Improving the Precision of Blueberry Frost Protection Irrigation[1]

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Figure 1. Blueberries from a Central Florida hobby farm (Source: Sally Lanigan, UF/IFAS)

Highlights

- This study estimates the potential diesel cost savings and water savings associated with precision cold protection irrigation for blueberry when the irrigation decision accounts for cold hardiness at different blooming stages.
- Precision cold protection irrigation is employed at critical temperatures (32°F and below), depending on the blueberry blooming stage. In practice, growers often follow a uniform strategy, initiating the irrigation systems at 31°F–35°F, with limited consideration of the blueberry blooming stage, to minimize the risk of losing yield and irrigation system freezing due to cold weather.
- For six production seasons (2009–2015) with growers in Alachua, Marion, Hillsborough, and Polk Counties, the number and duration of cold weather events that required cold protection irrigation were much higher given the uniform strategy, compared with the precision strategy, which translates into significant difference in pumping costs and water use.

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- The difference between the uniform and precision irrigation strategies was especially significant in northern counties, but it was noticeable for the southern counties as well.
- For six production seasons (2009–2015), the average estimated difference in water pumping costs for precision and uniform strategies was $515 per pump for growers in Alachua, and $170 per pump for the growers in Hillsborough and Polk Counties, respectively (or $15.8 and $8.5 per acre).
- There was also a significant difference between the volumes of water pumped for cold protection given precision and uniform practices. The estimated average water savings are 120 and 65 thousand gallons per acre per season for the growers in Northern (Alachua and Marion) and Central Florida (Hillsborough and Polk Counties), respectively. If the water is valued at $4 per thousand gallons (average residential water rate for customers using 8 thousand gallons per month), the value of the water use reduction is $481/acre and $259/acre, respectively.

Blueberry Production in Florida Is Growing in Importance

Florida's early-ripening southern highbush blueberry cultivars form the basis for potentially lucrative enterprises for Florida growers, allowing them to take advantage of an early market before other states can compete with higher volumes of berries sold at lower prices. During the months of April and May, Florida is the main supplier of blueberries in the United States (Williamson and Crane 2010; Williamson et al. 2012; Williamson et al. 2014). Because of the market advantage of these early-blooming and early-ripening cultivars grown in Florida, the acreage dedicated to blueberry production has increased significantly. From 2007 to 2012, the number of farms with harvested blueberry crops increased by 87 percent (from 442 to 825 farms), while the harvested acreage increased by 160 percent (from 2,376 to 6,179 acres) (USDA 2012a). By 2012, the production value for Florida blueberries had increased to $62 million (USDA 2012b).

Four counties had especially significant harvested blueberry acreage (USDA 2012a): Alachua and Marion (northern Florida), and Polk and Hillsborough (southern Florida). These counties provided the focal point for this study. Because blueberries grown in central and south Florida usually bloom about a week or 10 days before the berries in north Florida, the distinction between the two regions is economically important.

Potential Money Savings for Improved Precision in Cold Protection Irrigation

Even with Florida's generally warm climate, Florida's blueberries require frost and freeze protection to ensure that cold temperatures do not damage the buds, flowers, and young fruit, thus reducing marketable yields. The traditional practice is to use overhead sprinkler irrigation to reduce the effect of the cold air temperature on sensitive plant organs (Figure 2). More information on frost and freeze protection can be found by reading EDIS publication HS216 [Protecting Blueberries from Freezes in Florida] (Williamson et al. 2004). Researchers differentiate frost and freeze events (Perry 2001), but in this publication, we refer to both events as "cold weather."

An example of one practice that saves growers money on production and reduces per-acre water withdrawals is adjusting the cold protection irrigation to match cold

Figure 2. Cold protection at a private blueberry farm in Alachua County, Florida (Source: Thomas Wright, UF/IFAS)

hardiness for different blooming stages. We refer to this practice as the "precision cold protection irrigation scenario" (or just "precision scenario"). In this study, this practice is compared with the "uniform cold protection irrigation scenario" (or just "uniform scenario"), when the irrigation is applied without considering the cold hardiness for various blooming stages. The objective of this study is to estimate the potential savings in diesel costs and water withdrawal volumes associated with precision cold protection as compared with the uniform scenario.

Critical Air Temperatures during Blueberry Blooming

Existing research shows that the critical temperature depends on bud and flowering stages (also referred to as phenological stages of blueberry during bloom; Figure 3). The temperature can also depend on the blueberry cultivar. For example, EDIS publication HS216 [Protecting Blueberries from Freezes in Florida] (Williamson et al. 2004) summarizes past studies (i.e., Gerber and Martsolf 1965; Spiers 1978) and states that for rabbiteye cultivars, the critical temperature ranges from 25°F for swollen flower buds to 28°F and even higher for fully opened flowers. Similarly, Michigan State University (MSU 2012) and Longstroth (2012) discuss bud swell and tight cluster stages as being relatively cold-resistant, and petal fall/green fruit stage being the most cold-sensitive, even though these studies do not specify the blueberry cultivar or the research methods used to establish the critical temperatures.

Figure 3. Stages of blueberry blooming (Source: Elizabeth Conlan, Mercy Olmstead, and Jeffrey Williamson, UF/IFAS)

Given significant need for information to assist Florida producers with frost protection decisions, UF researchers are currently conducting laboratory experiments to evaluate the hardiness of southern highbush blueberry cultivars, which are typically grown in Florida. However, until this research is completed, Williamson et al. (2004), MSU (2012), and Longstroth (2012) are used as the general guidance for precision cold protection irrigation scenario.

Cold Protection Irrigation Practices Used by Growers

Informal discussions with several Florida blueberry growers and Extension experts revealed that growers typically initiate their irrigation systems between air temperatures of 31°F–35°F, especially during full-bloom and green-fruit stages. Turning the irrigation system on at temperatures above freezing can be warranted. For example, there is a brief initial *reduction* in temperature when the cold protection irrigation system is turned on and the plant becomes wet (due to evaporative cooling) (Bucklin and Haman 2013). Also, during cold and calm nights with no clouds, there may be pockets of cold air in lower-lying areas, or cold air may be trapped close to the ground (radiation freeze), potentially cooling the plants to temperatures below the temperatures reported by weather stations. Producers can also turn the irrigation system on at temperatures above 32°F to prevent the irrigation system from freezing later during the cold night. Growers are also aware of different cold tolerances at different blooming and post-blooming stages. However, several blooming stages can be observed on blueberry plants at the same time, making the cold protection irrigation decision more complex. Topography also affects the temperature in different farm locations, and these differences in temperature results in irrigating the whole farm to protect the most susceptible areas.

As can be seen from this discussion, the decision to turn the cold protection irrigation system on is usually based on past experiences of the producers (it is more art than science). There is also one common theme that arises when speaking with growers about their reasons for turning the irrigation systems on at specific temperatures: the risk of losing yield to a cold weather event. Growers would rather initiate their irrigation at a higher temperature to ensure that they will not wait too long and experience an unexpected temperature drop to dangerous levels.

Comparing Uniform and Precison Cold Protection Irrigation

Blueberries in the northern and southern counties of Florida are susceptible to cold weather damage at slightly different calendar periods due to differences in blooming times, but generally, the months of January, February, and March are the most important for cold protection. Most of March typically comprises the post-bloom period when cold protection is needed to protect young fruits. In this study, for the northern counties (Alachua and Marion), January 30th to February 25th are used as the blooming stage, and for the southern counties (Polk and Hillsborough), January 10th to February 5th are used as the blooming stage. These periods are divided into five equal intervals to approximately represent the transition between bud stages (Table 1).

Table 2 summarizes temperatures considered critical for turning on cold protection irrigation. To represent the uniform cold protection irrigation scenario, we consider periods with the average hourly air temperature of less than 33°F (32°F and below) as critical, for all phenological stages of blooming and post-blooming. In turn, while additional research is needed to provide recommendations given blueberry cultivars and production conditions specific for Florida, the Michigan State University publication is used as a general guidance for the precision cold protection irrigation scenario. Note that the critical temperatures are generally lower for the precision scenario (except post-blooming stage), implying that this strategy can lower water use and pumping costs in comparison with the uniform scenario.

For both precision and uniform scenarios, we assume that cold protection is applied only given a wind speed of less than 10 to 12 miles per hour (Williamson et al. 2004). Finally, once the irrigation system is turned on, we assume that it stays on until the *wet bulb* temperature rises to 33°F (Jackson et al. undated; Harrison et al. 1972).

The air temperatures for each year and each county with significant blueberry acreage were collected from the Florida Automated Weather Network (FAWN) online database (FAWN 2015). For each county, weather information was downloaded for one weather station, and the average hourly air temperature records measured at 60 cm (or approximately 2 feet) height were used. We also examined average hourly wind speed (measured at 10 meters or approximately 33 feet, since this data were readily available from FAWN), and wet-bulb temperature (calculated at 2 meter or 7 feet height).

Fuel Costs and Hourly Water Use

A farm diesel cost of $2.50/gallon was used, based on subtracting the 2015 federal and state taxes ($0.580 for Florida) (EIA 2015b) from the 2015 diesel prices for the lower Atlantic states ($3.08) (EIA 2015a). The cost estimate was verified through discussions with several growers.

The average diesel use per pump was assumed to be 8.5 gallons of diesel per hour. It was also assumed that pumps typically employed by growers have the capacity of pumping approximately 2.7 thousand gallons of water per minute (or 163 thousand gallons per hour, with an application rate of 0.3 inches/hour). Based on these assumptions, the cost of running a water pump is $21.25/hour, or $0.13/thousand gallons of water.

It was assumed that each pump serves approximately 20 acres. The size of blueberry farms varied significantly in Florida; hence, the total costs related to cold protection irrigation varied from farm to farm. We used the area served by one pump (20 acres) as the basis for our estimations. Table 2 summarizes the assumptions made in this study and can be used with weather data from blueberry-producing counties to determine the costs of growers for cold protection irrigation.

Altering Cold Protection Irrigation to Save Costs and Water Use

Duration of Cold Weather Events

When looking at 2010–2015, the number and the duration of cold weather events that required irrigation were significantly higher given the uniform cold protection irrigation as compared with the precision scenario (Table 3). In Alachua and Marion Counties, the number of cold weather protection events reduced from approximately 4 per season, to 2 to 3 per season. The total duration of cold weather events was significantly longer for the uniform scenario as compared with the precision scenario (with the average difference of 14.8 hours per season).

In Hillsborough and Polk Counties, the number of cold weather events per season is relatively small, still the precision scenario is estimated to reduce the number from 1 to 2 per season, to 0 or 1 event. The duration of cold weather protection irrigation shrinks by 8 hours per season on average.

Pumping Costs

For Alachua and Marion Counties, average reduction in cold weather protection irrigation associated with the precision scenario can be translated into $315 reduction in cost per pump per season (recall that we assumed that each pump serves 20 acres, and hence, the reduction is $15.8 / acre). For Hillsborough and Polk Counties, the average reduction in cold protection irrigation was 8 hours that is associated with $170 reduction in pumping costs per pump (or $8.5/acre). Table 4 summarizes estimated cold protection irrigation costs for the precision and uniform scenarios for the four counties examined. Not surprisingly, the cold protection irrigation costs are the highest for Alachua County, and the lowest for Polk County.

The diesel costs shown in Table 4 only account for one pump running at 8.5 gallons of diesel per hour. Many farms run more than one pump. On larger farms, there may be 20 or more pumps to consider. For example, consider a hypothetical farm in Alachua County that has 200 acres of blueberries served by 10 pumps. If the uniform scenario is followed, the average cost would be approximately $6,600 (assuming the cold protection irrigation needs to be turned on about 4 times per season, for the combined duration of 41 hours). In contrast, if the precision cold protection irrigation scenario is followed, the grower would pay almost 50 percent less, or an average of $3,700 per season (reducing the number of the irrigation events to 2 to 3 times per season, with the total duration of 17 hours). This is a difference of almost $3,000 per season for this large farm. For growers who wish to determine their own pumping costs based on their individual operations, Tables 6 and 6 illustrate the necessary calculations.

Cold Protection Irrigation Water Use

There is also a substantial difference in the volumes of water being pumped for cold protection given precision and uniform scenarios. We assume that cold protection requires 162.9 thousand gallons per hour to protect 20 acres of blueberry, or 8.1 thousand gallons to protect 1 acre for 1 hour (Table 5). Reduction in irrigation duration by 14.8 hours means 120.2 thousand gallon of water use reduction per acre per season for Alachua and Marion Counties. For Polk and Hillsborough counties, 8 hour reduction in cold weather protection duration results in 64.8 thousand gallon reduction in water use per acre per season. Note that in some seasons, the difference can be even higher. If the water is valued at $4 per thousand gallons (which is an estimated average price paid by residential customers using 8 thousand gallons per month, Raftellis Consultants Inc. 2012), then the water use reduction resulting from switching from the uniform to precision strategy would be valued at $481/acre for Alachua and Marion Counties, and $259/acre for Hillsborough and Polk Counties.

Study Limitations

The temperatures for the precision cold protection irrigation scenario used in this study are based on a publication developed by Michigan State University (MSU 2012); these temperatures are similar to the recommendations in Longstroth (2012), and are not developed specifically for Florida. Additional research will allow for a more accurate definition of the critical temperature for blueberry cultivars grown in Florida so that growers can ensure high yields while conserving water and saving money on cold protection irrigation.

Longstroth (2012) acknowledges slight damage in petals or flowers for temperatures close to the recommended temperatures. Not all petal or flower damage translates into yield losses; and neither Longstroth (2012) nor MSU (2012) offers any description of the effect (or the lack of effect) of petal or flower damage on yield.

In our analysis, we made a few assumptions that may oversimplify some cases. Specifically, we considered a fixed time interval for blooming and post-blooming stages; however, the timing of blooming can shift from year to year, depending on weather conditions. Furthermore, we made a set of assumptions to characterize common grower practices and farm setup, while acknowledging some variability in real grower decisions. Finally, in estimating water pumping costs, we accounted for diesel costs only, and we did not consider other possible costs, such as labor and pump depreciation and maintenance.

Conclusions

Growers who follow the research-based critical temperature recommendations for cold protection techniques given different flowering stages can decrease their diesel costs for cold protection irrigation. However, accurate temperature monitoring in blueberry fields is critical and may require several onsite strategically placed weather stations or sheltered thermometers. It is also important to understand the temperature differences between a weather station or sheltered thermometer and actual plant tissue. Depending on the county, growers can expect to reduce the length of cold protection irrigation by up to 41 hours per season, reducing pumping costs by up to $871 per pump per season (or $44 per acre per season). Average reductions are $315 per pump per season in Alachua and Marion Counties (or $15.8 / acre per season) and $170 per pump per season in Polk and Hillsborough Counties (or $8.5/acre). Growers can also expect *significant* reductions in water use for cold protection: averages per season are 120.2 thousand gallons per acre in Marion and Alachua, and 64.8 thousand gallons per acre for Polk and Hillsborough Counties. This water use reduction is valued highly (one of the metrics can be the average price of $4/thousand gallons paid by residential customers for tap water, Raftellins Consulting 2012).

It should be noted that this study does not consider the yields predicted using alternate cold protection strategies, or the possibility of irrigation system freezing if the irrigation system is not turned on. Some strategies may prove to be more effective than others in terms of amount of berries lost versus the amount of berries the grower is able to save and harvest following the cold weather events. More research is needed to determine the best strategies for cold protection that results in the highest yield. When coupled with the savings from adhering to the research-based critical temperatures, a high yield strategy will become even more lucrative for growers.

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Table 1. Florida blueberry bud stages and critical temperatures used in the study

Bud development, blooming, and post-blooming stages	Dates		Critical air temperatures for cold protection irrigation	
	Southern counties (Polk & Hillsborough)	Northern counties (Alachua & Marion)	Precision scenario	Uniform scenario
3–Tight Cluster	Jan 10–Jan 14	Jan 30–Feb 3	23°F (–5.0°C)*	33°F (0.6°C)
4–Early Pink	Jan 15–Jan 19	Feb 4–Feb 8	25°F (–3.9°C)*	33°F (0.6°C)
5–Late Pink	Jan 20–Jan 24	Feb 9–Feb 13	27°F (–2.8°C)*	33°F (0.6°C)
6–Full Bloom	Jan 25–Jan 29	Feb 14–Feb 18	28°F (–2.2°C)*	33°F (0.6°C)
7–Petal Fall	Jan 30–Feb 5	Feb 19–Feb 25	32°F (0.0°C)*	33°F (0.6°C)
8–Post-bloom – young fruit	Feb 6–Mar 15	Feb 26–Mar 31	33°F (0.6°C)**	33°F (0.6°C)

* Source: MSU (2012). ** assumed to be the same as common growers' practice.

Table 2. Assumptions made to characterize blueberry farming practices

Assumption description	Value
Area served by one water pump, acres	20.0
Water pump capacity, thousand gallons of water per minute	2.7
Water application rate for cold protection, inches per hour	0.3
Water pump diesel use, gallons of diesel per hour	8.5
Diesel cost, $/gallon	$2.50
Diesel cost per hour per pump, $/hour	$21.25
Cost of water pumping per acre per hour, $/(hour*acre)	$1.06
Cost of water pumping, $/thousand gallons of water	$0.13

Table 3. Cold weather events per county per year, 2010–2015

County (City)	Year	Number of cold events		Total duration of cold events (hours)		
		Precision cold protection irrigation	Uniform cold protection irrigation	Precision cold protection irrigation	Uniform cold protection irrigation	Difference
Northern Florida						
Alachua County (Alachua)	2010	6	12	40	81	41
	2011	0	5	0	32	32
	2012	2	3	22	34	12
	2013	7	10	48	69	21
	2014	0	1	0	3	3
	2015	5	5	36	46	10
Marion County (Citra)	2010	5	7	32	50	18
	2011	0	2	0	12	12
	2012	2	2	16	22	6
	2013	2	5	17	34	17
	2014	0	0	0	0	0
	2015	2	3	15	21	6
Average for Northern FL		2.4	4.2	17.4	31.1	14.8
Central Florida						
Hillsborough County (Dover)	2010	2	5	10	51	41
	2011	0	3	0	18	18
	2012	1	1	10	10	0
	2013	1	1	4	4	0
	2014	0	0	0	0	0
	2015	1	1	8	8	0
Polk County (Lake Alfred)	2010	1	4	2	37	35
	2011	0	1	0	6	6
	2012	1	1	5	5	0
	2013	1	1	2	2	0
	2014	0	0	0	0	0
	2015	0	0	0	0	0
Average for Central FL		0.6	1.4	3.2	10.5	8.0

Table 4. Estimataed cost and savings *per pump* (serving 20 acres) for cold weather events in four Florida counties, January 2010 – March 2015

Year	Alachua County			Marion County		
	Precision	Uniform	*Savings*	Precision	Uniform	*Savings*
2010	$850.0	$1,721.3	*$871.3*	$680.0	$1,062.5	*$382.5*
2011	$0.0	$680.0	*$680.0*	$0.0	$255.0	*$255.0*
2012	$467.5	$722.5	*$255.0*	$340.0	$467.5	*$127.5*
2013	$1,020.0	$1,466.3	*$446.3*	$361.3	$722.5	*$361.3*
2014	$0.0	$63.8	*$63.8*	$0.0	$0.0	*$0.0*
2015	$765.0	$977.5	*$212.5*	$318.8	$446.3	*$127.5*
Year	Hillsborough County			Polk County		
	Precision	Uniform	*Savings*	Precision	Uniform	*Savings*
2010	$212.5	$1,083.8	*$871.3*	$42.5	$786.3	*$743.8*
2011	$0.0	$382.5	*$382.5*	$0.0	$127.5	*$127.5*
2012	$212.5	$212.5	*$0.0*	$106.3	$106.3	*$0.0*
2013	$85.0	$85.0	*$0.0*	$42.5	$42.5	*$0.0*
2014	$0.0	$0.0	*$0.0*	$0.0	$0.0	*$0.0*
2015	$170.0	$170.0	*$0.0*	$0.0	$0.0	*$0.0*

Table 5. Estimation of diesel cost per gallon of water

Assumptions	
Water application rate:	0.3 inches per hour
Area irrigated by one pump:	20 acres
Farm diesel cost:	$21.25 per pump per hour
Convert water application rate into gallons per hour	
1 acre-inch per hour:	27,154.29 gallons of water
Water application rate per hour per acre by one pump (at 0.3 inches/hour):	27,154.29 gallons*.3 inches per hour = 8,143.59 gallons per acre per hour
Total water application rate per hour for 20 acres served by one pump	8,143.59*20 acres=162,871.74 gallons water per pump per hour
Estimate cost of water pumping	
	$21.25 / 162,871.74 gallons = $0.00013/gallon of water or $0.13/thousand gallons of water

Table 6. Pumping cost estimation

Diesel price ($/gallon):	$2.50
Assumed gallons of diesel used per pump per hour (gallon/hour)	8.5
Diesel cost for one pump per hour ($/hour)	$2.50*8.5= $21.25 of diesel per pump per hour
Diesel cost per hour per farm:	Diesel cost per hour per pump ($21.25) * number of pumps
Diesel cost per hour per acre	Diesel cost per hour per pump/acres served by the pump