Effect of Aminoethoxyvinylglycine (AVG) on Preharvest Drop, Fruit Quality, and Maturation of 'McIntosh' Apples. II. Effect of Timing and Concentration Relationships and Spray Volume

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Abstract. AVG was evaluated for its effect on controlling preharvest drop and influencing ripening of 'McIntosh' apples in Maine and Massachusetts. AVG consistently and effectively retarded preharvest drop. AVG was superior to NAA and comparable to daminozide in drop control. Dilute or 2× applications were more effective than applications made at lower water volumes. One application of AVG made 4 weeks before anticipated normal harvest was more effective in controlling preharvest drop than split applications of the same amount made earlier or later. In general, AVG delayed ripening as assessed by a retardation in the development of red color, maintenance of flesh firmness, delayed degradation of starch, and a delayed onset of the ethylene climacteric. We conclude that AVG is an effective drop control compound that is also useful as a management tool to extend the harvest window for blocks of 'McIntosh' that would otherwise ripen simultaneously. Chemical names used: aminoethoxyvinylglycine (AVG), naphthaleneacetic acid (NAA), succinic acid-2,2-dimethylhydrazide (daminozide, Alar).

For a number of years growers in the Northeast had largely depended upon daminozide to control preharvest drop, retard ripening, and allow an orderly harvest of the 'McIntosh' apple crop. Little effort was put forth to reevaluate old drop control materials, or look for new chemical solutions because daminozide proved to be such a satisfactory compound. The withdrawal of the registration of daminozide for use on apples stimulated new interest in looking for alternative ways to accomplish these goals and to allow an orderly harvest of 'McIntosh' apples (Shafer et al., 1995). One such material was AVG. A review of early research on AVG is contained in the first paper in this series (Schupp and Greene, 2003). Early work focused on evaluating handgun applications of relatively high concentrations of AVG, applied to the drip point, a method that does not reflect commercial spray application technology. In order to make recommendations to apple growers about the application of AVG it was necessary to evaluate efficacy of AVG applied by air-blast sprayers at commonly used spray volumes. Multiple applications of plant growth regulators may improve efficacy. Marini et al. (1993) showed that repeated applications of naphthaleneacetic acid (NAA) delayed fruit abscission more than a single application.

This paper examines the effect of time, concentration, and spray volume of AVG on

preharvest drop and fruit maturity and quality of 'McIntosh' apples.

Materials and Methods

Experiments to evaluate the effect of AVG on 'McIntosh' apples were carried out at the University of Maine Highmoor Farm, Monmouth Maine and at the University of Massachusetts Horticultural Research Center, Belchertown, Massachusetts. Mature 'Macspur McIntosh'/MM.111 growing on a Dixfield fine sandy loam with a tree row volume (TRV) of 946 L·ha⁻¹ were used in all experiments conducted in Maine. 'Marshall McIntosh'/Mark planted in 1985 and 'Marshall McIntosh'/M.26 planted in 1986 growing in a Hincly loamy sand were used in spray volume and split application and the concentration experiments conducted in Massachusetts. All treatments were assigned in a randomized complete block design with six replications. Treatments were applied to two-tree plots with a pto-powered airblast sprayer and all treatments were separated by at least one buffer tree. One tree in each pair was used to collect fruit drop data, while the other was used to collect fruit samples for quality and maturity analysis.

Experiment 1. Concentration and water volume, Maine. AVG (ABG-3097; Abbott Laboratories, North Chicago, Ill.) was applied with 0.1% ABG-7034 surfactant at a rate of 124, 247, 371, 494, 618, and 741 g·ha⁻¹ a.i. in 568 L

water, 60% of volume required for a dilute application based upon calculated tree row volume (TRV). The effect of water volume was assessed by applying 351 g·ha⁻¹ AVG in 0.1% ABG-7034 surfactant in 189, 379, or 568 L applied by airblast sprayer or in 946 L of water applied by a handgun. Treatments were applied on 25 and 26 Aug., 1992. Naphthaleneacetic acid (NAA, Fruitone N, AMVAC Corp., Newport Beach, Calif.) was applied at 20 mg·L⁻¹ on 16 Sept.

Fruit quality at harvest was assessed at four weekly intervals starting on 21 Sept. Twenty fruit were sampled randomly from the periphery of the tree at each sampling date. Fruit diameter and weight were determined and then the percent red color on each fruit was estimated to the nearest 10%. Flesh firmness was determined by puncturing each fruit once with a press-mounted Effegi penetrometer (McCormick Fruit Co., Yakima, Wash.). A composite sample of juice collected during the pressure test was used to measure soluble solids with a hand-held refractometer (McCormick Fruit Co.). Starch status of the fruit was rated using the method of Priest and Loughheed (1981). The chroma and hue of the red blush of each fruit was measured with a chromameter (Minolta, Corp., Ramsen, N.J.).

Ten fruit per tree were randomly sampled at weekly intervals from several treatments for determination of internal ethylene using the method of Bramlage et al. (1980). A 1-ml air sample from the core cavity of each fruit was injected into a gas chromatograph equipped with an alumina column and an FID detector. The resulting peaks were compared to that of a 10 µL·L⁻¹ ethylene standard and the internal ethylene concentration (IEC) was calculated.

Drop was assessed by tagging one or two limbs per tree that contained 40 fruit. The fruit were counted three times per week for four weeks. Fruit drop for each two or three-d interval was calculated by subtracting the current count from the initial count.

On the second harvest date, 28 Sept., an additional fruit sample was collected and placed in a nonsegregated air storage held at 1 to 3 °C. Fruit were removed after 150 d and weight, flesh firmness, decay and physiological disorders evaluated.

Experiment 2. Concentration, Massachusetts. AVG was applied to 'Marshall McIntosh' as the ABG-3097 formulation in 0.1% ABG-7034 surfactant at rates of 62, 124, 247, 371, 494, and 618 g·ha⁻¹ a.i. in 936 L·ha⁻¹ of water (80% tree row volume dilute) on 24 Aug. 1992. NAA was applied at 10 mg·L⁻¹ on 8 Sept. Fruit quality was assessed at harvest by taking four weekly samples starting on 15 Sept. On each harvest date a 20-fruit sample was taken at random around the periphery of the tree. It was weighed and then red color was estimated on each fruit to the nearest 10%. Ten apples characteristic of the sample were selected and flesh firmness determined on two sides with an Effegi penetrometer. Soluble solids and starch rating were done as previously described.

All fruit were picked up under the trees designated for evaluation of drop on 31 Aug. Starting the first week in September and extending through 9 Nov., fruit was picked up under these

trees twice per week and counted. At that time all remaining fruit on the tree were harvested and counted. Drop was calculated based upon the total number of fruit on the tree.

Experiment 3: Water volume, Massachusetts. AVG was applied to 'Marshall McIntosh' as the ABG-3097 formulation in 0.1% ABG-7034 surfactant at a rate of 175 g·ha⁻¹ a.i. in 189, 284, 379, or 473 L·ha⁻¹ of water (full dilute tree row volume) on 25 Aug., 1992. NAA was applied at 10 mg·L⁻¹ on 8 Sept. Fruit quality was assessed at harvest by taking four weekly samples starting on 17 Sept. Fruit quality and preharvest drop were assessed similar to that described for Expt. 2.

Experiment 4. Concentration and multiple applications, Maine. Two formulations of AVG were evaluated; an 85% formulation, ABG-3097, used previously and ABG-3168 (Abbott laboratories, North Chicago, Ill.), a 15% technical powder. Both formulations were applied at 124 g·ha⁻¹ a.i. at 6, 4, and 2 weeks before harvest (WBH) on 9 Aug., 23 Aug. and 6 Sept. The AVG

formulations were also applied at 185 g·ha⁻¹ a.i. on 23 Aug. and 6 Sept., and 371 g·ha⁻¹ a.i. was applied on 23 Aug., 4 WBH. One group of trees received AVG as the ABG-3168 formulation on 23 Aug., and one group was unsprayed and served as the control. All AVG treatments were applied in 1235 L·ha⁻¹ water (TRV 2338 L·ha⁻¹) and ABG-7034 surfactant at 0.1% (v/v) was included. NAA at 10 mg·L⁻¹ was applied to a final group of trees on 6 and 13 Sept. Fruit quality and preharvest drop, were determined in a similar manner to that described in Expt. 1. Ten fruit were sampled each week, starting 20 Sept., for IEC analysis. The evaluation was similar to that described in Expt. 1.

Experiment 5. Concentration and multiple applications, Massachusetts. AVG as the ABG-3168 formulation was applied at 124, 185 and 371 g·ha⁻¹ a.i. at 6, 4, and 2 WBH on 5 Aug., 19 Aug., and 2 Sept. as described in Expt. 4. One group of trees received 750 mg·L⁻¹ daminozide on 5 Aug. and another 10 mg·L⁻¹ NAA on 9 Sept. All treatments were applied in 1122

L·ha⁻¹ of water with 0.1% (v/v) ABG-7034 surfactant. Twenty fruit per tree were harvested at four weekly intervals starting on 16 Sept. and fruit quality assessed as described in Expt. 3. All fruit were picked up under trees on 3 Sept. and drop determined until 8 Nov. as described in Expt. 3.

Analysis of variance was used in all experiments to determine significance of treatments. Where appropriate, means were separated by orthogonal polynomial comparison, analysis of regression, or Duncan's multiple range test.

Results

Experiment 1. Concentration and water volume, Maine. AVG application delayed preharvest drop linearly with increasing concentration (Table 1). 'McIntosh' is normally harvested by the end of September, and 10% preharvest drop is an arbitrary threshold for acceptable drop control. It appears that at least 371 g·ha⁻¹ a.i. was required to achieve this level of drop control.

Table 1. Effect of AVG concentration and spray volume, and NAA on preharvest drop of 'McIntosh' apples, Maine, 1992, Expt. 1.

AVG ²		Spray vol (L·ha ⁻¹)	Cumulative drop (%)										
(g·ha ⁻¹ a.i.)	(g/acre a.i.)		23 Sept.	25 Sept.	28 Sept.	30 Sept.	2 Oct.	5 Oct.	7 Oct.	9 Oct.	12 Oct.	14 Oct.	16 Oct.
Control 0	(0)	---	3	3	8	14	15	22	27	46	62	76	87
124	(50)	568	2	3	4	11	13	19	29	44	66	75	85
248	(100)	568	1	2	7	8	11	16	19	28	52	68	83
371	(150)	568	2	3	3	4	4	4	6	17	39	46	57
494	(200)	568	2	2	4	5	6	7	8	13	36	38	45
618	(250)	568	0	0	3	4	5	5	5	9	18	24	35
741	(300)	568	0	0	0	1	2	2	2	3	6	15	16
351	189 (5×)	189 (5×)	1	1	3	4	5	14	15	22	48	58	68
351	379 (3×)	379 (3×)	1	1	2	2	3	4	5	13	32	44	61
351	568 (2×)	568 (2×)	0	0	1	1	1	2	3	12	18	28	44
351	946 (dilute)	946 (dilute)	3	3	3	4	5	5	5	6	16	24	33
NAA 20 mg·L ⁻¹		568	3	3	5	9	10	21	28	46	73	77	79
Significance													
AVG concentration			NS	L*	L*	L***	L***	L***	L***	L***	L***	L***	L***
Water volume			NS	NS	NS	NS	L**	NS	NS	NS	L***	L***	L***
NAA vs. control			NS	NS	*	*	*	NS	NS	NS	*	NS	NS
NAA vs. AVG			NS	NS	NS	NS	NS	*	*	**	***	***	**

²AVG was applied 25 and 26 Aug. 1992 and naphthaleneacetic acid was applied on 16 Sept. 1992.

NS, *, **, *** Nonsignificant or significant at *P* = 0.05, 0.01, or 0.001, respectively; L = linear response.

Table 2. Effect of aminoethoxyvinylglycine (AVG) concentration and spray volume on fruit characteristics at harvest, Maine, 1992, Expt. 1.

AVG ² (g·ha ⁻¹ a.i.)	Spray vol (L·ha ⁻¹)	Fruit wt (g)	Red color (%)	Fruit diam (mm)	Color L*	Hue angle	Flesh firmness (N)	Soluble solids (%)	Starch rating (1–9)
Mean of harvest on 21 and 28 Sept., 5 and 12 Oct.									
AVG 0 (control)	---	156	70	74	35.0	34.6	55.1	10.5	6.7
AVG 124	568	163	64	76	35.5	35.8	54.9	10.6	6.6
AVG 248	568	159	66	75	35.1	34.6	5.5	10.3	6.2
AVG 371	568	166	67	76	34.6	33.0	57.1	10.9	5.8
AVG 494	568	167	69	76	34.8	32.9	56.3	11.0	5.9
AVG 618	568	172	68	77	34.7	32.6	57.8	10.9	5.3
AVG 741	568	168	60	76	35.4	35.2	57.4	10.9	5.7
AVG 351	189 (5×)	163	69	75	35.8	34.5	58.0	10.6	6.1
AVG 351	379 (3×)	161	71	75	34.7	33.0	57.7	10.8	5.9
AVG 351	568 (2×)	168	64	76	35.3	34.6	57.2	10.9	5.6
AVG 351	946 (dilute)	165	63	75	35.1	34.1	57.3	10.7	5.8
NAA 20 mg·L ⁻¹	568	173	71	77	34.6	35.3	52.4	10.9	7.0
Significance									
AVG concentration		L**	NS	L*	NS	NS	L**	L**	L***
Harvest time		***	***	***	***	***	***	***	***
AVG × time		NS	NS	NS	NS	NS	***	NS	**
Spray volume		NS	NS	NS	NS	NS	NS	NS	NS
NAA vs. control		NS	NS	NS	NS	NS	*	NS	NS
NAA vs. AVG		NS	NS	NS	NS	NS	***	NS	***

²AVG was applied on 25 and 26 Aug. 1992 and naphthaleneacetic acid was applied on 16 Sept. 1992.

NS, *, **, *** Nonsignificant or significant at *P* = 0.05, 0.01, or 0.001, respectively; L = linear response.

Table 3. Effect of aminoethoxyvinylglycine (AVG) concentration and spray volume on internal ethylene concentration, Maine, 1992, Expt. 1.

AVG ^z (g·ha ⁻¹ a.i.)	Spray vol (L·ha ⁻¹)	Internal ethylene concn (mg·L ⁻¹)				
		H1-H4 ^y (mean)	21 Sept.	28 Sept.	5 Oct.	12 Oct.
AVG 0 (control)	568	14.6	3.2	10.1	19.3	32.4
AVG 124	568	13.2	1.0	8.1	21.8	31.2
AVG 248	568	9.3	0.9	2.2	7.2	32.1
AVG 741	568	3.7	0	0.1	0.3	19.0
AVG 351	189 (5×)	7.9	0.1	0.3	5.0	29.8
AVG 351	568 (1.5)	5.5	2.4	0	1.2	25.4
AVG 351	946 (1×)	4.5	0	0.7	2.6	21.0
Significance						
AVG concentration		L***	NS	L***	L***	L***
Harvest time		***				
AVG volume		NS	NS	NS	L*	L*
AVG × time		***				
AVG vs. control		***	NS	***	*	NS

^zAVG was applied 25 and 26 Aug. 1992 and naphthaleneacetic acid on 16 Sept. 1992.

^yMean internal ethylene concentration across all four harvest dates.

NS,*,***Nonsignificant or significant at $P = 0.05$ or 0.001 , respectively; L = linear response.

Table 4. Effect of aminoethoxyvinylglycine (AVG) concentration and naphthaleneacetic acid (NAA) on cumulative drop of 'Marshall McIntosh'/M.26 apples, Massachusetts, 1992.

Treatment ^z (g·ha ⁻¹ a.i.)	Cumulative drop (% of total on tree)						
	Sept. 7 ^y	Sept. 14	Sept. 21	Sept. 28	Oct. 5	Oct. 12	Oct. 19
Control 0	1	2	16	35	64	89	97
AVG 61.8	1	3	9	23	57	90	97
AVG 123.5	1	1	8	22	51	83	94
AVG 247.0	1	2	6	12	25	61	81
AVG 371.5	1	1	3	8	26	55	75
AVG 494.0	1	1	2	5	12	43	67
AVG 617.5	1	1	2	3	6	18	356
NAA 10 mg·L ⁻¹	1	2	16	41	69	90	97
Significance							
AVG	L*	L*	L***Q*	L***	L***	L***Q*	L***Q***
AVG vs. NAA	NS	***	***	***	***	***	***
Control vs. NAA	NS	NS	NS	NS	NS	NS	NS

^zAVG was applied 24 Aug. 1992 and naphthaleneacetic acid on 9 Sept. 1992.

NS,*,***Nonsignificant or significant at $P = 0.05$, 0.01 , or 0.001 , respectively; L = linear and Q = quadratic response.

Drop control was best when AVG was applied as a full dilute rate (1×) or in the 2× volume. As the amount of water that AVG was applied to the tree in was reduced there was a linear reduction in the drop, first becoming apparent on 2 Oct. and becoming highly significant on 12 Oct. and later. NAA reduced drop marginally for a little more than 1 week. During the majority of the season, AVG was superior to NAA as a drop control agent.

AVG significantly and linearly increased fruit weight, fruit diameter, and soluble solids

(Table 2). AVG maintained flesh firmness and delayed ripening based on starch index, but there was an AVG × time interaction for both factors. AVG reduced flesh firmness only on the last harvest date, 12 Oct. (data not shown). Conversely, AVG delayed the loss of starch from the fruit for the first three harvests, but not on the final harvest date. The volume of water used to deliver AVG did not influence any fruit quality parameter. NAA advanced maturity relative to AVG based upon color, flesh firmness, and starch rating.

IEC was reduced linearly by AVG but there was an AVG × time interaction (Table 3). IEC was reduced uniformly by all AVG concentrations during the first harvest but at the later harvests there was a linear reduction with increasing concentration. Overall, spray volume did not influence ethylene evolution. However, while spray volume did not influence fruit ethylene during the first harvest, a significant inverse relationship between spray volume and ethylene evolution was detected for the last two harvests.

AVG increased the amount of superficial scald that developed on fruit during 150 d regular air storage (storage data not shown). Fruit weight was greater for AVG-treated fruit following storage. AVG spray volume did not influence any variables measured. NAA reduced flesh firmness of fruit following storage.

Experiment 2. Concentration, Massachusetts. AVG retarded preharvest drop over an 8-week period. The response was primarily linear early in the season when fruit would have been harvested commercially (Table 4). Normal commercial harvest in this block would have occurred between 20 Sept. and 1 Oct. Therefore, it appears that at least 247 g·ha⁻¹ a.i. was required to get a good commercial control of drop (10% or less) to the end of the harvest season. AVG was superior to NAA as a drop control agent except on the first evaluation date when there was less than 2% drop. AVG maintained flesh firmness and reduced fruit red color development, while NAA reduced red color but increased starch rating (data not shown).

Experiment 3. Water volume, Massachusetts. AVG retarded drop until from 21 Sept. to 19 Oct. (Table 5). AVG applied in a larger volume of water appeared to more effectively retard preharvest drop, although to only a small extent. At no time during the drop collection period did NAA controlled drop relative to the control. AVG retarded red color development and spray volume appeared to have little influence on fruit quality (data not shown).

Experiment 4. Concentration and multiple applications, Maine. Both formulations of AVG, ABG-3097 and ABG-3168, reduced preharvest drop (Table 6), but the technical 15% formulation, ABG-3168 was more effective on the last two drop evaluation days. Drop control from the 372 g·ha⁻¹ a.i. rate through the first three

Table 5. Effect of volume of water aminoethoxyvinylglycine (AVG) (175 g·ha⁻¹ a.i.) was applied in and naphthaleneacetic acid (NAA) on fruit cumulative drop on 'Marshall McIntosh'/M.26 apples, Massachusetts, 1992, Expt. 3.

Treatment ^z		Cumulative drop (% of total on tree)						
Chemical a.i.	L·ha ⁻¹	7 Sept.	14 Sept.	21 Sept.	28 Sept.	5 Oct.	12 Oct.	19 Oct.
Control	0	1 a	3 a	7 b	15 b	39 b	82 ab	95 a
AVG 175 g·ha ⁻¹	189 (2.5×)	1 a	1 b	3 b	8 b	19 c	69 bc	91 ab
AVG 175 g·ha ⁻¹	284 (1.67×)	0 a	1 b	1 b	3 b	11 c	47 e	83 b
AVG 175 g·ha ⁻¹	379 (1.25×)	1 a	1 b	2 b	7 b	23 c	66 cd	89 ab
AVG 175 g·ha ⁻¹	473 (1×)	1 a	2 b	4 b	6 b	13 c	52 de	82 b
NAA 10 mg·L ⁻¹	473 (1×)	1 a	2.ab	13 a	33 a	61 a	90 a	98 a
Significance								
AVG		NS	NS	**	***	***	***	**
AVG spray volume		NS	NS	NS	C*	C*	C*	NS
AVG vs. control		NS	*	*	NS	***	***	*
AVG vs. NAA		NS	NS	***	***	***	***	**
Control vs. NAA		NS	NS	*	**	*	NS	NS

^zAVG was applied 25 Aug. 1992 and naphthaleneacetic acid on 9 Sept. 1992.

NS,*,***Nonsignificant or significant at $P = 0.05$, 0.01 , or 0.001 , respectively; C = cubic response.

Table 6. Effect of AVG formulation, time of application, and NAA on preharvest drop of 'McIntosh' apples, Maine, 1993, Expt. 4.

Treatment (g·ha ⁻¹ a.i.)	Application ² time (weeks before harvest)	Cumulative drop (%)									
		20 Sept.	22 Sept.	24 Sept.	Sept. 27	29 Sept.	1 Oct.	4 Oct.	6 Oct.	8 Oct.	10 Oct.
Control		3 a	3.8 a	6 a	14 a	29 a	46 a	71 a	78 a	87 a	95 a
ABG 3097 124	6, 4, 2	0 b	0 b	1 bc	3 bc	5 cd	8 cd	17 cd	21 d	34 c	43 c
ABG 3097 185	4, 2	0 b	0 b	1 c	2 bc	3 d	4 d	8 d	9 de	13 d	21 de
ABG 3097 372	4	0 b	0 b	0 c	0 c	1 d	1 d	2 d	6 de	9 d	15 de
ABG 3168 124	6, 4, 2	0 b	0 b	1 c	1 c	3 d	5 d	9 d	13 de	16 d	24 d
ABG 3168 185	4, 2	0 b	0 b	1 c	2 bc	3 d	4 d	5 d	5 e	5 d	8 de
ABG 3168 372	4	0 b	0 b	0 c	2 bc	2 d	2 d	3 d	3 e	3 d	4 e
ABG 3168 124	4	2 ab	3 ab	4 ab	7 b	12 bc	16 bc	29 c	38 c	54 b	65 b
NAA-10 mg·L ⁻¹	2, 1	2 ab	2 ab	3 bc	4 b	15 b	20 b	42 b	54 b	64 b	78 b
Significance											
ABG 3097		**	**	***	***	***	***	***	***	***	***
ABG 3097 No. of applications		NS	NS	NS	NS	NS	NS	L*	L**	L***	L***
ABG 3168		**	**	***	***	***	***	***	***	***	***
ABG 3168 No. of applications		NS	NS	NS	NS	NS	NS	NS	NS	NS	L*
ABG 3097 vs. ABG 3168		NS	NS	NS	NS	NS	NS	NS	NS	**	**

²AVG was applied on 9 and 23 Aug. and 9, 23, and 6 Sept. and NAA on 6 and 13 Sept. 1993.NS,*,**,***Nonsignificant or significant at *P* = 0.05, 0.01, or 0.001, respectively; L = linear response.

Table 7. Effect of aminoethoxyvinylglycine (AVG) formulation, time of application and naphthaleneacetic acid (NAA) on fruit quality assessment at harvest, Maine, 1993.

Treatment ² (g·ha ⁻¹ a.i.)	Application time (weeks before harvest)	Fruit wt (g)	Red color (%)	Fruit size (mm)	Color L*	Hue angle	Flesh firmness (N)	Soluble solids (%)	Starch rating	IEC (μL·L ⁻¹)
Mean of harvests on 20 and 27 Sept. and 4 and 11 Oct.										
1) Control		164 b ^y	87 a	75 b	34.7 b	32.6 a	61.8 bc	11.5 a	7.2 ab	86 a
2) NAA-10 mg·L ⁻¹	2, 1	166 ab	86 ab	75 b	35.3 cd	33.0 a	58.8 c	11.3 a	7.5 a	100 a
3) ABG 3097 123.5	6, 4, 2	169 ab	84 abc	76 ab	35.2 ab	32.7 a	65.5 ab	11.4 a	6.7 b	39 bc
4) ABG 3097 185.3	4, 2	182 a	81 bc	78 a	35.2 ab	34.2 a	64.6 ab	11.5 a	7.0 ab	21 de
5) ABG 3097 371.5	4	167 ab	83 abc	75 b	35.5 ab	33.9 a	68.7 a	11.4 a	6.6 b	26 cde
6) ABG 3168 123.5	6, 4, 2	172 ab	82 abc	76 ab	36.0 a	34.6 a	66.4 ab	11.3 a	6.7 b	33 cd
7) ABG 3168 185.3	4, 2	170 ab	80 c	76 ab	35.7 ab	33.9 a	66.3 ab	11.6 a	6.8 b	14 e
8) ABG 3168 371.5	4	166 ab	84 abc	75 b	34.9 ab	32.7 a	67.9 a	11.4 a	6.6 b	11 e
9) ABG 3168 123.5	4	163 b	87 ab	75 b	35.2 ab	32.9 a	65.7 ab	11.5 a	6.9 ab	52 b
Significance										
AVG		NS	NS	NS	NS	NS	**	NS	*	***
Times of application		***	***	***	***	***	***	***	***	***
AVG × time		NS	NS	*	NS	NS	***	NS	*	***
ABG 3097		NS	*	NS	NS	NS	*	NS	NS	***
ABG 3097 application times		*	NS	*	NS	NS	NS	NS	NS	NS
ABG 3168		NS	NS	NS	NS	NS	**	NS	*	***
ABG 3168 applications times		NS	NS	NS	NS	NS	NS	NS	NS	**
ABG 3097 vs. ABG 3168		NS	NS	NS	NS	NS	NS	NS	NS	*

²AVG was applied on 9 and 23 Aug. and 6 Sept. and NAA on 6 and 13 Sept. 1993.NS,*,**,***Nonsignificant or significant at *P* = 0.05, 0.01, or 0.001, respectively.

Table 8. Effect of aminoethoxyvinylglycine (AVG), naphthaleneacetic acid (NAA), and daminozide (Alar) on preharvest drop of 'Marshall McIntosh' apples, Massachusetts, 1993, Expt. 5.

Treatment ² (g·ha ⁻¹ a.i.)	Dates of application	Cumulative drop (%)						
		13 Sept.	20 Sept.	27 Sept.	4 Oct.	11 Oct.	18 Oct.	25 Oct.
Control	---	5 a	13 a	34 a	69 a	92 a	99 a	100 a
AVG 124	5 and 19 Aug., 2 Sept.	1 b	1 b	4 c	8 c	36 b	60 b	82 b
AVG 185	19 Aug., 2 Sept.	1 b	1 b	3 c	7 c	22 b	36 c	58 c
AVG 371	19 Aug.	0 b	2 b	2 c	5 c	20 b	31 c	53 c
AVG 124	19 Aug.	1 b	2 b	13 bc	43 b	80 a	91 a	96 a
NAA 10 mg·L ⁻¹	9 Sept.	3 ab	5 b	19 b	60 a	91 a	97 a	99 a
Daminozide 750 mg·L ⁻¹	5 Aug.	1 b	2 b	5 bc	10 c	35 b	55 b	78 b
Significance								
AVG		***	***	***	***	***	***	***
No. of AVG applications		NS	NS	NS	NS	***	***	***
AVG vs. NAA		NS	NS	*	***	***	***	***
AVG vs. Daminozide		NS	NS	NS	***	***	***	***

NS,*,**,***Nonsignificant or significant at *P* = 0.05, 0.01, or 0.001, respectively.

harvests was comparable regardless of formulation or number of applications. However, one application of AVG made 4 WBH more effectively controlled preharvest drop at the end of the season than an identical amount applied in split applications. AVG was superior to NAA in controlling drop after 27 Sept. AVG at 124 g·ha⁻¹ a.i. applied three times controlled drop compara-

bly to NAA, but it was less effective than when a total of 372 g·ha⁻¹ a.i. was applied.

AVG slowed the loss of flesh firmness and reduced IEC (Table 7). However, AVG did not influence flesh firmness on the first harvest but on the last three evaluation dates AVG-treated fruit softened less than control fruit. IEC from all apples receiving 371.5 g·ha⁻¹ a.i. was uni-

formly low for the first three harvest dates (data not shown). However, IEC of fruit receiving one application at 4 WBH was less than from those receiving similar amounts but in multiple applications. Although significant, the effect of AVG on starch degradation was small and erratic over time. AVG formulations were comparable except that IEC was less on ABG-3168 on the

Table 9. Effect of aminoethoxyvinylglycine (AVG), naphthaleneacetic acid (NAA) and daminozide (Alar) on quality of 'Marshall McIntosh' apples at four harvests made between 16 Sept. and 7 Oct. 1993, Massachusetts.

Treatment (g·ha ⁻¹ a.i.)	Application time 1993	Fruit wt (g)	Red color (%)	Flesh firmness (N)	Soluble solids (%)	Starch rating
Mean of harvests on 16, 23, and 30 Sept. and 7 Oct.						
1) Control	---	175 b ^y	89 b	65.1 c	13.1 ab	6.4 b
2) AVG 124	5 and 19 Aug., 2 Sept.	180 ab	85 c	68.3 ab	13.2 a	5.7 c
3) AVG 185	19 Aug., 2 Sept.	182 ab	82 d	67.4 ab	13.0 abc	5.9 c
4) AVG 371	19 Aug.	184 a	82 d	67.9 ab	12.9 bcd	5.8 c
5) AVG 124	19 Aug.	184 a	87 c	65.6 c	13.0 abc	6.2 b
6) NAA 10 mg·L ⁻¹	9 Sept.	184 a	90 b	63.8 d	12.9 cd	6.8 a
7) Daminozide 750 mg·L ⁻¹	5 Aug.	180 ab	92 a	69.3 a	12.8 d	6.0 c
Significance						
AVG		NS	***	***	***	***
Times of application		***	***	***	***	***
AVG × time		NS	**	***	NS	*
No. of applications		NS	***	NS	*	NS
AVG vs. NAA		NS	***	***	NS	***
AVG vs. daminozide		NS	***	**	NS	NS

NS, *, **, *** Nonsignificant or significant at $P = 0.05$, 0.01 , or 0.001 , respectively.

last two harvest dates (data not shown).

Experiment 5. Concentration and multiple applications, Massachusetts. AVG retarded preharvest drop through the first two fruit evaluation periods to at least 27 Sept. (Table 8). Preharvest drop became severe after 4 Oct., but it was less on trees receiving one application of 371.5 g·ha⁻¹ a.i. than on trees that received more than one application of lower rates of AVG. NAA and AVG at 123.5 g·ha⁻¹ a.i. retarded drop minimally. AVG at 371.5 g·ha⁻¹ a.i. and 750 mg·L⁻¹ daminozide retarded drop comparably until 27 Sept., but after that AVG was more effective.

AVG delayed the development of red color but there was a treatment × time interaction (Table 9). However, while red color was retarded by AVG by as much as 10% on the first two harvest dates, with additional time on the tree, the difference in color between AVG-treated and control fruit diminished to become small or nonsignificant (data not shown). AVG-treated fruit were firmer than control fruit, but there was an AVG × harvest time interaction. There was only a small difference in fruit flesh firmness at the early harvest dates, but later in the season AVG-treated fruit lost firmness less rapidly so that they were firmer at the later harvest dates (data not shown). AVG retarded the degradation of starch but there was an AVG × time of harvest interaction. With time on the tree, differences between AVG-treated and control fruit diminished (data not shown). Degradation of starch in AVG-treated fruit was retarded. Fruit treated with daminozide were firmer and had more red color than AVG-treated fruit. Fruit receiving NAA had more red color but were less firm and contained less starch than AVG-treated fruit.

Discussion

Bangerth (1978) first suggested that AVG may be a useful compound to control preharvest drop in apples. This study confirms that observation as well as the recent reports by Byers (1997a, 1997b) and Greene (2002a). Daminozide was the primary drop control compound used on 'McIntosh' because it not

only controlled preharvest drop effectively but it also increased red color and flesh firmness at harvest (Edgerton et al., 1967; Southwick et al., 1968). Drop control by AVG was comparable to that caused by daminozide throughout the whole harvest period (Table 8). When drop was followed later into the season, AVG was more effective than daminozide. NAA remains registered as a drop control compound on apples. It has had a history of erratic response (Greene et al., 1987) that was confirmed in this investigation. In one experiment NAA accelerated drop (Table 5), in another one it had no effect (Table 4), while in two others it was marginally effective in retarding drop (Tables 6, 8). Only in Expt. 1 (Table 1), did NAA produce commercially acceptable preharvest drop control, and in this experiment AVG was superior.

The results we obtained were without the use of an organosilicone surfactant, which have since been shown to increase the efficacy of AVG application, thereby allowing the use of lower concentrations. Greene (2002b) showed that 62 and 124 g·ha⁻¹ AVG was effective for delaying fruit maturity and preharvest drop of 'McIntosh' apples when applied with 0.1% (v/v) Silwet L-77 organosilicone surfactant.

Efficacy of most plant growth regulators is dependent upon good spray coverage. The most uniform spray coverage is often achieved when growth regulators are applied in a dilute spray (1×). Since dilute applications are very time consuming, growers attempt to apply the appropriate dose in a smaller water volume to save time and money associated with application costs. While AVG applied in all spray volumes caused effective drop control, there was a linear decrease in efficacy with a reduction in spray volume (Table 1). Further, fruit from trees sprayed with a lower volume of water started to produce a substantial amount of ethylene earlier than fruit from trees where AVG was applied at 1× or 2× water volume. This can be interpreted to mean that spray coverage was not as good with the lower water volumes. Based upon these observations we suggest that a 2× spray volume is a good compromise between AVG efficacy and cost savings in application.

The easiest and most convenient way to apply

AVG is in one application. In this investigation one application made 4 WBH was more effective at controlling preharvest drop than applying a comparable amount split before and after the 4 weeks before anticipated harvest date. Byers (1997a) reported that a split application made 4 and 2 WBH on 'Delicious' had better drop control than one application made 4 WBH. In another study using 'Golden Delicious' and 'Law Rome', Byers (1997b) reported that AVG application 4 weeks or 4 plus 2 WBH resulted in comparable drop control.

Preharvest application of AVG can reduce ethylene production and retard ripening in a number of apple cultivars (Autio and Bramlage, 1982; Bangerth, 1978; Bramlage et al., 1980; Schupp and Greene, 2004). The mode of action of AVG is through inhibition of ethylene biosynthesis (Boller et al., 1979) and delayed ripening is believed due to reduced ethylene production. The magnitude of response to AVG is cultivar dependent, with 'McIntosh' being one of the least responsive cultivars because it is a high ethylene-producing cultivar (Autio, and Bramlage, 1982; Bramlage et al., 1980). Delay in ripening can manifest itself by a reduction in red color, retardation in the loss of flesh firmness, and a delay in starch hydrolysis. In this investigation AVG did not uniformly and consistently delay ripening. Red color was reduced in 3 of 5 experiments (Expts. 4 and 4, Table 9), loss of flesh firmness was slowed in 4 of 5 experiments (Tables 2, 5, 7, and 9), and starch hydrolysis was reduced in 3 of 5 experiments (Tables 2, 7, and 9). The lack of a uniform response on ripening was also reported by Byers (1997a, 1997b).

'McIntosh' must be harvested over 2 to 2.5 weeks for optimum quality and storage potential. 'McIntosh' is also the dominant cultivar grown in New York and New England so a large volume of fruit must be harvested in a short period of time. A delay in ripening of selected blocks will be important in the timely and efficient harvest of quality apples. The challenge is to find optimum concentrations, times of application and identify weather conditions that will allow a consistent and uniform delay in ripening of this challenging cultivar. Fruit size at harvest may be influenced by the drop control compound used. Daminozide reduced fruit size, primarily as a carryover effect (Lord, 1971). NAA does not influence fruit size, but because it advances ripening, the harvest of high quality fruit usually must occur within 10 to 14 d of application (Southwick et al., 1953), thus limiting the time on the tree that the fruit has to size. AVG does not increase fruit size *per se* but larger fruit may be harvested on AVG-treated trees because harvest will be delayed longer than on nontreated trees. In all experiments reported in this investigation there was a highly significant effect of harvest date on fruit size. Fruit increase in size ≈ 1% per day that they remain on the tree near harvest (Batjer et al., 1957). Therefore, in most instances delaying harvest 2 to 3 weeks resulted in an increase in fruit size of 15% to 20%. The increase in size may have an additional benefit if the increase in size moves fruit from one size category to a larger one that is selling at a higher price.

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