New Zealand Journal of Crop and Horticultural Science, 2004, Vol. 32: 235–241
0014–0671/04/3202–0235 $7.00

Influence of time of overhead shading on yield, fruit quality, and subsequent flowering of hardy kiwifruit, *Actinidia arguta*

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Abstract The effect of overhead shading on yield, fruit quality, and subsequent flowering was studied in 4-year-old *Actinidia arguta* 'Ananasnaya' vines in Oregon, United States in 1998 and 1999. Experimental vines were shaded to 45% of full sun from 14 July to 14 August, 14 July to 10 September (harvest date), or 10 September to 16 November, 1998. Control vines were not shaded. Shading treatments were not repeated in 1999. Fruit fresh and dry weight development followed a similar growth pattern in all treatments. Shading had no effect on yield per vine or fruit fresh weight, length, diameter, and % soluble solids in 1998. Shading for 2 months before harvest significantly reduced fruit dry weight in 1998. Shading in 1998 did not affect percentage of budbreak or the number of buds, shoots, or fruitful shoots per vine in 1999. However, vines that were shaded had a significantly lower percentage of fruitful shoots than unshaded vines, especially vines shaded for 2 months before harvest in 1998. Vines shaded for 2 months before harvest had 48% fewer flowers and thus less yield than unshaded vines. Percent fruit set was not significantly affected by flower number per vine or by shading in the previous season. Unshaded vines produced an average of one more cluster per shoot distally (at node 12) than vines shaded for 1 or 2 months before harvest the previous year. There was no treatment effect on fruit fresh weight, dry weight, length, diameter, seed number, or % soluble solids of marketable fruit in 1999. Results show that overhead shading, as might occur with dense canopies, did not have a large impact on fruit quality or yield in the current season, but reduced yield the following season. Overhead shading for 2 months before fruit harvest, led to the greatest reduction in flower number the following season confirming that the period before fruit harvest is an important time for flower bud evocation in this species.

Keywords fruit set; fruit development; flower bud evocation; shade; summer pruning

INTRODUCTION

The hardy kiwifruit (*Actinidia arguta* (Sieb. et Zucc.) Miq. 'Ananasnaya') is grown commercially on c. 100 ha in the United States, New Zealand, Canada, and Chile (Williams et al. 2003).

Hardy kiwifruit plants are very vigorous with pruning and training being important tools for maintaining the vine canopy (Strik 2004). Without adequate dormant and summer pruning, growers have observed very dense canopies with fruit heavily shaded compared with well-managed vines. Adjacent wind breaks can also shade vines for part of the day. The effect of shade on current season fruit quality and subsequent yield in this species of kiwifruit is not known.

Within-canopy shading of *A. deliciosa* (A. Chev.) C.F. Liang et A.R. Ferguson 'Hayward' vines reduced fruit size and shoot dry weight in the current season, and reduced shoot survival and flower bud formation the following season (Grant & Ryugo 1984). Snelgar et al. (1992a) shaded 'Hayward' vines to 45% of full sun and noted that shading before anthesis did not affect fruit fresh weight, whereas post-anthesis shading reduced fruit weight.

†Author for correspondence.
H03074; Online publication date 15 June 2004
Received 11 August 2003; accepted 30 March 2004

Shading in midsummer reduced the number of flowers the following spring by 15% whereas late-summer shading reduced flower numbers by 23% (Snelgar et al. 1992a). In Italy, Fabbri et al. (1991) shaded 'Hayward' vines to 30% of full sun for 4 to 19 weeks and found that return bloom was reduced depending on length and time of shading.

Flower bud evocation in 'Hayward' occurs the growing season before flowering (Davison 1990; Fabbri et al. 1991; Snelgar et al. 1992b; Walton et al. 1997), but differentiation occurs in late winter to early spring just before budbreak (Brundell 1975; Fabbri et al. 1991; Snowball 1995, 1997b). In *A. arguta*, Walton & Wu (1999) found that flower development was similar to that of *A. deliciosa* with second-order axillary meristems present in first-order axillary buds, whereas Snowball (1997a) did not observe second-order axillary structures during the current season.

The objectives of this study were: (1) to determine the influence of time of overhead canopy shading on fruit development, yield, and fruit quality of 'Ananasnaya' in the current season; and (2) to determine the effect of vine shading on flowering, yield, and fruit quality in the following season.

MATERIALS AND METHODS

This study was carried out in a commercial hardy kiwifruit vineyard in Sheridan, Oregon, United States in 1998 and 1999. Two-year-old ungrafted vines were planted in 1995 at a 4.6 × 4.6 m spacing on raised beds and trained to a 2-m-high pergola. Canopy size was c. 21 m^2 per vine. Experimental vines were pruned and otherwise maintained by the commercial grower as standard for commercial production (Strik 2004). Fruit thinning was not done in this study according to standard commercial practice.

In 1998, individual vines were shaded to 45% of full sun with shade cloth (OBC Northwest, Canby, OR, United States). This type of shade cloth was chosen based on earlier studies in *A. deliciosa* (Grant & Ryugo 1984; Snelgar et al. 1992a). Overhead shading was placed over vines on one of three treatment periods: c. 1 month after anthesis to 1 month before harvest (14 July–14 August); c. 1 month after anthesis to fruit harvest (14 July–10 September); and from harvest to leaf senescence (10 September–16 November). Shade cloth (4.6 × 4.6 m) was placed over the entire canopy, resting on the vines, and affixed to the wires of the pergola trellis. Control vines were left unshaded. There was one vine per experimental unit and seven replicates of each treatment arranged in a randomised complete block design. The shade cloth remained in place for the entire treatment period in 1998 and was then removed. Shading treatments were not repeated in 1999.

A six fruit subsample per vine was randomly collected per treatment replicate, avoiding mis-shapen fruit, c. 10 times during the growing season (14 July–harvest) to study fruit development. Average fruit diameter, fresh weight, dry weight, firmness (Penetrometer, AMETEK Hunter Spring Division, Hatfield, PA, United States), and % total soluble solids (°Brix; digital refractometer PR-100, ATAGO Co. Ltd, Tokyo, Japan) were recorded. Dry weight was obtained by placing cut fruit in an oven at 70°C until at a constant weight.

Fruit were harvested when considered mature for commercial production (8–10°Brix) on 8 September 1998. Total yield per vine was separated into non-marketable (fruit <1.7 cm in diam.), overripe, and marketable fruit (>1.7 cm in diam.) and weighed. Average fruit diameter, fresh weight, firmness, °Brix, and dry weight were recorded on each of 20 marketable fruit and 10 non-marketable fruit per vine.

In 1999, data were collected on the same treatment vines to study the impact of time of shading in the previous year. The number of nodes, shoots (just after budbreak), growing shoots (at 15 cm long), fruitful shoots, flowers, and fruit per vine were counted. The percentage of budbreak, fruitful shoots, and fruit set per vine were calculated. The number of flowers at each leaf axil on 40 flowering shoots originating from canes and 10 flowering shoots originating from spurs were counted per vine.

In 1999, vines were harvested on 21 September. At harvest, the total number of fruit per vine was counted. Fruit were separated into marketable, non-marketable, and overripe and weighed, and individual fruit data collected as in 1998. Seed number per fruit (extracted and counted), fresh weight, and fruit length and average diameter were recorded from a subsample of 20 marketable fruit and 10 non-marketable fruit per vine.

Treatment effects were analysed using analysis of variance (PROG GLM) with treatment means compared using a protected LSD. The relationship between seed number and fruit fresh weight was determined by regression (SAS System, Version 6.12, SAS Institute Inc., Cary, NC, United States).

RESULTS AND DISCUSSION

Effect of shading on current season's yield and fruit quality

Fruit fresh weight development was not significantly affected ($P > 0.1$) by shading treatments on any sample date or at harvest (Fig. 1). In 'Hayward', fruit on exposed shoots were larger than those on shaded shoots trained under the vine canopy (Grant & Ryugo 1984; Snelgar & Hopkirk 1988). In this study, fruit dry weight followed a similar developmental pattern to that of fresh weight (Fig. 1). However, shading reduced fruit dry weight by 20% at harvest (1.0 g for unshaded and 0.8 g in vines shaded from 14 July–10 September, $P < 0.05$). Low light intensity (40–50% of full sun) reduced dry matter production of 'Hayward' (Morgan et al. 1985).

Shading tended ($P < 0.1$) to decrease the percentage of soluble solids (°Brix) of fruit at harvest (Fig. 2). Shading of individual 'Hayward' fruit without canopy shading had no significant effect on percentage of dry matter or total soluble solids of fruit indicating the importance of the contribution of leaves to fruit development (Lawes 1989). In 'Hayward', shading of whole vines decreased °Brix at harvest and increased rate of fruit softening during storage, but differences were not commercially significant (Snelgar et al. 1991). In this study, shading had no significant effect on fruit firmness or fruit colour at harvest (data not shown). However, if fruit had been allowed to vine ripen, we likely would have observed a treatment effect on fruit colour, as sun-exposed fruit in this cultivar of hardy kiwifruit typically develop a red skin colour later in fruit development.

There was no significant effect of shading in the current season on total yield (28.0 kg per vine for unshaded and average of 26.9 kg per vine for shaded treatments). Vines were shaded after anthesis or fruit set and the impact of shading on fruit fresh weight was not significant.

Effect of shading on subsequent flowering

Shading in 1998 did not affect the number of buds per vine (after pruning), percentage of budbreak, the number of shoots, growing shoots, and fruitful shoots per vine in 1999 (Table 1). Shading before or after fruit harvest reduced the percentage of fruitful shoots. Vines shaded from 1 month after anthesis until harvest had the lowest percentage of fruitful shoots (Table 1). This pattern was also apparent in the treatment effect on flowers per vine (Table 2), where vines shaded for 2 months before harvest had 48% fewer flowers per vine than unshaded vines. Shading from 1 month after anthesis to 1 month before harvest also reduced flower number per vine whereas shading after harvest had no significant effect (Table 2). In 'Hayward', shading for 4 weeks before leaf fall had no effect on return bloom (Fabbri et al. 1991). In our study, shading before harvest reduced the number of flowers per vine (48%) more than that reported by Snelgar et al. (1992a) in 'Hayward' (15–23%), perhaps because of a difference among species of *Actinidia* or sampling method as they counted flowers on subsampled canes whereas we counted the whole vine. Snelgar et al. (1992a) reported shading for 3 months before harvest reduced the number of flowers per winter bud in 1 out of 2 years in 'Hayward'. In our study, shading 2 months before harvest reduced the number of flowers per winter bud by 40% whereas earlier shading or postharvest shading had no effect (data not shown).

Shading before harvest in 1998 decreased the number of flowers and clusters per shoot originating from canes, but did not reduce the number of flowers per cluster in 1999 compared with unshaded vines (Table 3), contrary to what has been reported on individually shaded shoots in 'Hayward' (Grant & Ryugo 1984), but similar to the findings of Snelgar et al. (1992a). Vines shaded for 2 months before harvest the previous year had the fewest flowers and clusters per shoot. Shading had no impact on the position of the proximal flowering cluster. However, unshaded vines produced c. 1 more cluster per shoot distally (at node 12) than vines shaded for 1 or 2 months before harvest (Table 3). Shading after harvest, however, had no significant effect on the number of flowers per shoot or flower cluster position. The position of flowers on shoots in unshaded vines was consistent with earlier reports (Tiyayon & Strik, 2003). Shading in 1998 had no effect on flowers or clusters per shoot originating from spurs in 1999 (data not shown).

Our results support the observations of Walton & Wu (1999) that flower bud evocation in *A. arguta* begins the year before flowering. The effect of shading on the number of clusters per shoot in our study implies that a significant amount of flower bud development also occurs the season before flowering. Shading for 1 month (from 14 July to 14 August) was intermediate in vine effects as compared with the 2-month shading treatment (14 July–10 September) whereas postharvest shading had little effect, indicating that the entire period 2 months before harvest is an important time for flower

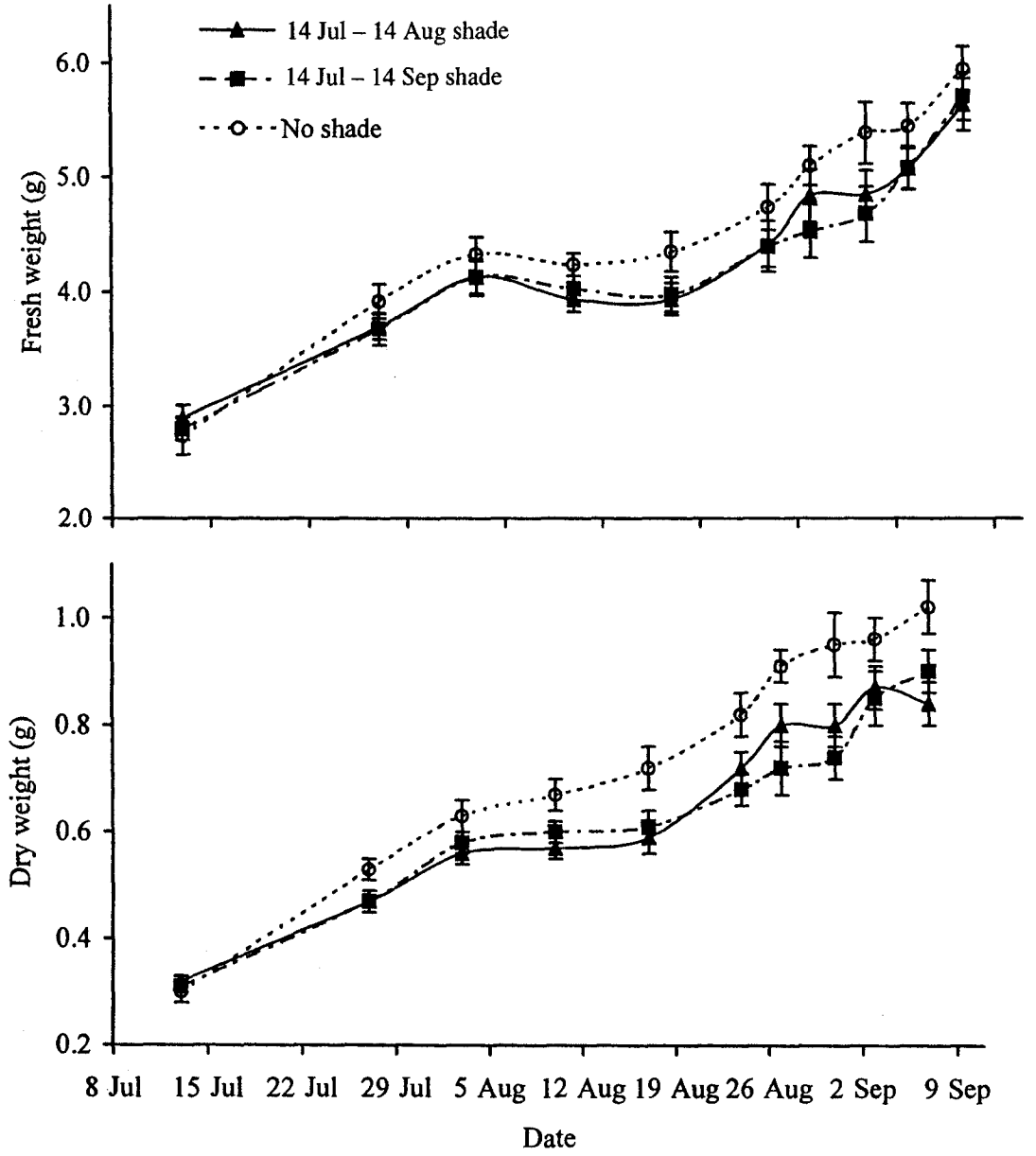

Fig. 1 Development of fruit weight of (*Actinidia arguta*) 'Ananasnaya' from 14 July (1 month after anthesis) to 8 September 1998 as affected by shading in 1998 ($n = 7$; means and standard errors are provided for each sample date).

bud evocation or development and that adequate light exposure is important. Walton et al. (2000) speculated that, in 'Hayward', greater photosynthesis or carbohydrate status was responsible for greater shoot productivity in early-initiated canes as compared with late-initiated canes. In addition, 'Hayward' shoots that were defoliated from post-bloom to harvest had reduced flowering at the terminal ends the following season (Snowball 1997b).

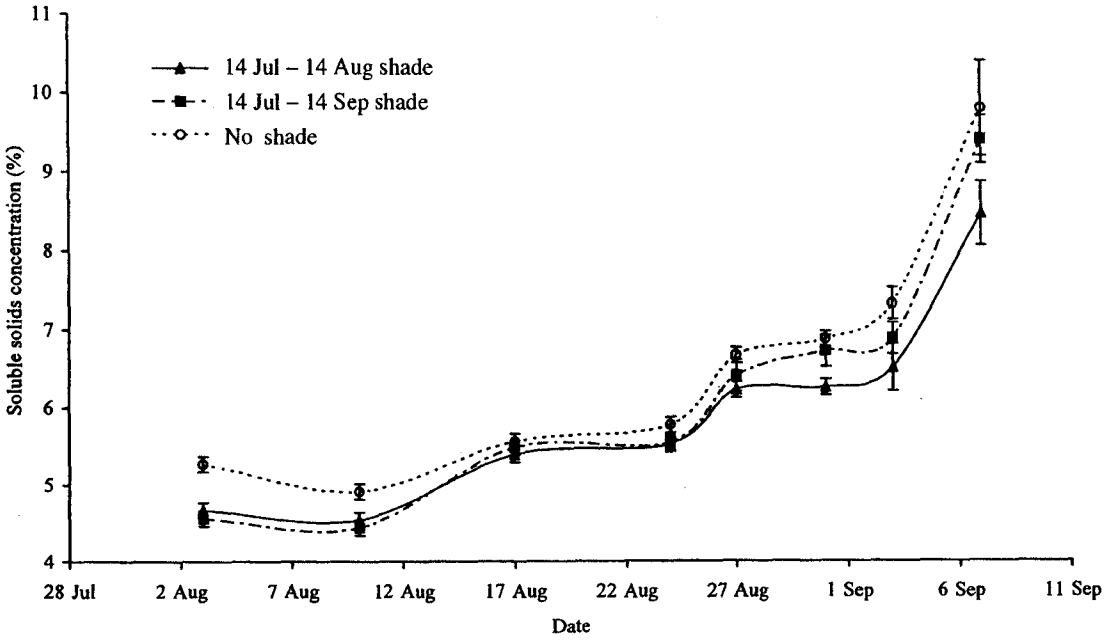

Fig. 2 Changes in % soluble solids (°Brix) of (*Actinidia arguta*) 'Ananasnaya' fruit from 14 July (1 month after anthesis) to 8 September 1998 as affected by shading in 1998 ($n = 7$; means and standard errors are provided for each sample date).

Table 1 Effect of shading treatments in 1998 on vine components of hardy kiwifruit (*Actinidia arguta*) in 1999 (data were collected on 7 whole vine replicates; NS, non-significant; means followed by the same letter are not significantly different by LSD, $P \geq 0.05$).

Time of shading (1998)	Bud no.	Shoot no.	Budbreak (%)	No. of growing shoots*	Growing shoots* (%)	No. of fruitful shoots*	Fruitful shoots* (%)
14 Jul – 14 Aug	2048	893	44	798	90.2 a	608	76.1 b
14 Jul – 10 Sep	1861	849	47	704	83.4 b	486	68.0 c
10 Sep – 16 Nov	2155	961	45	790	82.0 b	602	75.3 b
Unshaded	2177	987	45	834	84.8 ab	677	81.1 a
Signif.	NS	NS	NS	NS	$P < 0.05$	NS	$P < 0.001$
LSD	634	257	5	205	6.1	172	4.8

*Recorded when shoots were 15 cm long.

Table 2 Effect of shading in 1998 on yield components of hardy kiwifruit (*Actinidia arguta*) in 1999 (data were collected on 7 whole vine replicates; NS, non-significant; means followed by the same letter are not significantly different by LSD, $P \geq 0.05$).

Time of shading (1998)	No. of flowers	No. of fruit	% fruit set	Yield (kg/vine)		
				Marketable	Non-marketable	Total
14 Jul – 14 Aug	7559 b	5531 a	75	36.5 ab	3.9 ab	41.9 ab
14 Jul – 10 Sep	4853 c	3434 b	70	26.7 b	2.7 b	30.9 b
10 Sep – 16 Nov	8540 ab	5864 a	70	37.1 ab	4.6 a	43.5 a
Unshaded	9367 a	6936 a	74	44.0 a	5.4 a	51.4 a
Signif.	$P < 0.001$	$P < 0.001$	NS	$P < 0.05$	$P < 0.05$	$P < 0.01$
LSD	1485	1426	19	10.4	1.8	11.2

Table 3 Effect of shading in 1998 of 'Ananasnaya' (*Actinidia arguta*) on fruitfulness of shoots from canes in 1999 (data are average of 40 subsampled shoots per vine, $n = 7$; NS, non-significant; means followed by the same letter are not significantly different by LSD, $P \geq 0.05$).

Time of shading (1998)	Flowers/shoot	Clusters/shoot	Flowers/cluster	Fruitful node	
				Proximal	Distal
14 Jul – 14 Aug	15.8 bc	6.1 bc	2.5	6.0	11.1 b
14 Jul – 10 Sep	13.9 c	5.6 c	2.5	6.2	10.8 b
10 Sep – 16 Nov	16.8 ab	6.4 ab	2.6	6.0	11.5 ab
Unshaded	18.2 a	6.9 a	2.5	6.1	12.0 a
Signif.	$P < 0.05$	$P < 0.05$	NS	NS	$P < 0.05$
LSD	1.9	0.6	0.2	0.4	0.6

Table 4 Effect of shading in 1998 on 'Ananasnaya' (*Actinidia arguta*) fruit in 1999 (data are the average of a subsample of 20 marketable fruit and 10 non-marketable fruit per vine, $n = 7$; NS, non-significant; means followed by the same letter are not significantly different by LSD, $P \geq 0.05$).

Time of shading (1998)	Marketable fruit			Non-marketable fruit		
	Fresh weight (g)	Seeds/fruit	mg/seed	Fresh weight (g)	Seeds/fruit	mg/seed
14 Jul – 14 Aug	7.7	137	56.5	2.1	18.8 b	119.6 ab
14 Jul – 10 Sep	7.6	138	56.5	2.1	15.1 b	137.3 a
10 Sept – 16 Nov	7.6	138	55.4	2.2	18.3 b	124.3 a
Unshaded	7.3	151	49.2	2.3	23.8 a	99.1 b
Signif.	NS	NS	NS	NS	$P < 0.01$	$P < 0.05$
LSD	0.5	22	7.8	0.2	4.3	21.5

Effect of shading on following season's yield and fruit quality

The percentage of fruit set in 1999 averaged 72% and was not affected by the number of flowers per vine in 1999 (Table 2). No fruit drop was observed and fruit were not thinned. Thus, vines shaded for 2 months before harvest in 1998 that had fewer flowers in 1999 also had fewer fruit and a lower yield than unshaded vines (Table 2). Shading in 1998 had no effect on fruit fresh weight (Table 4), fruit length, fruit diameter, colour, or °Brix (data not shown) in 1999. In non-marketable fruit, unshaded vines had a significantly higher number of seeds per fruit, but a lower fruit fresh weight per seed than vines shaded for 2 months before harvest (Table 4). This may have been the result of unshaded vines having more fruit. It thus appears that although shading did impact flower bud evocation, it did not affect flower quality based on seed number per fruit (assuming no treatment effect on % seed set).

The relationship between fruit fresh weight and seed number per fruit was linear for all treatments ($y = 0.036x + 1.76$; $r^2 = 0.876$, $P < 0.001$). Pescie & Strik (2004) reported a quadratic relationship between fruit fresh weight and seed number in 'Ananasnaya' in Oregon, United States. In their study on fruit thinning, there were more fruit with a low seed number than in this study. It appears that the relationship between fruit weight and seed number can be quite variable. In 'Hayward', Lawes et al. (1990) found, within the same season, a linear, curvilinear, and asymptotic relationship between fruit weight and seed dry weight depending on whether fruit from different single vines were assessed or fruit from many vines were pooled.

Results show that shading did not have much of an effect on fruit quality in the current season or the following season. However, shading, especially during the period 2 months before harvest, reduced flower bud development for next year's crop.

ACKNOWLEDGMENTS

We appreciate the contributions of our grower cooperator, Mark Hurst of Hurst's Berry Farm.

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