A Survey of the Effectiveness of Current Methods Used for the Freeze Protection of Vegetables in South Florida

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Additional index words. chilling damage, weather stress, cover, seepage, solid set irrigation

Florida ranks second nationally in fresh market vegetable production with 192,600 acres planted with a value of $1.4 billion in 2008–09. Seventy percent are grown in southern Florida with a harvest season from October to June during which growers may have to deal with hurricanes, droughts, and extremes in temperature. The objective of this survey was to document the effectiveness of current freeze protection methods for vegetables grown in southern Florida. During the 2009–10 season, freezing temperatures were recorded on 11 to 13 Jan. in Collier, on 10 and 11 Jan. in Miami-Dade, and on 13 Jan. 2010 in Palm Beach County. Adding to the problems caused by the freeze(s), the season was atypically cold, which slowed or precluded recovery of many crops. Losses and damage crops (acres/year) included: 0 to 35% and 0 to 100% (Southwest Florida), 60% to 90% and 5% to 10% (Miami-Dade) and 0 to 30% and 24% to 70% (Palm Beach County), respectively. The most common method of freeze protection was elevated water tables. In all counties, there was limited use of row cover/hoops, Styrofoam cups, compost, soil and hay cover, tissue paper, chemical treatments, solid set irrigation, helicopter flights and hill cultivation. The effectiveness of current freeze control methods provided poor to fair protection in Southwest Florida and Miami-Dade, but fair to good protection in Palm Beach County.

Florida's fresh vegetable market season is from October to June with the greatest production from November to January and April to May (Ozores-Hampton et al., 2007). The vegetable industry experiences occasional extreme weather events, especially hurricanes and freezes (Hansen et al., 1999). Frost refers to the condition that exists when air temperatures drop to the freezing point of water (32 °F), or lower, but which may or may not result in freeze damage to crops (Bootsma and Murray, 2009). Vegetable growers can potentially suffer losses due to chilling stress or frost/freeze from November to January when vegetables are at various stages of development (Hansen et al., 1999). The National Weather Service Office in Miami-Dade reported that the most probable time period for frosts and/or freezes in southern Florida is 1 Dec.–15 Mar. with a cold event likely to occur somewhere in the area on a biennial basis (R. Pfost and R. Biedinger, personal communications). These weather events are difficult to predict, but damage to the vegetable industry can be severe. An unanticipated freeze that occurred on 19 Jan. 1997, for example, caused $200 million damage to Florida's winter vegetable industry and displaced thousands of migrant workers (Sharp, 1997). During the 2009–10 season, a long stretch of cold weather affected southern Florida between 4 and 13 Jan. 2010. Freezing temperatures were recorded 11 to 13 Jan., destroying an estimated 30% to 40% of round plums, cherry and grape tomatoes (*Lycopersicon esculentum* L.) for important production areas such as Collier, Palm Beach, and Dade counties (Layden, 2010). For the 4 months starting 1 Jan. and ending 30 Apr. 2010, average temperatures were below those for the same period in the preceding 5 years. There were a total of 82, 83, and 85 d with average temperatures below "normal" as compared to the 5 preceding years in Belle Glade, Homestead, and Immokalee, respectively (FAWN database, accessed June 2010).

The majority of the vegetables grown in southern Florida are chilling sensitive crops species such as tomato, bean (*Phaseolus vulgaris* L.), cucumber (*Cucumis sativus* L.), and bell pepper (*Capsicum frutescans* L.), etc. Chilling sensitive plants are not able to tolerate freezing of tissue water and are damaged at 32 to 30.2 °F and killed by temperatures of 30.2 to 26.6 °F (Bootsma and Murray, 2009). Chilling stress can result from temperatures between 32 to 50° F and has the potential to injure (even kill crops depending on chilling intensity) through physiological dysfunctions, leading to slow growth and development, resulting in low yield, delayed maturity and harvest with poor quality produce (Li, 1993). In tomatoes, 5–6 d of chilling stress (37.4/39.2 °F) at anthesis can result in poor fruit quality (Li, 1993).

Protecting plants with frost/freeze methods can modify the environment around the plant, favorably resulting in more rapid growth, earlier maturity, and possibly increased yields as compared with no protection (Hochmuth et at., 2009). Success and the efficacy of frost/freeze protection depend on several factors such as type of frost/freeze event, radiational or advective. In general, interventions are more likely to be effective in a radiational event vs. an advective one. Radiation freezes are characterized by clear skies with dry air (Bootsma and Brown, 2009). Often the day was

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Table 1. Weather conditions noting deviations from the previous 5 years for the period from 1 Jan. to 30 Apr. 2010, including minimum temperatures the week of 10–16 Jan. 2010, by FAWN station location.

	1 Jan.–30 Apr. 2010			Minimum temp
Location/county	No. days with below avg temps at 60 cm	No. days with below avg minimum temps at 60 cm	No. days with below avg dew points at 2 m	[total duration (hrs) ≤32 °F], week of 10–16 Jan. 2010
Belle Glade (Palm Beach)	82	76	61	29.7 (5 h – 1 night)
Homestead (Miami-Dade)	83	78	67	31.0 (7 h – 1 night)
Immokalee (Collier)	85	69	60	25.7 (27 h over 3 nights)

warm and pleasant when the sun was out. After sundown there was no mixing of the air and temperatures fall rapidly until reaching the dew point, past which the temperature drop will slow as water is condensed out of the air as frost. A generally accepted rule of thumb is that the temperature can fall around 20 °F from that at sunset. Even the passage of a few clouds will raise the temperature and reduce damage. Advective freezes occur when a large, dry, cold air mass, several thousand feet thick, moves into an area with windy conditions (Bootsma and Murray, 2009). When this occurs, the air temperature was often colder than the plant temperature. Under such conditions, site location, as well as many frost protection systems, were of little benefit. Therefore, the objective of this study was to describe the effectiveness of the current frost/freeze protection methods during a frost/freeze event in southern Florida.

Materials and Methods

A formal and informal survey was conducted 2 to 8 weeks after the freeze on 11 to 13 Jan. 2010 in Collier, Hendry, Lee, Glades, Charlotte, Palm Beach, and Miami-Dade counties. The survey questionnaires included questions on lost and damaged acreage by crops, freeze protection methods used during the freeze event, cost per acre, and the effectiveness of the methods by crop and plant developmental stages. The survey was conducted in person, phone, and e-mail. At least 60% of the vegetable acreage in all counties were covered in the survey. Temperatures were obtained at the 24 inches above soil level from the Florida Automated Weather Network (FAWN) for all the counties.

Results and Discussion

The persistent cold weather, day and night, had pre-chilled the ground and the cold damage to the vegetables was the hardest on the morning of the last day of the period, which was 11 Jan. 2010 for Collier and Miami-Dade, and 13 Jan. 2010 for Palm Beach County. Table 1 lists the number of days that average and minimum daily temperatures were lower than in the previous 5 years and also the lowest temperature reached during the Jan. 2010 freeze(s) and the number of hours at or below freezing temperatures as recorded by the FAWN during the week before and after the frost/freeze event. The FAWN site for Immokalee recorded 27 h at or below 32 °F over a 4-d period starting on 10 Jan. 2010. The Southwest Florida area acreage losses were 0 to 35% and 0 to 100% acreage damage, based on total vegetable production for the year, respectively (Table 2). At the FAWN site in Homestead, there were 7–8 h at or below 32 °F. The Homestead area acreage losses were 60% to 90% and 5% to 10% acreage damage (Table 2). In Palm Beach County, there were 5 h lower than 32 °F. According to FAWN, the coldest temperatures were 25.7 (Immokalee), 31.0 (Miami-Dade), and 29.7 °F (Belle Glade) (Table 1).

Table 2. South Florida percentages of total acres lost or damaged by county and vegetable crop during the freezes from 11 to 13 Jan. 2010 (as a percentage of the yearly total).

Crop	Total acres (total no.)	Acreage loss (%)	Acreage damage (%)
Collier, Hendry, Lee, Charlotte, Glades counties			
Tomato, round	20,000	15	15
Bell pepper	7,000	20	20
Hot pepper	3,500	15	15
Squash and zucchini	2,500	25	5
Potatoes	4,500	0	100
Bush beans	13,000	30	0
Sweet corn	3,000	30	0
Cucumbers	1,500	25	5
Watermelon	13,000	10	20
Cantaloupe	2,000	NP	NP
Eggplant	1,200	35	5
Misc. vegetables	7,500	5	15
Total	78,700	0–35	0–100
Miami-Dade County			
Tomato, round	2,267	90	10
Tomato, grape/cherry	1,133	90	10
Bush and pole beans	20,300	60	0
Squash (all)	5,000	60	0
Sweet corn	2,610	90	10
Boniato (sweetpotato)	3,000	60	5
Total	32,585	60–90	0–10
Palm Beach County			
Pepper	5,000	0	70
Sweet corn	40,000	29	44
Leafy greens	10,000	26	60
Celery	2,500	26	62
Radish	10,000	30	70
Tomato	2,000	27	63
Chinese vegetables	1,500	23	70
Basil	100	43	43
Squash	2,000	18	27
Cucumbers	3,000	16	24
Total	76,100	0–30	24–70

Damage to crops with no freeze control methods applied ranged from none (cool weather leafy greens) to complete loss depending on the crop (Table 3). The primarily reason for crop losses and damage was that the majority of the vegetables growing in South Florida were chilling sensitive warm-season crop species such as tomato (Fig. 1), bell peppers, bean, cucumber, squash, and eggplants, etc. Chilling sensitive plants were not able to tolerate freezing of water tissue and were killed by a 30.2 to 26.6 °F frost (Li, 1993). Chilling stress can result from tempera-

Table 3. Southwest Florida, Miami-Dade and Palm Beach Counties (Rating: Very good, Good, Fair, Poor, and Not acceptable).

Freeze control method	County	Plant development (weeks)	Rate/acre	Cost/acre ($)	Rating	Comments
			Tomatoes, round and grape			
Nothing	All	All ages	n/a	None	Not acceptable to poor	Variable results; some plants survived & some did not.
Elevated water tables damage to 8” (seepage)	All except Miami-Dade	All ages	n/a	6	Fair to good	5% to 10% mortality on younger crops <10 inches tall, more in older ages, works best with temperatures of 29 °F or above.
Elevated water tables and drip or drip alone	All, except Miami-Dade	All ages	n/a	15	Poor	50% to 100% mortality (*Erwinia* problems), more problems old ages
Solid set irrigation	Miami-Dade County only	All ages	0.1”/hr	75/night	Variable from poor to fair	Variable, depending on when irrigation was turned on and disease incidence in crop. After freeze initial appearance was good, but crops did not set for older fields.
Row cover (0.5 oz)	All except Miami-Dade	All ages	Depends on row spacing	1200	Good–very good	Better in older crops, burn areas in contact with the crop, less protection and difficult to use in windy conditions, heavier thickness gives more protection at lower temperature, rain proceeding freeze can reduce protection/efficacy.
Styrofoam coffee cups 16 oz)/takeout boxes/ nursery pots (1 gal)	All	2–3 weeks old	3500 cups/acre	300	Very good	Cups can fly away with wind.
Compost	Collier	2–3 wks old	2 lb/plant	120	Good	Removed by hand and increased bacterial spot.
Paper and soil	Hendry	2–4 wks	1 sheet/plant	80	Very good	Application by hand, good to 24 °F or lower.
Chemical (Copper, Vapor Gard Chemitrol, Crop Life, Freeze Prove)	All	All ages	Label	30–50	Poor	May help reduce effects of desiccating cold winds.
			Bell peppers and hot peppers			
Nothing	All	All ages	n/a	None	Not acceptable to poor	Variable results; some plants survived & some did not.
Elevated water tables tables to 8” (seepage)	All, except Miami-Dade	All ages	n/a	6	Fair	More damage old ages, burn leaves but not crown.
Elevated water tables and drip or drip alone	All, except Miami-Dade	All ages	n/a	15	Poor	More damage old ages, burn leaves but not crown.
Hay	Collier	All ages	10–12 Bales/acre	100–150	Fair	Hay & equipment available for application, burn leaves but not crown
Row cover with hoops (0.5 oz)	All except Miami-Dade	All ages	Depends on row spacing	1200	Very good	Burn areas in contact with crop, less effective in windy advective freezes or extended duration of prolonged cold or heavy rains.
			Eggplants			
Nothing	All	All ages	n/a	None	Not acceptable to poor	Variable results; some plants survived & some did not.
Elevated water tables to 8” (seepage)	All except Dade	All ages	n/a	6	Fair	More problems old ages, burn the tops. Less tolerant of cold than peppers & tomatoes; eggplants damaged severely at 28 °F or below.
Elevated water tables and drip or drip alone	All except Dade	All ages	n/a	15	Poor	More problems old ages, burn the tops
Copper	Collier and Hendry	All ages	Label	30	Poor	May help prevent/reduce frost formation at temps above freezing
Paper and soil	Hendry	<12” (no stakes)	1 sheet/plant	80	Very good	Application by hand – very labor intensive

Table 3 continued on next page.

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Freeze control method	County	Plant development (weeks)	Rate/acre	Cost/acre ($)	Rating	Comments
			Bush beans			
Nothing	All	All ages	n/a	None	Not acceptable	Plants died
Elevated water tables to 8" (seepage)	All except Miami-Dade	All ages	n/a	6	Fair to good depending on size, best on smaller plants	More problems in older ages, where the tops burnt, best in marginal freeze and frost events, less effective below 28 °F and extended periods of cold/windy weather accompanying freeze.
Solid set irrigation	Miami-Dade only	Up to bloom	0.1"/hr	75/acre/night	poor	Initially look good, but didn't set and had high incidence of disease.
Helicopter flights	Palm Beach only	All ages	Variable	83	Good	Only works at quiet nights when radiation chilling occurs.
			Squash and zucchini			
Nothing	All	All ages	n/a	None	Non-acceptable	Plants died
Elevated water tables to 8" (seepage)	All, except Miami-Dade	All ages	n/a	6	Fair to good	More problems old ages, burnt leaves, helps with frost mild freeze.
Solid set irrigation	Miami-Dade only	Young: ~6 wks	0.1"hr	75/acre/night	Poor	Did not live up to expectations; high incidence of disease, and poor fruit set.
Styrofoam coffee cups, takeout boxes for larger plants (16 oz)	Collier and Hendry	<3 wks old	3500 cups/acre	300	Very good	Cups can fly away with wind – can cover with soil to reduce wind and increase protection.
Compost	Collier	<3 wks old	2 lb/plant	120	Good	Remover by hand and increased *Fusarium* and *Pythium*.
Hay	Collier	All ages	10-12 Bales/acre	120 plus labor	Good	Hay and equipment available for application, the thicker the better.
			Sweet corn (Zea mays L.)			
Nothing	All	All ages	n/a	None	Non-acceptable	Plants died
Elevated water tables to 8" (seepage)	All, except Dade	All ages	n/a	6	Fair	Best for young plants, works with marginal events only.
Cultivation hilling	Palm Beach only	Young & below knee high	n/a	10	Good	Works better for young corns that the growth point is low enough for the hilling soil to cover.
Helicopter flights	Palm Beach only	All ages	Variable	83	Good	Only works on quiet nights when radiation chilling occurs.
			Leafy greens			
Nothing	All	All ages	n/a	None	Very good	Not affected by the weather
Elevated water tables to 8" (seepage)	All, except Dade	All ages	n/a	6	Very good	Not affected by the weather. Leafy greens cold resistant to 32–33 °F.
			Basil			
Nothing	All	All ages	n/a	None	Non-acceptable	Plants died.
Elevated water tables to 8" (seepage)	All, except Dade	All ages	n/a	6	Poor	Plants died.
Row cover and hoops (0.5 oz) tunnels	All except Dade	All ages	Depends on the row spacing	1200	Very good	Burn areas in contact with the crop & less effective in windy advective freezes or extended duration of prolonged cold or heavy rains.
Copper	All except Dade	All ages	Label	30	Poor	Plants died.

Fig. 1. Aerial view of tomato damage in Immokalee, Collier County. Photo: Philip Stansly.

tures between 32 to 50 °F and have the potential to injure (even kill crops depending on chilling intensity) through physiological dysfunctions, retarded growth and development, resulting in low yield, delayed maturity and harvest with poor quality produce (Li, 1993). In some cases, the lower portion of the plant may survive (crown), but not upper parts on crops such as peppers and eggplants. Some fields had scattered surviving plants, but would have needed to have had existing fruit removed along with dead tissue, practices that would be cost prohibitive.

Elevated water tables to 8 inches were the most common under seepage irrigation and least expensive freeze protection method in all counties in South Florida, except Miami-Dade where it cannot be used due to the lack of a perched water table. Seepage irrigation was possible in most of southern Florida because vertical water movement was decreased by an impervious Spodic layer at an average depth of 3 ft resulting in a perched water table (Ozores-Hampton et al., 2009). Elevated water tables were the least effective method and the lower of the water volume applied (such as drip) the less protection was obtained for most of the crops, except leafy greens (Table 3). In general, application of water provided only a few degrees of protection and was less effective the lower the temperature and the longer the duration of the freezing temperatures. Elevated water tables and drip or drip alone performed best with frost and marginal freezes. This method works best with temperatures of 29 °F or above, for all crops and developmental stages, except in a sensitive crop such as basil (*Ocimum basilicum* L.), damaged at 38 °F or below.

Many tomato and a few bean and squash growers used overhead or solid set irrigation in Miami-Dade County (Table 3). This method employed a high volume solid-set irrigation system with a water delivery rate of 0.1 inch per hour. It was commonly used from December to February (Li et al., 2009a, 2009b; USDA, 1993). The cost was approximately $75 per acre per night of use. The use of overhead sprinkler irrigation for frost protection could carry a risk of doing more damage than the frost might otherwise do (Parsons et al., 1985). The principle of sprinkler freeze protection was that relatively warm water gives up heat upon contact with the colder air and/or foliage. When the temperature dropped to or below freezing, the water froze and released the heat of fusion to the leaves and fruit. Sprinkler irrigation should be started before the temperature dropped to freezing and run until the ice melted the next morning. It was also important that sufficient water be used for clear, rather than cloudy, ice to be formed. Particular attention must be given to the predicted dew point temperature. If the predicted dew point was 5 °F below the anticipated low temperature, sprinkler irrigation would cause evaporative cooling and aggravate the cold injury rather than prevent it (Parsons et al., 1985). This was particularly true under advection freeze conditions. Tomato growers were reluctant to water plants that had already been exposed to bacterial pathogens as a result of heavy rainfall in December, so some may have delayed the time at which pumps were started. There were actually two points at which temperatures fell to or below freezing, between 9 and 11 PM on 10 Jan. and starting at 2 AM on 11 Jan. 2010. In general, tomatoes, beans, and squash had reduced yields because the irrigation used for cold protection increased the incidence of disease (M. Lamberts, personal communication).

Covers have been shown to be most effective and the thicker grades provide the most protection (Hochmuth et al., 2009; Parsons et al., 1985; Wells and Loy, 1885). Covers were used in Collier and Palm Beach in tomatoes, peppers, and basil (Fig. 2). Row covers were prone to be blown by the wind and soaked by the rains, which often preceded cold fronts, and were then pushed onto plants, reducing the level of protection. They were also the most expensive at about $1200/acre (Table 3). Basil was a crop very sensitive to cold damage below 38 °F. In Palm Beach County, some basil growers were able to protect basil from cold damage using low tunnels, at temperatures as low as 35 °F during the Jan. 2010 cold weather, whereas unprotected basil had 80% to 100% losses (D. Sui, personal communication).

Innovative systems for protecting crops from freezes include covering individual young plants (less than 3 weeks old) such as tomatoes, eggplants (*Solanum melongena* L.), and squash (*Cucurbita pepo* L.) with Styrofoam cups, nursery pots, paper, and/or soil and compost, which provided a good to very good degree of protection (Table 3). This winter, these methods proved to be effective to temperatures as low as 24 °F with freezing temperatures for 8 h or more (G. McAvoy, personal communication). All were laborious to apply and removal cost ranged from $80 to $300/acre. In addition, the Styrofoam cups or pots could be blown away if not capped with soil (Fig. 3).

Chemical freeze control methods were used in all counties on tomatoes and bell peppers because it was an attractive method with relatively low cost of $30–$50/acre and ease of application (Table 3). Hundreds of chemical products such as growth regulators, root stimulator, bio-catalyst, copper-based fungicides (acts as

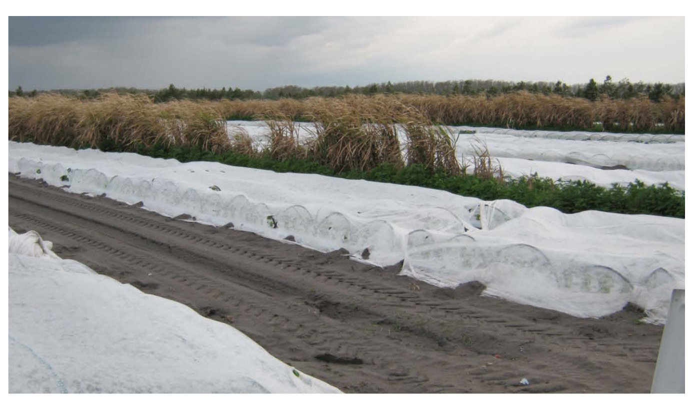

Fig. 2. Row covers and hoops (0.5 oz thick) or low tunnels protecting basil in Hendry County. Photo: Monica Ozores-Hampton.

Fig. 3. Styrofoam coffee cups (16 oz) protecting young tomato plants (3 weeks or less) in Immokalee, Collier County. Photo: Philip Stansly.

an anti-nucleating agent through its effect on nucleating bacteria), potassium (liquid form of potassium silicate), anti-transpirant (latex and acrylic-based creates a coating of protection), heat generating chemicals (tri-sodium phosphate and tri-sodium chloride), and oils have been used to increase cold hardiness of vegetable crops. Copper was the most popular chemical across vegetable crops. These chemicals have been claimed to have the potential to provide freeze protection and prevent crop damage by unknown modes of action and some may help reduce desiccation from cold winds. However, inconsistent results over the last decades have precluded the widespread use of chemical frost protection; and growers should be cautious about believing the promotional claims of these materials. The majority of these products need to be sprayed days or weeks in advance of freezing. Also, when heavy rains follow the application, the product was washed off and it became ineffective unless reapplied.

Helicopters were used only in beans and sweet corn in Palm Beach. The helicopters were most effective against radiation chilling by hovering or passing over the site at slow speeds (5 to 10 mph). However, helicopters must still be able to return over a portion of a site about every 5 to 6 min before air stratification re-occurred. The use of helicopters was a high-cost method of freeze protection, currently costing over $800 to $1200 per hour or $83 per acre.

In conclusion, all methods had limits: the colder the temperatures and the longer the duration, the more potential for crop damage. There was a number of promising methods that resulted in good and very good freeze protection that need to be studied in the near future. The best, though not necessarily the least expensive, method of freeze protection was the use of some form of covers.

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