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Evaluation of kaolin-based particle film coatings on insect and disease suppression, and heat stress in apples

FINAL REPORT

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The Organic Farming Research Foundation of Santa Cruz, CA generously provided grants of $3,479 in 1999 and $4,171 in 2000 to conduct this study at the Southwest Research Center, Mt. Vernon, MO. The two-year study was completed October, 2001. The particle film technology tested in this study appears to offer tremendous potential in safely suppressing both insects and disease in Midwestern apple production.

Objective

The objective of the study was to evaluate and document the efficacy and potential of a safe kaolin-based particle film coating in suppressing plum curculio, codling moth, red-banded leafroller, oriental fruit moth, San Jose scale, and certain fungal pathogens in apples, while fine-tuning application recommendations for Midwestern growers. An evaluation of the particle-film's ability to protect apple trees from heat stress was also conducted.

Background

Organic production of quality apples remains extremely difficult in the Midwestern USA, while demand for high-quality organically-grown fruit continues to increase. Conventional apple production typically requires as many as 17 applications of pesticides annually that still do not always achieve adequate pest control. Many of these pesticides are toxic and may pose a threat to workers, consumers, neighbors, beneficial insects, animals, and the environment. Organic growers need better methods of controlling devastating insect pests in apples, while conventional growers would likely embrace pest-control products that are effective yet safer to use in their overall pest management programs.

Particle film technology is an exciting recent development with tremendous potential in organic and integrated pest management of agricultural and horticultural crops. This technology may be capable of suppressing pests and diseases that have historically been very difficult to control. Fine film coatings of safe, microscopic particles are sprayed onto leaves and fruit to form a protective barrier that controls or suppresses many insects and mites simply by repelling or irritating them. Beneficial insects such as lady beetles and honey bees that do not feed on the leaf or fruit generally remain unharmed. The films may also be able to confound the infection and propagation mechanisms of certain fungal and bacterial pathogens. At the same time, the particles can provide physiological benefits to crops by lowering canopy temperature, reducing heat stress to leaves, and protecting fruit from sunburn.

One of the most promising particle films is manufactured from kaolin, a naturally-occurring clay mineral that is safe enough to have been approved by the U.S. Food and Drug Administration as a human food additive. Scientists with the U.S. Department of Agriculture have developed and researched these coatings under a Cooperative Research and Development Agreement with Engelhard Corporation, Iselin, NJ. Engelhard has modified the kaolin mineral to make it uniform, sprayable, and of optimum size for insect adhesion and irritation while allowing the passage of photosynthetically-active radiation and reflection of infrared radiation. Sales of its kaolin-based plant protection product began in 2000 under the trade name "Surround WP Crop Protectant". Surround WP has now been federally labeled for use on many important horticultural crops. It is safe and legal to purchase and use, according to directions, in nearly all states. Additionally, on March 7, 2000, the Organic Materials Review Institute (OMRI) officially listed the Surround WP product as "allowed" in organically-certified farms.

Plum curculio, codling moth, oriental fruit moth, and red-banded leafroller are four of the most important apple insect pests in the Midwest, often rendering organic apple production uneconomical. If not kept in check, they can easily and rapidly ruin an entire crop. Earlier research has suggested that some control of these pests may be possible if adequate kaolin particle films are present on leaves and fruit at times when insects are vulnerable, such as during oviposition, hatch, or feeding. However, detailed data is needed on optimizing application rates and timing in relation to pest population levels in order to achieve adequate pest control. This much-needed information is key to confidently recommending safe particle film technology to both organic and conventional growers, and prompted this study.

Materials and Methods

The study involved two separate apple orchards, both planted in 1991 at the University of Missouri's Southwest Research Center at Mt. Vernon (37^o 4' lat, 93^o 53' long, and 378 m alt). The soil is a prairie-derived Keeno cherty silt loam (loamy-skeletal, siliceous, mesic Mollic Fragiudalfs) that is moderately well-drained with a 3% slope. Average annual rainfall is 1,106 mm (43.5 in), average maximum temperature is 19.3 ^{o}C (66.7 ^{o}F), and average minimum temperature is 6.8 ^{o}C (44.2 ^{o}F).

Orchard 1 consisted of 90 trellised dwarf 'Liberty' and 'Jonafree' apple trees on 'Mark' rootstock, spaced 1.5 m (5 ft) apart. The orchard was set up in linear plots of three trees per cultivar, alternating cultivars within the row, resulting in 15 plots of three trees per cultivar. Three replications of five treatments were randomly assigned to each cultivar's 15 plots in a completely randomized design. Treatments were: 50 lbs/acre Surround WP once per week, 50 lbs/acre every two weeks, 25 lbs/acre once per week, 25 lbs/acre every two weeks, and untreated control. Data in this orchard were collected only from the middle tree of each three-tree plot to avoid border effects from neighboring closely-spaced plots. Orchard 2 contained 20 semi-dwarf trees, ten each of the cultivars 'Ultragold' and 'Jonagold' on 'M7' rootstock, planted 4.0 m (13 ft) apart and alternating cultivars within the row. Each individual tree served as a plot. Two replications each of the same five treatments were randomly established per cultivar.

Experiments were conducted during the growing seasons of 2000 and 2001. The trees had not been sprayed with chemical pesticides during the previous four years. Dormant oil was applied pre-bloom both years to help control scale insects and aphids. No other pesticides were used outside the experimental materials. Irrigation water was applied as needed via a drip system. Weeds were controlled manually. A fertilization program using a locally-produced organic alfalfa-based 3-1-5 fertilizer (Bradfield Industries, Springfield, MO) was initiated in 2000. Applications of Surround WP treatments began at petal fall (25 Apr 2000; 26 Apr 2001) and continued until about one week before harvest (1 Aug 2000; 5 Aug 2001). Trees were hand-sprayed with a tractor-mounted PTO-driven sprayer at 150 psi pressure or greater, thoroughly covering both top and bottom of foliage and fruits.

Insect traps were used to monitor populations of several serious insect pests common to the region so that we could correlate damage, or lack thereof, with the known presence of certain insect species. Ten appropriate pheromone-based sticky insect traps (Trécé, Inc. Salinas, CA) each for codling moth, oriental fruit moth, red-banded leafroller, and San Jose scale (2001 only) were placed throughout the two orchards and refreshed every four weeks during the growing season. Trapped insects were removed and counted weekly to document insect population patterns throughout the season. Plum curculio were monitored weekly via two "Tedders Traps" (Gempler's, Belleville, WI) to determine when adults were present in the orchard, but data are not reported because the trap is not considered as reliable as pheromone-based traps which are not available for this insect.

Detailed observations and data were collected periodically throughout the growing season on both insect damage and fungal disease on both leaves and fruit. Most fruit data, however, were collected upon harvest (August 7-11, 2000; August 10-13, 2001) when fruits were picked, cut open, and individually examined to ascertain precisely what type of damage, if any, had occurred. Final leaf data were collected in September both years to document what type of damage had accumulated throughout the entire growing season.

At harvest, apples were scored for the following damage: Fungal diseases flyspeck (*Zygophiala jamaicensis*) and sooty blotch (*Gloeodes pomigena*), and insect damage from plum curculio (*Conotrachelus nenuphar*), codling moth (*Cydia pomonella*), red-banded leafroller (*Argyrotaenia velutinana*) and San Jose scale (*Quadraspidiotus perniciosus*) (2001 only). Oriental fruit moth (*Grapholitha molesta*) damage was not evaluated because of the very low population of these insects in the orchard. Apples were then graded, with "1" being a near-perfect marketable apple, "2" being an apple of good quality suitable for cider, and "3" an unusable apple. Apple fruit yields were also documented. Between 50 and 100 apple fruits per plot were examined for insect and disease damage with a general target of 50 fruits. If a plot had less than 50 apples, all fruits were examined. Individual fruits were first scored positive or negative for the superficial fungal diseases sooty blotch and flyspeck before being cut open to identify insect damage. Leaves were examined for the fungal diseases cedar apple rust (*Gymnosporangium juniperi-virginianae*) and Phoma leaf spot (*Phoma* spp.), and surface feeding damage by red-banded leafroller larvae. For each condition, 100 leaves from within each plot were individually and randomly examined. Leaves were scored as either affected or not for each pest being evaluated.

Data on heat stress and leaf temperature were measured with a LI-6400 Portable Photosynthesis System (LI-COR Biosciences, Lincoln, NE). We generally tried to perform these measurements on very hot, windy, and dry days when the plants would likely be under stress. Five leaves per treated tree were measured in either Orchard 1 or Orchard 2 on nine occasions. Similar, average-appearing leaves at between 1 and 2 m height on the plant were measured.. The following data were recorded: net photosynthesis (♠CO_2 : Φmol CO_2 m^{-2} s^{-1}), stomatal conductance (mol H_2O m^{-2} s^{-1}), transpiration rate (Φmol H_2O m^{-2} s^{-1}), air temperature (^oC), and leaf temperature (^oC).

Results

Insect traps revealed very little presence of codling moth and oriental fruit moth in the orchard during both growing seasons. San Jose scale was present but not in economically-important numbers. Red-banded leafroller, however, was abundant both years with a large peak of adults in mid-June followed by a smaller peak in late July (Fig. 1 and 2). Plum curculio was present throughout both seasons with larger numbers of adults trapped in mid-May and late July. Because populations of codling moth and oriental fruit moth in the orchard were so low, we were not able to obtain reliable data on the efficacy of Surround WP treatments against those two species. Red-banded leafroller and plum curculio were the most important insects present in the orchard, and were therefore most thoroughly evaluated.

Both cultivars in Orchard 1, Liberty and Jonafree, produced fruit in both 2000 and 2001 while neither of the cultivars in Orchard 2, Ultragold and Jonagold, produced fruit either year. Fruit and leaf data from each cultivar were analyzed separately. Because we were not particularly interested in insect and disease differences specifically due to cultivar, that data is not presented; however cultivar by treatment interactions are noted. For statistical purposes, least squares means were calculated and analyzed.

Our results and statistical analyses show that Surround WP is able to significantly (*P* # 0.05) suppress a variety of insect and fungal pests in apples. A portion of our data is presented in Tables 1 through 6. Plum curculio, one of the most devastating apple pests in Missouri, was significantly suppressed by Surround WP. In 2000, only 16 % of Jonafree and 15 % of Liberty fruits treated with 50 lbs/acre weekly (50 W) were infested by plum curculio, whereas 71 % of Jonafree and 65 % of Liberty fruits in untreated plots were destroyed. In 2001, 4 % of Jonafree and 22 % of Liberty in 50 W plots were infested, while 46 % and 81 % in untreated plots, respectively, were destroyed. Little cultivar by treatment interaction was evident.

Suppression of red-banded leafroller damage to fruit was not consistent, while almost complete control of larval leaf feeding was achieved. Much of the leafroller fruit damage occurred early in the season when coverage of the young, small fruit with the particle-film material was perhaps less effective. Data on leaf surface damage caused by red-banded leafroller were taken only in 2001. Among all four cultivars evaluated, leaf damage was significantly suppressed by any of the Surround WP treatments compared with untreated trees. No differences were detected among any of the treated plots. For example, among Jonafree plots, leaves treated with any Surround WP treatment had between 1 and 4% of its leaves damaged while 36% of untreated leaves were destroyed. Similarly, with Liberty, between 1 and 5% of treated leaves and 32% of untreated leaves were damaged. No cultivar by treatment interactions were detected.

San Jose scale damage to fruits did not occur in economically-important numbers. Control of this pest with the Surround WP treatments was not consistent. Perhaps a larger infestation of this insect would be needed to determine if suppression is possible with this product.

Flyspeck and sooty blotch are superficial fungal diseases that ruin the appearance of the apple fruit, reducing their market value especially for pick-your-own operations where it cannot be washed off before sales. Surround WP significantly suppressed both flyspeck and sooty blotch on Jonafree fruit in 2000 and 2001. With Liberty, sooty blotch was largely controlled in 2001, but not in 2000, nor was flyspeck controlled either year. No cultivar by treatment interactions were detected. In most cases with these two diseases, a trend toward less disease with stronger and more frequent applications was evident even though significant differences to that effect may not have been detected.

Cedar apple rust, an important foliar disease, was significantly higher in untreated trees compared with all treated trees for both Jonafree and Jonagold in 2000. No differences were detected, however, with Ultragold in 2000. In 2001, no consistent or significant differences in rust infection were detected among any of the treatments for Jonafree and Ultragold, whereas with Jonagold, two of the treated plots actually had more rust than control (Table 5). Liberty is resistant to cedar apple rust and was not evaluated. This inconsistency from one year to the next is difficult to explain, but was perhaps due to differences in weather conditions, cultivar susceptibility, and virulence of the pathogens from one year to the other. These results underscore the need for further research with this disease to determine if it might be more consistently suppressed by Surround WP under certain specific conditions.

Phoma leaf spot was evaluated only in 2001. Control of this leaf disease was highly significant with Surround WP treatments among all four cultivars. Infection rates ranged from 0 to 5 % for 50W trees to between 14 % and 23 % of leaves on untreated trees.

Grade of apple fruits was significantly improved by Surround WP treatments. In both 2000 and 2001, not a single untreated apple was rated Grade 1 (near perfect) whereas 19 % and 54 % of Liberty and 5 % and 21 % of Jonafree were rated Grade 1 in 2000 and 2001, respectively, with nothing more than 50W Surround treatments. For Grades 2 and 3, significant differences were detected between untreated apples and any of the Surround WP treatments, regardless of rate or frequency. Even though significant differences were not detected among the various Surround WP treatments, the trends toward the better quality apples were with the highest rate and frequency of application. Cultivar by treatment interactions were also detected among nearly all cultivars. Fruit yield by weight for both Liberty and Jonafree was not affected by treatment either year.

Orthogonal comparisons were next used to attempt to more precisely sort out differences among the various treatments for specific diseases and insects that were affected by Surround WP. For both flyspeck and sooty blotch, significant differences were detected between weekly versus biweekly treatments in 2000, but not between the 25 and 50 lb rates. This pattern, however, was not consistent in 2001 as no differences were detected between frequency or rate. For plum curculio suppression in 2000, rate was more important than frequency, which was not significant. In 2001, both frequency and rate were statistically significant in reducing insect damage. These findings, while not highly consistent, may tend to suggest that frequency of application may be more important than application rate in suppressing fungal diseases whereas rate may be more important for suppressing insects – at least plum curculio. It seems logical that a consistent but not necessarily heavy coating of film on the fruit may be needed to modify the leaf surface characteristics enough to interfere with fungal infection, while a good strong dose of material may be needed to repel tenacious insects such as plum curculio. This hypothesis also tends to agree with the data in that a high dose sprayed frequently tends to repel the plum curculio better.

We were "fortunate" to have had several hot, windy, and dry days in 2001 to test the efficacy of Surround WP in protecting the trees from heat stress. Quality data were obtained on nine occasions using the LI-6400 Portable Photosynthesis System. The trees were well-irrigated, so should not have been under extreme stress, however late summer temperatures and surface evaporation remained extremely high for several weeks creating a potentially stressful situation for even the healthiest of plants. Weather conditions, including the air temperature recorded by the Licor machine during the sampling period (generally about 2.5 hours) are presented in Table 7. Because little, if any, rain occurred to wash the particle-film coatings from the leaves during much of this sampling period, a good, uniform coating was present during all samplings regardless of when the latest application had occurred. Leaves from the five treatments were analyzed separately.

Presumably, a tree under severe stress will partially or fully close its stomata, thereby reducing stomatal conductance and transpiration, and thereafter, photosynthesis. Out of the nine data samplings, only two showed evidence of significant differences in plant stress factors among treatments: Experiments 4 and 15. These two samplings were conducted on the hottest and most stressful days of all the nine experiments, as underscored by both air and leaf temperatures. The data from those two experiments tend to support the hypothesis that Surround WP coatings may reduce stress and therefore increase photosynthesis under extreme situations. Data from two samplings are presented in Tables 8 and 9. In general, photosynthesis, stomatal conductance, and transpiration increased with increased application rate and frequency of Surround WP.

Conclusions

During two very busy and successful seasons of testing, the Surround WP product has proven to be extremely effective at suppressing a variety of important insects and fungal diseases in apples. It was also shown to significantly improve the overall quality or grade of fruit. The particle film coatings also appear to be able to relieve heat stress under extremely stressful weather situations. The statistical analyses provided evidence that frequency of application may be more important than rate in suppressing fungal diseases whereas rate of application may be more important for suppressing plum curculio and other insects.

As far as making specific application recommendations to farmers as a result of what we have learned, it certainly appears that in most cases and with most pests, the stronger the dose and the more frequent the application, the better. Our highest and most frequent rates of 50 lbs/acre sprayed weekly generally resulted in the best protected plots in the orchards. Because a strong and persistent coating seems to be most successful, we would recommend farmers maintain a good, even coating on their trees and fruit at all times that a particular targeted pest is present and virulent. The nature of this study was very academic in that we sprayed the plots right on schedule without taking into account rainfall, insect presence or virulence, etc. Most orchardists, whether organic or not, who choose to integrate a product such as Surround WP into their overall pest management system, would likely use it in a much more precise and targeted manner.

An interesting question raised by this study that cannot be presently answered is the following: If an entire orchard were treated with Surround WP, thereby leaving no unsprayed "control" trees for insects to find and easily attack, would the insects be forced to "break through" the particle film barrier to feed and lay eggs or would they be completely repelled from the entire orchard? A new, larger-scale study may be needed to address this question.

This study has been very exciting and challenging. We have learned a lot about the challenges of growing apples organically in the Midwest. Surround WP is not a panacea. It must be diligently and precisely applied at the most appropriate times. Without doubt, new and even better particle-film plant protection products will be developed and released as more research is conducted and the technology advances over the next several years. We are confident that this research will benefit Midwestern growers of organic and non-organic fruit as they consider how best to integrate new products such as Surround WP into their arsenal of plant protection products and strategies.

Farmer Cooperator

Dan Kelly, an organic apple grower in northeast Missouri conducted an on-farm experiment in tandem with our trial in 2000. He tested Surround WP kaolin particles against a commercially-available potters-type kaolin clay sold by Fedco Seeds (Waterville, ME) as a plant protectant. I should first make a statement that Surround WP is labeled for use on human food while potters clay is not. It is illegal to sell food that has been treated with a product not labeled for that crop. Nevertheless, such an experiment is very interesting, useful, and provocative.

Mr. Kelly sprayed the two types of kaolin products on two identical and neighboring blocks of his apple orchard. He sprayed weekly throughout much of the spring and summer, using an identical rate and frequency of each product in both blocks. The resulting data below clearly show that Surround WP protected apples better than the potters clay, although this can not be proven statistically. The yield of Grade 1 organic apples harvested from the Surround WP-treated trees was nearly double that harvested from the other trees. The apparent superiority of Surround WP is probably due to many reasons, but I would hypothesize that the main advantage is simply because Surround WP was developed and engineered as a plant protection product while potters clay was not. Surround particles have been designed and sized specifically to repel insects and to spray uniformly in concert with a very effective spreader-sticker.

Fruit Yield (lbs.) from Apple Trees Treated with Surround WP versus Potters Clay, Blue Heron Orchard, Canton, MO, Fall, 2000

	Surround WP	Potters Clay
Grade 1	22.3	12.3
Grade 2	5.5	8.1
Grade Cider	7.3	13.3
Total	35.1	33.7

Cost Benefit Analysis

One of the key components of any cost-benefit analysis is, of course, the cost of the product being evaluated. Surround WP is a very new product that is still rather difficult for many farmers to obtain economically. The standard retail price direct from the manufacturer is about $15.00 per 25 lb. bag plus an additional $2 or so shipping for large quantities ($17.00 total). One Missouri retailer is asking $31 per bag while Gardens Alive (Lawrenceburg, IN) is selling the same 25 lb. bag for $79.95 plus $15.35 shipping ($95.30 total). Gardens Alive also sells smaller bags at a substantially higher price per pound. Large commercial orchardists may be able to buy Surround WP by the pallet or truckload direct from the manufacturer.

According to Domoto (1995), most traditional Midwestern apple orchards will be sprayed about 15 times per season. The labor and machinery cost for this is estimated at $51.00 per acre per year. For maximum insect and disease control, Surround WP must be sprayed nearly as frequently, so no economic benefit is gained there. Costs for chemical insecticides and fungicides are estimated by Domoto (1995) at $345 per acre per year. Surround WP at $17 per 25 lb bag, if sprayed at the most effective, high rate of 50 lb/acre would cost approximately $510 per acre per year. The lower rate of 25 lb/acre would cost approximately $255 per acre per year. At $95.30 per bag (Gardens Alive) the cost of the higher rate is astronomical at $2,859 per year, while the lower rate would still be very expensive and uneconomical at $1,430. Many organic orchardists, however, might be more selective with such a product, carefully incorporating it as part of a total integrated pest management system, and possibly using less. For example, a farmer who carefully monitors insect levels in the orchard may spray Surround WP frequently and heavily to combat a target insect when it is most virulent, while spraying lower rates and/or less often when threats are reduced.

The purpose of our experiment and this report was not to speculate on the economics of organic versus chemical apple production in general. However, one can easily take the above figures of $345 (chemical), $510 (Surround WP high rate), and $255 (Surround WP low rate), assume a significant loss in Grade 1 apples for the organic farmer, but a substantial price increase for quality organic produce, and make a determination as to the potential economic benefit of using Surround WP. But probably the most important point to keep in mind is that an effective product such as Surround WP may be able to make the difference as to whether or not organic apple production is feasible (and economical) at all in the Midwest.

Reference

Domoto, Paul. 1995. Apple Orchard Establishment and Production Cost per Acre. Iowa State University Extension (unpublished).

Data Tables

Table 1. Mean percentage of fruits infested with plum curculio

Cultivar	Control	25Bi	25W	50Bi	50W*
2000					
Jonafree	71^a	37^b	31^b	6^c	16^{bc}
Liberty	65^a	20^b	20^b	21^b	15^b
2001					
Jonafree	46^a	46^a	6^b	13^b	4^b
Liberty	81^a	76^a	30^b	32^b	22^b

Table 2. Mean percentage of leaves damaged by red-banded leafroller, 2001

Cultivar	Control	25Bi	25W	50Bi	50W*
Jonafree	36^a	4^b	2^b	2^b	1^b
Liberty	32^a	5^b	2^b	2^b	1^b
Jonagold	22^a	4^b	1^b	1^b	1^b
Ultragold	24^a	3^b	2^b	3^b	1^b

Table 3. Mean percentage of fruits infested with flyspeck

Cultivar	Control	25Bi	25W	50Bi	50W*
2000					
Jonafree	91^{a}	51^{b}	45^{b}	55^{b}	28^{b}
Liberty	89^{a}	97^{a}	71^{a}	87^{a}	65^{a}
2001					
Jonafree	25^{a}	0^{b}	0^{b}	2^{b}	0^{b}
Liberty	29^{a}	19^{a}	15^{a}	7^{a}	4^{a}

Table 4. Mean percentage of leaves infested with cedar apple rust

Cultivar	Control	25Bi	25W	50Bi	50W*
2000					
Jonafree	40.7^{a}	10.7^{b}	6.0^{b}	1.7^{b}	5.0^{b}
Jonagold	5.0^{a}	1.5^{b}	2.5^{b}	2.0^{b}	2.7^{b}
Ultragold	2.5^{a}	2.7^{a}	4.0^{a}	2.3^{a}	2.5^{a}
2001					
Jonafree ‡	11.8^{a}	11.0^{a}	10.8^{a}	15.4^{a}	12.5^{a}
Jonagold	6.0^{b}	11.0^{ab}	7.0^{b}	17.0^{a}	7.3^{b}
Ultragold	15.5^{a}	13.0^{a}	11.0^{a}	8.0^{a}	12.0^{a}

‡ Mean of three late-summer samplings; no differences among any treatments in any sampling

Table 5. Mean percentage of leaves infested with Phoma leaf spot, 2001

Cultivar	Control	25Bi	25W	50Bi	50W*
Jonafree	19.0^{a}	2.7b	1.0^{b}	1.7^{b}	0^{b}
Liberty	19.7^{a}	2.0^{b}	2.0^{b}	3.7^{b}	1.3^{b}
Ultragold	23.0^{a}	9.0^{b}	9.5^{b}	9.7^{b}	4.0^{b}
Jonagold	14.0^{a}	5.5^{ab}	9.5^{ab}	2.5^{b}	5.3^{b}

Table 6. Mean percentage of Grade 1 fruits

Cultivar	Control	25Bi	25W	50Bi	50W*
2000					
Jonafree	0^b	2^b	4^b	4^b	19^a
Liberty	0^a	1^a	1^a	0^a	5^a
2001					
Jonafree	0^d	7^d	42^b	32^c	54^a
Liberty	0^b	0^b	13^a	20^a	21^a

* 25Bi = 25 lbs/acre Surround WP sprayed every two weeks
25W = 25 lbs/acre Surround WP sprayed weekly
50Bi = 50 lbs/acre Surround WP sprayed every two weeks
50W = 50 lbs/acre Surround WP sprayed weekly

a, b, c, d: Means in a row with similar superscripts are not significantly different (*P* # 0.05).

Table 7. Date and weather conditions recorded during nine Licor plant stress sampling sessions

Exp't. #	Date	Air Temp ^oF **	Conditions
4	July 20	101.2	hot, sunny, calm
5	July 31	97.4	hot, windy, partly cloudy
6	July 31	99.6	hot, windy, partly cloudy
7	Aug 3	99.7	hot, sunny
9	Aug 7	94.0	humid, hazy, overcast
10	Aug 7	99.4	humid, hazy, overcast
11	Aug 14	98.1	sunny, windy, thin clouds
12	Aug 14	101.0	sunny, windy, thin clouds
15	Aug 21	101.5	extremely hot, windy, dry

** Average air temperatures recorded by Licor machine during sampling period

Table 8. Plant Stress Data from Experiment 4, Jonafree and Liberty combined *

Treatment	Photo	Cond	Transp	Leaf Temp
Control	8.6^{b}	0.0405^{c}	2.39^{b}	38.4^{ab}
25Bi	11.6^{ab}	0.0559^{abc}	3.30^{ab}	39.2^{a}
25W	11.2^{ab}	0.0557^{ac}	3.24^{ab}	38.8^{a}
50Bi	15.3^{a}	0.0765^{a}	3.91^{a}	36.5^{b}
50W	14.7^{a}	0.0646^{ab}	3.68^{a}	39.0^{a}

Table 9. Plant Stress Data from Experiment 15, Jonagold and Ultragold combined **

Treatment	Photo	Cond	Transp	Leaf Temp
Control	3.9^{b}	0.030^{b}	1.35^{b}	40.1^{a}
25Bi	6.4^{a}	0.053^{a}	2.41^{a}	39.2^{ab}
25W	5.1^{ab}	0.050^{a}	2.15^{a}	37.8^{b}
50Bi	5.2^{ab}	0.061^{a}	2.76^{a}	39.4^{ab}
50W	6.1^{ab}	0.057^{a}	2.64^{a}	39.2^{ab}

*** Photo: net photosynthesis (♠CO_2 : Φmol CO_2 m^{-2} s^{-1})
Cond: stomatal conductance (mol H_2O m^{-2} s^{-1})
Transp: transpiration rate (Φmol H_2O m^{-2} s^{-1})
Leaf Temp: leaf temperature (^oC).

a, b, c: Means in a column with similar superscripts are not significantly different (*P* # 0.05).