	145 a	50 a	58 a	213 c	87 a	216 b
1,500 l ha^{-1} (whole tree)	159 ab	58 ab	66 a	185 ab	95 a	189 ab
1,000 l ha^{-1} + 500 l ha^{-1}	177 ab	74 bc	69 a	198 bc	105 ab	183 ab
1,000 l ha^{-1} (top)	213 bc	85 c	71 ab	193 bc	142 bc	177 a
750 l ha^{-1} (top)	198 abc	78 bc	73 ab	177 ab	126 abc	162 a
500 l ha^{-1} (top)	198 abc	78 bc	80 ab	177 ab	118 abc	164 a

* Mean separation within a column was by Duncan's multiple range test at $P = 0.05$. Values followed by different lower-case letters are significantly different.

reduced from control (102) to run-off (58), or 1,500 l ha^{-1} (66), or 1,000 l ha^{-1} plus 500 l ha^{-1} (69). No significant thinning happened in the upper half of the canopy when 100 mg l^{-1} BA was sprayed at 1,000 l ha^{-1}, 750 l ha^{-1}, or 500 l ha^{-1} to the upper part of the canopy alone. The NAA and BA thinning results indicated that the upper half of the canopies could be thinned successfully in the case of whole tree spraying, but that 1,000, 750, or 500 l ha^{-1} NAA or BA sprayed to the upper half alone did not thin enough in the top canopy position.

The lower half of the canopy was also estimated, separately, for fruit retention. Differences between the types of spraying were similar to those observed for the upper-half retention data (Table I). When NAA was sprayed on the whole canopy to run-off using a knapsack sprayer, or with an axial fan + tractor sprayer to 1,500 l ha^{-1}, or to 1,000 l ha^{-1} (top) plus 500 l ha^{-1} (bottom), average fruit numbers in the lower half of the tree were reduced significantly to 75, 78, or 73, respectively, compared to the average of control trees (106 fruit). Insignificant thinning in the lower canopy occurred if 1,000 l ha^{-1}, 750 l ha^{-1}, or 500 l ha^{-1} NAA was applied only to the upper half of the trees.

Similarly, when BA was applied to the whole canopy, the average number of fruit in the lower part of the canopy was reduced significantly from 150 fruit (control) to 87 (for run-off), 95 (at 1,500 l ha^{-1}), or 105 (at 1,000 l ha^{-1} + 500 l ha^{-1}). BA (100 mg l^{-1}) spraying to only the top of the canopy at 1,000 l ha^{-1}, 750 l ha^{-1}, or 500 l ha^{-1}, did not significantly diminish the final fruit number in the lower part of the canopy.

The concept of applying thinning agents such as NAA or BA to only the upper part of the canopy, in order to reduce spray use (because the lower part of the canopy did not need PGR thinner) was rejected. When 10 mg l^{-1} NAA or 100 mg l^{-1} BA was applied at 1,000 l ha^{-1}, 750 l ha^{-1}, or 500 l ha^{-1} to only the upper half of the crown, thinning was unsuccessful in both the upper and lower halves of the canopy. Some workers have suggested that PGR thinning in the lower canopy is unnecessary, or should be minimised, because of its stronger response to chemical thinning or to self-thinning caused by lower light conditions (Unrath, 2002). In our trials, the need for PGR thinning was clear, because mean fruit weights in the control trees, in both the upper and lower canopy positions, were low (< 160 g). The average weight of fruit from the lower part of the crown on control trees from the NAA experiment was 121 g, and was 145 g in the BA experiment (i.e., much lower than commercially marketable 'Jonagold' apples). When overall canopy spraying was performed (i.e., to run-off; at 1,500 l ha^{-1}; or at 1,000 l ha^{-1} above, plus 500 l ha^{-1} below), significant fruit thinning occurred, and mean fruit weights were increased significantly in both the upper and lower parts of the canopy in both experiments. But, when only the upper part of the canopy was sprayed with 10 mg l^{-1} NAA or 100 mg l^{-1} BA at 1,000 l ha^{-1}, 750 l ha^{-1}, or 500 l ha^{-1}, insignificant thinning was noted in the lower canopy positions, and the apples stayed small and did not differ significantly from control tree fruit. In general, at least 1,500 l ha^{-1} of spray solution should be applied to the whole canopy in order to thin both the upper and lower parts of the canopy successfully in this size and type of apple orchard.

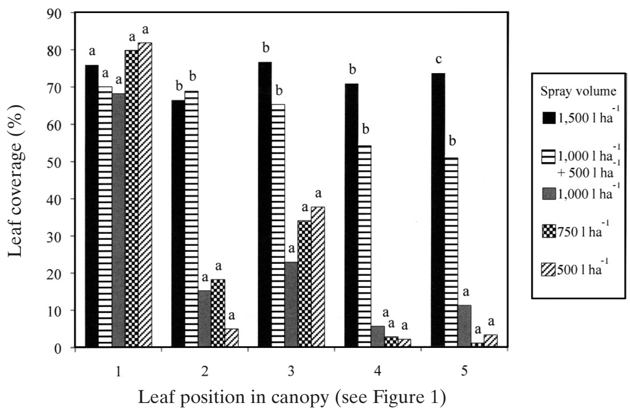

FIG. 2
Spray coverage (% area) on the lower (abaxial) leaf surfaces at five canopy positions (1, top; 2, middle internal; 3, middle external; 4, bottom internal; 5, bottom external) in a partial tree spraying experiment when 100 mg l^{-1} BA was sprayed at 1,500 l ha^{-1} to the whole canopy; or at 1,000 l ha^{-1} to the upper half plus 500 l ha^{-1} to the lower half; or when 1,000 l ha^{-1}, or 750 l ha^{-1}, or 500 l ha^{-1} was sprayed only to the upper half of the canopy. Different lower-case letters above each column indicate statistically significant differences between spray treatments within each canopy position by Duncan's multiple range test at $P = 0.05$.

The experiments with partial spray delivery to the crown were also used to measure spray deposits on the leaves (Figure 2). Spray coverage on the lower leaf surfaces was measured because of the greater importance of the abaxial (lower) leaf surface for the effectiveness of PGR sprays (Black *et al.,* 1995; Crabtree and Bukovac, 1980). However, average spray coverages on the lower and upper leaf surfaces were similar (data not shown). When whole-tree spraying was performed at a uniform application of 1,500 l ha^{-1} to whole crowns, or with 1,000 l ha^{-1} to the upper half plus 500 l ha^{-1} to the lower half, good spray coverage (between 51% – 77%) was seen in the whole canopy. Significantly less leaf coverage at the middle (2, 3) and lower (4, 5) canopy positions was observed when only the upper half of each tree was sprayed at 1,000 l ha^{-1}, 750 l ha^{-1}, or 500 l ha^{-1}. In these cases, coverages at canopy position 2 were 15%, 18%, or 5%; at position 3 were 23%, 34%, or 38%; at position 4 were 5%, 3%, or 2%; and, at position 5, were 11%, 1%, or 3%, respectively. Only position 1 (top) was well covered (68% – 82%) using all volumes and types of tractor spraying. Nevertheless, yield measurements on trees were divided into the upper and lower parts of the crown, while spray deposits were measured in the top, middle, and lower parts of the canopy. It could be concluded that NAA or BA sprays should be delivered to all parts of the canopy in order to thin the whole canopy successfully. Furthermore, good spray deposits at the top of the canopy did not affect thinning at the top sufficiently, unless the whole crown was covered with the NAA or BA thinning agent.

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