Effect of Aminoethoxyvinylglycine (AVG) on Preharvest Drop, Fruit Quality, and Maturation of 'McIntosh' Apples. I. Concentration and Timing of Dilute Applications of AVG

James R. Schupp

Department of Horticultural Science, Hudson Valley Laboratory, Cornell University, Highland, NY 12528

Duane W. Greene

Department of Plant and Soil Sciences, University of Massachusetts, Amherst, MA 01003

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Abstract. To compare the effects of growth regulators on preharvest fruit drop and fruit maturity, aminoethoxyvinylglycine (AVG) was applied to 'McIntosh' apple trees at 75, 150, or 225 mg·L⁻¹, at 8, 4, or 2 weeks before harvest (WBH). These treatments were compared to NAA, daminozide, and to an untreated control. All AVG treatments and timings except 75 mg·L⁻¹ applied 8 WBH delayed preharvest drop and fruit maturity. AVG applied at 225 mg·L⁻¹ was more effective in delaying drop and development of maturity than other rates when applied 8 or 2 WBH, but at 4 WBH, 150 mg·L⁻¹ gave equivalent results to 225 mg·L⁻¹. AVG at 150 mg·L⁻¹ was superior to NAA or daminozide as a stop-drop agent. No concentration, or time of application of AVG influenced fruit size at harvest. AVG reduced internal ethylene concentration (IEC) in 'McIntosh' apples linearly with increasing AVG concentration. There was a linear relationship between time of AVG application (8, 4, or 2 WBH) and IEC in the fruit after harvest, and the time required for harvested fruit to enter the ethylene climacteric. Development of red color was delayed by AVG. This was attributed to a delay in ripening as determined by a slower increase in IEC and starch hydrolysis. In general, earlier application of AVG resulted in reduced effectiveness of lowering IEC following harvest. Chemical names used: aminoethoxyvinylglycine (AVG), naphthaleneacetic acid (NAA), succinic acid-2,2-dimethylhydrazide (daminozide).

'McIntosh' is the most heavily planted apple cultivar in New York and New England, representing a substantial portion of the region's apple production. Its faults include uneven ripening and the tendency to have excessive preharvest fruit drop (Proctor, 1990). With the dominance of 'McIntosh', growers are faced with the dilemma of harvesting most of their crop within the 2 to 3 weeks when 'McIntosh' ripen. In a normal year 25% of the crop can drop and in a severe year >50% of the fruit can fall to the ground before harvest (Greene, 1996). The problem of preharvest drop of 'McIntosh' was studied extensively following the discovery that auxin-type plant growth regulators could retard preharvest drop (Batjer and Marth, 1945; Edgerton and Hoffman, 1951; Hoffman and Edgerton, 1952; Mattus and Moore, 1954; Southwick et al., 1953).

Naphthaleneacetic acid (NAA) and 2,4,5-trichlorophenoxypropionic acid (2, 4, 5-TP) emerged as the two compounds most capable of controlling drop on a number of apple cultivars (Edgerton and Hoffman, 1951; Hoffman and Edgerton, 1952; Southwick et al., 1953).

2,4,5-TP proved to be less useful in the Northeast United States because it could stimulate excessive ripening and result in unacceptable fruit softening (Edgerton and Hoffman, 1952; Southwick et al., 1953). It is no longer registered for use on apples.

NAA was more frequently used as a drop control compound on 'McIntosh'. Drop control from one application lasted from 7 to 14 d (Southwick et al., 1953). However, two applications of NAA or warm weather following the first application accelerated fruit softening (Smock and Gross, 1947). In some years NAA may be ineffective as a drop control compound (Greene et al., 1987).

The discovery and ultimate registration of daminozide for use on apples was a nearly perfect fit for 'McIntosh'. Daminozide provided excellent control of preharvest drop (Batjer et al., 1964; Edgerton et al., 1967; Southwick et al., 1968). In addition, it substantially increased flesh firmness at harvest and retarded ripening, allowing growers to more easily manage and spread out the concentrated harvest of 'McIntosh'. The registration of daminozide for use on apples was withdrawn in 1989. This left growers with NAA as the only registered drop control chemical.

Aminoethoxyvinylglycine (AVG) is a naturally occurring compound that was discovered in the early 1970s. Its primary mode of action is to inhibit ethylene biosynthesis (Boller et al., 1979). Bangerth (1978) showed that multiple applications of AVG retarded preharvest drop of 'King of the Pippin' apples. AVG also delayed ripening (Bramlage et al., 1980), and resulted in higher flesh firmness at harvest and following storage (Bramlage et al., 1980; Williams, 1980). The commercial development of AVG was started by Maag Chemical Company but it was later discontinued because of the apparent high cost of production. Abbott Laboratories initiated further development of AVG as a drop control compound following the loss of registration of daminozide on apples (Clarke et al., 1996).

The purpose of this investigation was to evaluate and confirm the efficacy of different concentrations of AVG, applied at three different timings, for drop control of 'McIntosh' apples and to determine its effect on ripening and fruit quality at harvest.

Materials and Methods

Experiment 1. Concentration and timing, Maine. Experiments to evaluate the effect of AVG on 'McIntosh' apples were carried out at the University of Maine Highmoor Farm, Monmouth, Maine in 1991 and 1992. Mature 'Macspur McIntosh'/M.26 trees growing on a Dixfield fine sandy loam were selected and blocked into six replications of 15 trees. On 29 July, 8 weeks before harvest (WBH), one tree in each block received a dilute spray of 75, 150, or 225 mg·L⁻¹ AVG (ABG-3097, Abbott Laboratories, North Chicago, Ill.) containing 0.1% (v/v) Regulaid surfactant (Kalo, Inc, Overland Park, Kans.). Similar applications were made on different and unsprayed trees in each block on 26 Aug. and 9 Sept., 4 and 2 WBH, respectively. Three trees in each block were not sprayed and served as controls for the three timings of AVG application. Three trees per block were sprayed on 16 Sept. with 20 mg·L⁻¹ NAA (Fruitone N, AMVAC Corp., Newport Beach, Calif.).

Forty fruit on one to two tagged limbs per tree were counted at the beginning of the study. All remaining fruit were counted three times weekly, and the cumulative percent fruit drop was calculated. On 30 Sept., 20 fruit per tree were harvested from the perimeter of each tree. Fruit weight and diameter were measured then red color was estimated visually on each fruit to the nearest 10%. Fruit firmness was determined on two sides of each fruit with a press-mounted Effigi penetrometer (Mc Cormick Fruit Co., Yakima, Wash.). Juice was collected during the flesh firmness determination and soluble solids content of the composite sample was measured with a hand-held refractometer (Atago; Mc Cormick Fruit Co.). A second 20-fruit sample was collected, placed on fiberboard fruit packing trays and held at room temperature (≈20 °C) for 15 d. Fruit firmness was then measured as previously described.

Ten fruit per tree were sampled on 16, 23, and 30 Sept. and 7 Oct. Internal ethylene of each fruit was measured with a gas chromatograph

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equipped with an activated alumina column and an FID detector, using the method of Bramlage et al. (1980).

Experiment 2. Concentration and timing, Massachusetts. Seven-year-old 'Marshall McIntosh'/'M.26 trees growing in a Hinckly loamy sand were selected and blocked into six replications of 17 trees in 1991. AVG with Regulaid surfactant was applied at the concentrations and relative timings as described in Expt. 1. The dates of the AVG sprays in Massachusetts were 11 July, 12 Aug., and 26 Aug., respectively. Three trees in each block were not sprayed and served as controls for the three timings of AVG application. Three trees per block were sprayed with a dilute hand gun application on 15 July with 750 mg·L⁻¹ daminozide (Alar, Ronyal Chemical Co., Middlebury, Conn.)

Fifty fruit on one to two tagged limbs per tree were counted at the beginning of the study. All remaining fruit were counted twice weekly, and the cumulative percent fruit drop was calculated. On 9 Sept., 20 fruit per tree were harvested from the perimeter of each tree. Fruit weight and diameter were measured, then red color was estimated visually on each fruit to the nearest 10%. Fruit that were in the U.S. Extra Fancy category were determined by recording the number of fruit with at least 50% red color that was also typical for the 'McIntosh' cultivar. Fruit firmness was determined on two sides of each fruit with an Effigi penetrometer (Mc Cormick Fruit Co.). Juice was collected during the flesh firmness determination and soluble solids content of the composite sample was measured with a hand-held refractometer (Fisher, Pittsburgh, Pa.).

Five fruit per tree were harvested on 11 Sept. from trees receiving 0, 75, 150, or 225 mg·L⁻¹ AVG applied four WBH, or daminozide. The IEC in each fruit was determined by a gas chromatograph equipped with an activated alumina column, using the method of Bramlage et al. (1980). Fruit were allowed to remain at a room temperature of 20°C and IEC of the same fruit was again determined on 15, 17, 19, and 21 Sept., 4, 6, 8, and 10 d after harvest, respectively. On 16 Sept., five fruit per tree were harvested from trees receiving daminozide, 150 mg·L⁻¹ AVG eight, four or two WBH, and untreated controls. IEC was determined, as previously described, at harvest, and on 18, 20, 22, 24, and 26 Sept., 2, 4, 6, and 8 d after harvest, respectively.

Experiment 3. Concentration, Massachusetts. To study the effects of AVG concentration in Massachusetts a block of 'Marshall McIntosh'/'M.26 apples were selected and blocked

into 6 groups (replications) of 16 trees each in 1992. Within each block, trees were paired and sprayed on 21 Aug. with AVG at 75, 100, 150, 200, or 300 mg·L⁻¹, with 0.1% (v/v) Regulaid surfactant. Two trees in each block received daminozide at 750 mg·L⁻¹ on 4 Aug., another pair received 10 mg·L⁻¹ NAA on 8 Sept., and another pair received no spray and served as an untreated control. All treatments were applied with a hand gun to the drip point. One tree of each pair was not harvested, but dropped fruit were picked up under each tree and the number recorded twice a week. Twenty fruit were harvested randomly from each sample tree on 15, 22, and 29 Sept. and 6 Oct. Fruit weight, red color, flesh firmness, and soluble solids were evaluated as previously described. Starch index was rated using the method of Priest and Lougheed (1988).

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

Results

Experiment 1. Concentration and timing, Maine. All treatments reduced preharvest drop (Tables 1 and 2). The duration of drop control increased linearly with increasing AVG concentration, especially at the later application dates. The efficacy of NAA for drop control was of shorter duration than that of AVG 75 mg·L⁻¹. AVG delayed drop at all application dates, but application at 4 or 2 WBH resulted in greater drop control than when applied at 8 WBH. The time of AVG application influenced the extent of drop control starting on 27 Sept., the time of commercial harvest. A treatment × time interaction was noted after the first week in Oct. The lower concentration of AVG controlled drop less effectively when the application was made early. Higher rates of AVG controlled drop late into the season when application was made either 4 or 2 weeks before the anticipated start of normal harvest.

AVG or NAA did not affect IEC on 16 Sept., the day NAA was applied (data not presented). All concentrations of AVG reduced IEC linearly with concentration on all four harvest dates (Table 3). Fruit from trees treated with AVG 225 mg·L⁻¹ had the lowest IEC on 7 and 14 Oct., while AVG 75 mg·L⁻¹ was not different from the untreated control or NAA on these dates.

AVG and NAA did not affect fruit weight at harvest (data not shown). AVG-treated fruit were firmer and NAA-treated fruit were softer, compared with fruit from control trees at harvest (Table 4). Fruit treated with 150 or 225 mg·L⁻¹ remained firmer than all other treatments after 15 d at room temperature. Red fruit surface was reduced slightly but soluble solids were increased by AVG. Time of application did not affect any fruit characteristics.

Experiment 2. Concentration and timing, Massachusetts. AVG reduced preharvest drop linearly (Table 5). Daminozide reduced preharvest drop to commercially acceptable levels only to 13 Sept., the time when commercial harvest would begin in this block. There was a highly significant AVG × time of application interaction starting on 27 Sept.. Fruit drop under trees receiving lower rates of AVG applied at the earlier timing became greater, whereas drop under trees receiving high rates of AVG at 2 WBH was considerably less (data not shown). After 13 Sept., the start of commercial harvest, AVG was a superior drop control compound compared with daminozide, regardless of AVG application date.

AVG reduced IEC at harvest and during the 10 d fruit were held at room temperature (Table 6). IEC of daminozide-treated fruit did not differ from controls at harvest, but was lower thereafter. Fruit treated with AVG 150 or 225 mg·L⁻¹ had lower IEC than daminozide-treated fruit throughout the 10-d evaluation period, whereas fruit treated with AVG 75 mg·L⁻¹ had lower IEC than daminozide-treated fruit only at harvest and after being held at room temperature for 10 d.

The time of application of 150 mg·L⁻¹ AVG influenced IEC at harvest and following a period at room temperature (Table 7). Clearly, application of AVG 150 mg·L⁻¹ resulted in less control of IEC during the shelf life studies at ≈20 °C. The IEC was always less on daminozide-treated fruit compared with untreated fruit.

The onset of the ethylene climacteric was delayed linearly with increasing AVG concentration, but not by daminozide (Table 8). The time after harvest that was required for fruit to enter the ethylene climacteric was linearly related to the date AVG was applied (Table 9). Daminozide delayed slightly the time of ripening. AVG application at 4 or 2 weeks before anticipated harvest delayed ripening more than daminozide.

AVG did not affect fruit weight, flesh firmness, or soluble solids content but it reduced red

Table 1. Effect of aminoethoxyvinylglycine (AVG) and naphthaleneacetic acid (NAA) on preharvest drop of 'Macspur McIntosh' apples in Maine, 1991. Data are the mean of AVG applications made 8, 4, and 2 weeks before harvest, Expt. 1.

Treatment (mg·L ⁻¹)	Preharvest drop (% of total)											
	16 Sept.	18 Sept.	20 Sept.	23 Sept.	27 Sept.	30 Sept.	2 Oct.	4 Oct.	7 Oct.	9 Oct.	11 Oct.	16 Oct.
AVG 0	11	15	22	32	51	69	79	84	94	94	96	97
AVG 75	7	8	10	14	21	29	37	45	63	65	72	82
AVG 150	5	7	8	9	14	18	24	29	40	42	46	57
AVG 225	5	6	7	7	9	11	13	19	29	30	33	40
NAA 20	6	8	8	11	34	55	66	73	83	85	86	89
Significance												
AVG	*	**	***	***	***	***	***	***	***	***	***	***
Time	NS	NS	NS	NS	*	**	**	***	***	***	***	***
AVG × time	NS	NS	NS	NS	NS	NS	**	***	***	***	***	***

NS, ***, *** NONSIGNIFICANT OR SIGNIFICANT AT $P = 0.05$, 0.01 , or 0.001 , respectively.

Table 2. Effect of aminoethoxyvinylglycine (AVG) and naphthaleneacetic acid (NAA) on preharvest fruit drop of 'Macspur McIntosh' apples in Maine, 1991, Expt. 1.

Treatment (mg·L ⁻¹)	Preharvest drop (% of total)											
	16 Sept.	18 Sept.	20 Sept.	23 Sept.	27 Sept.	30 Sept.	2 Oct.	4 Oct.	7 Oct.	9 Oct.	11 Oct.	16 Oct.
Applied 8 weeks before harvest												
AVG 0 (control)	8	12	20	30	51	73	80	86	95	95	97	98
AVG 75	9	11	13	23	34	51	64	71	89	91	94	98
AVG 150	6	6	9	13	23	33	49	61	81	84	86	93
AVG 225	3	5	5	6	7	11	17	29	51	55	61	72
NAA 20	8	9	9	14	41	65	74	78	88	89	92	94
Significance												
AVG	L*	L*	L***	L***	L***	L***	L***	L***	L**	L**	L*	NS
NAA vs. control	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
NAA vs. AVG 75	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NAA vs. AVG 150	NS	NS	NS	NS	*	**	*	NS	NS	NS	NS	NS
NAA vs. AVG 225	NS	NS	NS	*	***	***	***	***	***	***	**	*
Applied 4 weeks before harvest												
AVG 0 (control)	17	23	29	38	54	71	81	85	93	94	96	97
AVG 75	6	6	7	7	14	16	21	30	46	47	56	68
AVG 150	2	3	3	3	4	5	6	7	13	16	22	37
AVG 225	5	7	7	8	9	9	12	17	21	22	24	30
NAA 20	5	6	6	7	32	49	62	68	79	83	83	88
Significance												
AVG	L*	L*	L*	L**	L**	L***	L***	L***	L***	L***	L***	L***
NAA vs. control	*	*	*	**	*	*	NS	NS	NS	NS	NS	NS
NAA vs. AVG 75	NS	NS	NS	NS	NS	**	***	***	***	***	***	***
NAA vs. AVG 150	NS	NS	NS	NS	**	***	***	***	***	***	***	***
NAA vs. AVG 225	NS	NS	NS	NS	*	***	***	***	***	***	***	***
Applied 2 weeks before harvest												
AVG 0 (control)	8	11	17	27	48	63	74	81	89	92	94	96
AVG 75	7	9	9	11	15	20	25	35	54	57	67	81
AVG 150	8	11	11	12	14	15	18	19	24	25	29	41
AVG 225	8	8	8	9	10	11	12	12	14	14	14	16
NAA 20	6	7	10	12	28	50	62	71	81	83	83	86
Significance												
AVG	NS	NS	L*	L***	L***	L***	L***	L***	L***	L***	L***	L***
NAA vs. control	NS	NS	NS	NS	*	**	NS	NS	NS	NS	NS	NS
NAA vs. AVG 75	NS	NS	NS	NS	NS	***	***	***	***	***	*	*
NAA vs. AVG 150	NS	NS	NS	NS	NS	***	***	***	***	***	***	***
NAA vs. AVG 225	NS	NS	NS	NS	*	***	***	***	***	***	***	***

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

color at harvest, which resulted in a reduction in the number of fruit that could be classified as U.S. Extra Fancy Fruit (data not shown). Time of application of AVG influenced red color. Applications made 2 and 4 weeks before anticipated harvest appeared to reduce red color more than when application was made a 8 WBH (data not shown).

Experiment 3. Concentration, Massachusetts. Increasing AVG concentrations reduced preharvest drop linearly throughout the measurement period, and the relationship was also significant as a quadratic function between 21 Sept. and 2 Nov. (Table 10). Drop control from AVG was superior to that provided by NAA or daminozide as of 21 and 28 Sept., respectively.

No treatment influenced fruit weight when evaluated over the 3-week sampling period (Table 11). AVG was linearly associated with higher fruit flesh firmness, daminozide-treated fruit had higher flesh firmness, while NAA had no effect. There was an AVG $\times$ harvest time interaction for flesh firmness. AVG-treated fruit had higher flesh firmness on 15 and 22 Sept. compared with flesh firmness at the later harvest dates (data not shown).

AVG was associated with reduced fruit soluble solids. It also delayed starch degradation as indicated by lower starch ratings. There was an AVG $\times$ harvest time interaction, which was attributed to delayed harvests on 15, 22, and 29

Table 3. Effect of aminoethoxyvinylglycine (AVG) concentration and naphthaleneacetic acid (NAA) on internal ethylene concentration of 'Macspur McIntosh' apples in Maine held at room temperature, 1991, Expt. 1.

Treatment (mg·L ⁻¹)	Ethylene concn in core cavity (mg·L ⁻¹)			
	Date of sample			
	23 Sept.	30 Sept.	7 Oct.	14 Oct.
AVG 0	24	27	52	52
AVG 75	10	11	32	40
AVG 150	1	4	14	16
AVG 225	1	1	6	9
NAA 20	24	33	33	33
Significance:				
AVG	L***	L***	L***	L***
NAA vs. AVG 75	*	*	NS	NS
NAA vs. AVG 150	*	*	*	*
NAA vs. AVG 225	*	*	*	*

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

Sept., but not on the last harvest date of 6 Oct. Over the 3-week sampling period AVG did not influence red color although AVG reduced red color on the last sampling date on 6 Oct.

Discussion

Preharvest AVG sprays have been shown to delay the climacteric rise in ethylene synthesis and respiration of apple fruit, leading to delayed preharvest fruit drop and delayed fruit maturity (Autio and Bramlage, 1982; Bangerth, 1978; Bramlage et al., 1980). These cited field studies evaluated the response of apple to AVG

concentrations of 500 mg·L⁻¹ and higher. AVG is an expensive compound to synthesize, and application of AVG at 450 mg·L⁻¹ resulted in undesirable carry-over effects of increased vegetative growth and increased fruit set of 'Delicious' apple in the season following application Williams (1980). For all these reasons, it was highly desirable that lower concentrations of AVG be tested.

Previously Autio and Bramlage (1982) showed that apple cultivars differ in their response to AVG. Specifically, 'McIntosh' was shown to be a difficult cultivar in which to control fruit maturity. When labeled for this

Table 4. Effect of aminoethoxyvinylglycine (AVG) and naphthaleneacetic acid (NAA) on fruit characteristics of 'Macspur McIntosh' apples at harvest in Maine, 1991, Expt. 1.

Treatment (mg·L ⁻¹)	Flesh firmness (N)		Soluble solids (%)	Red color (%)
	At harvest	Harvest + 15 d		
Applied 8 weeks before harvest				
AVG 0	62.1	38.7	11.9	90
AVG 75	65.6	40.7	12.7	87
AVG 150	67.1	43.1	12.2	84
AVG 225	69.3	42.1	12.4	83
NAA 20	55.9	37.2	11.7	89
Applied 4 weeks before harvest				
AVG 0	59.6	38.7	11.9	88
AVG 75	68.5	40.7	12.9	85
AVG 150	70.2	41.2	12.7	84
AVG 225	68.6	43.6	12.1	74
NAA 20	55.4	39.7	12.6	90
Applied 2 weeks before harvest				
AVG 0	60.3	38.2	12.2	88
AVG 75	62.7	37.2	12.2	81
AVG 150	67.6	42.1	12.6	82
AVG 225	70.6	43.1	12.6	84
NAA 20	54.6	40.2	12.6	85
Significance				
AVG	L***	L***	L***	L***
Time	NS	NS	NS	NS
AVG × time	NS	NS	NS	*
NAA vs. AVG 0	*	NS	NS	NS
NAA vs. AVG 75	***	NS	NS	*
NAA vs. AVG 150	***	*	NS	*
NAA vs. AVG 225	***	**	NS	*

ns,*,**,*Nonsignificant or significant at $P = 0.05, 0.01, \text{ or } 0.001$, respectively; L = linear response.

use, daminozide was an effective commercial product for controlling fruit maturity and drop in 'McIntosh'. Our studies suggest that the level of control of preharvest drop and fruit maturity of 'McIntosh' that can be achieved with dilute AVG applications of 150 mg·L⁻¹ is superior to that of daminozide, while 75 mg·L⁻¹ AVG provides similar maturity and drop delays compared with daminozide and superior drop control to NAA.

The optimal timing of AVG application in these studies was 4 to 2 WBH. Most previously reported applications were made within one month of normal harvest date for the cultivar under investigation. Autio and Bramlage (1982) found little difference in response of 'Puritan' to applications of AVG at 6, 4, or 2 WBH, however the over-all response of this summer-ripening cultivar, to 500 mg·L⁻¹ AVG was not great, which may have partially obscured differences attributable to time of application. AVG at 75 mg·L⁻¹ controlled drop better than NAA or daminozide when applied 4 or 2 WBH,

but not when applied 8 WBH, while higher concentrations of AVG provided superior drop control than either NAA or daminozide, regardless of application date.

Daminozide was the product of choice by orchardists for >25 years to retard drop and increase flesh firmness on 'McIntosh' apples. AVG appears to be an acceptable if not better commercial alternative to daminozide, and this was confirmed by Greene (2002) on 'Delicious'. AVG was a superior drop control compound in this investigation as well as in a companion report (Greene and Schupp, 2003). Growers frequently depended upon about a 4.5 N increase in firmness following daminozide application, which was confirmed in this investigation. Although AVG-treated fruit were firmer than untreated fruit, AVG-treated fruit were less firm than those receiving daminozide. NAA is registered as a drop control compound on apples. In this investigation AVG controlled drop better and longer than NAA; similar to results reported by Byers (1997a, 1997b).

Table 5. Effect of AVG and daminozide on preharvest drop of 'Marshall McIntosh' apples. Data are the means of AVG applications made 8, 4, and 2 weeks before harvest in Massachusetts, 1991, Expt. 2.

Treatment (mg·L ⁻¹)	Preharvest drop (% of total)								
	6 Sept.	13 Sept.	20 Sept.	27 Sept.	4 Oct.	11 Oct.	18 Oct.	25 Oct.	1 Nov.
Control	12	36	64	79	99	99	99	100	100
AVG 75	3	13	25	43	77	88	95	98	99
AVG 150	2	8	12	19	38	58	68	79	89
AVG 225	1	4	9	16	31	43	49	58	69
Daminozide 750	7	15	41	60	88	95	97	99	99
Significance									
AVG	L***	L***	L***	L***	L***	L***	L***	L***	L***
Time	NS	NS	***	***	***	***	***	***	***
AVG × time	NS	NS	NS	**	***	***	***	***	***
Daminozide vs. control	*	*	**	*	NS	NS	NS	NS	NS
Daminozide vs. AVG	NS	NS	**	**	***	**	**	**	*

ns,*,**,*Nonsignificant or significant at $P = 0.01 \text{ or } 0.001$, respectively; L = linear response.

Table 6. Effect of aminoethoxyvinylglycine (AVG) concentration and daminozide on ethylene evolution from 'Marshall McIntosh' apples at and following harvest in Massachusetts, 1991, Expt. 2.

Treatment (mg·L ⁻¹)	Ethylene concn in core cavity (mg·L ⁻¹)				
	Time after harvest (d)				
	0	4	6	8	10
AVG 0 (control)	42.8	127.4	198.2	208.4	251.4
AVG 75	3.4	26.5	48.7	128.2	185.1
AVG 150	0.1	0.5	1.8	8.0	19.1
AVG 225	0.1	0.5	1.0	3.9	11.0
Daminozide 750	34.5	59.7	88.9	96.4	128.0
Significance					
AVG	L***Q*	L***Q***	L***C**	L***Q*C*	L***Q*
Daminozide vs. AVG 0	NS	*	***	***	***
Daminozide vs. AVG 75	*	NS	NS	NS	*
Daminozide vs. AVG 150	*	*	**	***	***
Daminozide vs. AVG 225	*	*	**	***	***

NS,*,**,*Nonsignificant or significant at $P = 0.05, 0.01, \text{ or } 0.001$, respectively; L = linear, Q = quadratic, and C = cubic response.

Table 7. Effect of time of aminoethoxyvinylglycine, (AVG) application and daminozide on ethylene evolution from 'Marshall McIntosh' apples at and following harvest in Massachusetts, 1991, Expt. 2.

Chemical treatment (mg·L ⁻¹)	Time applied before harvest (weeks)	Ethylene concn in core cavity (mg·L ⁻¹)					
		Time after harvest (d)					
		0	2	4	6	8	10
Control	---	131.3	213.0	291.8	307.6	364.6	290.1
AVG 150	8	13.3	41.6	64.5	106.6	164.2	221.3
AVG 150	4	1.0	1.8	7.9	18.2	44.2	60.8
AVG 150	2	5.1	6.9	5.5	10.9	26.8	32.8
Daminozide 750	8	17.7	31.1	69.8	128.1	188.7	180.4
Significance							
AVG		NS	NS	L*	L**	L***Q*	L***Q*
AVG vs. Control		***	***	***	***	***	***
Daminozide vs. control		***	***	***	***	***	***
Daminozide vs. AVG 8 weeks		NS	NS	NS	NS	NS	NS
Daminozide vs. AVG 4 weeks		NS	NS	NS	***	***	***
Daminozide vs. AVG 2 weeks		NS	NS	NS	***	***	***

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

Table 8. Effect of aminoethoxyvinylglycine, (AVG) concentration and daminozide on the time after harvest 'Marshall McIntosh' apples enter the ethylene climacteric (1 mg·L⁻¹ ethylene) in Massachusetts, 1991, Expt. 2.

Treatment ^z (mg·L ⁻¹)	Time after harvest to reach 1 mg·L ⁻¹ fruit internal ethylene (d)
1 AVG 0 (control)	2.9
2 AVG 75	5.0
3 AVG 150	8.4
4 AVG 225	10.1
5 Daminozide 750	3.8
Significance	
AVG	L***
Daminozide vs. control	NS
Daminozide vs. AVG 75	NS
Daminozide vs. AVG 150	***
Daminozide vs. AVG 225	***

^zAVG applied 4 weeks before harvest; daminozide applied 8 weeks before harvest.

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

Table 9. Effects of time of AVG application and daminozide on the time after harvest 'Marshall McIntosh' apples entered the ethylene climacteric (1 mg·L⁻¹ internal ethylene), Massachusetts, Expt. 2.

Chemical treatment (mg·L ⁻¹)	Time applied before harvest (weeks)	Time after harvest to reach 1 mg·L ⁻¹ fruit internal ethylene (d)
1 Control	---	0.5
2 AVG 150	8	3.9
3 AVG 150	4	6.1
4 AVG 150	2	8.1
5 Daminozide 750	8	2.5
Significance		
AVG		L**
Daminozide vs. control		*
Daminozide vs. AVG 8 weeks		NS
Daminozide vs. AVG 4 weeks		**
Daminozide vs. AVG 2 weeks		***

NS,*,**,*Nonsignificant or significant at $P = 0.05, 0.01, \text{ or } 0.001$, respectively; L = linear response.

This coupled with the greater flesh firmness accrued with the use of AVG, makes AVG a much better choice by orchards for use on 'McIntosh' apples.

Following harvest, fruit are frequently put in the marketing channels where storage conditions either do not exist or are marginal. In this investigation IEC was lower, and flesh firmness was higher on AVG-treated fruit over 2 weeks after harvest. This suggests that AVG may improve the fruit quality of 'McIntosh' apples consumers receive after harvest.

We tested both the influence of AVG concentration and time of application on preharvest drop and fruit quality. In general, applications made 8 weeks before harvest and the low rate of AVG at later application dates were less effective. Therefore, it appears that AVG may be metabolized or otherwise inactivated so that it is less effective if applied too early or at a low rate (75 mg·L⁻¹).

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Table 10. Effect of aminoethoxyvinylglycine (AVG) concentration, naphthaleneacetic acid (NAA), and daminozide when applied as a dilute handgun spray on cumulative drop of 'Marshall McIntosh' in Massachusetts, 1992, Expt. 3.

Treatment ² (mg·L ⁻¹)	Cumulative drop (%)									
	7 Sept.	14 Sept.	21 Sept.	28 Sept.	5 Oct.	12 Oct.	19 Oct.	26 Oct.	2 Nov.	9 Nov.
AVG 0 (control)	2	5	11	27	52	87	95	96	97	98
AVG 75	2	3	5	12	17	32	55	71	71	85
AVG 100	2	3	4	5	7	15	29	50	62	73
AVG 150	2	2	4	4	6	10	20	31	39	49
AVG 200	0	1	1	2	3	5	8	13	18	27
AVG 300	1	1	1	3	3	5	6	7	10	15
NAA 10	2	3	7	33	57	83	93	96	91	97
Daminozide 750	1	3	4	13	26	50	74	91	83	88
Significance										
AVG	NS	L*	L***Q**	L***Q***	L***Q***	L***Q***	L***Q***	L***Q***	L***Q*	L***
Control vs. NAA	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
AVG vs. NAA	NS	NS	**	***	***	***	***	***	***	***
AVG vs. daminozide	NS	NS	NS	*	***	***	***	***	***	***
NAA vs. daminozide	NS	NS	NS	***	***	***	*	NS	NS	NS

²Daminozide applied 4 Aug.; AVG applied 21 Aug., and NAA applied 8 Sept.

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

Table 11. Effect of aminoethoxyvinylglycine (AVG) concentration, naphthaleneacetic acid (NAA), and daminozide when applied as a dilute handgun application on fruit characteristics at harvest on 'Marshall McIntosh' in Massachusetts, 1992, Expt. 3.

Treatment ² (mg·L ⁻¹)	Fruit wt (g)	Flesh firmness (N)	Soluble solids (%)	Red color (%)	Starch rating
Mean of Harvest on 15, 22, and 29 Sept. and 6 Oct.					
AVG 0 (Control)	162	68.8	13.5	86	5.7
AVG 75	168	69.2	13.0	84	5.3
AVG 100	169	68.3	13.0	83	5.3
AVG 150	172	69.2	12.9	86	5.1
AVG 200	168	70.2	13.0	84	4.9
AVG 300	167	72.5	13.1	86	5.0
NAA 10	167	68.3	13.1	89	6.1
Daminozide 750	160	72.5	13.4	88	5.4
Significance					
AVG	NS	L**	Q*	NS	L***
Harvest time	***	***	***	***	***
AVG × harvest time	NS	*	NS	NS	*
Control vs. NAA	NS	NS	NS	NS	NS
AVG vs. NAA	NS	NS	NS	NS	***
AVG vs. daminozide	*	*	*	NS	NS
NAA vs. daminozide	NS	**	NS	NS	***

²Daminozide applied 4 Aug., AVG applied 21 Aug., and NAA applied 8 Sept.

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

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