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Chapter

Water Management Strategies and Cultural Practices for Strawberry Establishment in Florida

Emmanuel Torres-Quezada, Isabel Torres-Quezada and Bielinski Marcelo Santos

Abstract

Florida's strawberry (*Fragaria × ananassa* Duch) production system is mainly dependent on short-day cultivars produced as bare-root (BR) transplants, which are high-yielding and low-cost options for Florida growers. The strawberry industry in Florida is greatly dependent on early yield (mid-November, early December). Therefore, Florida growers must secure rapid establishment of the BR transplants and for that reason, high volumes of irrigation water are applied to reduce air temperature around plant crowns and mitigate desiccation. This practice accounts for nearly 14.7 million m^3 of irrigation water between mid-September and early October. Several alternatives are available to growers to reduce irrigation water for establishment. One of those alternatives suggests replacing BR transplants for actively growing strawberry plugs (SPs). However, the higher price of SP transplants seems to be the main limitation for their implementation. Alternately, growers could explore the possibility of introducing intermittent irrigation or low-volume sprinklers into their system to establish BR transplants. An inexpensive option, based on a large body of research, would be the application of crop protectants against excessive sun radiation, which could reduce irrigation water for establishment by up to 30%. Despite the suggested alternatives, there is still a great deal of work needed to increase grower's confidence in these technologies.

Keywords: crop protectants, kaolin clay, strawberry plugs, bare-root, intermittent irrigation, low-volume sprinklers

1. Introduction

Florida is the second largest strawberry producer in the U.S. with 3799 ha planted in 2017 [1]. The strawberry season in Florida goes from mid-September to April, depending on the production system and location in the state. The highest strawberry prices are obtained early in the season, between late November and the first few weeks of December, before strawberry imports flood the market. Mexico and California are the biggest competitors to the Florida strawberry. Imported strawberry from Mexico competes directly with Florida during the winter months. Mexican strawberry usually enters the U.S. market during the third week of December, making Florida strawberry growers greatly dependent on early yield to secure profitability in their individual production systems.

In order to secure their first harvest between November and early December, Florida growers rely on BR transplants, which are shipped to Florida from northern-latitude states in the U.S., Canada, or high-altitude nurseries. During nursery stage, BR transplants are grown under inductive conditions for flowering, which translate to early flowering after transplanted in Florida. In addition, their low acquisition cost make BR transplants an attractive option for Florida growers. Days before the beginning of the strawberry season, BR transplants are dug out from the ground, cleaned up, packed, and shipped to southern states in the U.S. for the winter season. Handling of the transplants usually leads to reduced number of functional leaves and roots, creating sites for pathogen infection and increases variability in transplant size and flowering patterns. Moreover, for growers to secure rapid establishment of BR transplants in Florida in September and October, high volumes of irrigation water are used to reduce air temperature around plant crowns as well as to decrease leaf desiccation. This practice represents an underground water depletion of nearly 14.7 million m^3 between mid-September and early October. Controversy surrounds this establishment practice, as in combination with water consumption for freeze protection; it has been related to an increasing occurrence of sinkholes in urban areas near the production sites.

Strawberry yield is strongly influenced by environmental conditions, plant physiology, and the grower's management practice. Furthermore, grower profitability will be partially determined by the time of entry in the market and transplant quality. Given the interaction among several factors that affect profitability in strawberry production, this chapter touches on the physiological characteristics of strawberry transplants, followed by the application of the traditional establishment practices and potential alternatives to this method with aims to reduce irrigation water consumption during strawberry establishment in Florida, USA.

2. Strawberry response to high temperatures

The commercial strawberry is a perennial hybrid commonly described as herbaceous, though it is a true woody plant, given the presence of secondary xylem in roots and crowns [2]. The stem (also called crown) consists of a compressed central core surrounded by a vascular ring [3]. The crown gives origin to leaves, runners, lateral crowns, roots, and flowers. The modern strawberry originated from the hybridization of two wild octoploid species [4, 5], *F. virginiana* and *F. chiloensis* [6]. Darrow [7] extensively reviewed the history of this hybrid. The plant is commonly propagated by stolon or crown division [8], and while the crop can be successfully cultivated in a broad range of climates, the most common production areas are limited to temperate and Mediterranean climates between latitudes 27 and 60 [9]. The strawberry root system originates from the base of the crown in plant clones. Adventitious roots emerged from the pericycle and depending on soil conditions, roots might develop into a fibrous mass, with about 70% concentrated in the upper 15 cm of soil. The plant produces leaves arranged spirally in short intervals, roots in the base, and a flower meristem at the terminal position, terminating in a primary blossom, followed by two lateral secondary flowers, four tertiaries, and sometimes eight quaternary flowers [10]. The strawberry plant is composed of multiple meristems regulated by plant age, water and nutrient availability, temperature, and photoperiod [3, 9, 11].

Heat stress can be defined as a rise in temperature above a particular threshold level long enough to cause irreparable damage to plant growth and development [12]. Strawberry roots, leaves, and crowns are particularly susceptible to high temperatures. Soil temperatures above 25°C reduced crown dry weight by 22%

compared to 17°C, while soil temperatures above 17°C reduced root dry weight by 15% compared to 10°C, culminating in root death at 32°C in 'Aliso' strawberry [13]. Authors suggested an increase in oxygen and carbohydrate consumption due to increasing tissue temperatures [13]. Electrolyte leakage, protein denaturalization, and inhibition of protein synthesis are common on leaf tissues following high temperature exposure [14]. Although crop response differs when exposed to gradual heat stress and shock heat stress [15, 16]. Gradual heat stress (5°C increased every 48 h until 45°C) triggered heat acclimation in strawberry with reduced electrolyte leakage. On the contrary, shock heat stress (45°C; common in newly transplanted BR) increased electrolyte leakage from leaves and decreased total protein content, leading to protein denaturalization and reduction of protein synthesis [15, 16].

Multiple authors reported that growth analyses are usually dependent on genotype, cultivation systems, and seasonal changes in the environment [10, 16]. Kesici et al. [12], evaluated 15 strawberry cultivars under high temperature conditions (5°C increased every 24 h until 50°C). The authors identified differences in the leaf relative water and chlorophyll contents and heat stress tolerance among cultivars. 'Elsanta', 'R. Hope', and 'Camarosa' were reported as relatively heat tolerant, while 'Whitney', 'Fern', and 'Festival' were relatively heat-sensitive [12]. Additionally, water stress can aggravate the effects of heat stress, decreasing fruit weight and total yield. Ikeda et al. reported a decrease of 37% in fruit weight of 'Sachinoka' when grown on 30/15°C under water stress compared to plants with adequate water. Besides induced differences, the annual strawberry cropping system also plays a major role in the plant response to high temperatures and water stress [17].

3. The Florida production system

Florida strawberry production is specifically designed based on its soils and weather patterns. Commercial strawberry production in Florida started in 1878, at Plant City (28° N latitude) becoming the largest production area of the state. Strawberries are grown in an annual hill culture system [18, 19] with planting dates ranging from mid-September to mid-October. Transplants are set in double rows (30–35 cm apart) with plants 30–40 cm apart (avg. plant density 47,500 plants/ha), in a fumigated bed seeking to reduce nematodes, diseases, and weed pressures [20]. Beds are covered with a black polyethylene mulch and a single drip line in the middle. Nitrogen (N) requirements are 170 kg/ha for a 200 days season [21], although recommendations can change depending on the cultivar selected. Most of the N fertilizer is injected through the irrigation system, as preplant applications do not necessarily improve yield [22]. Although some growers tend to incorporate part of the phosphorus and potassium requirements as preplant applications. Most irrigation schedules are based on grower's experience. However, statewide recommendations suggest that irrigation amounts should be scheduled to meet monthly evapotranspiration, ranging from 7570 L/ha in October to 28,387 L/ha in April [22]. Strawberry growers strongly rely on early yield (mid-November to mid-December) to secure profitability of the system, before Mexican strawberry imports diminish market prices [18, 24, 25]. Average commercial yield ranges from 26,363 kg/ha to 30,000 kg/ha, depending on cultivar selection, season, and variations in production system.

3.1 Bare-root transplants

Florida production system is mainly dependent on short-day cultivars produced as BR transplants. BR is a high yielding, low-cost option for Florida growers, with prices ranging from $0.13–0.14 per transplant [25]. However, growers need to meet several conditions to overcome the challenges that accompany the use of BR in Florida. Strawberries are commonly classified into short-day (June bearing), long-day (ever bearing), or day-neutral cultivars, according to their photoperiodic requirements for flower induction [2]. However, this classification system is deceiving of the physiological responses of the plant, as flower induction is influenced by air temperature, plant development, CO_2 concentration, and photoperiod [2, 7, 27]. In general, short-day cultivars will initiate flowering under photoperiods of 14 h, while long-day cultivars will require photoperiods longer than 13 h, as long as air temperature is permissive. Additionally, the plant needs a minimum of inductive cycles, ranging from 7 to 24 depending on cultivar and air temperature [27]. Increments in air temperature will generally increase the number of inductive cycles required by short-day plants to flower. High air temperatures (28°C) tend to inhibit flower induction, while temperatures ranging between 10°C and 15°C will promote flowering in short day plants.

BR transplants are generally produced in northern latitudes of the U.S., Canada, or at high altitude, to take advantage of the low air temperatures to pre-induce flowering in short-day cultivars. During nursery stage, BR transplants are exposed to the photoperiod and air temperature at the nursery site. Plants are commonly planted in April and grown throughout the summer, before being shipped to the different planting areas in Florida and other southern states.

Maximum air temperatures at the nursery site in June and July are comparable to the early months of the Florida strawberry season (**Figure 1**). However, minimum air temperatures from June to August at the nursery site allow fully-grown transplants to accumulate chilling induction cycles before being shipped, despite photoperiod being longer than 14 h (depending on nursery latitude) (**Figure 2**). In early September, transplants are dug out from the ground, cleaned, and shipped to southern planting areas.

Under Florida conditions, at the beginning of the season, photoperiod in the Plant City area is around 12 h, dropping to 11 h in December and January. Minimum temperatures range from 19.6°C to 2.8°C from September to December, allowing flower induction conditioning after mid-October (**Figure 1**). Average air temperature in September is 26.1°C, dropping to 23.4°C in October and 19.5°C in December

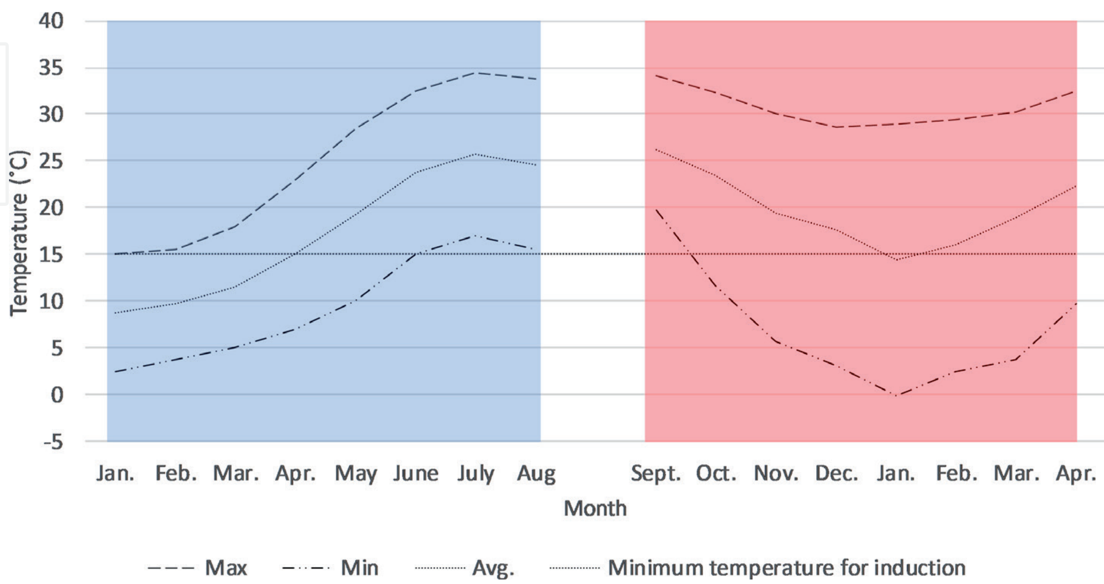

Figure 1.
Ten-year summary of maximum, minimum, and average air temperature at MacDoel, California, USA during strawberry nursery stage (blue) and at Balm, Florida, USA during the strawberry growing season (red).

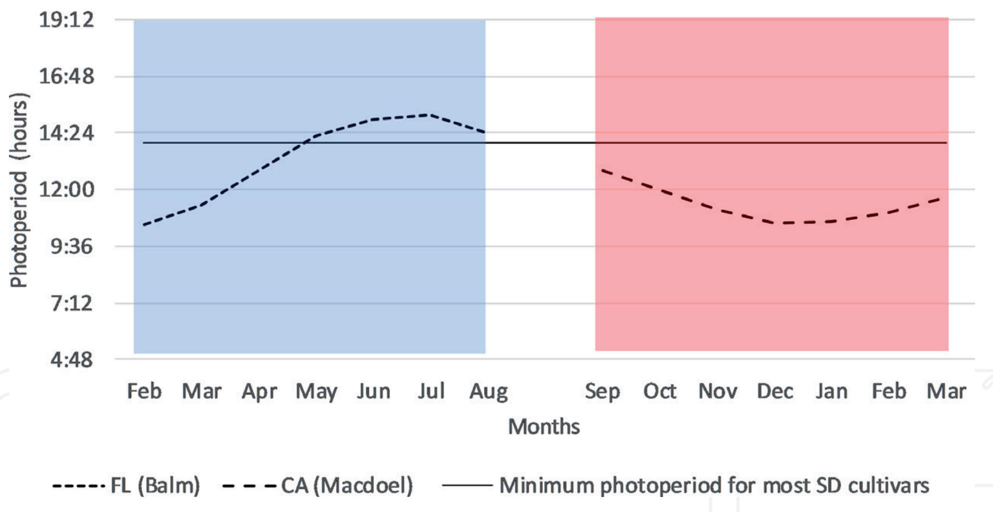

Figure 2.
Monthly photoperiod at MacDoel, California, USA during the strawberry nursery stage (blue) and at Balm, Florida, USA during the strawberry growing season (red).

and January, to later come back up to 22°C in late February and March, around the end of the strawberry season (**Figure 1**). Hence, as photoperiod is already less than 14 h at the time of planting and minimum temperatures are adequate for flower induction after mid-October, the main challenge for Florida growers is transplant establishment under high air temperatures of mid-September and early October (**Figure 1**).

3.2 Strawberry BR establishment

Because of the impaired root system of the traditional BR transplants, in addition to Florida's high air temperature at the time of planting, growers rely on sprinkler irrigation for transplant establishment to moderate air temperatures around the crown and promote root development. Traditionally, BR transplants require 8–10 h of high-impact sprinkler irrigation during the first 10–12 days after transplanting to be fully established. This technique reduces the air temperature around the crown and promotes root and shoot growth of the transplants. The physical phenomenon is based on the energy balance between the water applied and the rest of the production system. Water at the surface of the plant tissue and plastic mulch will evaporate, absorbing approximately 540 calories/mL, as long as the air vapor pressure is lower than the saturated vapor pressure.

Sprinkler heads are usually spaced 14.5 m × 14.5 m apart, averaging 48 sprinklers per ha. Each sprinkler head delivers an average of 15–19 L/min [28], resulting in a water depletion of roughly 3,883,410 L/ha, with close to 3% [29] reaching the planting whole. This amount of water is equivalent to two-thirds of the total water required during the season [30], without considering freeze protection. Overhead irrigation costs were estimated at $11,507/ha in 2012–2013, accounting for 16% of the total cost [23]. This system is only applicable under Florida conditions, as the sandy soils surrounding the Plant City area will allow for a rapid drainage of the irrigation water. The system has generated controversy for many years. The two primary water withdrawals in Florida are the general public and agricultural consumption. In the Plant City area, water resources are shared between agricultural and urban uses [29, 31]. Special regulations for water use in agriculture were implemented in 2010, when several freeze events took place and a high amount of water was used to protect the crop from freeze damage. This activity allegedly caused a drop in the Floridian aquifer level of 18 m. It appears that, because of these events, about 140 sinkholes and more than 750 dried wells occurred in the area [32]. Additionally, overhead water spreads water-dispersed pathogens and promotes weed germination in furrows [33]. Consequently, there is a need to reduce the amount of water used for strawberry production, particularly during transplant establishment. Current research focuses on applying several strategies to decrease irrigation volumes during strawberry transplanting, such as the use of containerized transplants to minimize the need for sprinkler irrigation, reducing irrigation volumes with low-volume sprinklers, and the application of crop protectants or anti-transpirants for lessening water needs and plant stress [28].

4. Alternative establishment methods

4.1 Strawberry plugs

SPs are a suitable alternative to BR transplants. The active root system and water retention capacity of the growing media allows for a quicker establishment of the transplants with minimal irrigation requirement, reduced diseases pressure and higher yield [26, 31, 34–36]. The main limitation of SP implementation is their higher cost ($0.37–$0.38 per transplant) compared to BR transplants. The price difference is related to higher labor and shipping costs, since fewer transplants can be transported per shipping unit. The transition from BR to SP transplants represents an increment in production cost of $10,455/ha, assuming a plant density of 43,560 plants/ha [26].

Several authors had evaluated the performance of SP transplants in Florida reporting higher early yield, quicker transplant establishment rate, and higher fruit size [26, 31, 34, 36]. Hochmuth et al. [31] reported a 98% increment in earlier fruit weight for SP transplants compared to BR transplants without irrigation establishment. Although, total fruit yield was similar for both transplants. The differences in early yield between transplants signified an increment in profitability of the SP system of $2855/ha. Similarly, Giménez et al. [37] reported 24.5% higher early yield for SP compared to BR in soilless media. The increased early yield of SP is related to a quicker establishment rate and accumulation of chilling hours during nursery stage [38]. SP transplants have a similar production process as BR with the added cost of establishing the runners in the planting trays and maintenance under protected conditions until an active root system develops. SPs are grown from unrooted runners called tips. The tips are planted into plastic trays containing usually a peat-based media.

Producing short-day SP transplants in Florida could lower the costs of transplants and increase its application in the relatively warm climates. However, SP exposed to Florida growing conditions without adequate conditioning for flower induction results in similar total yield as BR but reduced early yield [26]. Torres-Quezada et al. [26] evaluated requirements for time in nursery and tray sizes for Florida-produced SP from 2012 to 2016. Strawberry mother plants from three cultivars 'Florida Radiance', 'Strawberry Festival', and 'Florida 127' were planted in soilless media under greenhouse conditions. After 4 months, runners tips were collected from the mother plants and established in either 30-, 40-, 50-, or 75-cell trays. Additionally, SPs were grown for either 4 or 6 weeks before planted at the field. SP transplants did not receive conditioning for flower induction and were established at the field with 20% of the total water required for BR transplants for establishment.

Overall, BR transplant resulted in 63% higher early yield than all SP treatments, although both transplant types resulted in the same total yield with an average of

29,300 kg/ha. Furthermore, SP transplants growth in 50-cell trays for 4 weeks was recommended as an adequate production system for Florida-produced SP. The difference in early yield was attributed to the high air temperatures of September (avg. 26.5°C) in Florida. These temperatures led to a delay in flower bud initiation for SP compared to BR. Furthermore, the high air temperatures probably promoted excessive vegetative growth of SP. Florida-produced SP had a higher dry biomass accumulation compared to the BR transplants, likely related to the active formation of runners and crowns. The increased vegetative growth could explain the increment in production later in the season, as flower buds are originated at the crown site, while BR had lower dry biomass accumulation probably related to pre-season induction and continuous flowering. Early yield differences between transplants are influenced by growing conditions before transplanting. However, SP with or without conditioning can be established with 80% less water than BR transplants, resulting in water savings of almost 820,800 gal per acre per season [26].

4.2 Intermittent irrigation and low-volume sprinklers

It is possible to modify irrigation scheduling for strawberry establishment to reduce the amount of water applied. Similar yield was found for BR transplants established with constant overhead irrigation, and interval of (min on/off) 5/15, 10/20, 5/10, and 15/15 [38]. Intermittent irrigation allows for water savings ranging from 50 to 75% of the traditional water used through high-impact sprinklers. Several authors concluded that foliage should not be allowed to wilt, and low humidity and wind speed greater than 16 km/h can accelerate leaf drying. Golden et al. [39] stated "Keen observations during the establishment period will determine intermittent irrigation cycles of transplants that can reduce water usage and fertilizer leaching without affecting early or seasonal fruit yield".

Similarly, low-volume sprinkler irrigation had been reported to be a suitable option for strawberry establishment. In 2011–2012, Santos et al. [29] evaluated intermittent irrigation with sprinklers delivering 5.7 L/min (10 min on and 10 min off), continuous irrigation with sprinklers delivering 5.7 L/min, and continuous irrigation with sprinklers delivering 17 L/min (control). 'Treasure' BR transplants with three to five leaves from a Canadian nursery were planted in early October 2011 in Florida. Data showed no significant differences among treatments for early yield and fruit number, regardless of the water volumes or intermittent scheduling (**Figures 3** and **4**). Low-volume sprinkler irrigation in combination with intermittent irrigation might allow water savings ranging from 16 to 33% compared to traditional overhead irrigation.

4.3 Crop protectants

Another alternative for strawberry establishment are crop protectants [28–30, 40]. Crop protectants provide a shield that reduces environmental stress on plants. Several naturally occurring materials are available in the market for growers for foliar application, such as kaolin clay, calcium carbonate, or aluminum silicate. Kaolin clay is natural degradable white mineral that, when applied to leaves, reflects infrared and ultraviolet radiation, thus reducing temperature rises in the tissue.

During the 2008–2009 and 2009–2010 strawberry seasons in Florida, seven transplant establishment treatments originated from the combination of duration of sprinkler irrigation and kaolin clay foliar application were evaluated. Kaolin clay treatments were applied with a handheld foliar sprayer using a rate of 28 kg/ha. Authors compared 10 days of sprinkler irrigation (control), to 8, 6, and 4 days of sprinkler irrigation with and without a kaolin clay application at next day on

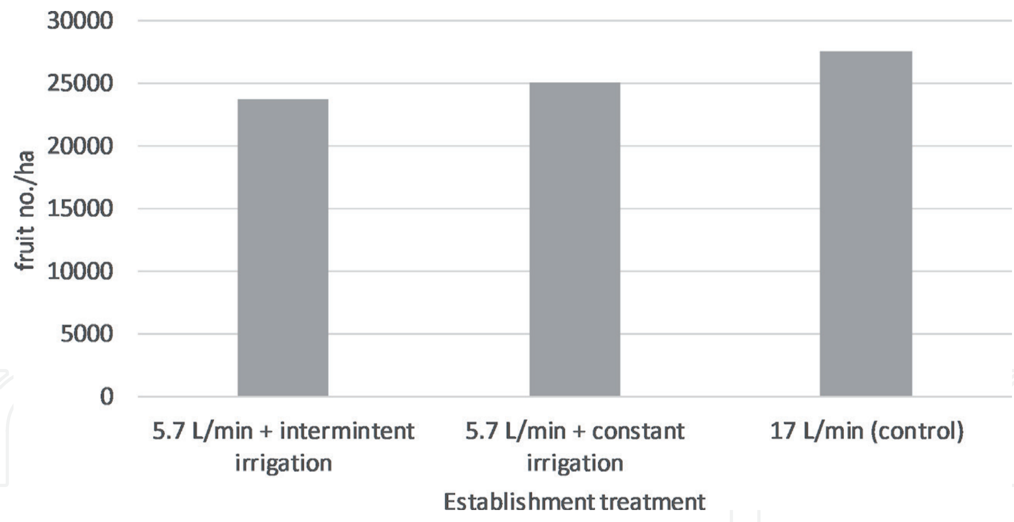

Figure 3.
Effect of irrigation volume and scheduling on strawberry early fruit number at balm, Florida, USA in the 2011–2012 strawberry season [29].

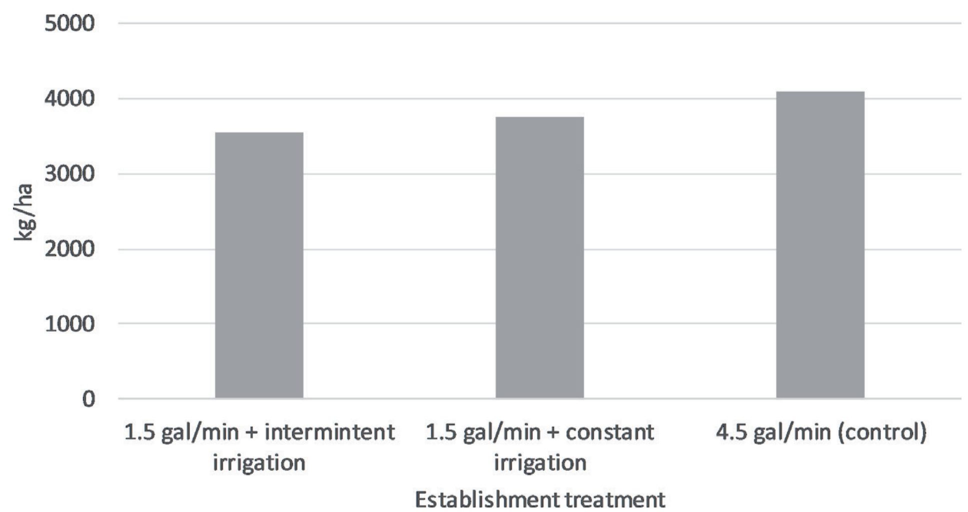

Figure 4.
Effect of irrigation volume and scheduling on strawberry early yield at balm, Florida, USA in the 2011–2012 strawberry season [29].

BR establishment. Data indicated that 6 days of sprinkler irrigation followed by a kaolin clay application at the 7 day resulted in similar early and total yield as 10 days of sprinkler irrigation [28]. Application of this establishment system represents potential water savings of 164,160 gal/acre.

Similarly, Hernández-Ochoa [30] evaluated 10 days of sprinkler irrigation (control) against 7 days of sprinkler irrigation with or without kaolin clay (11 kg/ha), aluminum silicate (11 kg/ha), or calcium carbonate (28 L/ha). Data indicated no difference among control and 7 days of sprinkler irrigation with either kaolin clay, aluminum silicate, or calcium carbonate. Furthermore, 7 days of sprinkler irrigation without a crop protectant application resulted in 22% lower early yield.

Given the promising results on different research stations, Santos et al. [29] evaluated the effect of reduced-volume irrigation programs for strawberry establishment and kaolin clay at larger scale in Plant City, Florida. A study was conducted in Hillsborough County, Florida, at six growers' farms covering 6.4 ha. Authors evaluated 7 days of sprinkler irrigation delivering 17 L/min of water plus kaolin clay in the 8th day at the rate of 28 kg/ha with an application volume of 568 L/ha of water. Additionally, 10 days of sprinkler irrigation delivering 17 L/min of water were used as a control. Experimental plots consistent of an average of 500 plants with six replications. Authors found no differences in plant establishment, leaf greenness, and plant diameter between treatments, with a 30% reduction of irrigation water for establishment. It was estimated that the cost of application of kaolin clay was $90/ha at the moment of the study. This expense was less than three times the cost of diesel fuel needed for the extra 3 days of overhead irrigation.

5. Conclusion

About 14.7 million m^3 of water are used for strawberry establishment in Florida between mid-September and early October. Several research initiatives had been conducted to find alternatives to reduced irrigation water for establishment. Strawberry growers could reduce their consumption of irrigation water for establishment to less than 20% of their current usage, by introducing SP or completely substituting BR for SP transplants in their system. However, the higher prices of SP seem to be a limitation for their implementation, reducing grower's interest into exploring the applications of SP transplants. Additional research is needed to optimize the production of Florida-produced SP. Newly resealed cultivars with tendencies toward day-neutrality ('Florida Beauty') could be a suitable option to increase early yield of SP with no preconditioning.

Alternately, growers could explore the possibility of introducing intermittent irrigation into their system, as research suggest potential water savings of nearly 33% without effecting early or total yield, with minimal modifications to their irrigation systems. Grower's adoption of low-volume sprinkler irrigation seems less likely, as it will involve a higher investment to modify the nozzles and number of sprinkler per acre. In addition, the traditional overhead irrigation currently used for plant establishment is also commonly used to protect the plants against potential cold snaps later in the season.

The less expensive option to reduce irrigation water for establishment is the application of crop protectants. There is a large body of research evaluating the effect of kaolin clay on strawberry establishment, with similar results across seasons and locations. Nevertheless, grower's adoption of this technology has been minimal. It is necessary to increase the efforts of in-farm demonstrations to promote the use of this technology. Additionally, interactions with planting dates and stress reducing amendments, such as silica application should be evaluated. An ideal scenario will combine alternatives to completely eliminate the use of overhead irrigation for establishment. However, there is still a great deal of work needed to increase grower's confidence in these technologies.

Author details

Emmanuel Torres-Quezada[1*], Isabel Torres-Quezada[2]
and Bielinski Marcelo Santos[3]

1 Horticultural Sciences Department, University of Florida, Gainesville, Florida, USA

2 Instituto Hispano-Luso de Investigaciones Agrarias, Universidad de Salamanca, Salamanca, Spain

3 Freedom Ag Research LLC, Riverview, Florida, USA

*Address all correspondence to: etorres1618@ufl.edu

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