Nitrogen Fertilization, Midsummer Trunk Girdling, and AVG Treatments Affect Maturity and Quality of ‘Jonagold’ Apples

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Abstract. ‘Jonagold’ apples [*Malus sylvestris* (L.) Mill var. *domestica* (Borkh.) Mansf.] often fail to develop adequate red coloration at maturity and become soft and greasy in storage. During two growing seasons, we tested factorial combinations of three preharvest treatments affecting ‘Jonagold’ quality at harvest and after storage: 1) three nitrogen (N) treatments [36 kg·ha⁻¹ soil applied N, 6.9 kg·ha⁻¹ of urea-N (1% w/v) in foliar sprays mid-May and June, or no N fertilizers]; 2) trunk girdling in early August each year; and 3) foliar applications of aminoethoxyvinylglycine (AVG, formulated as ReTain) 3 weeks before the first scheduled harvest. Fruit were sampled at four weekly intervals each year and evaluated for maturity and quality at harvest and after storage. Foliar urea and soil-applied N delayed red color development in 1998 but not 1999, increased fruit size in girdled and nonAVG treated trees in both years, and increased greasiness in 1999 only. AVG reduced fruit greasiness after storage both years. Nitrogen uptake was reduced in the dry Summer 1999, but N treatments still increased poststorage flesh breakdown. Midsummer trunk girdling increased red coloration and intensity both years and improved market-grade packout. This effect was not caused by advanced maturity, although trunk girdling slightly increased skin greasiness. Girdling reduced fruit size only on trees of low N status. The AVG applications delayed maturity and red color development by 7 to 10 days in both years compared with untreated fruit. In 1998, the combination of AVG and N fertilization delayed red color development more than either treatment alone. Fruit softening and greasiness were reduced in AVG-treated fruit harvested at the same time as untreated fruit, but this effect was not observed when AVG treated fruit were harvested at comparable maturity 7 to 10 days later. Trunk girdling and withholding N fertilizer were the best treatments for enhancing red coloration, and foliar N concentrations of ≈2.0% (W/W) resulted in better packouts compared with higher leaf N levels. AVG was an effective tool for delaying fruit maturity and maintaining fruit quality awaiting harvest, but not for improving red coloration of ‘Jonagold’ apples.

‘Jonagold’ is a high-quality dessert apple that has gained widespread popularity since its commercial release in 1968. It has become an important cultivar in Europe, but its acceptance in North America has been limited by problems of insufficient red coloration at harvest and loss of fruit firmness during storage. Growers sometimes delay harvesting ‘Jonagold’ beyond optimal maturity to attain adequate red coloration, but fruit in some orchards nevertheless fail to develop adequate color. Late-harvested ‘Jonagold’ often become greasy and soft in storage.

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Applications of AVG inhibit ethylene biosynthesis, thereby delaying fruit ripening and reducing preharvest drop (Bramlage et al., 1980a; Child et al., 1984; Stover et al., 2003). Other reported benefits of AVG include firmer fruit at harvest or after storage (Kondo and Hayata, 1995; Williams, 1980) and delayed skin greasiness and scald development following storage (Watkins et al., 1997; Woolard et al., 1997). Applying AVG to delay fruit maturation may improve red coloration of fruit exposed to cooler weather conditions during that delay interval (Greene, 1997; Thompson, 1998). However, some reports suggest that AVG can indirectly suppress red color development by delaying fruit maturation (Greene, 1996; Watkins et al., 1997). Reported inconsistency of responses to AVG may be due to site and climatic variation, or to differences in time and rate of AVG application in relation to fruit maturity and subsequent harvest (Child et al., 1984), although little is known about such possible interactions.

Excessive N supply decreases red color-

ation and market value of apples (Boynton and Burrell, 1944; Fisher, 1952) and could inhibit red color development in AVG-treated fruit. Insufficient red coloration is associated with lower anthocyanin (Faust, 1965) and higher chlorophyll concentrations in fruit skins (Marsh, 1996; Reay et al., 1998). Fruit high in N also tend to be softer, lower in soluble solids, and more prone to premature drop (Boynton and Oberly, 1966). High N apples are also more susceptible to postharvest storage disorders such as senescent breakdown, scald, and internal browning (Bramlage et al., 1980b). Palmiter and Hamilton (1954) reported that red fruit coloration improved when properly timed foliar urea sprays were applied instead of soil N fertilizers. Inhibited red coloration was observed when foliar urea was applied in late spring and summer compared with early spring applications (Fisher et al., 1952). For late-coloring cultivars such as ‘Jonagold’, early spring and postharvest urea sprays may be the most efficient N fertilization method (Swietlik and Faust, 1984).

Girdling trunks or large branches has enhanced fruit set and color development when performed at specific growth stages on fruit trees in several studies. If girdling increases carbohydrate supply during fruit maturation, this could enhance red coloration by increasing substrates for anthocyanin synthesis (Noel, 1970). Early spring trunk girdling increased fruit set and flower bud formation and reduced vegetative growth on apple trees (Greene and Lord, 1983; Hoying and Robinson, 1992). Color on stone-fruits (*Prunus* spp.) improved after trunk girdling at the pit-hardening stage (Agusti et al., 1998; Day and DeJong, 1990). Girdling apple trees 10 d after petal fall only slightly improved red color in two of three cultivars but increased background yellow color development of fruit skin (Schumacher et al., 1986).

The objectives of our study were to determine the effects and interactions of N fertilization, midsummer trunk girdling, and AVG, on red color development and fruit quality of ‘Jonagold’ apples. To our knowledge, this is the first study investigating potential interactions among these orchard management practices.

Materials and Methods

Fourteen-year-old original strain ‘Jonagold’ trees on M.9/MM.111 interstem rootstocks were selected for this study. Trees were spaced at 3 × 5.5 m, and trained to a central leader system. The experiment was located on a silty clay loam soil (mixed, mesic, Glosaquic Hapludalf) with pH 6.8, and soil organic matter content averaging 5%, at a Cornell research orchard in Lansing, N.Y. Orchard ground cover was managed as weed-free herbicide strips 2 m wide within tree rows and mowed sod in the alley ways. Leaf N concentrations of experimental trees the year before our study averaged 1.99%, at the low end of optimal range for ‘Jonagold’ (Stiles and Reid, 1991). Except for foliar urea sprays at pink-tip and petal-fall stages of growth, no N fertilizers had been applied to these trees for 5 years before

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this experiment. All other cultural practices were typical of commercial apple production in New York.

The experiment was a completely randomized three-way factorial design with three replications for each treatment combination ($n = 36$). Treatments were 1) three N fertilizer treatments [$36 \text{ kg} \cdot \text{ha}^{-1}$ soil applied N, $6.9 \text{ kg} \cdot \text{ha}^{-1}$ of urea-N ($1\% \text{ w/v}$) in foliar sprays mid May and June, or no N fertilizers]; 2) trunk girdling in early August each year; and 3) foliar applications of aminoethoxyvinylglycine (AVG—formulated as ReTain, Valent BioSciences, Chicago, Ill.) 3 weeks before the first scheduled harvest. Treatments were randomly assigned to single-tree experimental units in April 1998, selecting for uniformity of tree vigor and bloom density. A buffer tree was left untreated on both sides of each experimental tree to minimize spray drift and edge effects from adjacent treatments. All treatments were applied to the same trees for 2 successive years, and each year there were four sampling dates from each tree for fruit analysis, providing repeated measures of treatment effects.

Granular ammonium nitrate was applied in early May each year providing $34 \text{ kg} \cdot \text{ha}^{-1}$ of N, equivalent to 55 g N per tree. Soil-applied N was broadcast within the herbicide treated area beneath the drip-line of each tree. Foliar sprays of $10 \text{ g} \cdot \text{L}^{-1}$ of urea were applied to runoff at petal fall and again 14 d after petal fall each year with a motorized backpack sprayer. In 1998, a third urea spray was applied at the same concentration in late October after harvest. For foliar urea applications, 2.5 L of solution was applied to each treatment tree, equivalent to 11.5 g/tree or $6.9 \text{ kg} \cdot \text{ha}^{-1}$ of N. Foliar urea treatments provided a total of $20.7 \text{ kg} \cdot \text{ha}^{-1}$ of N in 1998 and $13.8 \text{ kg} \cdot \text{ha}^{-1}$ in 1999; the higher rate in 1998 was due to the third postharvest application.

Trunk girdling was done in the first week of August both years. In 1998, a knife was used to make a circumferencing cut $\approx 1 \text{ cm}$ deep through the bark down to the wood, at 35 cm above the graft union. Girdling cuts were made in a spiral so that a 3- to 5-cm strip of bark was left intact between the upper and lower overlap of the wound. In 1999, a pruning saw (1 mm wide) was used to reopen each girdling cut from the year before.

We applied AVG at the rate of $124 \text{ g} \cdot \text{ha}^{-1}$ of a.i. with a motorized backpack sprayer. These applications were scheduled 4 weeks before expected normal harvest date for 'Jonagold' in western N.Y., and 3 weeks before our first scheduled experimental harvest. Each experimental tree received 207 mg AVG dissolved in 2.5 L water including an organosilicone surfactant ($0.1\% \text{ v/v}$ Silwet L-77).

At full bloom each year, fifteen randomly selected flower clusters from the perimeter of each tree were collected, immediately dried, and analyzed for total N and C content with a C-N combustion analyzer (Carlo-Erba ThermoQuest Ft.A, Rodano-Milano, Italy). Twenty-five leaf samples were collected from each tree 60 to 70 d after petal fall each year and dried to constant weight, and elemental N concentrations were determined by a micro-

Kjeldahl procedure (Greweling, 1976).

Fruit were sampled on four harvest dates over a 3-week period in both years. Harvest dates were 1 week apart (22 Sept., 29 Sept., 6 Oct., and 13 Oct. 1998; and 27 Sept., 4 Oct., 11 Oct., and 18 Oct., 1999). The first harvest occurred 1 week before the predicted optimal harvest window for long-term storage each year (Blanpied and Silsby, 1992). To obtain representative samples over time, each experimental tree was divided into four sectors (S.E., S.W., N.E., and N.W.), and all the fruit in one sector were harvested on each successive sampling date. Harvest of sectors was randomized by treatment in 1998, but in 1999 fruit were collected from the same sector on each replicate at each harvest. Fruit count and total yield were recorded at each harvest and average fruit weight was determined. Dropped fruit were counted throughout the harvest period to assess percentage fruit drop.

The incidence of bitter pit was recorded at each harvest and affected fruit were discarded. A 10-fruit subsample from each treatment was then selected for evaluation of fruit maturity and quality on the day of harvest. These fruit were selected visually to represent the approximate color distribution of fruit from each tree on each harvest date and were within $\pm 5\%$ of the average fruit weight for each replicate. The internal ethylene concentration (IEC) in 1-mL samples from the core cavity of each fruit was determined by gas chromatography (series II; Hewlett Packard 5890, Wilmington, Del.). Red skin color was assessed with a chromameter (CR-100; Minolta Corp, Ramsey, N.J.), by taking one reading from the blushed side of fruit. Chromaticity values were recorded in Commission Internationale d'Eclairage (C.I.E.) L^* , a^* , and b^* color space coordinates and these values were transformed to hue angle and chroma (McGuire, 1992). The percent red blushed area was estimated by the same person on each harvest date. Fruit with $>50\%$ red surface area were counted as Extra Fancy according to standards of the United States Department of Agriculture (USDA). Background skin color was rated on a scale of 1 to 5 (1 = yellow, 5 = green), according to the Cornell Color Chart for 'McIntosh' Apples (Anonymous, 1948).

Flesh firmness was measured on opposite sides of each fruit using a pressure tester (EPT-1; Lake City Technical Products, Lake City, Canada) fitted with an 11.1-mm Effegi tip. The juice resulting from these punctures was combined and assessed for soluble solids concentration (SSC) with a digital refractometer (Atago PR-100; McCormick Fruit Tech., Yakima, Wash.). Titratable acidity (TA) was measured on juice extracted from a composite of wedges taken from opposite sides of each apple with an autotitrator (DL12; Mettler,

Hightstown, N.J.). Starch-iodine tests of sliced fruit were carried out using the Cornell Generic Starch-Iodine Index Chart, where 1 = 100% starch and 8 = 0% starch (Blanpied and Silsby, 1992). Fruit were assessed manually for skin greasiness using a subjective index where 0 = none, 1 = slight, 2 = moderate, and 3 = severe. On the first harvest date a 1-cm equatorial slice of tissue was taken from each sample fruit, and two 1-cm diameter plugs of cortical tissue were removed from opposite sides of the apple beneath the skin (Turner et al., 1977). The composited fruit tissue was immediately frozen and later analyzed for N and C content using combustion-analysis methods as previously described.

All fruit remaining after harvest evaluations were kept in refrigerated storage (0°C) for 2 months, then held 7 d at room temperature (22°C), and then a 10-fruit subsample was evaluated for flesh firmness, soluble solids, greasiness, and storage disorders. For the 1998 crop, we held an additional 18-kg sample of fruit for 5 months in cold storage and then evaluated the incidence of internal and external storage disorders.

Statistical analysis. Data from all samples each year were analyzed as a $3 \times 2 \times 2$ three-factor model with three replications of each treatment combination and repeated measures over four harvest dates and 2 years (StatView 5.0, SAS Inc., Cary, N.C.). When the repeated-measures model was not appropriate, data were analyzed as a three-way ANOVA model with N, trunk girdling, and AVG as main factors. Each year's data were analyzed separately due to significant year $\times$ treatment interactions.

Fig. 1. Interactions of N and AVG treatments affecting mean fruit weight of 'Jonagold' apples in 1998 and 1999. Interactions significant at $P < 0.001$ in 1998; and $P < 0.01$ in 1999. Values are means of 24 observations $\pm$ SE bars.

Fig. 2. Interactions of N fertilizers and mid-summer trunk girdling affecting mean fruit weight of 'Jonagold' apples in 1998 and 1999. Treatment interactions significant at $P = 0.001$ in 1998 and $P = 0.08$ in 1999. Bars represent means of 24 observations $\pm$ SE of treatment means.

Results and Discussion.

Treatment effects on tree growth, N concentrations and yield. Soil-applied N and foliar urea sprays slightly increased leaf N concentrations in 1998 but not 1999 relative to control treatments (data not shown). In 1998, leaf N concentrations in the soil-applied N treatment averaged 2.10%, compared with

2.05% for foliar urea trees and 1.97% in the unfertilized control. Leaf N averaged 1.61% across all treatments in 1999; these low levels were attributed to a hot, dry summer that year in our nonirrigated planting (Goode and Higgs, 1977). There were no significant treatment effects on bloom density, percentage fruit set, and N content of flower clusters or fruit (data not shown). Soil N and foliar urea sprays increased shoot growth in 1998 but not 1999 (data not shown). Preharvest fruit drop was not affected by N or girdling treatments, but was reduced $\approx 50\%$ by AVG treatments—averaging 10% in 1998 and 11% in 1999 without AVG, vs. 4% in 1998 and 6% in 1999 with AVG.

Mean fruit yields per tree did not differ among trunk girdling, N, or AVG treatments in either year of our study (data not shown). The $N \times AVG \times$ girdling interaction was not significant ($P > 0.05$), but there were significant $N \times AVG$ interactions for mean fruit weight in both years (Fig. 1). Without AVG applications, fruit size was greater in foliar urea and soil-N applications relative to unfertilized controls. With AVG treatment, fruit size was not increased consistently by N fertilizer applications. Other studies have shown that AVG-treated 'Jonagold' fruit were smaller than untreated controls harvested on the same date (Watkins et al., 1997). In our study, fruit weight increased linearly over the 3-week harvest periods by 4 to 13 g/week in 1998 and 5 to 7 g/week in 1999. Delaying harvest of AVG-treated fruit 7 to 10 d would increase fruit size substantially under

these circumstances. Girdling and N treatments interacted strongly for fruit size in 1998, and slightly in 1999 (Fig. 2). Nitrogen applications increased fruit size for girdled trees both years, but had no consistent effect on fruit size for nongirdled trees in either year.

Treatment effects on fruit maturity and quality. We observed lower IEC, and delayed starch hydrolysis and softening in AVG-treated fruit both years (Table 1), with ripening processes delayed by 7 to 10 d (Fig. 3A–F). In 1998, the IEC in AVG-treated fruit remained $< 0.5 \text{ uL} \cdot \text{L}^{-1}$ even on the last harvest date, never exhibiting autocatalytic ethylene production (Fig. 3A). During unusually warm weather between the second and third harvest dates in 1999, IEC values were more erratic in untreated fruit compared with those from AVG treatments (Fig. 3B). AVG delayed starch hydrolysis on the first two harvest dates in 1998 and across all four harvests in 1999 (Fig. 3C–D).

Nitrogen fertilization had minimal effects on fruit physiological maturity in either year of our study, but soil N applications slightly reduced SSC in fruit during 1998, and foliar urea sprays exacerbated fruit greasiness in 1999 (Table 1). Midsummer trunk girdling delayed fruit starch hydrolysis and increased SSC at harvest in 1999. Girdling also increased fruit greasiness in 1998, but had no effect on IEC, titratable acidity, or fruit firmness in either year (Table 1). Previous reports have shown that girdling in late spring advanced apple maturation (Autio and Greene, 1994; Watkins et al., 1992). Elfving et al. (1991) showed that trunk girdling delayed fruit starch hydrolysis and reduced IEC when performed in late July but not when it was done in early June. Trunk girdling in late spring or early summer reportedly increases carbohydrate supply in the tree canopy (Greene, 1937; Murneek, 1941). Therefore, increased carbohydrate accumulation during late summer in fruit on girdled trees in our study may have

Table 1. Main effects and interactions of N fertilizers, midsummer trunk girdling, and AVG treatments affecting fruit maturation and quality characteristics of 'Jonagold' apples during 2 years. Values are the combined means from four harvest dates each year and represent 72 observations for trunk girdling and AVG, and 48 observations for N applications.

Treatment	Ethylene ($\mu\text{L}\cdot\text{L}^{-1}$)		Starch ² index (1–8)		Firmness (N)		Soluble solids (%)		Greasiness ^y (0–3)		Titratable acidity (%)
	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999	1998
Nitrogen											
None	0.967	0.726	7.4	6.0	67.8	84.9	15.6	15.6	0.40	0.27	0.312
Soil N	0.946	1.178	7.5	6.0	67.1	85.2	14.9	16.2	0.53	0.29	0.310
Foliar urea	0.709	1.135	7.5	6.2	66.7	84.4	15.3	15.9	0.48	0.67	0.313
Significance	NS	NS	NS	NS	NS	NS	*	NS	NS	*	NS
Girdling											
Not girdled	0.912	0.819	7.5	6.2	67.3	84.0	15.1	15.5	0.33	0.33	0.309
Girdled	0.837	1.207	7.5	5.8	67.1	85.6	15.4	16.3	0.61	0.49	0.315
Significance	NS	NS	NS	*	NS	NS	NS	**	*	NS	NS
AVG											
No AVG	1.381	1.376	7.7	6.6	66.3	83.5	15.8	15.9	0.83	0.53	0.312
AVG	0.368	0.650	7.3	5.5	68.1	86.2	14.7	15.9	0.11	0.29	0.311
Significance	***	**	**	***	**	**	***	NS	***	NS	NS
Pooled SE of mean	0.09	0.10	0.05	0.11	0.34	0.39	0.16	0.08	0.05	0.04	0.004
Interaction											
N $\times$ AVG	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	*
N $\times$ girdling	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
Girdling $\times$ AVG	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
N $\times$ girdling $\times$ AVG	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

²Cornell Starch Chart: 0 = no starch hydrolysis; 8 = complete starch hydrolysis.

³Scale of 0 to 3, where 0 = none and 3 = severe. Values are the means of 10 fruit samples harvested on 13 Oct. 1998 and 18 Oct. 1999.

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

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Fig. 3. Effects of AVG on internal ethylene concentration (A–B); starch index (C–D); and fruit firmness (E–F) of ‘Jonagold’ apples over four harvest dates in 1988 and 1999. Values are means of 18 observations $\pm$ SE.

reduced the fraction of starch reserves that was hydrolyzed at harvest time, so that IEC would

have been more reliable than starch–iodine tests for assessing fruit maturity.

Fruit treated with AVG were firmer on all but the first harvest dates in both years, and softening was delayed by 4 to 7 d (Table 1, Fig. 3E–F). The SSC values were higher in AVG-treated fruit on all harvest dates in 1998 but not in 1999. In 1999, there was a significant interaction between AVG and N that affected fruit softening (Table 1, Fig. 4). Without AVG, N applications led to softer fruit at harvest in both years; with AVG, N applications increased fruit firmness in 1999, presumably by delayed ripening (Fig. 4). Such interactions of N $\times$ AVG may explain discrepancies in reports about AVG effects on fruit firmness. Some previous

Fig. 4. Interactions between N and AVG affecting flesh firmness of ‘Jonagold’ apples in 1998 and 1999. Interactions significant at $P = 0.07$ in 1998, and $P = 0.03$ in 1999. Bars represent the means of 24 observations $\pm$ SE.

studies have shown greater firmness with AVG both at harvest and after storage (Bangerth, 1978; Bramlage et al., 1980a) or only after storage (Child, et al., 1984; Williams, 1980). Others have reported no increase in firmness of AVG-treated fruit either at harvest or after storage (Greene, 1997; Watkins et al., 1997). Nitrogen supply is a highly variable factor in orchards, and N interactions with AVG could cause inconsistent fruit ripening and quality responses to this ethylene inhibitor.

Treatment effects on fruit coloration and market grade. Soil-applied N and foliar urea sprays reduced percentage red blush of fruit in 1998 but not 1999 (Table 2). Nitrogen applications delayed blush development by 3 to 7 d in 1998 (data not shown), and the percentage of Extra Fancy fruit (>50% red blush) was reduced by 11% to 13% in N treatments relative to controls. The N-treated fruit also remained greener (less yellow background color) at harvest in 1998 but not in 1999 (Table 2). These year-to-year color differences could be attributed to lower tree N status in all treatments approaching harvest in a drought year (1999), which was confirmed by our leaf-N analyses (Hansen, 1980).

The intensity of red coloration on the blushed side of fruit was influenced by N treatments in 1998 and by girdling and AVG treatments on most harvest dates in both years (Table 2; Fig. 5A–D, Fig. 6A–D). Nitrogen treatments in 1998 increased hue angle and decreased chroma values. Blushed areas of fruit from girdling and AVG treatments were darker (lower L^* values) than controls. Midsummer girdling intensified red coloration and AVG decreased red intensity compared with fruit from control treatments on earlier harvest dates both years (Fig. 5A–D, Fig. 6A–D). Reductions in hue angle associated with midsummer girdling and increases associated with AVG and N could be attributed to differences in anthocyanin content of fruit skin (Singha et al., 1991). Reduced anthocyanin and increased chlorophyll concentrations in fruit receiving N fertilizers have been reported in previous studies (Marsh et al., 1996). These observations indicate that red coloration in slow-to-color cultivars such as ‘Jonagold’ can be suppressed by N fertilizers even when applied to foliage at low rates during early fruit developmental stages (Reay et al., 1998).

Midsummer trunk girdling increased the percent red blush of fruit in both years, especially on earlier harvest dates in 1999 (Table 2, Fig. 5A–B). Girdling also increased the packout of Extra Fancy fruit by about 10% compared with that from nongirdled trees (Table 2), and advanced yellow background color development on fruit (Fig. 5E–F). It was noteworthy that midsummer girdling enhanced red coloration without advancing fruit maturity in our study. Agusti et al. (1998) reported that girdling during mid to late summer enhanced fruit color of peaches or nectarines, but it also advanced fruit maturity. For apple, Schumacher et al. (1986) reported that girdling had little effect on red coloration, and others have shown that girdling in spring (as opposed to mid summer) had little effect on fruit blush or background

Table 2. Main effects and interactions for N fertilizers, midsummer trunk girdling, and AVG treatments on surface color characteristics of ‘Jonagold’ apples over four harvest dates in 1998 and 1999. Values are the combined means from four harvest dates each year, and represent 72 observations for trunk girdling and AVG, and 48 observations for N applications.

Treatment	Blush (%)		Background color ^z		L value ^y		Hue angle ^x		Chroma ^w		Extra fancy fruit ^v (%)	
	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999
Nitrogen												
None	66	62	2.1	2.5	47.2	47.5	41.9	38.7	30.8	31.5	76	62
Soil N	55	64	2.5	2.2	48.8	47.8	47.3	38.1	29.8	32.8	63	65
Foliar urea	59	62	2.4	2.3	48.6	47.7	46.0	38.7	30.1	32.0	65	63
Significance	**	NS	*	NS	NS	NS	*	NS	**	NS	**	NS
Girdling												
Not girdled	57	59	2.5	2.6	48.9	48.7	46.6	40.6	29.9	31.4	63	58
Girdled	63	66	2.2	2.2	47.5	46.6	43.5	36.4	30.5	32.8	73	69
Significance	**	**	*	**	*	**	NS	***	*	**	*	*
AVG												
No AVG	67	67	1.9	2.2	46.9	46.1	42.1	36.6	30.5	32.4	78	72
AVG	53	58	2.6	2.6	49.5	49.2	47.9	40.4	29.9	31.8	58	55
Significance	***	***	***	**	***	***	***	***	**	NS	***	***
Pooled SE of means	1.6	1.4	0.08	0.08	0.43	0.47	1.11	0.64	0.14	0.26	2.7	2.6
Interaction												
Harvest × nitrogen	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Harvest × girdling	NS	*	NS	**	NS	NS	NS	**	NS	NS	NS	*
Harvest × AVG	NS	NS	NS	*	NS	NS	NS	*	NS	NS	NS	NS

^z1 = yellow, 5 = green.
^y0 = black, 100 = white, measured on blushed side of fruit skin.
^xHue angle for blush = [TAN (b*/a*)], 0° = red-purple, 90° = yellow, 180° = bluish-green, 270° = blue.
^wChroma for blush = [(a*² + b*²)^{1/2}] (degree of departure from gray toward pure chromatic color).
^vPercent of sample having >50% red blushed surface, average of three harvest dates in 1998, four in 1999.
 NS,*,**,***Nonsignificant or significant differences at P = 0.05, 0.01, or 0.001, respectively.

color (Greene and Lord, 1983; Watkins et al., 1992). Downward phloem-transport inhibition caused by girdling decreases rapidly as the wound heals and closes (Noel, 1970). Therefore, one might expect less influence on fruit color when girdling is performed long before fruit maturation. We did not observe reduced leaf or fruit N concentrations on girdled trees

in either year of our study, suggesting that increased carbohydrate reserves in fruit and branches were the primary factor increasing red and yellow fruit coloration in this treatment. Treatment with AVG reduced red blush development across all harvest dates in both years (Fig. 6A–B) and reduced the amount of Extra Fancy fruit by 17% to 20% (Table 2). Red

color development was delayed by 5 to 14 d in 1998, and 5 to 7 d in 1999; and fruit treated with AVG were greener at almost all harvest dates in both years (Fig. 6E–F). Delayed red coloration with AVG apparently is an indirect result of delayed fruit maturity, rather than direct inhibition of color development. Improved red coloration of apples treated with AVG has

Fig. 5. Effects of midsummer trunk girdling (scoring) on percentage red blush (A–B); hue angle (C–D); and background color (E–F) where 1 = yellow and 5 = green; for ‘Jonagold’ apples over four harvest dates in 1998 and 1999. Values are means of 18 observations ±SE.

Fig. 6. Effects of AVG on percentage red blush (A–B); hue angle (C–D); and background color (E–F) where 1 = yellow and 5 = green, for ‘Jonagold’ apples over four harvest dates in 1998 and 1999. Values are means of 18 observations ±SE.

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Fig. 7. Additive effects of soil N applications and AVG treatments alone, and combined, on red blush development of 'Jonagold' apples on four harvest dates in 1998. Bars represent means of three observations $\pm$ SE.

been observed when harvest was delayed by 7 to 14 d for treated vs. untreated fruit (Greene, 1997; Thompson, 1998). If delaying harvest results in fruit exposure to cooler preharvest weather conditions, then red coloration may be enhanced; but the internal quality and storage potential of fruit may also decline if they become over-mature while awaiting sufficient red coloration. Therefore, using AVG to hold fruit on the tree longer to obtain better red color may not be a practical strategy in some situations.

There were additive effects of harvest date,

N and AVG treatments that influenced the percent red blush and grading of fruit into Extra Fancy categories (Fig. 7 and Table 2). Combining soil-N and AVG applications reduced the percent red blush coloration of fruit even more than either factor alone. This suggests that fruit responses to AVG are influenced by tree N supply or reserves, and can be affected by factors such as soil fertility, irrigation, or crop load.

Preharvest treatment effects on poststorage fruit qualities. After 2 months of storage at 0 °C and 7 d at 22 °C, AVG-treated fruit

remained firmer than untreated fruit harvested on the same dates in 1999 (Table 3). This trend occurred across all harvest dates, with both main effects and interactions paralleling our previous observations at harvest (Fig. 3E–F). In both years, AVG improved poststorage firmness of fruit at all harvest dates. However, comparisons of AVG-treated fruit harvested later than untreated fruit at equivalent stages of physiological maturity (based on color, IEC, and starch indices) revealed that poststorage fruit firmness declined in later harvested AVG-treated fruit (data not shown).

AVG treatments had no effect on SSC after 2 months of cold storage, but SSC values were higher in fruit from girdled trees after storage in both years (Table 3). There was a significant interaction between N and AVG treatments in 1999, but its effect on fruit SSC was not readily explainable. The AVG treatments reduced fruit-skin greasiness after storage for all harvest dates in 1998 and for earlier harvest dates in 1999 (Fig. 8). This was consistent with other reports that AVG provides substantial control of fruit greasiness in cultivars susceptible to this disorder (Watkins et al., 1997; Woolard et al., 1997).

Trunk girdling exacerbated fruit greasiness on the first two harvests in 1999, but not thereafter (Table 3). There were significant trunk girdling $\times$ AVG interactions affecting greasiness both years, but these effects were slight and inconsistent (data not shown). Foliar urea sprays increased greasiness on the first and last harvest dates in 1999. Senescent breakdown occurred in fruit only from the last harvest in 1998. AVG reduced the incidence of breakdown that year, but girdling and N treatments had no effect on its incidence. In 1999, soil-N applications increased senescent breakdown in fruit

Table 3. Main effects and interactions for N fertilizers, midsummer trunk girdling, and AVG treatments affecting fruit quality characteristics of 'Jonagold' apples after 2 months at 0 °C and then 7 d at 22 °C. Values are combined means from four harvest dates and represent 72 observations for trunk girdling and AVG, and 48 observations for N applications.

Treatment	Firmness (N)		Soluble solids (%)		Greasiness ^z (0–3)		Breakdown ^y (%)	
	1998	1999	1998	1999	1998	1999	1998	1999
Nitrogen								
None	46.8	56.4	14.2	16.2	1.4	1.8	35.0	17.5
Soil N	47.1	57.2	13.9	16.9	1.4	2.0	29.1	33.7
Foliar urea	46.1	56.9	14.1	16.5	1.4	2.2	30.0	24.7
Significance	NS	NS	NS	NS	NS	*	NS	*
Girdling								
Not girdled	47.1	57.0	13.8	16.1	1.4	2.0	23.8	28.6
Girdled	46.2	56.6	14.3	17.0	1.4	2.0	38.3	23.0
Significance	NS	NS	**	**	NS	NS	NS	NS
AVG								
No AVG	45.0	55.3	14.1	16.4	1.9	2.2	43.1	28.0
AVG	48.3	58.3	13.9	16.7	0.9	1.7	21.1	22.6
Significance	***	**	NS	NS	***	***	*	NS
Pooled SE of means	0.47	0.56	0.06	0.08	0.09	0.06	4.74	2.34
Interaction								
Nitrogen $\times$ AVG	NS	**	NS	*	NS	NS	---	NS
Nitrogen $\times$ girdling	NS	NS	NS	NS	NS	NS	---	NS
Girdling $\times$ AVG	NS	NS	NS	NS	*	**	---	NS
N $\times$ girdling $\times$ AVG	NS	NS	NS	NS	NS	NS	---	NS
Harvest date	***	***	***	***	***	***	---	***
Harvest $\times$ N	NS	NS	NS	NS	NS	*	---	*
Harvest $\times$ girdling	NS	NS	NS	NS	NS	**	---	NS
Harvest $\times$ AVG	NS	**	NS	NS	***	***	---	NS

^zScale of 0 to 3, where 0 = none, 1 = slight, 2 = moderate, 3 = severe greasiness of fruit surface.

^y1998 values are the means of fruit harvested on 13 Oct. only, 1999 values are the means from all four harvest dates.

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

Fig. 8. Effects of AVG on skin greasiness (0 = none and 3 = severe) of 'Jonagold' apples after 2 months at 0°C and 7 d at 22°C for fruit harvested on four dates in 1998 and 1999. Bars represent the means of 18 observations $\pm$ SE.

from the second and third harvests compared with fruit from unfertilized control treatments. Increased breakdown occurred in fruit from trees receiving soil-N applications, even though there were no significant differences in leaf or fruit N or Ca concentrations that year (data not shown). These results were similar to those of Blaszczyk and Ben (1996) who reported that N fertilization of 'Jonagold' increased susceptibility of fruit to internal breakdown, especially in years with low yields and insufficient fruit Ca concentrations.

A linear regression analysis of percent red blush color vs. leaf-N values that ranged from 1.8% to 2.3% for trees in 1998, revealed a negative correlation between these variables (red blush % = $170 - 50(\text{leaf N \%})$; $r^2 = 0.48$; $P = 0.003$). These observations suggest that applying N fertilizers to 'Jonagold' trees with leaf N concentrations $>2.0\%$ may not improve yields or fruit size, and can be detrimental to fruit quality. Considering that harvest timing of apples is often based on fruit color requirements, N fertilization that suppresses red color development is likely to require delays in harvest, at the expense of subsequent fruit quality and storage potential. Using AVG on trees with high N supply may help to maintain fruit firmness at higher levels but can also delay or decrease red color development. Since 'Jonagold' tends to produce large fruit, routine applications of N are of dubious value for fruit size enhancement of this cultivar. Where soil N supply is ample, eliminating N fertilizers to reduce the N status of trees that produce poorly coloring 'Jonagold' fruit may be an effective way to manage problems of inadequate fruit

coloration and internal quality.

The enhanced red blush of 'Jonagold' fruit on trees girdled in midsummer could increase the percentage of fruit that can be harvested early—with good fruit quality, prolonged storage potential, and minimal greasiness. We did not evaluate the long-term effects of girdling on tree health and productivity in this study, and disease infestation and winter injury are potential concerns with this practice. However, midsummer girdling did allow for callus formation and healing of wounds before trees entered dormancy, and no winter injury was observed during our study.

Preharvest treatments with AVG helped to maintain fruit firmness and delay greasiness, but also inhibited red color development. Once sufficient red color was attained, the firmness and greasiness in fruit from AVG treatments were equivalent to that of untreated fruit that had been harvested 7 to 10 d earlier. The inhibitory interactions of N and AVG treatments on red fruit coloration in our study indicated that AVG responses are influenced by other cultural practices that affect fruit size, color development, and internal quality. Withholding N fertilizers and midsummer girdling were the most favorable treatment combinations for improving fruit color and quality in 'Jonagold'; and AVG appeared to be a potentially useful management tool primarily in situations where delays in harvest time were necessary.

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