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Communication

Improved Sustainability through Novel Water Management Strategies for Strawberry Transplant Establishment in Florida, United States

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Abstract: Establishing bare-root transplants in Florida, United States, is an inefficient water-consuming activity. Between 3500 and 5500 m^3/ha are applied with sprinkler irrigation to lower temperatures around the transplant crown and aid early root development, but more than 97% of the water volume runs off the polyethylene-covered beds. Research has been conducted to evaluate the feasibility of producing containerized (plug) short-day cultivar transplants under Florida conditions, the effect of continuous and intermittent low-volume sprinklers on transplant establishment and the use of kaolin clay to reduce stress on young transplants. Research results demonstrated that growers may have alternatives to reduce water use and pumping costs during strawberry transplant establishment by the following: (a) plug transplants can be produced from mother plants from Florida's subtropical weather without chilling conditioning and still be competitive in the winter market; (b) using continuous and intermittent low-volume sprinkler irrigation saves between 16% and 33% of the water volumes for strawberry establishment; and

(c) using kaolin clay showed to be a low-cost (US$63/ha plus application costs) investment to reduce irrigation volumes by at least 30%.

Keywords: *Fragaria* × *ananassa*; freeze protection; sprinkler irrigation; best management practices; cold weather; kaolin clay; plug transplants

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1. Winter Strawberry Production in Florida Open Fields

Florida is the only state in the USA that produces large volumes of strawberry (*Fragaria* × *ananassa*) fruit during winter, mainly due to its subtropical weather. Production value reaches more than US$365 million in gross sales from about 4000 ha of open fields [1]. Florida strawberries are produced in annual hills using bare-root transplants from nurseries located in northern USA latitudes and Canada, where cool temperatures provide favorable environments for transplant conditioning of short-day cultivars. Annual hills are fumigated, covered with polyethylene mulch and irrigated and fertilized through a single drip line per bed. Bare-root transplants are relatively inexpensive in comparison with commercially-available containerized (plug) plants, and they are set into planting beds from late September to early October. Most planted cultivars are short-day flowering plants that bear marketable fruit between early December and late March. Market prices are the driving force behind how long the strawberry season lasts in Florida.

Sustainability of strawberry production is tightly linked to the use of essential resources, such as irrigation water. The majority of the strawberry fields are located in the Plant City-Dover production area in Hillsborough County, Florida. This area is characterized by the proximity of urban developments to strawberry farms, which obtain water from wells tapping into the same aquifers as their agricultural neighbors. As a result, water availability for public use is reduced when agricultural use of water is intense and environmental problems, such as sinkhole collapse and permanent dried wells, have been reported, causing decreased agricultural sustainability. Therefore, it is important to identify irrigation practices that could save water during strawberry production. Any modification to current practices has to consider the risk associated to the cost/benefit relationship for a crop that requires approximately US$32,000/ha to be produced in Florida. The objective of this paper is to summarize and describe recent results of science-based, alternative water management strategies during strawberry establishment to improve its environmental and economic sustainability in Florida, USA.

2. Reducing Water Volumes for Strawberry Transplant Establishment

From the standpoint of water management during winter strawberry season in Florida, there are three critical production phases: (a) transplant establishment, (b) crop maintenance, and (c) freeze protection. Out of those three phases, transplant establishment is the most inefficient activity. These transplants require overhead sprinkler irrigation during the hottest part of the day for the first seven to 12 days after planting [2]. The daily duration of this irrigation fluctuates between eight to 10 hours, depending on local evaporative conditions. This practice seeks to lower temperatures and replenish soil moisture around strawberry transplant crowns [2]. However, water volumes used for this purpose are extremely high (between 3500 and 5500 m^3/ha). Additionally, the efficiency of this method is very low because nearly 97% of the applied water drips down from the polyethylene mulched beds, into the row middles and, finally, into the drainage canals [3]. Current research focuses on applying several strategies to decrease irrigation volumes during strawberry transplanting: (a) using containerized transplants to minimize the need for sprinkler irrigation, (b) reducing irrigation volumes with low-volume sprinklers, and (c) applying anti-transpirants or crop protectants for lessening water needs and plant stress. This section seeks to describe current efforts on addressing these strategies.

2.1. Current Research on Developing Containerized Transplants to Minimize Using Sprinkler Irrigation

As previously mentioned, two types of transplants are produced in strawberry nurseries: (a) bare-root transplants, which are relatively inexpensive and the major transplant type used in Florida, and (b) containerized transplants (plugs), which can double the price of the former transplant type. Water use volume during strawberry crop establishment could be reduced by using plugs, which can also increase early and total marketable yield, hastening establishment, and improve plant survival compared to bare-root transplants [4,5]. However, high initial investment is needed for using containerized transplants (US$0.35 per plant) compared to bare-root transplants (US$0.15 per plant). The price difference is mostly because of shipping costs, since fewer transplants can be transported per shipping unit with plugs than with bare root transplants. Producing short-day plug transplants locally in Florida for strawberry production could lower the cost of this type of transplant and increase grower interest due to potential increased early yields and profits. Therefore, an evaluation of the performance of locally-produced plug strawberry transplants in comparison with bare-root transplants was needed.

A field study was conducted at the Gulf Coast Research and Education Center of the University of Florida in Balm, Florida, USA, from September 2010 to March 2011. The soil at the experimental site was a fine sandy spodosol with less than 1.5% organic matter and a pH of 7.2. The plug transplants were produced in a greenhouse located at the same site using 40-cell trays filled with a commercial potting mix. The temperature inside the greenhouse was maintained above 25 °C. Daughter plants (runners), obtained from local mother plants without cooling or short-day conditioning, were plugged into the trays. Bare-root transplants were purchased from a commercial nursery (Crown Nursery, Red Bluff, CA, USA). Treatments consisted of: (a) short-day cultivars ("Strawberry Festival", "Florida Radiance", and "Winterstar") and (b) combinations of transplant types (bare-root and plugs) and establishment practices. Cultivar runners were plugged into the trays either on 26 July or 16 August 2010. In the case of bare-root transplants, they were established with either 10 days of sprinkler irrigation (control) or six days of sprinkler irrigation followed by foliar application of kaolin clay application on the seventh day (28 kg/ha; Surround WP; Tessenderlo Kerley, Phoenix, AZ, USA) as described by Santos *et al.* [6]. All plots with plug plants were exclusively drip irrigated after the second day of sprinkler irrigation plus or minus the kaolin clay application on the third day.

After transplants reached a commercial size (three fully-expanded leaves and at least one 10-mm thick crown), they were set in the field on 27 September 2010 into 5.3-m long plots in the field in double rows, 38 cm apart with 30 plants per plot. A split-plot design was used with four replications with the combinations of transplant types and establishment practices in the main plots and cultivars in the subplots. Raised beds were 0.7 m at the base, 0.6 m at the top and 0.3 m high with beds separated 1.2 m apart. The soil was fumigated simultaneously with bedding using 328 L/ha of 1,3-dichloropropene + chloropicrin (65/35, v/v) in early September. The fumigation rig was on the same tractor as the bed presser and the fumigation chisels. Within one min after fumigation, a single drip tape line (2.85 L/100 m per min; T-Tape Systems International, San Diego, CA, USA) was buried 5 cm below the surface on bed centers, and beds were covered with black high-density polyethylene mulch (0.025 mm-thick, Intergro Co., Clearwater, FL, USA). The field was equipped with sprinkler heads (17 L/min) for freeze protection and transplant establishment. Current recommendations for nutrition and pest management were followed during the season [2]. Marketable fruit were defined as fruit of ≥10 g without any visible damage, and their number and weight were collected from 24 harvests starting on 29 November 2010. There were two harvests per week. Early fruit weight was determined for the first ten harvests. Single factor and interaction effects were analyzed using a general linear model (Statistix Analytical Software, Tallahassee, FL, USA [7]). Means were compared with a Fisher's-protected least significance difference test at the 5% significance level.

There was a significant interaction between the two factors (transplant types combined with establishment practices and cultivars) on early fruit weight. Within each cultivar, there were differences across establishment practices and transplant types (Table 1). For "Florida Radiance" and "Winterstar", early fruit weight from plots with bare-root plants did not differ from those plots established with plugs. In contrast, plots established with bare-root "Strawberry Festival" plants had significantly higher early fruit weight than those transplanted with plugs, regardless of the plugging dates. Only the combination of transplant types plus establishment practices had an effect on total fruit weight, ranging between 17.5 and 22 t/ha (Table 2). There were no total fruit weight differences among all the combinations of transplant types plus establishment practices, which demonstrated that Florida-produced containerized transplants performed as well as bare-root transplants from a California nursery, particularly for "Florida Radiance" and "Winterstar", two newer cultivars which have been observed to require less chilling compared to "Strawberry Festival". These preliminary results indicated that it is possible to obtain commercial-grade strawberry plugs using mother plants without previous cooling and short-day conditioning. Further research will focus on improving early fruit weight performance and planting dates for this type of transplant.

Table 1. Early fruit weight of strawberry cultivars from different transplant types and establishment practices in Balm, FL, USA, during the 2010–2011 season. Cultivars were "Florida Radiance", "Winterstar™" and "Strawberry Festival". Transplant types were bare-root and containerized (plug) plants, and establishment practices were 10 days of sprinkler irrigation, six days of sprinkler irrigation plus kaolin clay on the seventh day, two days of sprinkler irrigation and two days of sprinkler irrigation plus kaolin clay on the third day. Treatment means followed by the same letter do not differ at the 5% significance level according to Fisher's-protected least significance difference test.

Cultivars	Establishment practices	Early fruit weight (t/ha)
Florida Radiance	Bare-root transplants; 10 days irrigation	3.7 a,b
	Bare-root transplants; six days irrigation + kaolin clay on the seventh day	5.0 a,b
	Plugs planted on 26 July; two days irrigation	2.9 b
	Plugs planted on 26 July; two days irrigation + kaolin clay on the third day	2.5 b,c
	Plugs planted on 16 Aug.; two days irrigation	3.8 a,b
	Plugs planted on 16 Aug.; two days irrigation + kaolin clay on the third day	3.4 a,b
Winterstar	Bare-root transplants; 10 days irrigation	3.0 b
	Bare-root transplants; six days irrigation + kaolin clay on the seventh day	3.3 a,b
	Plugs planted on 26 July; two days irrigation	2.3 b,c
	Plugs planted on 26 July; two days irrigation + kaolin clay on the third day	3.8 a,b
	Plugs planted on 16 Aug.; two days irrigation	2.6 b
	Plugs planted on 16 Aug.; two days irrigation + kaolin clay on the third day	3.0 b
Strawberry Festival	Bare-root transplants; 10 days irrigation	5.2 a
	Bare-root transplants; six days irrigation + kaolin clay on the seventh day	7.0 a
	Plugs planted on 26 July; to days irrigation	0.7 c
	Plugs planted on 26 July; two days irrigation + kaolin clay on the third day	1.9 b,c
	Plugs planted on 16 Aug.; two days irrigation	2.8 b
	Plugs planted on 16 Aug.; two days irrigation + kaolin clay on the third day	2.8 b
	Significance ($P < 0.05$)	*

* = significant at $P < 0.05$.

Table 2. Total fruit weight of strawberry from different transplant types and establishment practices in Balm, FL, USA, during the 2010–2011 season. Transplant types were bare-root and containerized (plug) plants, and establishment practices were 10 days of sprinkler irrigation, six days of sprinkler irrigation plus kaolin clay on the seventh day, two days of sprinkler irrigation, and two days of sprinkler irrigation plus kaolin clay on the third day. NS = non-significant at $P < 0.05$.

Establishment practices	Total fruit weight (t/ha)
Bare-root transplants; 10 days irrigation	17.5
Bare-root transplants; six days irrigation + kaolin clay on the seventh day	21.1
Plugs planted on 26 July; two days irrigation	17.3
Plugs planted on 26 July; two days irrigation + kaolin clay on the third day	19.0
Plugs planted on 16 Aug.; two days irrigation	19.3
Plugs planted on 16 Aug.; two days irrigation + kaolin clay on the third day	22.0
Significance ($P < 0.05$)	NS

2.2. Current Research on Reducing Irrigation Volumes with Low-Volume Sprinklers

The establishment phase accounts for up to one-third of the total season use of water on the strawberry crop [5]. These studies focused on how water volumes used during transplant establishment could be reduced using low-volume sprinklers. Sprinklers delivering water at 17 L/min is a standard practice during strawberry establishment. Low-volume sprinklers providing 5.7 L/min have the potential to make this practice more efficient. A field study was conducted in the 2011–2012 strawberry season at the same research location. Bedding, mulching, fumigation and growing practices were the similar as those previously described. "Treasure" bare-root transplants with three to five leaves from a Canadian nursery were planted in early October 2011. The transplants were set in double rows, 15 inches apart. Treatments were: (a) intermittent irrigation with sprinklers delivering 5.7 L/min (10 min on and 10 min off), (b) continuous irrigation with sprinklers delivering 5.7 L/min, and (c) continuous irrigation with sprinklers delivering 17 L/min (control). Irrigation was turned on for 10 h/day for the first 10 days during establishment. Plots were 5.3 m with 30 plants (20 plants were used for harvest and 10 plants were for root biomass samples and were distributed in a randomized complete block design with three replications). Leaf number and fresh root weight were measured two weeks after transplanting (WAT). Plots were harvested twice a week. For early yield, marketable fruit weight and number were collected for the first eight harvests.

There were no significant differences among treatments in early yield and fruit number, regardless of the water volumes or intermittent scheduling. Early yield averaged 4.2 t/ha and fruit number averaged 25,297 fruit/ha (Table 3). The treatments did not affect fresh root weight and leaf number. Fresh root weight at 3 WAT averaged 101 g and leaf number at 3 WAT averaged five leaves per plant. Water savings in this study ranged from 33% with low-volume intermittent irrigation to 16% with low-volume constant irrigation, which would be equivalent to 2.2 and 4.6 million m^3 of water per season in the Plant City-Dover area, FL, USA. With low-volume sprinklers, the provided water volumes were enough to cool down the crowns and keep enough moisture to avoid heat stress in the transplants. In addition, by reducing water volumes during establishment, growers may: (a) have more water available for freeze protection during the season or (b) opt for lower water use and, therefore, lower irrigation costs.

Table 3. Effects of irrigation programs on the leaf number, fresh root weight and early fruit weight and number (first eight harvests) during the establishment of bare-root strawberry transplants in Balm, FL, USA, during the 2011–2012 season. NS = non-significant at $P < 0.05$.

Irrigation programs	Leaf number (Three weeks) (leaves/plant)	Fresh root weight (Three weeks) (g)	Early fruit weight (t/ha)	Early fruit number (No./ha)
5.7 L/min intermittent	5	100	3.9	23,470
5.7 L/min continuous	5	105	4.1	24,928
17 L/min (control)	4	98	4.5	27,493
Significance ($P < 0.05$)	NS	NS	NS	NS

2.3. Current Research on Application of Crop Protectants for Lessening Water Needs and Plant Stress

Kaolin clay is a natural degradable mineral, which forms a white film on the leaves that reflects infrared and ultraviolet radiation, thus reducing heat stress in new transplants. Previous studies combining days of irrigation and kaolin clay application showed that either six or eight days of sprinkler irrigation plus kaolin clay application on the next day resulted in the same establishment as 10 days of sprinkler irrigation [6]. The objectives for these studies were to: (a) evaluate the effect reduced-volume irrigation programs for strawberry establishment and early yields and (b) validate the effect of kaolin clay on the strawberry establishment and plant growth in growers' fields. A study was conducted in the Plant City-Dover area, Hillsborough County, FL, USA, at six growers' farms covering 6.4 ha. Bare-root strawberry transplants were established between the first and second week in October 2011. Treatments were: (a) seven days of sprinkler irrigation delivering 17 L/min of water plus kaolin clay at the eighth day at the rate of 28 kg/ha with an application volume of 570 L/ha of water, and (b) 10 days of sprinkler irrigation delivering 17 L/min of water (control) and were distributed in a randomized complete block design with each farm being a replication. Plots were between 400 and 600 plants per treatment with six replications (one for each farm). Kaolin clay (Surround WP; Tessenderlo Kerley, Phoenix, AZ, USA) was applied on the foliage of transplants with a conventional foliar nutrient sprayer. No other special equipment was needed.

Plant number, leaf greenness and canopy diameter of 20 randomly-selected plants were measured between 2 and 3 WAT. Greenness of leaves was measured with a handheld color meter (SPAD-502; Minolta, Ramsey, NJ, USA), which provides a numerical soil plant analysis development (SPAD) value, ranging from 0 to 80, where 0 = white and 80 = dark green. Data from the study were analyzed using a general linear model ($P < 0.05$), and treatment values were separated using Fisher's-protected least significant difference test [7]. There were no significant differences in the number of established plants between the treatments with about 99.5% plant survival (Table 4). Kaolin clay application did not affect leaf greenness and canopy diameter. Leaf greenness had a SPAD value of 43 and mean canopy diameter was 26 cm. With this technology, water savings were about 30%. This technology did not have a negative impact on early yield or plant growth compared with the standard practice of 10 days of sprinkler irrigation based on yield reports from cooperating growers (data not shown). These results are supported by previous studies done in strawberries and other crops, where kaolin clay application resulted in reduced heat stress and air vapor pressure on the treated plants [6,8,9]. In economic terms, kaolin clay costs about US$63/ha plus application expenses, which totals about US$27/ha, resulting in a total cost of US$90/ha. This expense is less than three times the cost of diesel fuel needed for an extra three days of sprinkler irrigation (10 h/day).

Table 4. Effects of irrigation programs in growers fields (6.4 ha) for strawberry transplant establishment on plant number, leaf greenness and canopy diameter between two and three weeks after transplanting in the Plant City-Dover area, FL, USA, during the 2011–2012 season. Establishment practices were 10 days of sprinkler irrigation and seven days of sprinkler irrigation plus kaolin clay on the eighth day. NS = non-significant at $P < 0.05$.

Farms	Irrigation programs	Plant number (No. per plot)	Dead plants (No. per plot)	Leaf greenness (SPAD value)	Canopy diameter (cm)
1	Sprinkler + kaolin clay	595.0	0.0	43.4	25.1
	Sprinkler only	601.5	1.3	42.8	24.6
2	Sprinkler + kaolin clay	417.3	5.5	47.1	26.9
	Sprinkler only	458.8	4.0	47.6	25.0
3	Sprinkler + kaolin clay	477.8	0.8	48.3	24.7
	Sprinkler only	401.3	0.5	46.4	24.6
4	Sprinkler + kaolin clay	386.0	4.0	40.8	25.9
	Sprinkler only	375.3	6.3	42.3	25.4
5	Sprinkler + kaolin clay	305.8	0.0	43.8	23.3
	Sprinkler only	317.3	0.0	42.8	23.7
6	Sprinkler + kaolin clay	483.8	2.0	41.4	31.0
	Sprinkler only	486.5	0.0	41.3	30.0
Totals	Sprinkler + kaolin clay	444.3	2.0	44.1	26.1
	Sprinkler only	440.1	2.0	43.8	25.5
Significance ($P < 0.05$)		NS	NS	NS	NS

3. Conclusions

With the combination of these technologies, growers may have alternatives to reduce water use and pumping costs during strawberry transplant establishment. First, it was demonstrated that plug transplants could be produced from mother plants from Florida's subtropical weather without precooling conditioning and still be competitive in the winter market. In an ideal scenario, application of this technology would eliminate the use of sprinkler irrigation for transplant establishment, saving between 3500 and 5500 m^3/ha for this part of the growing season. A careful assessment of the cost structure of these Florida-produced plugs needs to be conducted, but it is anticipated that it will be less per unit than plugs produced in northern nurseries. Second, using continuous and intermittent low-volume sprinkler irrigation saves between 16% and 33% of the water volumes for strawberry establishment. A potential drawback of this technology is the required purchase and retooling of the irrigation pipes and distribution system to accommodate the different sprinkler configuration in the fields. Lastly, using kaolin clay has shown to be a low-cost (US$63/ha + application costs) investment to reduce irrigation volumes by at least 30%. Further studies are needed into combining these technologies to improve water savings during strawberry transplant establishment and to assess the economic impact of these practices.

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