Evaluation of Freeze Protection Methods for Strawberry Production in Florida

Bielinski M. Santos*[1], David N. Moore[1], Teresa P. Salame-Donoso[1], Craig D. Stanley[1], and Alicia J. Whidden[2]

[1]*University of Florida, IFAS, Gulf Coast Research and Education Center, 14625 CR 672, Wimauma, FL 33598*

[2]*University of Florida, IFAS, Hillsborough County Extension, 5339 South CR 579, Seffner, FL 33584*

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A study was conducted to compare the performance of freeze protection methods on strawberry (*Fragaria ×ananassa* Duch.) growth and yields. Treatments consisting of using: a) 4.5 gal/min sprinkler heads (control), b) 3.5 gal/min sprinkler heads, c) heavy row covers on the crop canopy (0.9 oz/yd²), d) heavy row covers on 1.5-ft high minitunnel hoops, e) light row covers on the crop canopy (0.6 oz/yd²), f) light row covers on 1.5-ft-high minitunnel hoops, and g) 16-ft high tunnels. The minimum air temperature without freeze protection practices in the field during the season was 21 °F, but the minimum temperature directly above the crop canopy was 34 °F in covered plots regardless of the cover weight and the use of hoops and 33 °F inside the high tunnels. No water was needed in plots with row covers and inside high tunnels, whereas approximately 39 acre-inch/acre of water were needed in the control plots. Using non-irrigation alternatives for freeze protection resulted in the highest early and total fruit weights, where total yields in plots treated with these non-irrigation alternatives ranged between 15.1 and 15.4 ton/acre while there was approximately a 20% fruit weight decline when sprinkler irrigation was utilized, regardless of the output volume.

A large share of the water volumes used for strawberry production is dedicated to freeze protection. High-volume sprinklers that deliver water on the crop canopy were generally used. The principle associated with this phenomenon is called "heat of fusion" and it is described as the heat released by water during the freezing process. Specifically, 0.035 oz of water releases 80 calories of heat energy as it forms ice. To obtain adequate freeze protection with sprinklers, the correct amount of water needs to be applied (Locascio et al., 1967). Because of the "evaporative cooling", another property of water, as 0.035 oz of water evaporates, 600 calories of heat energy are absorbed from the surrounding environment, thus when compared to the 80 calories released by freezing, more than 7.5 times more water must be freezing than evaporating to provide a net heating effect (Perry, 2001).

One of the main disadvantages of this freeze protection method is that during long, prolonged freezing periods, it could quickly deplete underground water sources (e.g., aquifers) of large water volumes that are shared with urban settlements around the strawberry operations, especially in the Plant City and Dover areas of Hillsborough County, Florida. One night of freeze protection with high volume sprinklers could utilize between 2 to 3 acre-inch/acre of water (1 acre-inch = 27,154 gal), which might translate into 460 to 690 million gal of water in the 8500 acres planted in that county (U.S. Department of Agriculture, 2011). Furthermore, during the unusually cold winters of the 2009-10 and 2010-11 seasons, when about 13 freezing and near freezing nights (≤34 °F) per season occurred, many local residents in those areas complained to county and state authorities about wells either temporarily or permanently drying and they attributed this situation of extensive water pumping for freeze protection in neighboring strawberry fields. In spite of the actual reasons for this occurrence, research is needed to compare the biological performance and economic feasibility of non-irrigation freeze protection alternatives, such as high tunnels and row covers with sprinkler irrigation.

The use of row covers, either covering rows individually or large areas of rows has been common for many years, particularly in northern climates to warm the microclimate around transplants or emerging seeds thus speeding up germination or transplant growth. Hochmuth et al. (2009) indicated that "although row covers are evolving as part of an overall system for enhancing growth and yield, much research is still needed to refine the components for Florida. One area needing additional study is frost protection of vegetables." Although it has been reported that the combination of row covers and overhead irrigation could be used for improving earliness and marketable yields in strawberry (Hochmuth et al., 1986), questions remain on the appropriate specifications (i.e., thickness) and placement of row covers on crop canopy and their relationship with cold protection.

High tunnels are structures utilized around the world to improve vegetable and fruit yield and quality, improve earliness and steady product supply, reduce water use and nutrient leaching for freeze protection, and ameliorate the incidence of pests. High tunnels are temporary, unheated, plastic-covered structures, with passive ventilation through roll-up side walls. Their height might vary from 5 to 20 ft. One of the limitations of these structures is their cost ($25,000 to 30,000/acre) which has limited their use. Salame et al. (2008) illustrated the advantages of high tunnels in Florida for strawberry production, where early and total yield increased by 35% and 57%, respectively, and no water was needed for

*Corresponding author; phone: (813) 634-0000; email: bmsantos@ufl.edu

freeze protection as long as high tunnel doors were closed 36 h before the forecast freeze. Anecdotal information from early 2011 indicated that about 5% of the growers used plant covers and high tunnels to protect their crops. Although these methods worked well, some growers incorporated irrigation with these methods and reported plant damage when plants were covered. The objective of this study was to compare the performance of freeze protection methods on strawberry growth and yields.

Materials and Methods

A field study was conducted in the 2010–2011 season at the Gulf Coast Research and Education Center of the University of Florida in Balm. The soil at the experimental site was a sandy, siliceous, hyperthermic Oxyaquic Alorthod with <1.5% organic matter and pH of 6.6. Prior to the experiment, the soil was tilled twice at an approximate depth of 8 inches to ensure proper soil structure. In late Aug. 2010, planting beds were formed using a standard bedder, which pressed beds 27 inches wide at the base, 24 inches wide on the top, and 8 inches high. Beds were spaced 4 ft apart from centers. Simultaneously with bedding, the soil was fumigated with 35 gal/acre of 1,3-dichloropropene + chloropicrin (65/35, v/v) in early September. Within 1 min after fumigation, a single drip tape line (0.23 gal/100 ft per minute, T-Tape Systems International, San Diego, CA) was buried 2 inches below the surface on bed centers and beds were covered with black high-density polyethylene mulch (0.025 mm thick, Intergro Co., Clearwater, FL). The experimental area was equipped with 4.5 gal/min sprinklers for freeze protection and transplant establishment.

Bare-root 'Strawberry Festival' transplants with three to five leaves from nurseries in Canada (Lareault Nursery, Lavaltrie, Quebec, Canada) were planted on 13 Oct. 2010. The transplants were set in double rows, and plants were 15 inches apart within each row. Double rows were separated 12 inches from each other. Each plot consisted of four 30-ft-long rows and about 190 plants. There was a 25-ft-long non-treated buffer zone at the end of each plot. Immediately after transplanting, overhead irrigation was turned on at 8 AM each morning for 8 h/day during the first 10 d to ensure plant establishment. An approximate volume of 20 acre-inch/acre of water was used during those 10 d to establish the transplants.

During crop establishment and growth, plant nutrients, other than S, were supplied starting at 1 week after transplanting (WAT) through the drip lines and were applied three times per week with a hydraulic injector (Dosatron, Clearwater, FL). Phosphorus (P) and Ca were not applied because the soil at the experimental site had sufficient concentrations of these nutrients (>250 ppm of P and >1000 lb/acre of Ca) as revealed by soil tests conducted one month before planting. Plant nutrients, such as N, K, Mg, Fe, Zn, B, and Mn were applied under non-limiting conditions following current fertilization practices for the crop. Recommendations for insect and disease control were also followed depending on pest pressure (Peres et al., 2009). Irrigation lines were pressurized at 10 psi. Irrigation volumes were equivalent to the average reference evapotranspiration for the area from October to March, and they were split equally into two daily irrigation cycles beginning at 8 AM and 1 PM, respectively (Simonne and Dukes, 2009).

Treatments consisted of: a) 4.5 gal/min sprinkler heads (control), b) 3.5 gal/min sprinkler heads, c) heavy row covers on the crop canopy (0.9 oz/yd^2; Agribon row cover, Environmental Green Products, Phoenix, OR), d) heavy row covers on 1.5-ft-high minitunnel hoops (Gardener's Supply Company, Burlington, VT), e) light row covers on the crop canopy (0.6 oz/yd^2), f) light row covers on 1.5-ft-high minitunnel hoops, and g) 16-ft high tunnels (Haygrove, Redbank, Ledbury, UK). Treatments were set up in a randomized complete-block design with three replications during each season. Row covers were placed on the crop between 12 and 3 PM on the afternoon of the forecast freezing night and they were held in place using 5-lb sand bags. The ends and sides of the high tunnels were closed approximately at 10 AM of the morning prior to a forecast freezing event. Sprinklers were turned on when air temperature at 4 ft above the surface reached 34 °F and they were turned off when ice on strawberry leaves melted. To avoid water overlapping of plots protected with different sprinkler outputs, plots were separated at least 25 ft apart from each other.

Actively growing plants were counted on 6 Jan. and 25 Feb. 2011 and water use was estimated based on the sprinkler output and the length of irrigation time. Data loggers (HOBO data loggers, Onset Corp., Bourne, MA) were used to monitor maximum and minimum temperatures between 6 to 10 inches above and below the row covers, as well as inside high tunnels and in open field conditions (2 ft above ground). Marketable strawberry fruit with the calyxes attached were harvested twice per week and the weight was recorded for 24 harvests during the season starting in early Dec. 2010. A marketable fruit was defined as one over 0.35 oz in weight and physiologically mature with more than 80% of fruit dark red, free of mechanical defects and insects or disease injury. Early and total marketable fruit weight comprised the first 10 and 24 harvests, respectively. Fruit were harvested Mondays and Thursdays of each week for 12 weeks. Data were analyzed using general linear model ($P < 0.05$) and treatment values were separated using Fisher's protected least significant difference tests (Statistix Analytical Software, version 9, Tallahassee, FL).

Results and Discussion

During the 2010–11 strawberry season, there were 14 freezing and near freezing nights (≤34 °F) at the experimental site from early Dec. 2010 to late Feb. 2011, which required turning the sprinkler irrigation system on in the open fields, except where row covered plots were located. The minimum air temperature in non-irrigated areas during the season was 21 °F. In covered plots, the minimum temperature directly above the crop canopy was 34 °F, regardless of the cover weight and the use of hoops to raise the covers above the canopy (Table 1). Inside the high tunnels, the minimum seasonal temperature above the strawberry canopy was 33 °F. This indicated that row covers and high tunnels could warm up the air around the crop canopy up to 13 °F. With regards to water volumes needed for freeze protection, no water was needed in plots with row covers and inside high tunnels, whereas approximately 39 acre-inch/acre were used in the control plots (4.5 gal/min sprinklers) to protect the crop, which was 9 acre-inch/acre higher (23% more water) than in the plots protected with sprinklers delivering 3.5 gal/min.

There was a significant effect of freeze protection methods on early and total marketable fruit weight, but not on the plant numbers during the growing season (Table 1). The highest early marketable fruit weights were obtained in plots protected with row covers, regardless of cover weight or hoops, and inside the high tunnels, averaging 3.8 ton/acre. These values were 19% higher than those obtained in plots protected with either sprinkler irrigation treatment, which averaged 3.2 ton/acre. Using non-irrigation alternatives for freeze protection resulted in the highest total marketable fruit weights at the end of the strawberry

Table 1. Effects of freeze protection methods on the minimum seasonal air temperatures in each treatment, water use, and strawberry plant number, and early and total marketable fruit weight, Balm, FL, 2010–2011.

Freeze protection methods	Plant no. (no./acre)		Fruit wt (ton/acre)		Min. air temp	Water use
	Jan. 6	Feb. 25	Early	Total	(°F)	(acre-inch/acre)
4.5 gal/min sprinklers (control)	17243	17152	3.2 b	12.1 b	21	39
3.5 gal/min sprinklers	16970	16970	3.2 b	12.2 b	21	30
Heavy row covers on canopy	17333	17333	3.7 a	15.2 a	34	0
Heavy row covers on hoops	17061	16880	3.7 a	15.3 a	34	0
Light row covers on canopy	17333	17243	3.8 a	15.4 a	34	0
Light row covers on hoops	17061	16970	3.8 a	15.2 a	34	0
High tunnels	17424	17424	3.9 a	15.1 a	33	0
Significance ($P < 0.05$)	NS	NS	*	*	---	---

[z]Minimum air temperatures in the high tunnels and in the row covered plots were taken 6 inches above plant canopies, whereas the temperatures in the sprinkler-treated plots were the air temperatures without irrigation.

[NS, *]Nonsignificant or significant at $P < 0.05$, respectively. Values followed by the same letter do not differ according to Fisher's-protected least significant difference at the 5% level.

season. The total yields in plots treated with these alternatives ranged between 15.1 and 15.4 ton/acre. However, there was approximately a 20% fruit weight decline when sprinkler irrigation was utilized, regardless of the output volume (Table 1).

These results could be due to the water damage caused to flowers and on the skin of young and mature fruit mainly due to two reasons: a) the impact of high velocity droplets on these plant organs, and b) the effect of ice formation on the surface of fruit and recently-pollinated flowers. More research is needed to reassess the effects of these freeze protection methods in consecutive seasons and to determine the economic feasibility of these alternatives.

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