Eliminating Sprinkler Irrigation Use in Strawberry Transplant Establishment

Final Report

For the Southwest Florida Water Management District

Submitted by

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1. SUMMARY

The majority of Florida strawberry production utilizes bare-root transplants that require large volumes of sprinkler irrigation for establishment. Although plug transplants can be established without sprinkler irrigation, they are generally more than double the cost of bare-root transplants. We hypothesized that a combined use of plug transplants and heat stress management practices would be an effective strategy for water conservation and improving early yields for strawberry production.

Experiment 1 was conducted with 'Florida Radiance' Jiffy plug transplants on black plastic mulch. Trials were conducted at Citra, FL in 2015-16, 2016-17, and 2017-18 to optimize the rate of s-abscisic acid (s-ABA) for application as a 5-second root dip to reduce transpiration and thus protect strawberry plug transplants from heat stress during early-season transplant establishment. Transplants treated with a single (1X) kaolin spray (56 kg/ha) immediately after transplanting were compared to those that also received a second application at 7 days after transplanting (2X). Rates of s-ABA in the range 250 to 1000 mg mg.L^{-1} were phytotoxic and resulted high transplant mortality and reduced yields. Strawberry growth and development characteristics such as plant survival, plant vigor, photosynthesis, chlorophyll content, days to first flower, leaf area, dry weight of shoots, and marketable yield were adversely affected by abscisic acid rates greater than 100 mg.L^{-1}. Early and season total marketable yields were significantly higher with the 50 and 100 mg.L^{-1} s-ABA treatments. The double application of kaolin resulted in higher photosynthesis at 20 DAT and higher early marketable yield than the single application and improved transplant survival in one of three years and is thus recommended in which heat stress is anticipated.

Experiment 2 was conducted in Citra and Balm, FL in 2016-17 and in 2017-18 'Florida Radiance' plugs were transplanted in September 2016 and 2017 earlier than is typical for Florida strawberry production. Black mulch was compared with white-on-black mulch in the main plots of a split-plot experimental design while in the subplots nontreated Jiffy plug transplants and tray transplants were compared to Jiffy and tray transplants treated with either an s-ABA root dip or a double application of kaolin. Plant growth analysis conducted only at Citra during the first 10 weeks after transplanting (WAT) indicated that leaf number, leaf area, shoot dry weight and root dry weight were greater with white-on-black mulch than with black mulch. Leaf number and leaf area were consistently higher with Jiffy plug transplants with tray transplants although for shoot dry weight this difference was significant only at 4 and 10 WAT.

Early marketable fruit weight in Experiment 2 was higher with white-on-black mulch at Citra averaged over season and in one of the two seasons at Balm. Neither transplant type nor application type significantly affected early marketable fruit weight at Citra. However, at Balm early marketable fruit weight was generally lower with tray transplants than Jiffy plug transplants. The higher season total marketable fruit weight at Citra resulted from white-on black mulch with plug transplants and tray transplants than for black mulch with tray transplants. At Balm, season total marketable fruit weight was higher with black mulch than with white-on-black mulch and greater with plug transplants than tray transplants. Kaolin and s-ABA had no significant effect on season total marketable fruit weight at Citra and in season 1 at Balm. In season 2 at Balm s-ABA treated plants had a lower season total marketable fruit weight than with

the nontreated control and kaolin-treated plants. The results indicate that the best options for improving growth and yield with early planted strawberry plug transplants are white-on-black mulch instead of black plastic mulch and Jiffy plug transplants instead of tray transplants. Neither kaolin nor s-ABA treatment resulted in significantly better growth and yield than nontreated control transplants.

Also of interest was the effectiveness of a system utilizing plug transplants for conserving water use during transplant establishment and its economic feasibility compared with bare-root transplants. Early and total strawberry yield and the water use for production of Jiffy plug transplants on white-on-black plastic mulch (WP) planted in September were compared to those of bare-root transplants set in mid-October on beds mulched with black plastic mulch. 'Florida Radiance' Jiffy plug transplants were established with only drip irrigation and bare-root transplants with sprinkler irrigation. Despite having been planted earlier in the season, due to the elimination of sprinkler irrigation for plug transplant establishment, the WP system considerably decreased water use for the strawberry crop. Irrigation water use was 439,544 gallons per acre lower at Citra and 520,081 gallons per acre lower at Balm with the WP system than the bare-root system. Early yield increased by 683 flats.ac^{-1} (average of both seasons) and 346 flats.ac^{-1} (2017-2018 season) with the WP system at Citra and Balm, respectively, compared to the bare-root system. Total marketable yield with the WP system was 2,062 flats.ac^{-1} (average of both seasons) and 1,917 flats.ac^{-1} (2017-2018 season) greater than with the bare-root system at Citra and Balm, respectively. Partial budget analysis indicated that the WP system at Citra increased the net return by \$14,657 ac^{-1} and by \$13,765 ac^{-1} at Balm. The results indicate that earlier planting using white-on-black mulch and Jiffy plug transplants appears to a viable option for reducing transplant establishment water usage while increasing net income.

2. INTRODUCTION

Strawberries are a very important crop for Florida with a production area of approximately 10,800 ha and a production value of $337 million in 2017 (USDA/NASS, 2018). Florida and California produce about 99% of US strawberries (USDA, 2015). Florida is the leading producer of winter strawberries, although competition for this market has been increasing in recent years from Mexico and California. Shifting strawberry production in Florida to earlier in the season has been suggested as a means of increasing profits in a challenging market (Wu et al., 2015). Early season yields usually receive the best prices, thus providing the highest returns (Chandler et al., 2009). Herrington et al. (2012) found that a 10% reallocation of strawberry yield from late to early season could increase profit by 23% in Queensland, Australia.

Historically, the Florida strawberry industry has used bare-root strawberry transplants from California and Canada on an annual hill system of production. This method depends on high volumes of sprinkler irrigation during the first 10 to 14 days after transplanting to maintain a cool microclimate around the strawberry crowns and roots in order to promote crown health and new root growth. Strawberry establishment from bare-root transplants can utilize as much as 20 inches (equivalent to 540,000 gal/ac with sprinkler irrigation) of water, which is one-third of the total water required for strawberry production (Albregts and Howard, 1985).

In recent years, nurseries have been increasing their production of containerized or plug transplants that are grown from runner tips that are rooted in artificial media. The fragile fine-roots of fresh-dug, bare-root transplants do not survive the trauma of digging, soil removal, shipping, storage, and transplanting. Conversely, plug transplants, grown and shipped in Jiffy plugs and plastic trays have relatively intact root systems that are more efficient at water uptake when transplanted so that just drip irrigation is adequate for their establishment. The use of plug transplants, therefore, can considerably decrease the amount of water required for establishment of a strawberry crop (Santos et al., 2012b). In addition, plug transplants establish more quickly than bare-root transplants under field conditions due to less early establishment stress (Bish et al., 2001; Durner, 1999; Grout and Millam, 1985; Hochmuth et al., 1998; Poling, 1993; Poling and Maas, 2000; Poling and Parker, 1990). Further, plug transplants have superior vigor, resulting in better yield (Styer and Koranski, 1997). Hochmuth et al. (2006) reported that strawberry plug transplants began flowering at 3 weeks after transplanting, but bare-root transplants required a longer time to flower. Therefore, plug transplants may have the potential to provide greater early yield for strawberries and thus more profit to the producer. Additionally, transplanting bare-root plants requires more time and labor than planting plug transplants because bare-root transplants are planted by hand whereas a transplanter can be used for planting plugs (Durner et al., 2002).

However, earlier planting exposes transplants to higher soil and air temperatures, and heat-tolerant Florida-bred strawberry cultivars are not currently available. Heat stress is likely to be a major impediment for the early-season establishment of strawberry plug transplants. Further, recent temperature trends predict potentially more extreme heat stress in the future; there has been an increase of 1-2ºC in the early part of September for the last few years (http://fawn.ifas.ufl.edu/). Long-term temperature trends also need to be addressed since it is anticipated that mean global temperature will increase by 1.5 to 4.5°C during the twenty-first century (Houghton et al., 1992, IPCC, 2007).

High temperature has detrimental effect on strawberry growth and development (Kadir and Shidu, 2006). The optimum temperature for growth and development varies by cultivar. Generally, 30/25°C (day/night) is good for vegetative growth, flowering, and fruiting, and 20/15°C is best. Root growth is seriously affected when temperatures exceed 20/15°C. Moreover, high temperatures (40/35°C or above) are very harmful to photosynthesis and productivity of the plant. Fruit yield may be better at 20/15°C because strawberry plants have better source-sink relationship with those temperatures (Kadir and Shidu, 2006). Further, both day and night temperatures are very important for optimum growth and development of plants. Sometimes high day and night temperature drastically reduce the growth of horticultural crops like tomatoes and strawberries (Adams et. al., 2001, Renquist et al., 1983). Vara-Prasd et al. (1999) reported that high temperatures damage the reproductive system of peanuts. Speaking generally, the thylakoid membranes inside chloroplasts are seriously damaged by high temperatures, reducing the activity of PS II and ultimately hampering the photosynthetic activity of plants (Berry and Bjorkman, 1980). Speaking specifically, various strawberry plant characteristics, such as vegetative growth (Hellman and Travis, 1988), root growth (Fukuda and Matsumoto, 1988), fruit set (Nishiyama et al., 2003), pollen viability (Ledesma and Sugiyama, 2005), and fruit weight (Mori, 1988), are significantly reduced due to extreme temperatures during the strawberry growing period.

Root-zone temperature is important for proper growth of the strawberry plant, (Adebooye et al., 2010; Malik et al., 2013; Yan et al., 2013; Sakamoto and Suzuki, 2015a, 2015b) and air temperatures impact soil temperatures (Sigeno et al., 2001; Kinoshita et al., 2011). Strawberry fruit set is increased by low root-zone temperature (Ikeda et al., 2007). High root-zone temperature (30°C) acts on plant growth and development by decreasing root cell viability and oxygen availability, resulting in plant withering. High root temperatures also significantly impact strawberry photosynthesis and water uptake (Suzuki et al., 2008; He et al., 2013). Biomass production is higher when root-zone temperatures are low (10°C) compared to ambient temperatures (20°C). In contrast, fruit maturation is significantly slower when root-zone temperatures are low (Sakamoto et al., 2016). High temperature acts as a trigger for the strawberry plant to transition from vegetative to reproductive growth of plants (Heide, 1977; Verheul et al., 2006). Soil temperature has a great impact on biomass distribution between shoot and roots (Ericsson et al. 1996, Pregitzer et al. 2000). Finally, soil temperatures also affect the activity of organisms in the soil including increasing the populations of plant pathogens (Gold and Stanghellini, 1985).

Previous research aimed at mitigating heat stress during vegetable transplant establishment has included chemical approaches with substances such as the phytohormone abscisic acid (ABA) and the antitranspirant kaolin to reduce transplant shock, increase heat stress tolerance, and enhance crop establishment for many types of transplants (Racsko et al., 2014). Plants treated with s-ABA exhibit greater stress tolerance capacity and less heat stress. Products such as ConTego™ and ProTone® that contain s-ABA as an active ingredient are registered for heat stress protection in cucurbits, brassica, and fruiting vegetables, as well as leafy vegetables and herbs (Davies and Jones, 1991). Mitigation of water usage may be possible with s-ABA since it triggers stomatal closure and decreased leaf expansion rate. However, negative side effects also are possible at high s-ABA rates, including leaf chlorosis and abscission (Agehara and Leskovar, 2012).

Kaolin, an organic mineral compound rich in kaolinite, has had widespread use mitigating heat and drought stress in various crops. Spray application of kaolin (Surround® WP) results in a white film on the foliage of treated plants, which increases the reflection of incoming solar radiation, changing the radiation and heat balance and reducing the risk of heat stress from high temperatures and solar injury (Glenn, 2012; Rosati et al., 2006). Boari et al. (2015) and El-Khawaga (2013) reported that the anti-transpirant effect of kaolin is a very effective means of promoting transplant establishment. Kaolin-treated grape vines exhibited less heat stress and improved water use efficiency than the nontreated control (Shellie and Glenn, 2010). Santos et al. (2012b) found that kaolin can reduce water needs for bare-root strawberry transplant establishment by 30% and increases the capacity of the plants to withstand low soil moisture conditions. Moreover, the tissue of kaolin-treated plants is cooler than that of non-treated plants, and kaolin helps to protect plants from extreme heat and water loss due to radiation and transpiration, respectively, an effect which is attributed to the reflective properties of kaolin (Glenn et al., 2010; Nakano and Uehara, 1996). Kaolin can also be used to mitigate heat stress of the early fruit, maintain lower interior temperatures, and increase strawberry fruit size (Santos et al., 2012a).

Another method of managing heat stress in strawberries during early-season establishment maybe the use of reflective plastic mulch to moderate soil temperature. In strawberry production mulching plays a vital role in soil moisture conservation, weed control, regulation of soil-hydrothermal regime, and keeping the fruit clean. Commercial strawberry production in Florida utilizes black plastic mulch to provide warmer soil temperatures that confer frost protection as well as more optimal growth and yield when the weather is very cool. In vegetable production, white-on-black polyethylene film mulch is often used to reduce heat and water stress (Tarara, 2000). Plastic mulches predominantly affect the field microclimate by modifying surface radiation and inhibiting soil water evaporation. These microclimate factors have a large effect on the soil temperature and soil moisture in the root zone, which in turn may influence plant growth and productivity, enhancing yield quality of the crops (Ham et al., 1993). Mulching improves plant growth, berry weight, fruit yield, and strawberry quality.

While various synthetic and organic mulching materials are used in different parts of the world, black polyethylene film is the most widely used (Singh et al., 2006). High soil temperature beneath black polyethylene film is due to high shortwave absorptance of the film and conduction of heat from the film to the soil (Ham et al., 1993). Black mulches are, therefore, useful for maintaining warm soil temperatures appropriate for crop growth during cool weather (Bonanno and Lamont Jr., 1987; Ham et al., 1993; Teasdale and Abdul-Baki, 1995). Red and red-on-black films had a greater effect on strawberry yield and quality than black film (El-Yazied and Mady, 2012). Compared with black plastic mulch, clear/transparent plastic mulches absorb very little solar radiation and transmit around 85% to 95% depending on the thickness of the polyethylene (Hancock, 1999; Lament Jr., 1993; Sharma et al., 2004; Sharma et al., 2006). Loy et al. (1989) and William and Lament (1993) found that white or white-on-black mulches reduce soil temperature around 1.1°C compared to open soil because white mulches reflect most of the incoming solar radiation.

Partial budgeting is an effective tool used to evaluate the costs and benefits related to a precise change in a farm. This tool explicitly focuses on the consequences of the projected change in a farming operation by comparing the costs and benefits of the change with respect to the previous system (Tinger, 2006). This budgeting style is named partial because it does not comprise all costs, but only those altered from the farmer's present production practices to the projected one(s) (Roth, 2002). Alimi and Alofe (1992) reported that farmers are always making changes in their farms for optimum effectiveness and to accommodate changes between seasons and over time. Often, these choices include activities to boost monetary return of the farm, whereas other times these choices are required to diminish the effects of unfavorable conditions. Substitutions within an individual business can have a strong impact on farm viability and competitiveness in the larger market. Therefore, drawing the best conclusions may make the difference between revenue and loss for that business. New technology can be assessed in terms of its impact on the productivity, effectiveness, convenience and sustainability of a farming system (Herdt, 1987). Hochmuth et al. (2006) conducted a partial budget analysis that indicated that although plug transplants cost $1,853 more per acre, higher early yield offset the higher cost of production and resulted in a net return of $1,142 per acre beyond the offset higher cost. It is anticipated that strawberry transplants established earlier in the season to make strawberries available for Thanksgiving, Christmas, and Hanukkah can produce strawberries with price premiums that accommodate for the higher cost of plug transplants.

The overall objective of the project was to evaluate the effects of preplant kaolin, abscisic acid, and white-on-black polyethylene mulch on containerized strawberry transplant establishment, growth, and yield. The hypothesis was that chemical and physical methods can be used to mitigate heat stress that accompanies earlier planting of strawberries, resulting in enhanced early yields and greater profit.

3. EXPERIMENT 1: OPTIMIZATION OF HEAT STRESS MITIGATION MEASURES FOR STRAWBERRY PLUG TRANSPLANT ESTABLISHMENT

The objective of this experiment was to determine the optimum rate of s-ABA and to compare single and double applications of kaolin on the mitigation of heat stress during the early-season establishment of strawberry plug transplants.

Materials and Methods

In order to determine the effect of s-ABA and kaolin on heat stress mitigation during strawberry plug transplant establishment, an experiment was conducted at the Plant Science Research and Education Unit (PSREU), in Citra, FL, during the 2015–2016, 2016–2017 and 2017-2018 seasons. ‘Florida Radiance’ strawberry transplants grown in Jiffy peat pellets were used as the planting material. The experiment was laid out in a randomized complete block design with seven treatments and four replications. Three weeks prior to transplanting, the soil was fumigated (300 $lb.acre^{-1}$ Pic Clor 60) and the beds (7 inches tall x 30 inches wide) were prepared. Black plastic mulch was applied immediately after soil fumigation. Forty strawberry transplants per plot were set in two offset rows spaced one foot apart. The within-row spacing was also one foot. During the 2015–2016 season a-ABA (ProTone®, Valent USA Corp., Walnut Creek, CA) was applied at 250, 500, 750, and 1000 $mg.L^{-1}$, respectively, as a 5-second root dip just prior to transplanting. The rates were decreased in subsequent seasons to 100, 150, 200, and 250 $mg.L^{-1}$ in 2016–2017 and to 50, 100, 150, and 200 $mg.L^{-1}$ in 2017-2018. In both seasons, kaolin (Surround®, NovaSource, Phoenix, AZ) treatments (50 $lb.acre^{-1}$) were applied as foliar sprays with a backpack CO_2 sprayer: either a single spray application shortly after transplanting (1X) or two sequential spray applications (2X), the first at the time of the single spray application and the second at 7 days after planting. The seventh treatment was a nontreated control.

Net CO_2 assimilation rate was measured on the most recent fully-expanded trifoliate leaf using a portable photosynthesis system (LI - 6400 XT, LI-COR Inc., Lincoln, NE) on 2 plants per plot between 12 pm and 2 pm and exposed to 500 μ mol. $m^{-2}s^{-1}$ PPFD and a CO_2 concentration of 400 μ $L{\cdot}L^{-1}$. Photosynthesis data were collected in 2016-2017 and 2017-2018 growing season at 1 and 20 days after transplanting (DAT). Plant vigor was assessed using a scale of 0 to 10 with 0 being dead plants and 10 being the most vigorous plants. The number of surviving transplants was assessed at 2 and 4 weeks after transplanting and those data were used to calculate the percentage of strawberry transplant survival. Chlorophyll content was measured on the most recent fully expanded trifoliate leaf of sample plants using a SPAD 502 Plus Chlorophyll Meter (Spectrum Technologies, Inc., Aurora, IL).

Results

Effects of s-ABA on plant parameters and flowering

Photosynthesis and chlorophyll content. Photosynthesis was not measured during the 2015-2016 season. During the 2016-2017 and 2017-2018 growing seasons, photosynthesis was significantly affected by abscisic acid (s-ABA) at 1 day after transplanting, but the effect was no longer significant by 20 days after transplanting (Fig. 3-1). At 1 day after transplanting the effect of s-ABA application rate on photosynthesis was best described with a quadratic polynomial model with photosynthesis decreasing as s-ABA rates increased (Fig. 3-1). The decrease in photosynthesis was expected since our intention was to induce transient closure of the stomata, in order to protect transplants from heat stress related to wilting.

No significant effect on chlorophyll content was observed in response to s-ABA in 2015-2016 (Fig. 3-2). In 2016-2017, chlorophyll content was stimulated at 100 $mg.L^{-1}$ and 50 $mg.L^{-1}$ and declined with the 150, 200 and 250 $mg.L^{-1}$ s-ABA treatments. This suggests that the lower rates may offer good protection from heat stress, whereas the higher rates may induce some phytotoxicity (Fig. 3-2).

Survival, vigor, and days to first flower. In all three growing seasons, transplant mortality increased and plant vigor declined as rate of s-ABA increased (Figs. 3-3 and 3-4). In 2015-2016 and 2016-2017 days to first flower decreased as s-ABA increased (Fig. 3-5). However, in 2017-2018, s-ABA-treated plants responded differently, and plants treated with the 50 $mg.L^{-1}$ s-ABA flowered earlier than the control but transplants treated with the 150 and 200 $mg.L^{-1}$ rates of s-ABA began to flower after the nontreated control.

Effects of s-ABA on plant growth and productivity

Leaf number, leaf area, crown diameter, plant biomass. The effects of s-ABA application rate on plant parameters are shown in Figures 3-6 and 3-7. When leaf area and shoot dry weight were averaged over sampling date starting 30 days after transplanting, different s-ABA application rates produced significant differences. The significant quadratic model indicates suppression of leaf area and shoot dry weight with s-ABA rates greater than 50 $mg.L^{-1}$ (Figs. 3-6 and 3-7). However, for leaf number, crown diameter, and dry weight of roots the responses to s-ABA were not significant. The 50 $mg.L^{-1}$ rate appeared to have provided protection from injury and facilitated leaf and shoot growth while the higher rates appeared to have inhibited growth (Figs. 3-6 and 3-7).

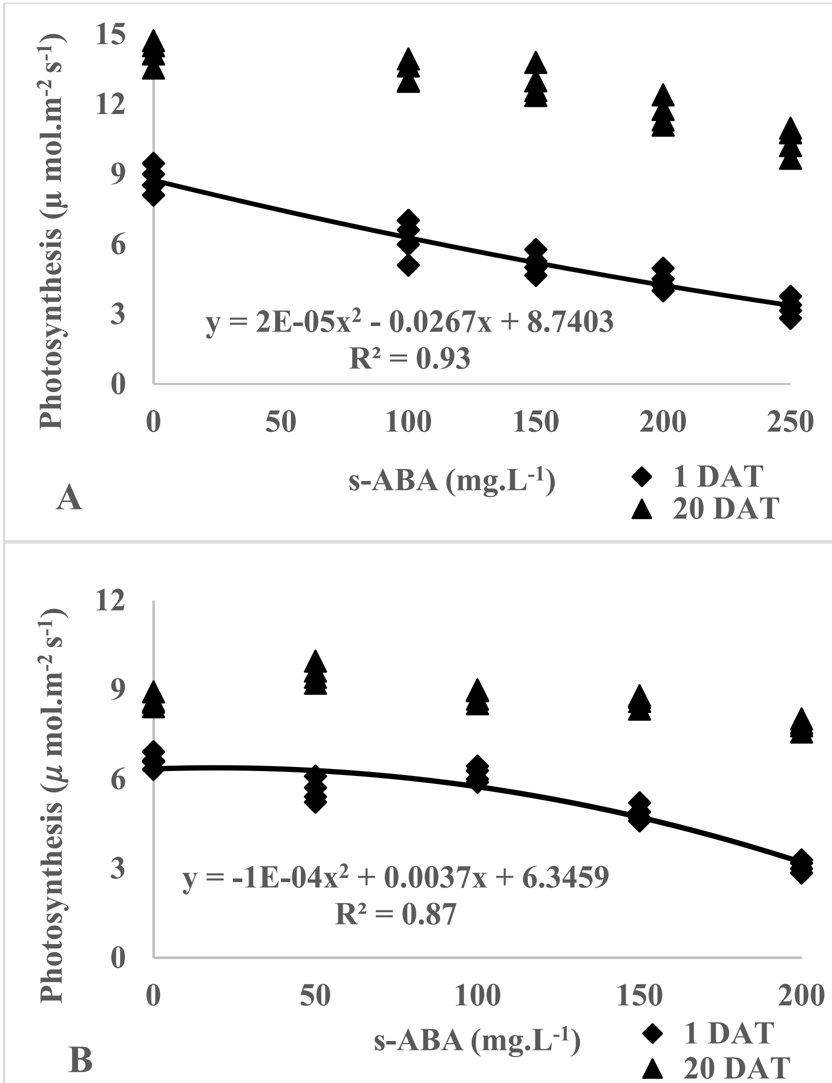

Figure 3-1. Effect of s-ABA application 1 day and 20 days after transplanting on photosynthesis. A. 2016-2017 and B. 2017-2018. A quadratic polynomial regression line indicates significant differences, and no line indicates non-significance.

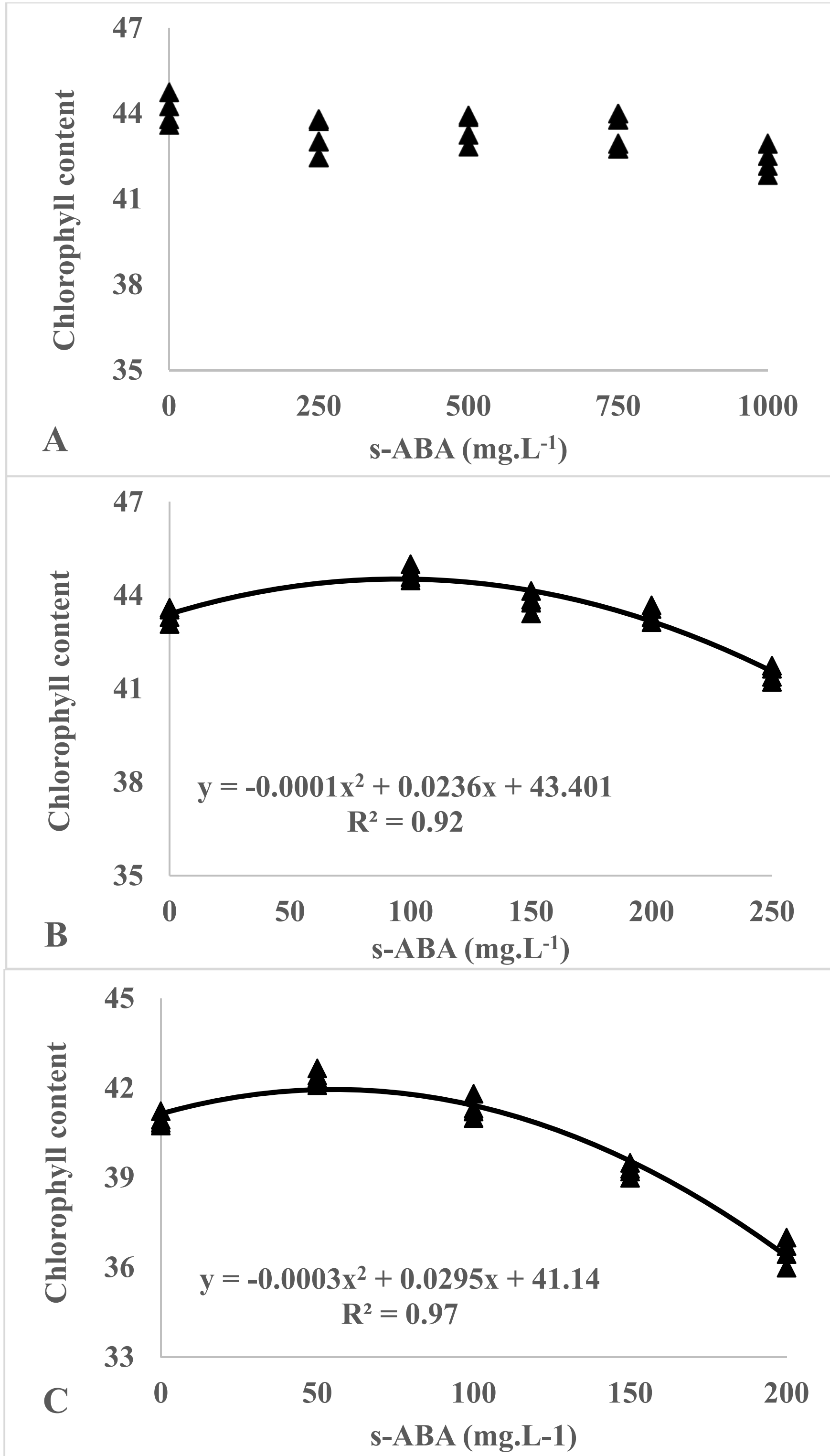

Figure 3-2. Effect of s-ABA application on chlorophyll content averaged over sampling date A. 2015-2016, B. 2016-2017, and C. 2017-2018. A quadratic polynomial regression line indicates significant differences, and no line indicates non-significance.

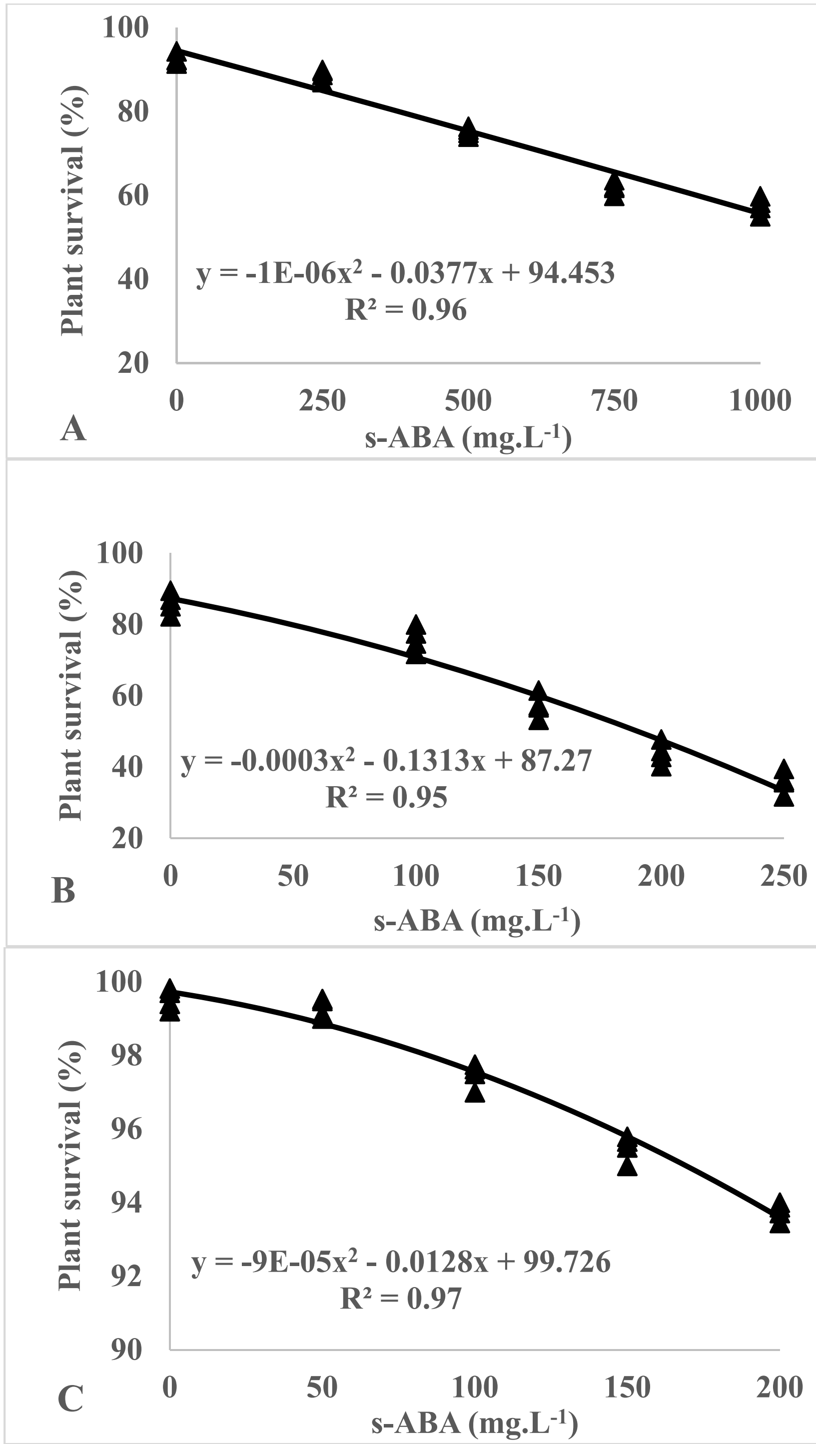

Figure 3-3. Effect of s-ABA application on plant survival averaged over sampling date. A. 2015-2016, B. 2016-2017, and C. 2017-2018. A quadratic polynomial regression line indicates significant differences.

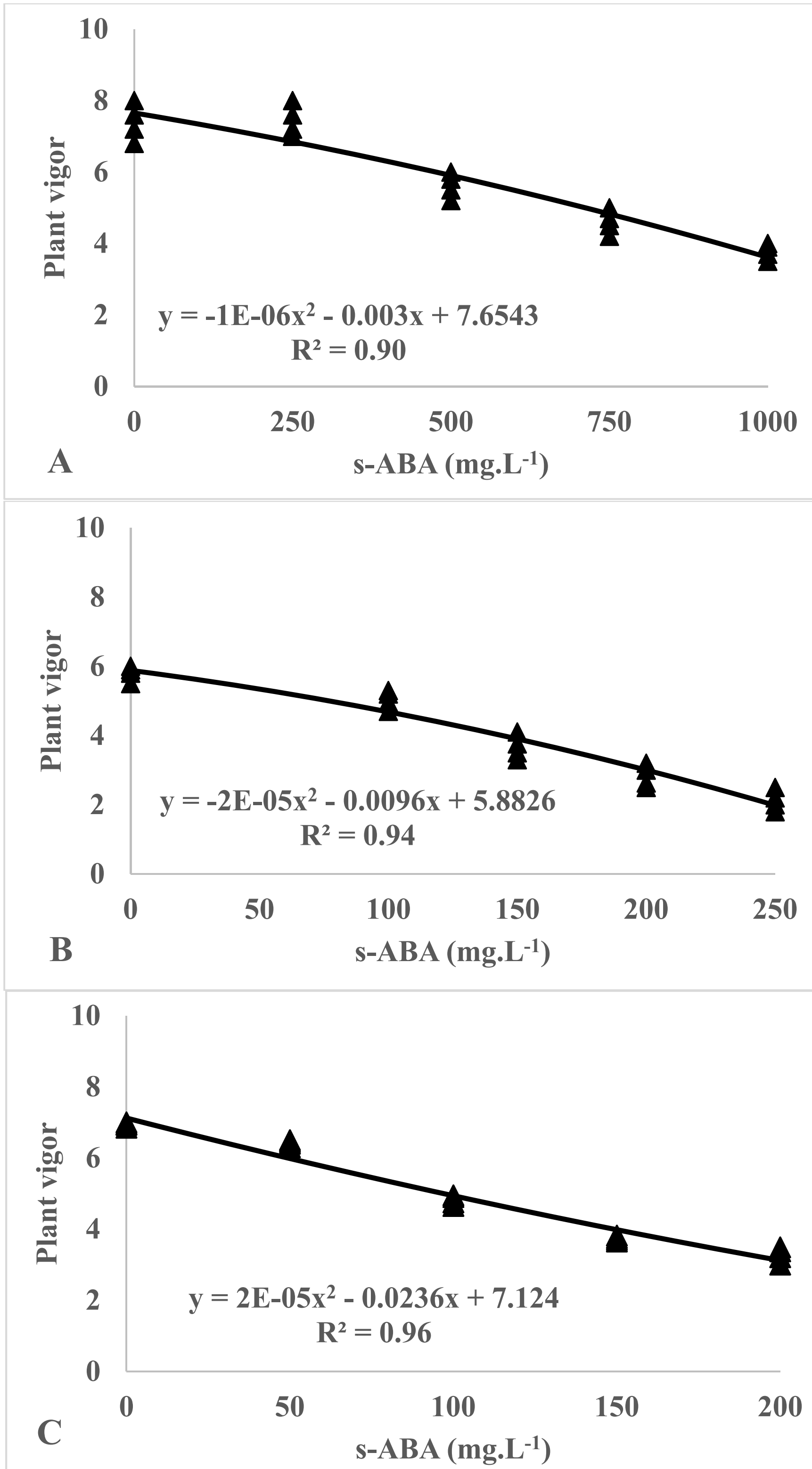

Figure 3-4. Effect of s-ABA application on plant vigor averaged over sampling date. A. 2015-2016, B. 2016-2017, and C. 2017-2018. A quadratic polynomial regression line indicates significant differences.

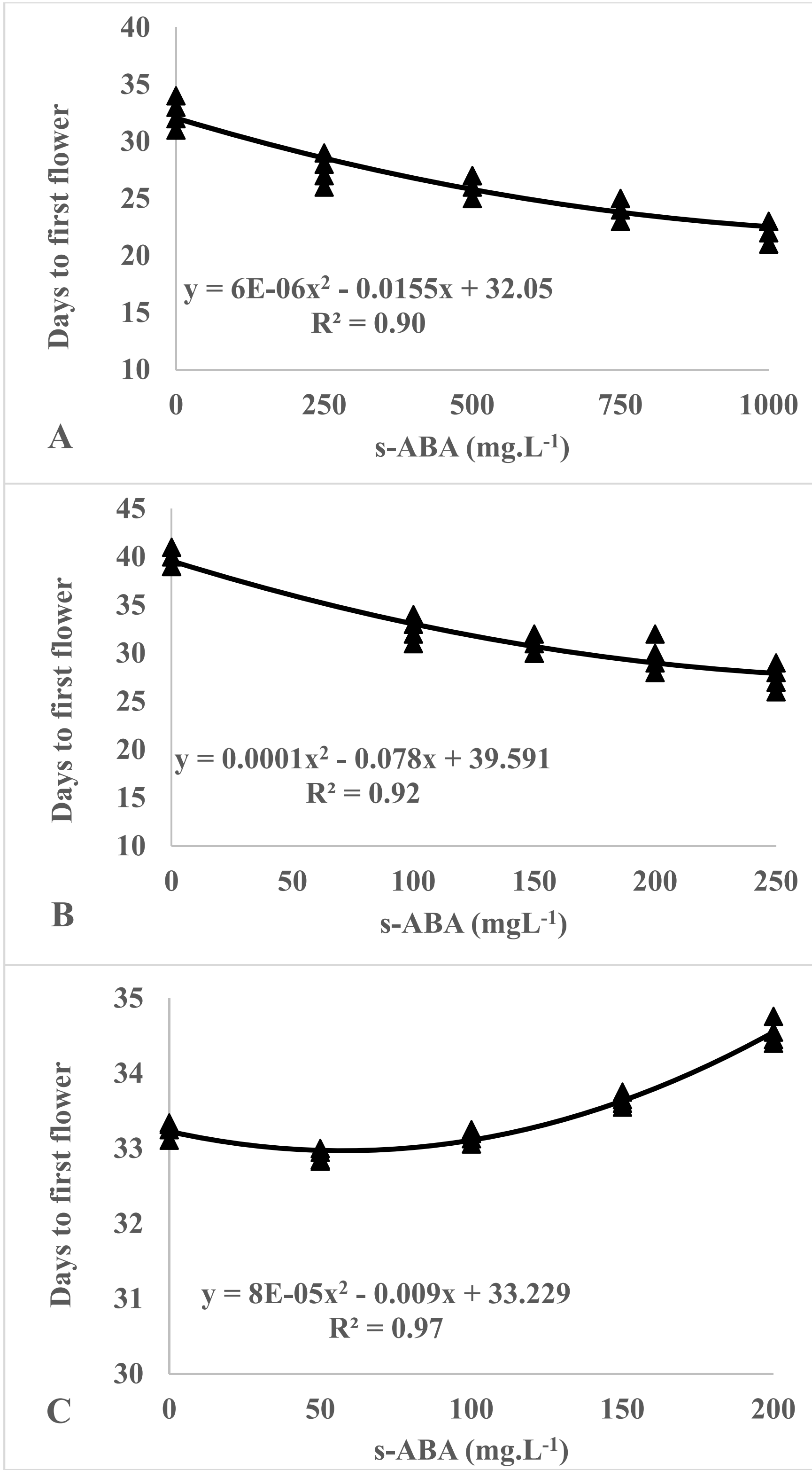

Figure 3-5. Effect of s-ABA application rate on days to first flower. A. 2015-2016, B. 2016-2017, and C. 2017-2018. A quadratic polynomial regression line indicates significant differences.

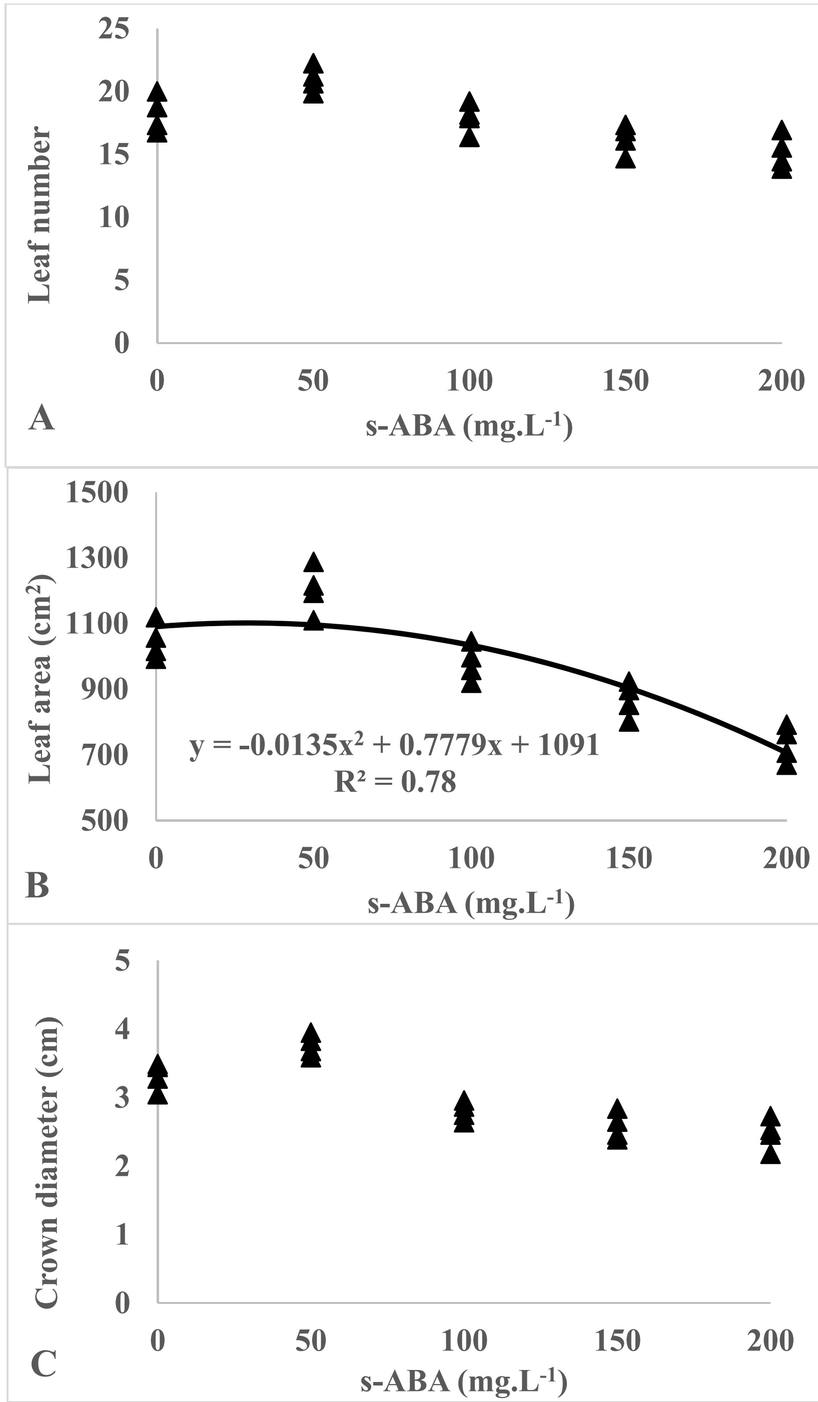

Figure 3-6. Effect of s-ABA application on A. leaf number, B. leaf area (cm^2), and C. crown diameter (cm) averaged over sampling date (2017-2018 growing season). A quadratic polynomial regression line indicates significant differences, and no line indicates non-significance.

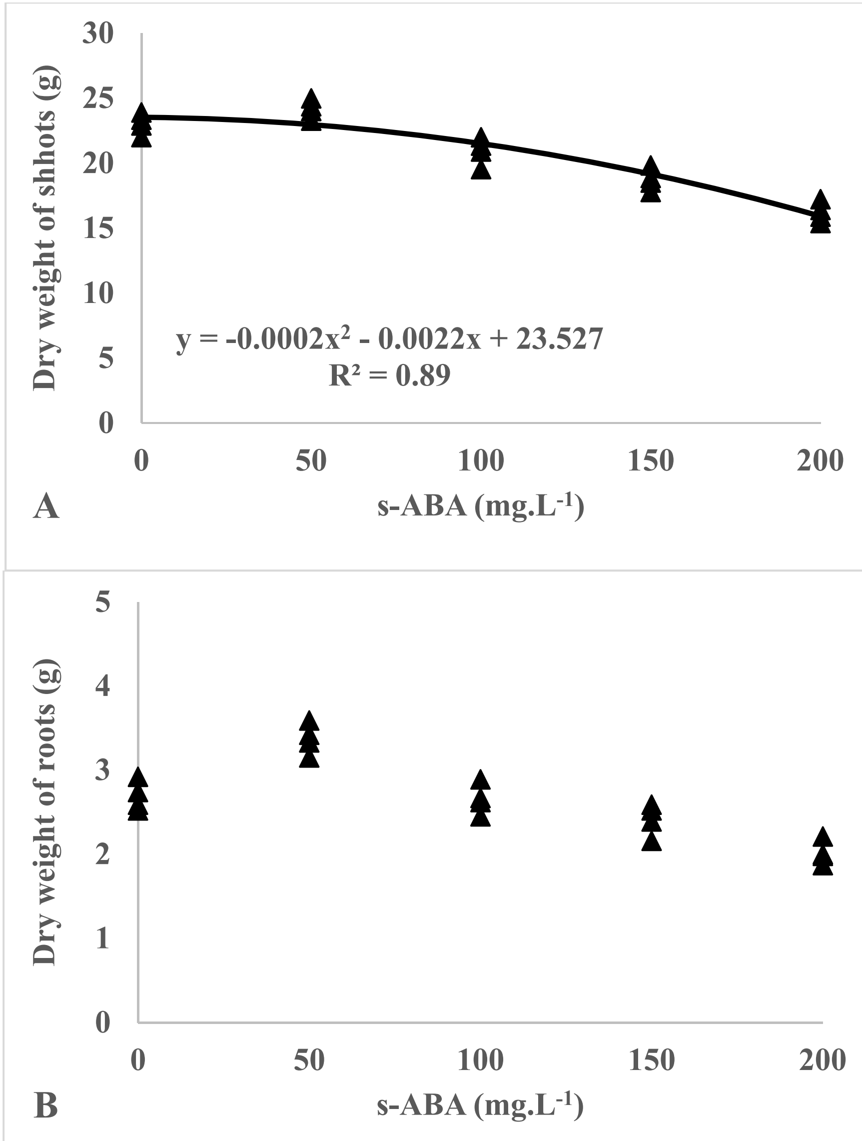

Figure 3-7. Effect of s-ABA application on A. dry weight of shoots and B. dry weight of roots averaged over sampling date (2017-2018 growing season). A quadratic polynomial regression line indicates significant differences, and no line indicates non-significance.

Effects of s-ABA on fruit yield

The response of early fruit yield and season total yield to s-ABA was quadratic (Tables 3-1, 3-3, and 3-5). Whereas all rates of s-ABA suppressed early and season total yields in 2015-2017 when s-ABA rates of 250 to 1000 $mg.L^{-1}$ were used, the lowest rates used in 2016-2017 (100 $mg.L^{-1}$) and 2017-2018 (50 $mg.L^{-1}$) resulted in the highest yields indicating that low rates of s-ABA can be successfully used for heat stress protection in early planted Jiffy plug transplants on black plastic mulch. The yield of cull fruits declined in a quadratic manner with increasing s-ABA rate all three seasons (Tables 3-2, 3-4 and 3-6).

Table 3-1. Effect of s-ABA application on yield of early and total marketable fruits, 2015-2016

s-ABA rate ($mg.L^{-1}$)	Nov.	Dec.	Jan.	Feb.	Early	Season total
	Marketable fruit number.h^{-1}					
0	10,123	61,532	132,696	223,237	71,655	427,588
250	6,325	49,231	109,234	181,423	55,556	346,213
500	5,231	38,190	90,324	134,067	43,421	267,812
750	3,563	29,689	58,310	90,428	33,252	181,990
1000	1,321	17,573	34,527	56,194	18,894	109,615
Significance						
Quadratic	**	*	*	**	*	**
	Marketable fruit weight ($t.ha^{-1}$)					
0	0.17	1.53	3.91	4.96	1.70	10.57
250	0.08	0.96	3.55	4.23	1.04	8.82
500	0.04	0.59	2.42	3.86	0.63	6.91
750	0.03	0.37	1.98	2.37	0.40	4.75
1000	0.01	0.21	1.03	1.87	0.22	3.12
Significance						
Quadratic	**	*	*	*	*	**

Early yield – November to December, Season total- November to February, *, **, significant at $P < 0.05$ and 0.01, respectively

Table 3-2. Effect of s-ABA application on yield of early and season total unmarketable fruits, 2015-2016

s-ABA rate ($mg.L^{-1}$)	Nov.	Dec.	Jan.	Feb.	Early	Season total
	Cull fruit number.h^{-1}					
0	4,296	21,452	34,731	87,502	25,748	147,981
250	2,186	14,385	21,256	65,319	16,571	103,146
500	1,567	10,329	15,502	42,673	11,896	70,071
750	1,123	7,192	9,423	21,432	8,315	39,170
1000	567	4,271	7,406	10,567	4,838	22,811
Significance						
Quadratic	*	*	*	**	*	*
	Cull fruit weight ($t.ha^{-1}$)					
0	0.05	1.03	1.89	2.67	1.08	5.64
250	0.02	0.23	1.22	1.96	0.25	3.43
500	0.02	0.16	0.78	1.45	0.18	2.41
750	0.01	0.10	0.56	1.10	0.11	1.77
1000	0.01	0.04	0.12	0.87	0.05	1.04
Significance						
Quadratic	NS	*	*	**	*	**

Early yield – November to December, Season total- November to February, NS, *, ** Nonsignificant or significant at $P < 0.05$ and 0.01, respectively.

Table 3-3. Effect of s-ABA application on yield of early and total marketable fruits, 2016-2017

s-ABA rate ($mg.L^{-1}$)	Nov.	Dec.	Jan.	Feb.	Early	Season total
	Marketable fruit number.h^{-1}					
0	13,778	122,278	367,696	519,253	136,056	1,023,005
100	22,383	129,597	383,626	528,294	151,980	1,063,900
150	12,056	111,083	329,375	440,891	123,139	882,640
200	6,889	98,167	285,469	430,126	105,056	824,527
250	3,445	40,042	111,945	191,168	43,487	343,155
Significance						
Quadratic	NS	*	NS	NS	*	*
	Marketable fruit weight ($t.ha^{-1}$)					
0	0.21	2.53	11.18	14.61	2.74	28.53
100	0.34	2.61	11.21	15.96	2.94	30.12
150	0.19	2.30	9.73	13.35	2.49	25.57
200	0.11	1.98	8.20	11.56	2.09	21.85
250	0.06	0.79	3.07	4.86	0.85	8.78
Significance						
Quadratic	NS	*	**	*	*	**

Early yield – November to December, Season total- November to February, NS, *, ** Nonsignificant or significant at $P < 0.05$, and 0.01, respectively.

Table 3-4. Effect of s-ABA application on yield of early and total unmarketable fruits, 2016-2017

s-ABA rate (mg.L^{-1})	Nov.	Dec.	Jan.	Feb.	Early	Season total
	Cull fruit number.h^{-1}					
0	8,611	41,333	46,500	220,014	49,944	316,458
100	6,028	37,458	52,528	179,972	43,486	275,986
150	4,306	36,167	46,069	179,111	40,473	265,653
200	2,153	32,292	42,625	136,917	34,445	213,987
250	1,722	10,333	11,625	75,778	12,055	99,458
Significance						
Quadratic	NS	NS	NS	NS	NS	*
	Cull fruit weight (t.ha^{-1})					
0	0.09	0.50	1.06	3.58	0.59	5.23
100	0.08	0.49	1.08	3.13	0.57	4.78
150	0.04	0.45	1.03	2.84	0.49	4.36
200	0.03	0.43	1.01	2.49	0.46	3.96
250	0.03	0.13	0.27	1.00	0.16	1.43
Significance						
Quadratic	NS	NS	NS	NS	*	*

Early yield – November to December, Season total- November to February, NS, *, Nonsignificant or significant at $P < 0.05$.

Table 3-5. Effect of s-ABA application on yield of early and total marketable fruits, 2017-2018

s-ABA rate (mg.L^{-1})	Nov.	Dec.	Jan.	Feb.	Early	Season total
	Marketable fruit number.h^{-1}					
0	95,153	89,986	297,945	477,917	185,139	961,001
50	117,542	95,153	364,250	550,681	212,695	1,127,626
100	93,112	85,681	270,820	532,598	178,793	982,211
150	89,067	83,097	241,972	522,264	172,164	936,411
200	69,320	81,375	237,236	431,417	150,695	819,348
Significance						
Quadratic	NS	NS	NS	NS	NS	*
	Marketable fruit weight (t.ha^{-1})					
0	1.35	2.03	10.60	13.18	3.38	27.16
50	1.65	2.30	12.53	15.01	3.95	31.49
100	1.32	1.61	9.80	14.38	2.93	27.11
150	1.28	1.59	8.59	14.22	2.87	25.68
200	0.94	1.48	7.66	11.37	2.42	21.45
Significance						
Quadratic	NS	NS	**	NS	*	*

Early total – November to December, Season total- November to February, NS, *, **, Nonsignificant or significant at $P < 0.05$ and 0.01, respectively.

Table 3-6. Effect of s-ABA application on yield of early and total unmarketable fruits, 2017-2018

s-ABA rate ($mg.L^{-1}$)	Nov.	Dec.	Jan.	Feb.	Early	Season total
	Cull fruit number.h^{-1}					
0	85,458	38,750	44,778	214,847	124,208	383,833
50	82,236	34,875	38,319	191,597	117,111	347,027
100	52,097	32,292	31,000	182,125	84,389	297,514
150	34,014	21,097	24,452	180,834	55,111	260,397
200	32,722	13,347	18,514	177,820	46,069	242,403
Significance						
Quadratic	NS	NS	NS	NS	*	*
	Cull fruit weight ($t.ha^{-1}$)					
0	0.69	0.30	1.06	4.12	0.99	6.17
50	0.55	0.22	0.97	3.70	0.77	5.44
100	0.37	0.21	0.76	3.60	0.58	4.94
150	0.25	0.15	0.62	2.99	0.40	4.01
200	0.23	0.13	0.56	2.88	0.36	3.80
Significance						
Quadratic	**	*	NS	NS	**	*

Early total – November to December, Season total- November to February, NS, *, **, Nonsignificant or significant at $P < 0.05$ and 0.01, respectively.

Effects of kaolin application on plant parameters and flowering

Photosynthesis and chlorophyll content. Photosynthesis rates 1 day after transplanting were higher in kaolin-treated plants than the nontreated control (Table 3-7). This suggests that the kaolin-treated plants were experiencing less heat stress than the nontreated control plants so that there was either no impairment or less impairment of photosynthesis. By 20 days after transplanting, a similar though slightly different trend was observed. Plants that had received the two sequential sprays of kaolin had a higher rate of photosynthesis than the nontreated control plants. There was no significant difference in photosynthesis between two sequential sprays of kaolin and single spray of kaolin, but there was also no significant difference between the plants that had received the single kaolin treatment and nontreated control plants (Table 3-7). Unlike with photosynthesis, no difference in chlorophyll levels occurred in response to kaolin application (Table 3-8).

Survival, vigor, and days to first flower. Unlike s-ABA, kaolin application improved strawberry plant survival and vigor. At 2 weeks after transplanting, no difference in plant survival and vigor was apparent (Tables 3-9 and 3-10). By 4 weeks after transplanting, the effect of kaolin on plant survival and vigor varied with season (Tables 3-9 and 3-10). There was no difference due to kaolin application in seasons 1 and 3, whereas two sequential kaolin sprays resulted in better transplant survival than the untreated control in season 2 (Tables 3-9). Similarly, kaolin affected days to first flower only in 2016-2017 with kaolin-treated plants flowering 5-6 days earlier than the nontreated control (Table 3-11). No significant difference in flowering occurred due to the second application of kaolin compared to a single application.

Table 3-7. Effect of kaolin application on photosynthesis

Treatment	Photosynthesis (µmol.m^{-2} s^{-1})	
	1 DAT	20 DAT
Application (A)		
Control	8.4 b	11.5 b
Kaolin 1X	9.7 a	12.8 ab
Kaolin 2X	10.3 a	14.1 a
Significance		
Season (S)	*	**
Application (A)	*	*
S x A	NS	NS

Means followed by the same letters within each day after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. DAT-Day after transplanting, 1X- single kaolin spray and 2X-double kaolin spray at 50 lb.acre^{-1}, Season 2- 2016-2017 growing season, Season 3- 2017-2018 growing season, NS, *, ** Nonsignificant or significant at P<0.05, and 0.01, respectively

Table 3-8. Effect of kaolin application on chlorophyll content.

Treatment	Chlorophyll content				
	1 WAT	2 WAT	3 WAT	4 WAT	At final harvest
Application (A)					
Control	37.2	42.0	46.3	46.4	45.9
Kaolin 1X	38.4	42.7	47.1	46.5	45.8
Kaolin 2X	39.9	43.0	47.1	48.4	46.4
Significance					
Season (S)	**	*	*	NS	NS
Application (A)	NS	NS	NS	NS	NS
S x A	NS	NS	NS	NS	NS

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-Week after transplanting, 1X- single kaolin spray and 2X-double kaolin spray at 50 lb.acre^{-1}, Season 1- 2015-2016 growing season, Season 2- 2016-2017 growing season, Season 3- 2017-2018 growing season, NS, *, ** Nonsignificant or significant at P<0.05, and 0.01, respectively

Table 3-9. Effect of kaolin application on plant survival.

Treatment	Plant survival (%)			
	2 WAT	4 WAT		
Application (A)		S_1	S_2	S_3
Control	96.5	99.5 ab	85.4 c	100.0 a
Kaolin 1X	96.0	99.3 ab	88.2 bc	98.3 ab
Kaolin 2X	98.1	100.0 a	94.2 ab	99.3 ab
Significance				
Season (S)	**		**	
Application (A)	NS		*	
S x A	NS		*	

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-Week after transplanting, 1X- single kaolin spray and 2X-double kaolin spray at 50 $lb.acre^{-1}$, S_1- 2015-2016 growing season, S_2- 2016-2017 growing season, S_3- 2017-2018 growing season, NS, *, ** Nonsignificant or significant at $P < 0.05$, and 0.01, respectively

Table 3-10. Effect of kaolin application on plant vigor.

Treatment	Plant vigor			
	2 WAT	4 WAT		
Application (A)		S_1	S_2	S_3
Control	6.0	8.7 ab	5.6 c	7.4 abc
Kaolin 1X	5.5	8.0 abc	6.4 bc	7.9 abc
Kaolin 2X	6.8	9.1 a	7.2 abc	8.5 ab
Significance				
Season (S)	NS		*	
Application (A)	NS		NS	
S x A	NS		*	

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-Week after transplanting, 1X- single kaolin spray and 2X-double kaolin spray at 50 $lb.acre^{-1}$, S_1- 2015-2016 growing season, S_2- 2016-2017 growing season, S_3- 2017-2018 growing season, NS, * Nonsignificant or significant at $P<0.05$

Table 3-11. Effect of kaolin application on days to first flower.

Treatment	Days to first flower		
Application (A)	S_1	S_2	S_3
Control	16.5 c	38.3 a	31.9 b
Kaolin 1X	16.1 c	33.3 b	30.1 b
Kaolin 2X	15.2 c	31.8 b	32.7 b
Significance			
Season (S)		***	
Application (A)		***	
S x A		**	

Means with the same letters within columns do not differ significantly whereas means with dissimilar letters differ significantly as per Tukey HSD test. 1X- single kaolin spray and 2X-double kaolin spray at 50 $lb.acre^{-1}$, S_1- 2015-2016 growing season, S_2- 2016-2017 growing season, S_3- 2017-2018 growing season, **, *** significant at $P < 0.01$, and 0.001, respectively

Effects of kaolin application on plant growth and productivity

Leaf number, leaf area, crown diameter, and plant biomass. Results are reported for samples collected at 4, 6, 8, and 10 weeks after transplanting (WAT) and at final harvest. No significant difference in plant growth occurred in response to kaolin application (Tables 3-12 to 3-14).

Table 3-12. Effect of kaolin application on leaf number and leaf area.

	Leaf number					Leaf area (cm^2)				
Treatment	4 WAT	6 WAT	8 WAT	10 WAT	At final harvest	4 WAT	6 WAT	8 WAT	10 WAT	At final harvest
Application (A)										
Control	5.4	8.1	11.5	17.2	33.6	159	300	562	912	2182
Kaolin 1X	6.0	7.9	13.4	17.0	38.7	159	297	629	844	2677
Kaolin 2X	6.3	8.7	13.5	17.4	41.8	204	343	646	896	2883
Significance										
Season (S)	**	**	*	*	NS	NS	NS	*	***	NS
Application (A)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-Week after transplanting, 1X- single kaolin spray and 2X-double kaolin spray at 50 $lb.acre^{-1}$, Season 1- 2015-2016 growing season, Season 2- 2016-2017 growing season, Season 3- 2017-2018 growing season, NS, *, ** Nonsignificant or significant at $P<0.05$, and 0.01, respectively

Table 3-13. Effect of kaolin application on crown diameter (cm).

Treatment	Crown diameter (cm)						
	4 WAT	6 WAT	8 WAT	10 WAT	At final harvest		
Application (A)					S_1	S_2	S_3
Control	1.0	1.4	2.1	2.6	3.6 cd	5.5 ab	5.0 bc
Kaolin 1X	1.0	1.4	2.1	2.7	3.4 d	6.1 ab	5.8 ab
Kaolin 2X	1.1	1.5	2.2	2.6	3.6 cd	6.7 a	5.4 ab
Significance							
Season (S)	***	***	**	***		***	
Application (A)	NS	NS	NS	NS		**	
S x A	NS	NS	NS	NS		**	

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-Week after transplanting, 1X- single kaolin spray and 2X-double kaolin spray at 50 lb.acre^{-1}, S_1- 2015-2016 growing season, S_2- 2016-2017 growing season, S_3- 2017-2018 growing season, NS, **, *** Nonsignificant or significant at P< 0.01, and 0.001, respectively

Table 3-14. Effect of kaolin application on dry weight of shoots and roots.

	Shoot dry weight (g)					Root dry weight (g)				
Treatment	4 WAT	6 WAT	8 WAT	10 WAT	At final harvest	4 WAT	6 WAT	8 WAT	10 WAT	At final harvest
Application (A)										
Control	2.0	4.0	6.7	10.8	51.8	0.9	1.0	1.0	1.6	3.8
Kaolin 1X	2.1	4.0	7.5	10.4	60.6	1.0	1.0	1.3	1.8	5.3
Kaolin 2X	2.4	4.2	7.7	10.8	67.1	1.0	1.2	1.1	1.8	5.6
Significance										
Seasons (S)	NS	**	***	*	*	***	*	NS	*	*
Application (A)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-Week after transplanting, 1X- single kaolin spray and 2X-double kaolin spray at 50 lb.acre^{-1}, Season 1- 2015-2016 growing season, Season 2- 2016-2017 growing season, Season 3- 2017-2018 growing season, NS, *, **, *** Nonsignificant or significant at P< 0.05, 0.01, and 0.001, respectively

Effects of kaolin application on fruit yield

Both kaolin applications were equally effective in increasing early and total marketable fruit number and total marketable fruit weight (Table 3-15). However, increase in early marketable fruit weight was greater with the 2X kaolin application than with the single application. The results indicate that kaolin application to early planted Jiffy plug transplants on black plastic mulch can result in heat stress reduction that has a positive effect on early and season total fruit number and weight. There were no apparent differences in number and yield of early and total cull fruit due to application except in January, where cull fruit number was significantly higher with the double kaolin application than with the single kaolin application or with the untreated control (Table 3-16).

Table 3-15. Effect of kaolin application on yield of early and season total marketable fruits.

Treatment	Marketable fruit number.h^{-1}					
	Nov.	Dec.	Jan.	Feb.	Early	Season total
Application (A)						
Control	39,685	91,265	266,112 b	406,802	130,950 b	803,865 b
Kaolin 1X	72,919	114,343	404,799 a	506,252	187,262 a	1,098,313 a
Kaolin 2X	83,621	135,862	424,946 a	508,999	219,483 a	1,153,428 a
Significance						
Season (S)	NS	**	*	NS	*	*
Application (A)	NS	NS	*	NS	*	*
S x A	NS	NS	NS	NS	NS	NS
	Marketable fruit weight (t.ha^{-1})					
Control	0.6	2.0 b	8.6 b	10.9 b	2.6 b	22.1 b
Kaolin 1X	1.1	2.5 b	12.6 a	13.7 ab	3.6 b	29.9 a
Kaolin 2X	1.2	3.1 a	12.7 a	14.4 a	4.3 a	31.4 a
Significance						
Season (S)	*	*	*	NS	NS	*
Application (A)	NS	*	*	*	*	*
S x A	NS	NS	NS	NS	NS	NS

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. 1X- single kaolin spray and 2X-double kaolin spray at 50 lb.acre^{-1}, Season 1- 2015-2016 growing season, Season 2- 2016-2017 growing season, Season 3- 2017-2018 growing season, Early yield – November to December, Season total- November to February, NS, *, ** Nonsignificant or significant at P< 0.05 and 0.01, respectively.

Table 3-16. Effect of kaolin application on yield of early and season total unmarketable fruits.

Treatment	Nov.	Dec.	Jan.	Feb.	Early	Season total
	Cull fruit number.h^{-1}					
Application (A)						
Control	32,788	33,845	42,003 b	174,221	66,633	282,857
Kaolin 1X	35,303	29,312	58,522 b	225,219	64,615	348,356
Kaolin 2X	35,905	27,011	102,047 a	218,330	62,916	383,293
Significance						
Season (S)	***	**	NS	NS	NS	NS
Application (A)	NS	NS	*	NS	NS	NS
S x A	NS	NS	NS	NS	NS	NS
	Cull fruit weight (t.ha^{-1})					
Control	0.28	0.61	1.34	3.46	0.89	5.69
Kaolin 1X	0.27	0.35	1.23	3.82	0.62	5.67
Kaolin 2X	0.32	0.37	1.67	3.88	0.69	6.24
Significance						
Season (S)	NS	**	NS	NS	NS	NS
Application (A)	NS	NS	NS	NS	NS	NS
S x A	NS	NS	NS	NS	NS	NS

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. 1X- single kaolin spray and 2X-double kaolin spray at 50 lb.acre^{-1}, Season 1- 2015-2016 growing season, Season 2- 2016-2017 growing season, Season 3- 2017-2018 growing season, Early yield – November to December, Season total- November to February, NS, **, *** Nonsignificant or significant at P< 0.01, and 0.001, respectively

Discussion

The decrease in photosynthesis by s-ABA was expected since our intention was to induce transient closure of the stomata, in order to protect transplants from heat stress related to wilting. Agehara and Leskovar (2012) reported that photosynthesis was expected to decline with s-ABA treatment due to its effect on stomatal closure. The s-ABA acts as a trigger for adaptive growth responses when plants experience water stress (Davies and Jones, 1991). The stimulation of chlorophyll content, plant survival and vigor, and days to flower by s-ABA were rate sensitive. Consistent with our results, negative side effects have been recorded with high ABA rates—for example leaf chlorosis and abscission (Agehara and Leskovar, 2012). The high s-ABA rates in this study impaired plant growth and productivity. The results also suggest that a low rate of s-ABA is optimum, as a low rate may have a positive effect, preventing negative impacts on plant growth and development. The optimum rate appears to provide protection from injury and facilitate growth while the higher rates appear to inhibit growth. This also provides an explanation for other reported results that ABA reduced transplant shock, increased heat stress tolerance, and enhanced crop establishment for many types of transplants (Racsko et al., 2014). Agehara and Leskovar (2012) found that growth modification by exogenous application of ABA had no harmful effect on fruit yield of two field grown pepper cultivars. Racsko et al. (2014) reported that ABA-treated leafy vegetative transplants withstood post-transplanting shock and performed better even in hot field conditions with high solar radiation than the untreated control.

In previous studies, nontreated transplants exhibited lower rates of photosynthesis than kaolin-treated transplants, possibly due to greater heat stress occurring in the nontreated transplants. In previous studies, the white particle film that formed on the leaf surface increased the reflection of incoming solar radiation, changing the radiation and heat balance and reducing the risk of heat stress from high temperatures and solar injury, ultimately improving photosynthesis (Glenn, 2012; Rosati et al., 2006). High temperatures can damage the leaf thylakoid membranes and reduce the activity of PS II, hampering the photosynthetic activity of plants (Berry and Björkman, 1980). The protection provided by the kaolin from high temperature injury may explain the higher photosynthetic rate of the kaolin-treated plants in this study compared to the untreated control. Improved survival and vigor of kaolin-treated strawberry transplants is also consistent with the literature, as previous reports confirm that kaolin can protect plants against heat stress. Application of a kaolin clay suspension was reported to have resulted in cooler temperatures on treated as opposed to nontreated leaves of tomato plants (Cantore et al. 2009). According to Cantore et al. (2009), kaolin aids in reducing the loss of water from the plant from transpiration and increases the drought tolerance of the plant. The tissue of kaolin-treated plants is cooler than that of non-treated plants, and kaolin helps to protect plants from extreme heat and water loss due to radiation and transpiration, respectively, an effect which is attributed to the reflective properties of kaolin (Glenn et al., 2010; Nakano and Uehara, 1996). The kaolin treatment performed better than the control in respect to mitigating heat stress and assisting water use efficiency in grape vines (Shellie and Glenn, 2008). Boari et al. (2015) observed that the antitranspirant effect of kaolin promotes transplant establishment under adverse conditions. In the present study, kaolin created a white layer on the foliage and the surface of the black plastic mulch. As a result, the leaves and mulch reflected the incoming solar radiation and kept the plants cool. It is likely that transpiration was also reduced with the kaolin applications, allowing the plants to resist dehydration. The microenvironment around the plants may have also been cooler with the kaolin treatments, which may explain the improvement in plant survival and vigor.

Regarding chlorophyll content, in previous studies, the amount of chlorophyll content was related to how long the leaves were exposed to stress, the crop species, and the source of stress (Dekov et al., 2000; Gulen and Eris, 2003).

Kaolin facilitated earlier flowering, consistent with Rosati et al. (2006), who found that kaolin helps to diminish the negative impact of heat stress and water stress on plants while improving the physiology and productivity of plants. Kaolin may have moderated the root zone temperature by creating a white layer on the surface of the black plastic mulch. Root-zone temperature is important for proper growth of strawberry plants and it also influences the chemical composition of plants (Adebooye et al., 2010; Malik et al., 2013; Yan et al., 2013; Sakamoto and Suzuki, 2015a, 2015b). Soil temperatures also have a large impact on biomass distribution between shoot and roots (Ericsson et al. 1996, Pregitzer et al. 2000). Finally, in this study, improved early and total marketable yield in the kaolin treatments compared to the control is consistent with the literature regarding horticultural crop productivity and kaolin. Kaolin-treated tomato plants had larger fruit and higher total crop yield (Cantore et al., 2009) and total yield was increased in kaolin-treated pepper plants (Makus 2005). Research shows that kaolin helps to reduce sunburn injury of strawberry fruit in high temperature environments (Glenn, 2012; Schupp et. al., 2002; Wand et al., 2006). For grapes, kaolin-treated grape vines exhibited no negative impacts from kaolin with respect to cluster size and weight of clusters (Shellie and Glenn, 2010).

Conclusion

Rates of s-ABA in the range 250 to 1000 mg mg.L^{-1} were phytotoxic and resulted high transplant mortality and reduced yields. Strawberry growth and development characteristics such as plant survival, plant vigor, photosynthesis, chlorophyll content, days to first flower, leaf area, dry weight of shoots, and marketable yield were adversely affected by abscisic acid rates greater than 100 mg.L^{-1}. Early and season total marketable yields were significantly higher with the 50 and 100 mg.L^{-1} s-ABA treatments. The double application of kaolin resulted in higher photosynthesis at 20 DAT and higher early marketable yield than the single application and improved transplant survival in one of three years and is thus recommended for planting dates when heat stress is anticipated. Further evaluation of s-ABA as a foliar application or at lower root drench rates than 50 mg.L^{-1} will be needed for a broader understanding of its applicability for heat stress mitigation in early planted strawberry plug transplants.

4. EXPERIMENT 2: ALLEVIATING HEAT STRESS DURING EARLY-SEASON ESTABLISHMENT OF CONTAINERIZED STRAWBERRY TRANSPLANTS

The objective was to evaluate the effects of s-ABA, kaolin, and white-on-black plastic mulch on the establishment, growth, and yield of early-planted containerized strawberry transplants.

Materials and Methods

In order to evaluate the effects of s-ABA, kaolin, and white-on-black polyethylene mulch on the establishment, growth, and yield of containerized strawberry transplants, trials were conducted at the Plant Science Research and Education Unit (PSREU) in Citra and at the Gulf Coast Research and Education Center (GCREC) in Balm, Florida during the 2016-2017 and 2017-2018 growing seasons. Experimental design was a split-plot with plastic mulch as the main plot treatment (either white-on-black or black) and a factorial arrangement of strawberry transplant type (Jiffy plug or tray plug) and stress-prevention application (nontreated control, s-ABA or kaolin application) randomly assigned as the subplot treatments. Three weeks prior to transplanting, the soil was fumigated (Pic Clor 60 at 300 $lb.ac^{-1}$) and the beds were prepared. At Citra beds were 30 in wide on 5-ft centers and 7 in in height, and at Balm bed tops were 28 in wide (32 in at the base) on 4-ft row centers with an 8-in bed height.

Strawberry transplants within beds were set in two rows with 40 and 24 transplants per plot at Citra and Balm, respectively. Transplants at both locations were planted in two offset rows per bed with a between-row spacing of 12 inches and a 15-inch within-row spacing. ‘Florida Radiance’ plug and tray transplants were treated either with s-ABA as a 5-second root dip immediately before transplanting or with kaolin (50 $lb.ac^{-1}$) as two consecutive sprays: the first shortly after transplanting and the second at 7 days after planting. The s-ABA was applied at 150 $mg.L^{-1}$ in the 2016-2017 trials and at 75 $mg.L^{-1}$ in the 2017-2018 trials). The strawberry transplants were set on September 13, 2016 and September 6, 2017 in Citra and on September 28, 2016 and September 29, 2017 in Balm.

In 2016, soil temperature to a depth of 2 cm was measured with a soil probe thermometer (HOBO Pro v2, Onset®_U23-004_dataloggers). Soil temperatures were recorded at a 15-min interval from September 13, 2016 to February 28, 2017 at Citra and from September 28, 2016 to February 28, 2017 at Balm. In 2017, soil temperature to a depth of 2 cm and air temperature to a height of 6 cm were measured with a soil probe thermometer (Onset®_S-TMB-M006_ 12-bit temperature sensors and Onset®_H21-USB_ dataloggers) at Citra and Decagon (Em50) dataloggers and RT-1 sensors were used to measure soil and air temperature at Balm. Soil and air temperatures were recorded at 15-min intervals from September 9, 2017 to February 28, 2018 at Citra and from September 29 to December 31, 2017 at Balm.

Data collection was as described above for Experiment 1. Data were analyzed statistically using the GLIMMIX procedure of SAS and Tukey’s HSD test was used for mean comparison at a 5% level of significance.

Results

Effect of mulch color, transplant type, and application type on plant growth and productivity

Photosynthesis and chlorophyll content. At Citra, no difference in photosynthesis rate was observed within 3 DAT in response to mulch color and transplant type (Table 4-1). However, at 3 DAT photosynthesis rate was higher with kaolin application than with the nontreated control. The fact that photosynthesis with s-ABA not significantly different from the nontreated control at 3 DAT suggests that the effect on stomatal closure was no longer occurring. At Balm, while there was no evidence of kaolin or s-ABA conferring heat stress protection on photosynthesis rate, by 20 DAT photosynthesis rate with black plastic mulch was lower than with white-on-black mulch and lower with tray plugs than with Jiffy plugs (Table 4-2).

At Citra, at 1 WAT tray transplants on black mulch had the lowest chlorophyll content unless they had received the kaolin treatment (Table 4-3). By 2 WAT only the tray transplants on black mulch treated with s-ABA had a relative chlorophyll content of 38.6 compared with greater than 41.6 in all other treatment combinations. At Balm, chlorophyll content was lower with tray transplants than with Jiffy plug transplants in season 2, but not in season 1 (Table 4-4). At 3 WAT, kaolin-treated transplants contained higher chlorophyll content than control or s-ABA-treated transplants.

Survival, vigor, and days to first flower

Significantly higher plant survival was obtained at Citra with white-on-black mulch than black mulch at season 1, with no differences in season 2 (Table 4-5). At Balm, plant survival was adversely affected by s-ABA on either black mulch or white-on-black mulch, and lower survival was obtained with s-ABA-treated tray transplants than with s-ABA-treated Jiffy plug transplants (Table 4-6).

Plant vigor at Citra was lower with black mulch that with the white-on-black mulch at 2 and 4 WAT and lower with tray transplants than with Jiffy plug transplants at 4 WAT (Table 4-5). Plant vigor with kaolin treatment was higher than with both the s-ABA and control treatments in season 2 at Citra; however, this enhancement of plant vigor by kaolin was not apparent at Balm (Tables 4-5 and 4-6). At Balm, at 2 WAT the effect of mulch color and transplant type was the same as at Citra with better performance with white-on-black mulch than with black mulch and better vigor with Jiffy plug transplants than with tray transplants.

Earlier flowering occurred with white-on black mulch than with black mulch in season 1 with no differences in season 2 (Table 4-7). Jiffy plug transplants flowered in 29.4 days compared with 32.5 days with tray transplants. Compared to the nontreated control, which flowered in 33 days, s-ABA and kaolin-treated transplants flowered in 31.4 days. However, the difference was not statistically significant.

Table 4-1. Effect of mulch color, transplant type, and application type on photosynthesis at Citra

Treatments	1 DAT	2 DAT		3 DAT	20 DAT	
Mulch color (M)		($\mu mol.m^{-2} s^{-1}$)				
White	7.7	9.8		9.9	-	
Black	7.0	8.9		9.1	-	
Transplant type (T)						
Jiffy	7.6	9.5		9.7	18.0	
Tray	7.0	9.2		9.3	17.2	
Application type (A)		S_1	S_2		White	Black
Control	7.1 ab	7.6 b	10.2 ab	9.5 b	17.2 ab	15.9 b
s-ABA	6.2 b	8.3 b	9.1 ab	9.1 b	18.1 ab	17.6 ab
Kaolin	8.7 a	8.6 ab	12.3 a	12.4 a	18.8 a	18.0 ab
Significance						
Season (S)	NS	*		*	**	
Mulch color (M)	NS	NS		NS	*	
Transplant type (T)	NS	NS		NS	NS	
Application type (A)	*	*		*	NS	
S x M	NS	NS		NS	NS	
S x T	NS	NS		NS	NS	
S x A	NS	*		NS	NS	
M x T	NS	NS		NS	NS	
M x A	NS	NS		NS	*	
T x A	NS	NS		NS	NS	
S x M x T	NS	NS		NS	NS	
S x M x A	NS	NS		NS	NS	
S x T x A	NS	NS		NS	NS	
M x T x A	NS	NS		NS	NS	
S x M x T x A	NS	NS		NS	NS	

Means followed by the same letters within each day after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. DAT-days after transplanting. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 $lb.acre^{-1}$. s-ABA applied at 150 $mg.L^{-1}$ (2016-2017) and at 75 $mg.L^{-1}$ (2017-2018). NS, *, **. Nonsignificant or significant at $P < 0.05$, and 0.01, respectively.

Table 4-2. Effect of mulch color, transplant type, and application type on photosynthesis at Balm

Treatments	1 DAT		2 DAT		3 DAT		20 DAT
			(μmol.m^{-2} s^{-1})				
Mulch color (M)	S_1	S_2	S_1	S_2			
White	8.0 b	9.4 a	9.1 bc	10.7 ab	-		17.8 a
Black	7.0 c	9.8 a	8.1 c	12.2 a	-		15.5 b
Transplant type (T)			S_1	S_2	S_1	S_2	
Jiffy	-		9.1 b	12.8 a	9.7 b	10.0 a	17.7 a
Tray	-		8.1 b	9.9 b	8.8 c	9.8 ab	15.9 b
Application type (A)			S_1	S_2			
Control	-		9.1 bc	13.3 a	-		16.6 ab
s-ABA	-		6.7 c	7.2 bc	-		15.5 b
Kaolin	-		10.0 b	13.5 a	-		17.8 a
Application x mulch	Jiffy	Tray					
Control x White	9.2 ab	10.0 ab	-		9.7 c		-
s-ABA x White	5.5 c	5.2 c	-		7.8 d		-
Kaolin x White	11.3 a	11.0 ab	-		12.1 a		-
Control x Black	10.7 ab	8.8 b	-		9.9 bc		-
s-ABA x Black	5.4 c	5.9 c	-		7.1 d		-
Kaolin x Black	9.7 ab	9.9 ab	-		10.9 ab		-
Significance							
Seasons (S)	**		***		NS		***
Mulch color (M)	NS		NS		*		*
Transplant type (T)	NS		NS		NS		*
Application type (A)	***		***		***		*
S x M	**		*		NS		NS
S x T	NS		**		*		NS
S x A	NS		*		**		NS
M x T	NS		NS		NS		NS
M x A	*		NS		*		NS
T x A	NS		NS		NS		NS
S x M x T	NS		NS		NS		NS
S x M x A	NS		NS		NS		NS
S x T x A	NS		NS		NS		NS
M x T x A	*		NS		NS		NS
S x M x T x A	NS		NS		NS		NS

Means followed by the same letters within each day after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. DAT-days after transplanting. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 lb.acre^{-1}. s-ABA applied at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-3. Effect of mulch color, transplant type, and application type on chlorophyll content at Citra

Treatments	1 WAT		2 WAT		3 WAT	4 DAT	At harvest
Mulch color (M)							
White	-		-		47.2	47.2	46.2
Black	-		-		46.5	46.6	45.3
Transplant type (T)							
Jiffy	-		-		47.4 a	47.5	45.9
Tray	-		-		46.2 b	46.5	45.5
Application type (A)							
Control	-		-		46.6	46.6	44.7
s-ABA	-		-		46.9	46.5	45.9
Kaolin	-		-		47.0	47.5	46.6
Application x Mulch	Jiffy	Tray	Jiffy	Tray			
Control x White	41.3 ab	40.4 abc	43.3 a	42.6 a	-	-	-
s-ABA x White	42.7 a	40.5 abc	43.7 a	42.9 a	-	-	-
Kaolin x White	42.8 a	41.2 ab	44.7 a	44.7 a	-	-	-
Control x Black	39.2 bc	38.0 cd	41.7 ab	41.6 ab	-	-	-
s-ABA x Black	39.6 bc	36.1 d	41.8 ab	38.6 b	-	-	-
Kaolin x Black	40.3 abc	38.8 bcd	42.8 a	41.7 ab	-	-	-
Significance							
Season (S)	***		***		NS	NS	NS
Mulch color (M)	NS		NS		NS	NS	NS
Transplant type (T)	***		***		*	NS	NS
Application type (A)	***		*		NS	NS	NS
S x M	***		***		NS	NS	NS
S x T	NS		**		NS	NS	NS
S x A	NS		NS		NS	NS	NS
M x T	NS		NS		NS	NS	NS
M x A	NS		NS		NS	NS	NS
T x A	**		*		NS	NS	NS
S x M x T	NS		NS		NS	NS	NS
S x M x A	NS		NS		NS	NS	NS
S x T x A	NS		NS		NS	NS	NS
M x T x A	***		**		NS	NS	NS
S x M x T x A	NS		NS		NS	NS	NS

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-weeks after transplanting. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 lb.acre^{-1}. s-ABA applied at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, **,***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-4. Effect of mulch color, transplant type, and application type on chlorophyll content at Balm

Treatments	1 WAT		2 WAT	3 WAT	4 WAT	
Mulch color (M)					Jiffy	Tray
White	37.5		40.1	42.2	46.3 a	43.6 b
Black	38.7		41.3	42.7	44.8 ab	43.7 b
Transplant type (T)	S_1	S_2				
Jiffy	38.6 ab	39.3 a	41.1	43.0	-	
Tray	38.9 a	35.6 b	40.2	41.9	-	
Application type (A)						
Control	38.0		40.8 ab	41.8 b	44.3	
s-ABA	37.4		39.3 b	41.9 b	44.6	
Kaolin	38.9		42.0 a	43.6 a	45.0	
Significance						
Season (S)	NS		NS	NS	**	
Mulch color (M)	NS		NS	NS	NS	
Transplant type (T)	*		NS	NS	***	
Application type (A)	NS		*	*	NS	
S x M	NS		NS	NS	*	
S x T	**		NS	NS	NS	
S x A	NS		NS	NS	NS	
M x T	NS		NS	NS	*	
M x A	NS		NS	NS	NS	
T x A	NS		NS	NS	NS	
S x M x T	NS		NS	NS	NS	
S x M x A	NS		NS	NS	NS	
S x T x A	NS		NS	NS	NS	
M x T x A	NS		NS	NS	NS	
S x M x T x A	NS		NS	NS	NS	

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-weeks after transplanting. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 $lb.acre^{-1}$. s-ABA applyied at 150 $mg.L^{-1}$ (2016-2017) and at 75 $mg.L^{-1}$ (2017-2018). NS, *, **,***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-5. Effect of mulch color, transplant type, and application type on plant survival and vigor at Citra

Treatments	Plant survival (%)				Plant vigor		
	2 WAT		4 WAT		2 WAT		4 WAT
Mulch color (M)	S_1	S_2	S_1	S_2			
White	100.0 a	99.9 a	99.8 a	99.9 a	8.2 a		9.5 a
Black	98.6 b	99.9 a	95.6 b	99.8 a	7.a b		8.5 b
Transplant type (T)							
Jiffy	99.7		98.9		7.9 a		9.3 a
Tray	99.5		98.6		7.3 a		8.7 b
Application type (A)					S_1	S_2	
Control	99.6		98.2		7.6 bc	7.4 bc	8.8 b
s-ABA	99.4		98.9		7.6 abc	7.0 c	8.7 b
Kaolin	99.8		99.2		8.0 ab	8.3 a	9.4 a
Significance							
Season (S)	NS		***		NS		NS
Mulch color (M)	**		***		***		***
Transplant type (T)	NS		NS		***		**
Application type (A)	NS		NS		***		**
S x M	**		***		NS		NS
S x T	NS		NS		NS		NS
S x A	NS		NS		**		NS
M x T	NS		NS		NS		NS
M x A	NS		NS		NS		NS
T x A	NS		NS		NS		NS
S x M x T	NS		NS		NS		NS
S x M x A	NS		NS		NS		NS
S x T x A	NS		NS		NS		NS
M x T x A	NS		NS		NS		NS
S x M x T x A	NS		NS		NS		NS

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-weeks after transplanting. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 $lb.acre^{-1}$. s-ABA applied at 150 $mg.L^{-1}$ (2016-2017) and at 75 $mg.L^{-1}$ (2017-2018). NS, **, ***. Nonsignificant or significant at $P < 0.01$ and 0.001, respectively.

Table 4-6. Effect of mulch color, transplant type, and application type on plant survival and vigor at Balm

Treatments	Plant survival (%)				Plant vigor			
	2 WAT		4 WAT		2 WAT		4 WAT	
Mulch color (M)	S_1	S_2						
White	98.4 ab	94.9 c	-		6.9 a		-	
Black	99.4 a	97.6 b	-		6.5 b		-	
Transplant type (T)			S_1	S_2				
Jiffy	-		99.7 a	99.6 a	6.9 a		-	
Tray	-		96.1 b	91.5 c	6.5 b		-	
Application type (A)					S_1	S_2	S_1	S_2
Control	-		-		7.5 ab	6.5 c	8.7 ab	8.3 ab
s-ABA	-		-		7.1 bc	4.6 d	8.2 b	8.3 c
Kaolin	-		-		7.9 a	6.8 c	9.1 a	8.6 ab
Mulch x Application	Jiffy	Tray	Jiffy	Tray			Jiffy	Tray
Control x White	100.0 a	99.4 a	100.0 a	98.3 a	-		8.4 a-d	8.7 a-c
s-ABA x White	99.6 a	81.5 c	99.0 a	77.7 c	-		7.8 b-e	6.6 e
Kaolin x White	100.0 a	99.4 a	100.0 a	98.8 a	-		8.8 a-c	9.5 a
Control x Black	100.0 a	99.0 a	99.6 a	98.3 a	-		8.4 a-d	8.4 a-d
s-ABA x Black	100.0 a	92.9 b	99.6 a	90.5 b	-		7.1 de	7.5 c-e
Kaolin x Black	100.0 a	99.4 a	100.0 a	99.4 a	-		8.4 a-d	8.9 ab
Significance								
Seasons (S)	*		*		***		**	
Mulch color (M)	***		***		**		NS	
Transplant type (T)	***		***		**		NS	
Application type (A)	***		***		***		***	
S x M	*		NS		NS		NS	
S x T	***		***		NS		NS	
S x A	***		***		***		**	
M x T	***		***		NS		NS	
M x A	***		***		NS		NS	
T x A	***		***		NS		*	
S x M x T	*		NS		NS		NS	
S x M x A	***		NS		NS		NS	
S x T x A	***		***		NS		***	
M x T x A	***		***		NS		*	
S x M x T x A	NS		NS		NS		NS	

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-weeks after transplanting. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin apply at 50 lb.acre^{-1}. s-ABA apply at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01 and 0.001, respectively.

Table 4-7. Effect of mulch color, transplant types and application types on days to first flower at Citra

Treatments	Days to first flower	
Mulch color (M)	S_1	S_1
White	30.4 b	29.6 b
Black	36.7 a	31.2 b
Transplant type (T)		
Jiffy	29.4 b	
Tray	32.5 a	
Application type (A)		
Control	33.0	
s-ABA	31.4	
Kaolin	31.4	
Significance		
Season (S)	**	
Mulch color (M)	**	
Transplant type (T)	*	
Application type (A)	NS	
S x M	*	
S x T	NS	
S x A	NS	
M x T	NS	
M x A	NS	
T x A	NS	
S x M x T	NS	
S x M x A	NS	
S x T x A	NS	
M x T x A	NS	
S x M x T x A	NS	

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-weeks after transplanting. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin apply at 50 lb.acre^{-1}. s-ABA apply at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, and 0.01, respectively.

Soil and air temperatures at Citra and Balm, FL

Black mulch resulted in 3-4°C higher soil temperatures than white-on-black mulch when measured on a bed area without plants (empty space) at Citra (Table 4-8). Kaolin sprays to both black and white-on-black mulches resulted in lower soil temperatures than unsprayed empty space. Soil temperatures were 2-3°C higher with black mulch sprayed with kaolin than with white-on-black mulch sprayed with kaolin. Air temperature at canopy height did not appear to be influenced by mulch color (Table 4-9). At Balm, a similar trend was observed and black much gave 5-6°C higher soil temperatures than white-on-black mulch when measured on a bed area without plants (empty space) (Table 4-10). Likewise, at Citra kaolin sprays to both black and white-on-black mulches resulted in lower soil temperatures than unsprayed empty space. Soil temperatures were 1-2°C higher with black mulch sprayed with kaolin than with white-on-black mulch sprayed with kaolin. Air temperature at canopy height did not appear to be influenced by mulch color (Table 4-11).

Table 4-8. Soil temperature of empty beds and between plants at Citra, FL

Week	Date		Soil temperature (°C) of empty beds				Soil temperature (°C) between plants			
			Black mulch		White mulch		Black mulch + kaolin		White mulch + kaolin	
	Start	End	Max	Min	Max	Min	Max	Min	Max	Min
1	9/6	9/12	36.5	21.7	33.6	21.8	34.6	21.6	32.9	21.2
2	9/13	9/19	40.4	20.9	39.0	21.1	40.2	20.9	35.6	19.9
3	9/20	9/26	39.6	23.5	36.6	23.5	37.8	23.0	33.9	22.8
4	9/27	10/2	39.2	23.8	36.2	23.8	37.2	23.6	34.2	23.1
5	10/3	10/9	38.6	22.3	34.5	22.5	34.9	22.2	34.1	21.5
6	10/10	10/16	39.1	23.8	34.8	22.9	35.2	22.6	34.3	22.2
7	10/17	10/23	34.4	20.3	32.2	20.0	33.4	20.2	31.0	19.7
8	10/24	10/30	32.2	16.3	29.2	15.2	30.7	14.7	28.3	13.8
9	10/31	11/6	33.1	11.7	26.9	10.6	32.8	11.1	28.6	10.2
10	11/7	11/13	31.4	16.0	27.0	15.6	32.2	16.0	28.6	15.5
11	11/14	11/20	28.4	11.4	22.5	11.1	27.3	11.7	25.4	11.1
12	11/21	11/27	29.2	13.0	23.4	12.1	27.2	13.2	24.4	13.4
13	11/28	12/4	30.1	14.8	24.3	13.9	27.7	15.0	24.8	14.1
14	12/5	12/11	29.1	9.9	24.1	10.6	27.5	8.8	25.2	8.7
15	12/12	12/18	26.0	8.8	21.8	8.3	23.5	8.7	22.0	8.3
16	12/19	12/25	29.2	15.0	24.2	13.5	25.9	15.1	23.6	14.3
17	12/26	1/1	24.7	9.0	19.7	8.1	21.5	8.1	19.6	8.4
18	1/2	1/8	19.1	1.7	15.3	3.1	18.3	4.3	15.6	4.8
19	1/9	1/15	24.7	6.2	22.7	4.5	22.7	9.1	22.1	9.5
20	1/16	1/22	24.9	4.2	20.3	3.9	22.2	5.0	20.5	5.6
21	1/23	1/29	24.1	9.6	20.7	9.1	21.7	11.2	20.9	10.5
22	1/30	2/5	27.6	7.3	21.0	6.7	23.6	9.1	20.2	8.4
23	2/6	2/12	29.9	11.6	24.9	11.0	26.9	12.7	24.5	12.1
24	2/13	2/19	34.3	16.7	27.0	16.5	28.2	17.0	26.2	16.6
25	2/20	2/26	36.7	19.2	28.1	18.7	29.8	20.1	27.9	19.7
26	2/27	3/1	32.5	18.2	25.8	17.9	27.8	19.6	26.1	18.9

Table 4-9. Air temperature above empty beds and at canopy height at Citra, FL

Week	Date		Air temperature (°C) above empty beds				Air temperature (°C) at canopy height			
			Black mulch		White mulch		Black mulch + kaolin		White mulch + kaolin	
	Start	End	Max	Min	Max	Min	Max	Min	Max	Min
1	9/6	9/12	38.5	18.1	39.6	18.1	36.2	18.1	36.4	18.1
2	9/13	9/19	35.4	16.9	35.4	18.9	35.2	16.9	35.3	16.9
3	9/20	9/26	34.6	19.1	34.7	19.2	34.3	19.2	34.5	19.1
4	9/27	10/2	35.3	18.8	35.4	18.8	35.2	20.4	35.0	18.7
5	10/3	10/9	35.9	19.9	36.8	20.0	35.8	20.0	35.5	20.0
6	10/10	10/16	34.9	18.7	35.5	18.7	35.1	18.8	35.1	18.7
7	10/17	10/23	32.2	16.9	32.6	18.8	32.6	16.9	32.6	16.8
8	10/24	10/30	26.7	5.7	26.8	5.7	26.7	6.0	26.5	5.9
9	10/31	11/6	30.4	3.0	30.3	3.0	30.3	3.2	30.1	3.0
10	11/7	11/13	30.1	12.9	30.6	12.8	30.3	17.8	30.6	12.9
11	11/14	11/20	27.8	4.9	28.0	4.9	28.5	5.5	28.1	5.0
12	11/21	11/27	27.9	7.4	26.6	7.3	28.0	7.7	27.4	7.3
13	11/28	12/4	28.4	9.7	29.0	9.5	28.1	10.1	29.3	9.4
14	12/5	12/11	29.0	3.1	29.2	2.9	29.3	3.1	29.6	1.6
15	12/12	12/18	28.3	2.3	29.1	2.2	28.8	1.7	30.0	2.0
16	12/19	12/25	29.3	8.5	30.0	8.5	29.6	8.1	30.8	8.2
17	12/26	1/1	24.6	2.3	24.6	2.2	24.5	2.3	24.6	2.1
18	1/2	1/8	22.8	-3.8	22.3	-3.9	22.5	-2.2	22.3	-2.5
19	1/9	1/15	26.6	0.1	31.1	0.7	27.3	1.1	30.3	1.9
20	1/16	1/22	28.7	-4.5	28.1	-3.3	28.0	-3.8	28.1	-3.2
21	1/23	1/29	26.2	5.5	25.6	5.5	25.5	5.6	25.9	4.9
22	1/30	2/5	24.7	0.6	25.5	0.5	25.0	1.0	25.2	0.5
23	2/6	2/12	30.7	5.9	30.4	5.7	30.9	6.4	30.9	5.9
24	2/13	2/19	31.2	12.8	30.3	12.8	31.3	13.3	30.5	12.9
25	2/20	2/26	32.5	14.5	32.7	14.1	32.8	15.1	33.4	14.2
26	2/27	3/1	30.4	12.5	30.8	12.2	30.7	12.9	32.2	12.3

Table 4-10. Soil temperature of empty beds and between plants at Balm, FL

Week	Date		Soil temperature (°C) of empty beds				Soil temperature (°C) between plants			
	Start	End	Black mulch		White mulch		Black mulch + kaolin		White mulch + kaolin	
			Max	Min	Max	Min	Max	Min	Max	Min
1	9/29	10/5	43.4	23.5	37.4	24.1	40.8	23.3	40.0	23.8
2	10/6	10/12	43.2	22.8	37.0	23.8	36.1	22.7	35.1	22.9
3	10/13	10/19	44.2	20.8	36.3	21.0	36.3	21.1	36.1	21.2
4	10/20	10/26	36.8	18.4	32.1	18.6	31.9	18.6	31.4	18.7
5	10/27	11/2	36.9	11.0	31.0	12.0	31.2	10.9	31.3	11.5
6	11/3	11/9	41.2	18.0	33.5	18.6	35.0	18.0	34.6	18.7
7	11/10	11/16	35.5	16.0	30.2	16.8	30.0	16.6	30.1	17.2
8	11/17	11/23	37.0	12.1	29.9	13.4	30.1	16.2	29.2	14.1
9	11/24	11/30	35.2	14.0	30.3	15.3	31.9	14.8	28.8	15.7
10	12/1	12/7	36.3	16.6	30.4	17.6	31.5	17.2	29.7	18.0
11	12/8	12/14	34.3	6.4	30.0	8.0	28.6	9.1	31.5	3.8
12	12/15	12/21	37.2	13.9	30.9	14.7	26.8	15.5	34.4	11.9
13	12/22	12/28	33.9	13.8	39.6	14.6	25.9	15.8	32.8	11.1
14	12/29	1/4	24.9	0.1	33.8	0.7	21.2	6.1	27.1	0.2

Table 4-11. Air temperature above empty beds and at canopy height at Balm, FL

Week	Date		Air temperature (°C) above empty beds				Air temperature (°C) at canopy height			
	Start	End	Black mulch		White mulch		Black mulch + kaolin		White mulch + kaolin	
			Max	Min	Max	Min	Max	Min	Max	Min
1	9/29	10/5	35.8	21.9	36.6	22.0	35.9	22.0	36.8	22.0
2	10/6	10/12	36.7	19.5	37.0	19.7	36.7	19.7	36.9	19.7
3	10/13	10/19	34.6	19.8	35.1	19.8	35.0	19.8	35.6	19.8
4	10/20	10/26	33.2	15.4	33.3	15.5	33.5	15.4	33.7	15.2
5	10/27	11/2	30.6	7.8	31.2	7.9	33.3	7.8	33.3	7.9
6	11/3	11/9	34.5	15.2	33.5	15.2	34.6	15.5	35.8	15.3
7	11/10	11/16	30.5	13.4	30.6	15.8	30.8	13.5	32.7	13.6
8	11/17	11/23	30.8	8.1	30.9	8.2	32.6	8.2	32.2	8.7
9	11/24	11/30	30.6	10.9	31.2	10.9	30.7	11.0	33.4	11.1
10	12/1	12/7	31.6	14.0	31.7	14.0	31.8	14.2	34.0	14.2
11	12/8	12/14	31.6	3.6	31.3	3.9	31.9	3.8	31.2	3.6
12	12/15	12/21	32.3	11.9	33.0	12.0	31.8	12.2	33.5	12.2
13	12/22	12/28	30.3	10.9	30.7	11.2	31.0	10.9	30.8	11.3
14	12/29	1/4	24.8	0.2	25.4	0.4	24.1	1.1	26.7	0.7

Leaf number, leaf area, crown diameter, runner number, and biomass

Results are reported for samples collected at 4, 6, 8, and 10 weeks after transplanting (WAT) and at final harvest. At Citra, leaf number and leaf area were higher with white-on-black mulch compared to black at 4, 6, and 8 WAT (Tables 4-12 and 4-13). Likewise, leaf number and leaf area were greater for Jiffy plug transplants than tray transplants at 4, 6, 8, and 10 WAT. Whereas there was no significant difference in leaf number and leaf area due to kaolin application type compared to the nontreated control, at 4 WAT leaf number and leaf area with kaolin were higher than with s-ABA. By 10 WAT this effect was apparent with white-on-black mulch but not with black mulch.

Crown diameter was greater for white-on-black mulch than black mulch at 6 and 10 WAT (Table 4-14). At 8 WAT in season 1 only the crown diameter with the nontreated control on black mulch had the smallest crown diameter. Tray transplants tended to have smaller crown diameter than Jiffy plug transplants and this was significant at 6 and 8 WAT. The effect of application type on crown diameter was significant at final harvest, with kaolin resulting in a larger crown diameter than the nontreated control.

At Citra at 6 and 8 WAT, white-on-black mulch had a higher runner number than black mulch (Table 4-15). Jiffy plug transplants also tended to produce more runners than tray transplants. Application type had little effect on runner number with kaolin having a higher runner number than both the control and s-ABA treated plants only at 8 WAT.

At Balm, white-on black mulch produced significantly more runners than black mulch in season 1, with no significant differences during season 2 (Table 4-16). The effect of application type varied with transplant type so that s-ABA treated Jiffy and tray plugs produced the same number of runners. However, the nontreated Jiffy plugs had more runners than tray plugs and kaolin-treated Jiffy plugs both had more runners than kaolin-treated tray plugs.

Shoot dry weight at Citra was generally higher with white-on-black mulch than with black mulch even at final harvest (Table 4-17). Although shoot dry weight tended to be higher with Jiffy plug transplants than tray transplants, this difference was only significant at 4 and 8 WAT. Application type had little effect on shoot dry weight.

Root dry weight at Citra was generally higher with white-on-black plastic mulch than with black plastic mulch during the first 10 WAT (Table 4-18). However, transplant type and application type had little to no effect on root dry weight.

Table 4-12. Effect of mulch color, transplant type, and application type on leaf number at Citra

Treatments	4 WAT	6 WAT	8 WAT	10 WAT		At harvest
Mulch color (M)						
White	7.3 a	10.8 a	18.6 a	-		50.8
Black	5.8 b	8.1 b	13.7 b	-		46.6
Transplant type (T)						
Jiffy	7.0 a	10.4 a	17.3 a	22.4 a		49.0
Tray	6.1 b	8.4 b	15.1 b	20.9 b		48.3
Application type (A)				White	Black	
Control	6.5 ab	9.6	16.2	23.5 ab	19.6 c	45.2
s-ABA	5.9 b	9.0	15.1	21.4 bc	19.1 c	50.3
Kaolin	7.1 a	9.7	17.1	26.1 a	20.4 bc	50.4
Significance						
Season (S)	***	***	***	***		*
Mulch color (M)	***	***	***	***		NS
Transplant type (T)	**	**	*	*		NS
Application type (A)	*	NS	NS	*		NS
S x M	NS	NS	NS	NS		NS
S x T	NS	NS	NS	NS		NS
S x A	NS	NS	NS	NS		NS
M x T	NS	NS	NS	NS		NS
M x A	NS	NS	NS	*		NS
T x A	NS	NS	NS	NS		NS
S x M x T	NS	NS	NS	NS		NS
S x M x A	NS	NS	NS	NS		NS
S x T x A	NS	NS	NS	NS		NS
M x T x A	NS	NS	NS	NS		NS
S x M x T x A	NS	NS	NS	NS		NS

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-week after transplanting. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 lb.acre^{-1}. s-ABA applied at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-13. Effect of mulch color, transplant type, and application type on leaf area at Citra

Treatments	4 WAT	6 WAT	8 WAT		10 WAT		At harvest
Mulch color (M)			S_1	S_2			
White	272 a	514 a	897 b	1188 a	-		2847
Black	171 b	345 b	515 c	958 b	-		2720
Transplant type (T)							
Jiffy	248 a	480 a	950 a		1494 a		2791
Tray	195 b	379 b	778 b		1333 b		2776
Application type (A)					White	Black	
Control	223 ab	425	856		1563 ab	1301 bc	2589
s-ABA	194 b	397	782		1328 bc	1238 c	2811
Kaolin	248 a	467	954		1726 a	1325 bc	2991
Significance							
Season (S)	***	***	***		*		NS
Mulch color (M)	***	***	***		***		NS
Transplant type (T)	**	*	*		*		NS
Application type (A)	*	NS	NS		NS		NS
S x M	NS	NS	*		NS		NS
S x T	NS	NS	NS		NS		NS
S x A	NS	NS	NS		NS		NS
M x T	NS	NS	NS		NS		NS
M x A	NS	NS	NS		*		NS
T x A	NS	NS	NS		NS		NS
S x M x T	NS	NS	NS		NS		NS
S x M x A	NS	NS	NS		NS		NS
S x T x A	NS	NS	NS		NS		NS
M x T x A	NS	NS	NS		NS		NS
S x M x T x A	NS	NS	NS		NS		NS

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-week after transplanting. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 $lb.acre^{-1}$. s-ABA applied at 150 $mg.L^{-1}$ (2016-2017) and at 75 $mg.L^{-1}$ (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-14. Effect of mulch color, transplant type, and application type on crown diameter at Citra

Treatments	4 WAT	6 WAT	8 WAT		10 WAT		At harvest	
Mulch color (M)							S_1	S_2
White	1.5	2.2 a	-		3.5 a		6.3 a	5.4 bc
Black	1.4	1.8 b	-		3.1 b		5.9 ab	5.3 c
Transplant type (T)								
Jiffy	1.5	2.1 a	2.9 a		3.3		5.8	
Tray	1.4	1.9 b	2.6 b		3.2		5.7	
Application type (A)					S_1	S_2		
Control	1.5	1.9	-		2.8 c	3.7 ab	5.6 b	
s-ABA	1.4	1.9	-		2.9 c	3.4 bc	5.7 ab	
Kaolin	1.6	2.0	-		2.9 c	3.9 a	6.0 a	
Mulch x Application			S_1	S_2				
Control x White	-	-	2.7 abc	3.1 ab	-		-	
s-ABA x White	-	-	2.6 bc	3.2 ab	-		-	
Kaolin x White	-	-	2.9 ab	3.5 a	-		-	
Control x Black	-	-	1.9 d	3.1 ab	-		-	
s-ABA x Black	-	-	2.2 cd	2.8 abc	-		-	
Kaolin x Black	-	-	2.1 cd	3.1 ab	-		-	
Significance								
Season (S)	***	***	**		*		*	
Mulch color (M)	NS	***	***		***		NS	
Transplant type (T)	NS	*	***		NS		NS	
Application type (A)	NS	NS	*		*		*	
S x M	NS	NS	**		NS		*	
S x T	NS	NS	NS		NS		NS	
S x A	NS	NS	NS		*		NS	
M x T	NS	NS	NS		NS		NS	
M x A	NS	NS	NS		NS		NS	
T x A	NS	NS	NS		NS		NS	
S x M x T	NS	NS	NS		NS		NS	
S x M x A	NS	NS	*		NS		NS	
S x T x A	NS	NS	NS		NS		NS	
M x T x A	NS	NS	NS		NS		NS	
S x M x T x A	NS	NS	NS		NS		NS	

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-week after transplanting. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 $lb.acre^{-1}$. s-ABA applied at 150 $mg.L^{-1}$ (2016-2017) and at 75 $mg.L^{-1}$ (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-15. Effect of mulch color, transplant type, and application type on runner number at Citra

Treatments	4 WAT		6 WAT	8 WAT	10 WAT	
Mulch color (M)	S_1	S_2				
White	1.2 a	0.7 b	1.4 a	1.6 a	1.4	
Black	0.9 ab	1.0 ab	0.9 b	1.0 b	1.3	
Transplant type (T)	S_1	S_2			S_1	S_2
Jiffy	1.0 a	1.7 a	1.4 a	1.4	0.8 c	2.2 a
Tray	0.3 c	0.9 b	0.9 b	1.2	0.7 c	1.5 b
Application type (A)					S_1	S_2
Control	0.9 ab		1.2 ab	1.2 b	0.8 b	1.9 a
s-ABA	0.8 b		1.0 b	1.1 b	0.7 b	1.8 a
Kaolin	1.1 a		1.3 a	1.6 a	0.9 b	1.9 a
Significance						
Season (S)	NS		NS	***	***	
Mulch color (M)	**		***	***	NS	
Transplant type (T)	***		**	NS	***	
Application type (A)	**		*	*	NS	
S x M	**		NS	NS	NS	
S x T	**		NS	NS	***	
S x A	NS		NS	NS	*	
M x T	NS		NS	NS	NS	
M x A	NS		NS	NS	NS	
T x A	NS		NS	NS	NS	
S x M x T	NS		NS	NS	NS	
S x M x A	NS		NS	NS	NS	
S x T x A	NS		NS	NS	NS	
M x T x A	NS		NS	NS	NS	
S x M x T x A	NS		NS	NS	NS	

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-week after transplanting. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 $lb.acre^{-1}$. s-ABA applied at 150 $mg.L^{-1}$ (2016-2017) and at 75 $mg.L^{-1}$ (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-16. Effect of mulch color, transplant type, and application type on runner number at Balm in December

Mulch color (M)	S_1	S_2
White	1.3 a	0.2 c
Black	0.8 b	0.3 c
Transplant type (T)		
Jiffy	-	
Tray	-	
Application type (A)	Jiffy	Tray
Control	0.8 ab	0.4 c
s-ABA	0.7 abc	0.7 abc
Kaolin	0.9 a	0.6 bc
Significance		
Season (S)	***	
Mulch color (M)	***	
Transplant type (T)	***	
Application type (A)	NS	
S x M	***	
S x T	***	
S x A	**	
M x T	NS	
M x A	NS	
T x A	**	
S x M x T	NS	
S x M x A	NS	
S x T x A	NS	
M x T x A	NS	
S x M x T x A	NS	

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 $lb.acre^{-1}$. s-ABA applied at 150 $mg.L^{-1}$ (2016-2017) and at 75 $mg.L^{-1}$ (2017-2018). NS, **, ***. Nonsignificant or significant at $P < 0.01$ and 0.001, respectively.

Table 4-17. Effect of mulch color, transplant type, and application type on dry weight of shoots at Citra

Treatments	Dry weight of shoots (g)							
	4 WAT	6 WAT		8 WAT		10 WAT		At harvest
Mulch color (M)		S_1	S_2	S_1	S_2			
White	3.5 a	4.4 c	9.6 a	11.6 b	16.4 a	20.6 a		57.8 a
Black	2.5 b	3.8 c	7.7 b	8.5 c	12.8 b	15.1 b		51.5 b
Transplant type (T)								
Jiffy	3.2 a	5.2		12.8 a		18.5		55.4
Tray	2.7 b	4.8		10.4 b		17.2		53.9
Application type (A)						S_1	S_2	
Control	2.9 ab	4.8		11.6		15.5 c	21.1 ab	52.4
s-ABA	2.5 b	5.0		10.8		15.6 c	18.7 b	53.7
Kaolin	3.3 a	5.1		12.3		15.8 c	23.5 a	57.9
Significance								
Season (S)	***	***		***		***		NS
Mulch color (M)	***	*		***		***		*
Transplant type (T)	*	NS		***		NS		NS
Application type (A)	*	NS		NS		**		NS
S x M	NS	*		*		NS		NS
S x T	NS	NS		NS		NS		NS
S x A	NS	NS		NS		*		NS
M x T	NS	NS		NS		NS		NS
M x A	NS	NS		NS		NS		NS
T x A	NS	NS		NS		NS		NS
S x M x T	NS	NS		NS		NS		NS
S x M x A	NS	NS		NS		NS		NS
S x T x A	NS	NS		NS		NS		NS
M x T x A	NS	NS		NS		NS		NS
S x M x T x A	NS	NS		NS		NS		NS

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-week after transplanting. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 lb.acre^{-1}. s-ABA applied at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-18. Effect of mulch color, transplant type, and application type on dry weight of roots at Citra

Treatments	Dry weight of roots (g)					
	4 WAT	6 WAT		8 WAT	10 WAT	At harvest
Mulch color (M)		S_1	S_2			
White	1.1 a	1.6 c	2.9 a	2.6 a	3.0 a	5.9
Black	0.9 b	1.5 c	2.4 b	1.9 b	2.5 b	5.8
Transplant type (T)						
Jiffy	1.0	2.1		2.4	2.8	6.2
Tray	1.0	1.9		2.0	2.7	5.5
Application type (A)						
Control	0.9	2.0		2.1	2.7 ab	6.0
s-ABA	1.0	1.9		2.0	2.6 b	5.4
Kaolin	1.1	2.1		2.3	2.9 a	6.1
Significance						
Season (S)	**	***		*	*	**
Mulch color (M)	*	**		***	***	NS
Transplant type (T)	NS	NS		NS	NS	NS
Application type (A)	NS	NS		NS	*	NS
S x M	NS	*		NS	NS	NS
S x T	NS	NS		NS	NS	NS
S x A	NS	NS		NS	NS	NS
M x T	NS	NS		NS	NS	NS
M x A	NS	NS		NS	NS	NS
T x A	NS	NS		NS	NS	NS
S x M x T	NS	NS		NS	NS	NS
S x M x A	NS	NS		NS	NS	NS
S x T x A	NS	NS		NS	NS	NS
M x T x A	NS	NS		NS	NS	NS
S x M x T x A	NS	NS		NS	NS	NS

Means followed by the same letters within each week after transplanting do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. WAT-week after transplanting. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 lb.acre^{-1}. s-ABA applied at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Number and weight of early and total marketable fruits

At Citra white-on-black mulch had significantly more marketable fruits than black mulch at Citra (Table 4-19). Whereas early fruit number was not significantly affected by transplant type in season 1, Jiffy plug transplants produced more marketable fruits than tray plug transplants in season 2. Season total fruit number was higher with Jiffy plugs on white-on-black mulch than with tray plugs on black mulch, but not significantly different from tray plugs on white-on-black mulch and Jiffy plugs on black mulch. There was no significant effect of application type on either early fruit number or season total fruit number.

At Balm, white-on-black mulch resulted in more early marketable fruits than black mulch in season 1 with no differences in season 2 due to mulch color (Table 4-21). A significant season by transplant by application interaction indicated that the effect of application type on early marketable fruit number at Balm varied with season and transplant type. Jiffy plug transplants produced more marketable fruits than tray plug transplants in season 2. However, in season 1 only the nontreated Jiffy plugs and kaolin-treated Jiffy plugs resulted in higher numbers of early fruits than nontreated tray transplants. There was no significant difference due to mulch color for season total marketable fruit number at Balm (Table 4-22). Whereas Jiffy transplants produced more fruits in season 2 than tray transplants in season 1, within season this difference was not significant. Season total marketable fruit number was lower with s-ABA than the nontreated control, but the difference between the nontreated control plants and kaolin-treated plants was not significant (Table 4-22).

In Citra, early marketable fruit weight was greater with white-on-black mulch than black mulch (Table 4-23). There was no significant effect of either transplant type or application type on early marketable weight. Season total marketable fruit weight application type was also not affected by application type (Table 4-24). However, a significant season by mulch color by transplant interaction indicated that in both seasons tray transplants on black mulch produced lower season total fruit weights than both Jiffy and tray transplants grown on white-on-black mulch.

At Balm, the results for early marketable fruit weight were similar to those of early marketable fruit number. White-on-black mulch resulted in higher early marketable fruit weight than black mulch in season 1, with no differences due to mulch color observed in season 2 and there was a significant season by transplant by application interaction (Table 4-25). Jiffy plug transplants produced more early marketable fruit weight than tray transplants in season 1 with no significant effect of application type. Whereas in season 2, kaolin-treated plug transplants resulted in more than double the early marketable fruit weight of tray transplants irrespective of application type. At Balm, the early season advantage provided by white-on-black mulch did not persist so that black mulch resulted in a higher season total marketable weight than white-on-black mulch (Table 4-26). At Balm the effects of application type and transplant type differ with season. Season total marketable weight was 3.3 t/ha higher with Jiffy plugs than with tray plugs in season 1 and 4.8 t/ha higher in season 2. Whereas there was no significant effect of application type in season 1, in season 2 s-ABA application resulted in lower season total marketable yields than nontreated control plants and kaolin-treated plants.

Table 4-19. Effect of mulch color, transplant type, and application type on number of marketable fruits at Citra

Treatments	Marketable fruit number.ha^{-1}					
	NOV		DEC		Early	
Mulch color (M)						
White	185,067 a		171,446 a		356,486 a	
Black	114,356 b		108,574 b		222,930 b	
Transplant type (T)	S_1	S_2	S_1	S_2	S_1	S_2
Jiffy	109,932 c	211,977 a	156,252 a	153,160 a	266,184 bc	365,137 a
Tray	104,773 c	172,165 b	153,030 a	97,599 b	157,803 c	269,764 b
Application type (A)						
Control	152,652 ab		131,670		284,322	
s-ABA	135,618 b		141,015		176,633	
Kaolin	160,865 a		147,345		308,210	
Significance						
Season (S)	***		NS		NS	
Mulch color (M)	***		***		***	
Transplant type (T)	**		***		NS	
Application type (A)	**		NS		NS	
S x M	NS		NS		NS	
S x T	**		***		**	
S x A	NS		NS		NS	
M x T	NS		NS		NS	
M x A	NS		NS		NS	
T x A	NS		NS		NS	
S x M x T	NS		NS		NS	
S x M x A	NS		NS		NS	
S x T x A	NS		NS		NS	
M x T x A	NS		NS		NS	
S x M x T x A	NS		NS		NS	

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 lb.acre^{-1}. s-ABA applied at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, **, ***. Nonsignificant or significant at $P < 0.01$ and 0.001, respectively.

Table 4-20. Effect of mulch color, transplant type, and application type on number of marketable fruits at Citra

Treatments	JAN		FEB		Season total	
Application type (A)			fruit number.ha^{-1}			
Control	373,051 ab		557,015		930,066	
s-ABA	360,882 b		549,971		910,853	
Kaolin	403,973 a		563,634		967,607	
Mulch x transplant type	S_1	S_2	S_1	S_2	S_1	S_2
White x Jiffy	632,896 a	303,356 cd	511,818 c	669,785 a	1,450,542 a	1,311,103 a-c
White x Tray	621,488 a	265,651 d	498,625 c	681,857 a	1,372,887 ab	1,228,195 a-d
Black x Jiffy	405,440 b	271,590 cd	488,674 c	649,664 ab	1,174,972 b-d	1,117,373 cd
Black x Tray	347,862 bc	186,133 e	425,880 c	548,613 bc	1,112,924 d	1,038,944 d
Significance						
Season (S)	***		**		NS	
Mulch color (M)	***		**		***	
Transplant type (T)	NS		NS		NS	
Application type (A)	**		NS		NS	
S x M	***		NS		***	
S x T	***		*		NS	
S x A	NS		NS		NS	
M x T	NS		NS		NS	
M x A	NS		NS		NS	
T x A	NS		NS		NS	
S x M x T	***		**		**	
S x M x A	NS		NS		NS	
S x T x A	NS		NS		NS	
M x T x A	NS		NS		NS	
S x M x T x A	NS		NS		NS	

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 lb.acre^{-1}. s-ABA applied at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05, 0.01$, and 0.001, respectively.

Table 4-21. Effect of mulch color, transplant type, and application type on number of marketable fruits per hectare at Balm

Treatments	NOV		DEC		Early	
Mulch color (M)	Jiffy	Tray	S_1	S_2	S_1	S_2
White	114,668 a	59,156 c	256,557 a	153,931 b	306,401 a	278,891 ab
Black	95,823 b	55,931 c	209,937 ab	173,408 ab	245,584 b	289,111 ab
Appl. x transplant	S_1	S_2	S_1	S_2	S_1	S_2
Control x Jiffy	61,646 d	163,408 ab	265,389 ab	201,892 a-d	327,035 a-d	365,300 a-c
s-ABA x Jiffy	42,482 de	136,907 b	255,807 a-c	237,817 a-c	298,289 a-e	374,724 ab
Kaolin x Jiffy	57,347 de	170,682 a	285,331 a	226,096 a-c	342,678 a-c	396,778 a
Control x Tray	28,348 e	104,134 c	167,359 b-d	94,821 d	195,707 e	198,955 de
s-ABA x Tray	33,205 de	43,554 de	219,570 a-d	122,992 b-d	252,775 b-e	166,546 e
Kaolin x Tray	32,377 de	103,641 c	206,016 a-d	98,400 cd	238,393 c-e	202,041 de
Significance						
Season (S)	***		*		NS	
Mulch color (M)	**		NS		**	
Transplant type (T)	***		***		***	
Application type (A)	***		NS		NS	
S x M	NS		**		**	
S x T	***		*		***	
S x A	***		NS		NS	
M x T	*		NS		NS	
M x A	NS		NS		NS	
T x A	NS		NS		NS	
S x M x T	NS		NS		NS	
S x M x A	NS		NS		NS	
S x T x A	**		*		*	
M x T x A	NS		NS		NS	
S x M x T x A	NS		NS		NS	

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 $lb.acre^{-1}$. s-ABA applied at 150 $mg.L^{-1}$ (2016-2017) and at 75 $mg.L^{-1}$ (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-22. Effect of mulch color, transplant type, and application type on number of marketable fruits at Balm

Treatments	Marketable fruit number.ha^{-1}				
	JAN		FEB	Season total	
Mulch color (M)					
White	392,649 b		738,713 b	1,423,905	
Black	421,229 a		797,611 a	1,486,273	
Transplant type (T)	S_1	S_2		S_1	S_2
Jiffy	332,839 c	511,457 a	785,212	1,332,733 ab	1,787,155 a
Tray	382,089 bc	401,373 b	751,111	1,226,182 b	1,474,246 ab
Application type (A)					
Control	437,613 a		779,323	1,488,653 a	
s-ABA	349,873 b		734,635	1,356,584 b	
Kaolin	433,332 a		790,527	1,520,031 a	
Significance					
Season (S)	NS		*	NS	
Mulch color (M)	*		*	NS	
Transplant type (T)	*		NS	***	
Application type (A)	***		NS	***	
S x M	NS		NS	NS	
S x T	***		NS	**	
S x A	NS		NS	NS	
M x T	NS		NS	NS	
M x A	NS		NS	NS	
T x A	NS		NS	NS	
S x M x T	NS		NS	NS	
S x M x A	NS		NS	NS	
S x T x A	NS		NS	NS	
M x T x A	NS		NS	NS	
S x M x T x A	NS		NS	NS	

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 lb.acre^{-1}. s-ABA apply at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-23. Effect of mulch color, transplant type, and application type on weight of marketable fruits at Citra

Treatments	Marketable fruit weight ($t.ha^{-1}$)			
	NOV	DEC		Early
Mulch color (M)		S_1	S_2	
White	3.2 a	4.9 a	3.6 ab	7.4 a
Black	1.8 b	2.6 bc	2.0 c	4.1 b
Transplant type (T)				
Jiffy	2.5	3.5		6.0
Tray	2.4	3.1		5.5
Application type (A)				
Control	2.5 ab	3.0		5.5
s-ABA	2.3 b	3.3		5.6
Kaolin	2.7 a	3.4		6.1
Significance				
Season (S)	***	NS		NS
Mulch color (M)	***	***		***
Transplant type (T)	NS	NS		NS
Application type (A)	*	NS		NS
S x M	NS	*		NS
S x T	NS	NS		NS
S x A	NS	NS		NS
M x T	NS	NS		NS
M x A	NS	NS		NS
T x A	NS	NS		NS
S x M x T	NS	NS		NS
S x M x A	NS	NS		NS
S x T x A	NS	NS		NS
M x T x A	NS	NS		NS
S x M x T x A	NS	NS		NS

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 $lb.acre^{-1}$. s-ABA apply at 150 $mg.L^{-1}$ (2016-2017) and at 75 $mg.L^{-1}$ (2017-2018). NS, *, ***. Nonsignificant or significant at $P < 0.05$ and 0.001, respectively.

Table 4-24. Effect of mulch color, transplant type and application type on weight of marketable fruits at Citra

Treatments	Marketable fruit weight ($t.ha^{-1}$)					
	JAN		FEB		Season total	
Application type (A)						
Control	10.7 ab		13.2		29.4	
s-ABA	10.3 b		12.7		29.3	
Kaolin	11.3 a		13.4		30.1	
Mulch x transplant type	S_1	S_2	S_1	S_2	S_1	S_2
White x Jiffy	16.1 a	9.4 bc	10.8 cd	18.0 a	34.0 a	31.3 ab
White x Tray	16.0 a	7.8 cd	10.6 cd	17.4 a	32.0 a	30.8 ab
Black x Jiffy	11.3 b	9.1 c	10.5 cd	15.4 ab	29.4 a-c	29.2 a-c
Black x Tray	9.7 bc	6.3 d	8.9 d	13.2 bc	25.7 bc	24.2 c
Significance						
Season (S)	***		***		NS	
Mulch color (M)	***		***		***	
Transplant type (T)	**		NS		NS	
Application type (A)	*		NS		NS	
S x M	***		**		***	
S x T	NS		**		NS	
S x A	NS		NS		NS	
M x T	NS		NS		NS	
M x A	NS		NS		NS	
T x A	NS		NS		NS	
S x M x T	**		*		*	
S x M x A	NS		NS		NS	
S x T x A	NS		NS		NS	
M x T x A	NS		NS		NS	
S x M x T x A	NS		NS		NS	

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 $lb.acre^{-1}$. s-ABA applied at 150 $mg.L^{-1}$ (2016-2017) and at 75 $mg.L^{-1}$ (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-25. Effect of mulch color, transplant type, and application type on weight of marketable fruits at Balm

Treatments	Marketable fruit yield (t.ha^{-1})					
	NOV		DEC		Early	
Mulch color (M)	Jiffy	Tray	S_1	S_2	S_1	S_2
White	2.0 a	1.1 c	5.6 a	2.7 b	6.7 a	4.6 b
Black	1.6 b	1.0 c	4.3 b	2.9 b	5.1 b	4.7 b
Application x transplant type	S_1	S_2	S_1	S_2	S_1	S_2
Control x Jiffy	1.3 de	2.4 ab	5.9 a	3.7 a-c	7.3 ab	6.0 a-d
s-ABA x Jiffy	0.9 ef	2.0 bc	5.2 ab	3.9 a-c	6.1 a-d	5.9 a-d
Kaolin x Jiffy	1.3 de	2.6 a	6.4 a	4.2 a-c	7.7 a	6.8 a-c
Control x Tray	0.6 f	1.6 cd	3.3 bc	1.5 c	3.9 c-e	3.1 de
s-ABA x Tray	0.7 f	0.7 f	4.5 a-c	1.9 bc	5.1 c-e	2.6 e
Kaolin x Tray	0.8 f	1.7 cd	4.4 a-c	1.6 c	5.2 b-e	3.3 de
Significance						
Season (S)	***		**		NS	
Mulch color (M)	***		*		**	
Transplant type (T)	***		***		***	
Application type (A)	***		NS		*	
S x M	NS		**		**	
S x T	***		NS		*	
S x A	***		NS		NS	
M x T	**		NS		NS	
M x A	NS		NS		NS	
T x A	NS		NS		NS	
S x M x T	NS		NS		NS	
S x M x A	NS		NS		NS	
S x T x A	**		*		*	
M x T x A	NS		NS		NS	
S x M x T x A	NS		NS		NS	

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 lb.acre^{-1}. s-ABA apply at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-26. Effect of mulch color, transplant type, and application type on yield of marketable fruits at Balm

Treatments	Marketable fruit yield ($t.ha^{-1}$)					
	JAN		FEB		Season total	
Mulch color (M)						
White	8.7 b		14.4 b		28.7 b	
Black	9.5 a		15.7 a		30.1 a	
Transplant type (T)	S_1	S_2	S_1	S_2	S_1	S_2
Jiffy	6.3 c	12.5 a	11.4 b	19.3 a	24.8 b	38.1 a
Tray	7.1 bc	10.4 b	9.7 b	19.9 a	21.5 c	33.3 b
Application type (A)					S_1	S_2
Control	9.8 a		15.2		22.9 b	37.1 a
s-ABA	7.7 b		14.6		22.0 b	32.4 b
Kaolin	9.8 a		15.5		24.5 b	37.6 a
Significance						
Season (S)	**		**		**	
Mulch color (M)	**		**		**	
Transplant type (T)	*		NS		***	
Application type (A)	***		NS		***	
S x M	NS		NS		NS	
S x T	***		*		*	
S x A	NS		NS		*	
M x T	NS		NS		NS	
M x A	NS		NS		NS	
T x A	NS		NS		NS	
S x M x T	NS		NS		NS	
S x M x A	NS		NS		NS	
S x T x A	NS		NS		NS	
M x T x A	NS		NS		NS	
S x M x T x A	NS		NS		NS	

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 $lb.acre^{-1}$. s-ABA apply at 150 $mg.L^{-1}$ (2016-2017) and at 75 $mg.L^{-1}$ (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Number and weight of early and season total unmarketable fruits

Effect of mulch color on early unmarketable fruit number varied with season at Citra (Table 4-27). More early unmarketable fruits occurred with white-on-black mulch than with black mulch in season 1, with no significant differences due to mulch color observed in season 2. Jiffy plug transplants produced more unmarketable fruits than tray transplants (Table 4-27). Application type had no significant effect on early unmarketable fruit number. Averaged over season, a greater number of total unmarketable fruit were produced with white-on black mulch than black mulch (Table 4-28). Neither transplant type nor application type had any significant effect on total unmarketable fruits.

At Balm, the effect of mulch color on early unmarketable fruit numbers varied with transplant type (Table 4-29). White-on-black mulch with Jiffy plug transplants produced more early unmarketable fruits than black mulch with Jiffy plug transplants, but mulch color had no significant effect with tray transplants. Whereas kaolin-treated plants produced fewer unmarketable early fruit number than s-ABA treated plants, with no differences observed between kaolin-treated and the nontreated control (Table 4-29). Season total unmarketable fruit number was greater with white-on-black mulch than with black mulch in season 1, with no differences observed in season 2 due to mulch color (Table 4-30). Like Citra, transplant and application type had no significant effect on the number of total unmarketable fruits at Balm.

The effect of mulch color on early and season total unmarketable fruit weight at Citra varied with season (Tables 4-31 and 4-32). White-on-black mulch produced higher early unmarketable and season total fruit weight than black mulch in season 1, with no significant difference due to mulch color observed in season 2. Transplant type had no significant effect either on early unmarketable fruit weight or on season total unmarketable fruit weight. Whereas kaolin-treated plants produced more early unmarketable fruit weight than the nontreated control plants (Table 4-31) and application type had no significant effect on season total unmarketable fruit weight (Table 4-32).

At Balm, white-on-black mulch resulted in more early and more season total unmarketable fruit weight than black mulch (Tables 4-33 and 4-34). Although Jiffy plug transplants yielded more early unmarketable fruit weight than tray transplants, season total unmarketable fruit weight did not differ with transplant type. There was no effect of application type on either early unmarketable fruit weight or season total unmarketable fruit weight at Balm.

Conclusions

The results of Experiment 2 indicate that the best options for improving growth and yield with early planted strawberry plug transplants are white-on-black mulch instead of black plastic mulch and Jiffy plug transplants instead of tray transplants. Neither kaolin nor s-ABA treatment resulted in significantly better growth and yield than nontreated control transplants. Further research is recommended in the Hillsborough County area with earlier transplanting dates than the last week of September and with cultivars other than ‘Florida Radiance’.

Table 4-27. Effect of mulch color, transplant type, and application type on number of unmarketable fruits at Citra

Treatments	Number of unmarketable.ha^{-1}					
	NOV		DEC		Early	
Mulch color (M)	S_1	S_2			S_1	S_2
White	58,426 a	45,655 a	30,469		103,665 a	61,015 b
Black	23,082 b	62,838 a	30,710		69,300 b	78,183 b
Transplant type (T)	S_1	S_2	S_1	S_2		
Jiffy	37,848 b	66,427 a	49,898 a	12,829 c	83,711 a	
Tray	43,721 b	42,066 b	41,628 b	18,001 c	72,371 b	
Application type (A)						
Control	47,644		25,230 b		72,677	
s-ABA	43,458		32,756 a		76,899	
Kaolin	51,444		33,728 a		84,546	
Significance						
Season (S)	*		***		*	
Mulch color (M)	*		NS		NS	
Transplant type (T)	*		NS		*	
Application type (A)	NS		***		NS	
S x M	**		NS		***	
S x T	**		***		NS	
S x A	NS		NS		NS	
M x T	NS		NS		NS	
M x A	NS		NS		NS	
T x A	NS		NS		NS	
S x M x T	NS		NS		NS	
S x M x A	NS		NS		NS	
S x T x A	NS		NS		NS	
M x T x A	NS		NS		NS	
S x M x T x A	NS		NS		NS	

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 lb.acre^{-1}, s-ABA apply at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, ***. Nonsignificant or significant at $P < 0.05$ and 0.001, respectively.

Table 4-28. Effect of mulch color, transplant type, and application type on number of unmarketable fruits at Citra

Treatments	Number of unmarketable.ha^{-1}				
	JAN		FEB		Season total
Mulch color (M)	S_1	S_2			
White	148,969 a	112,564 ab	206,934		419,575 a
Black	63,430 c	79,812 bc	215,013		360,687 b
Transplant type (T)			S_1	S_2	
Jiffy	107,577		139,043 b	269,745 a	395,822
Tray	94,810		123,007 b	312,097 a	384,440
Application type (A)					
Control	94,146		221,619		387,680
s-ABA	102,291		199,340		378,345
Kaolin	107,145		211,961		404,368
Significance					
Season (S)	NS		***		**
Mulch color (M)	***		NS		*
Transplant type (T)	NS		NS		NS
Application type (A)	NS		NS		NS
S x M	*		NS		NS
S x T	NS		*		NS
S x A	NS		NS		NS
M x T	NS		NS		NS
M x A	NS		NS		NS
T x A	NS		NS		NS
S x M x T	NS		NS		NS
S x M x A	NS		NS		NS
S x T x A	NS		NS		NS
M x T x A	NS		NS		NS
S x M x T x A	NS		NS		NS

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 lb.acre^{-1}. s-ABA applied at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-29. Effect of mulch color, transplant type, and application type on number of unmarketable fruits at Balm

Treatments	Number of unmarketable.ha^{-1}					
	NOV		DEC		Early	
Mulch color (M)			Jiffy	Tray	Jiffy	Tray
White	10,115		68,833 a	39,264 bc	82,342 a	46,156 bc
Black	6,427		51,218 b	33,334 c	60,514 b	36,331 c
Transplant type (T)	S_1	S_2				
Jiffy	2,891 b	18,990 a	-		-	
Tray	2,788 b	8,415 b	-		-	
Application type (A)						
Control	7,439		48,145 ab		55,830 ab	
s-ABA	9,755		56,086 a		65,896 a	
Kaolin	7,619		40,255 b		47,281 b	
Significance						
Season (S)	***		NS		NS	
Mulch color (M)	NS		*		**	
Transplant type (T)	*		***		***	
Application type (A)	NS		*		*	
S x M	NS		NS		NS	
S x T	*		NS		NS	
S x A	NS		NS		NS	
M x T	NS		*		*	
M x A	NS		NS		NS	
T x A	NS		NS		NS	
S x M x T	NS		NS		NS	
S x M x A	NS		NS		NS	
S x T x A	NS		NS		NS	
M x T x A	NS		NS		NS	
S x M x T x A	NS		NS		NS	

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 lb.acre^{-1}. s-ABA applied at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-30. Effect of mulch color, transplant type, and application type on number of unmarketable fruits at Balm

Treatments	Number of unmarketable.ha^{-1}					
	JAN		FEB		Season total	
Mulch color (M)			S_1	S_2	S_1	S_2
White	130,468 a		500,248 a	143,100 c	755,933 a	276,314 c
Black	100,624 b		341,342 b	106,626 c	555,067 b	190,444 c
Transplant type (T)	S_1	S_2				
Jiffy	163,587 a	74,263 b	273,218		464,405	
Tray	171,023 a	53,311 b	272,439		424,275	
Application type (A)						
Control	124,136		292,392		473,282	
s-ABA	106,376		242,811		415,428	
Kaolin	116,126		283,283		444,609	
Significance						
Season (S)	***		***		***	
Mulch color (M)	***		**		***	
Transplant type (T)	NS		NS		NS	
Application type (A)	NS		NS		NS	
S x M	NS		*		*	
S x T	*		NS		NS	
S x A	NS		NS		NS	
M x T	NS		NS		NS	
M x A	NS		NS		NS	
T x A	NS		NS		NS	
S x M x T	NS		NS		NS	
S x M x A	NS		NS		NS	
S x T x A	NS		NS		NS	
M x T x A	NS		NS		NS	
S x M x T x A	NS		NS		NS	

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 lb.acre^{-1}. s-ABA applied at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-31. Effect of mulch color, transplant type, and application type on yield of unmarketable fruit weight at Citra

Treatments	Unmarketable yield (t.ha^{-1})					
	NOV		DEC		Early	
Mulch color (M)	S_1	S_2			S_1	S_2
White	0.6 a	0.4 b	0.5		1.4 a	0.6 b
Black	0.2 c	0.5 ab	0.4		0.9 b	0.7 b
Transplant type (T)	S_1	S_2	S_1	S_2		
Jiffy	0.4 ab	0.6 a	0.8 a	0.2 b	1.0	
Tray	0.5 ab	0.4 b	0.6 a	0.3 b	0.9	
Application type (A)						
Control	0.5		0.3 b		0.8 b	
s-ABA	0.4		0.4 a		0.9 ab	
Kaolin	0.5		0.5 a		1.0 a	
Significance						
Season (S)	NS		**		***	
Mulch color (M)	***		NS		**	
Transplant type (T)	*		NS		NS	
Application type (A)	NS		**		*	
S x M	***		NS		**	
S x T	***		**		NS	
S x A	NS		NS		NS	
M x T	NS		NS		NS	
M x A	NS		NS		NS	
T x A	NS		NS		NS	
S x M x T	NS		NS		NS	
S x M x A	NS		NS		NS	
S x T x A	NS		NS		NS	
M x T x A	NS		NS		NS	
S x M x T x A	NS		NS		NS	

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 lb.acre^{-1}. s-ABA applied at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-32. Effect of mulch color, transplant type, and application type on yield of unmarketable fruit weight at Citra

Treatments	Unmarketable yield ($t.ha^{-1}$)					
	JAN		FEB		Season total	
Mulch color (M)	S_1	S_2			S_1	S_2
White	3.1 a	2.6 a	3.6		6.7 a	8.3 a
Black	1.4 b	1.8 b	3.7		4.6 b	7.6 a
Transplant type (T)	S_1	S_2	S_1	S_2		
Jiffy	2.1 ab	2.7 a	2.4 c	4.6 b	6.8	
Tray	2.4 ab	1.7 b	2.0 c	5.6 a	6.7	
Application type (A)						
Control	2.2		3.8		6.9	
s-ABA	2.1		3.4		6.5	
Kaolin	2.3		3.7		7.0	
Significance						
Season (S)	NS		***		**	
Mulch color (M)	***		NS		***	
Transplant type (T)	*		*		NS	
Application type (A)	NS		NS		NS	
S x M	**		NS		*	
S x T	**		***		NS	
S x A	NS		NS		NS	
M x T	NS		NS		NS	
M x A	NS		NS		NS	
T x A	NS		NS		NS	
S x M x T	NS		NS		NS	
S x M x A	NS		NS		NS	
S x T x A	NS		NS		NS	
M x T x A	NS		NS		NS	
S x M x T x A	NS		NS		NS	

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 $lb.acre^{-1}$. s-ABA applied at 150 $mg.L^{-1}$ (2016-2017) and at 75 $mg.L^{-1}$ (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-33. Effect of mulch color, transplant type, and application type on yield of unmarketable fruit weight at Balm

Treatments	Unmarketable yield ($t.ha^{-1}$)			
	NOV		DEC	Early
Mulch color (M)				
White	0.1		0.9 a	1.1 a
Black	0.1		0.6 b	0.7 b
Transplant type (T)	S_1	S_2		
Jiffy	0.1 a	0.3 a	0.1 a	1.1 a
Tray	0.1 a	0.2 b	0.5 b	0.6 b
Application type (A)				
Control	0.1		0.8	0.9
s-ABA	0.1		0.9	1.0
Kaolin	0.1		0.7	0.8
Significance				
Season (S)	**		**	NS
Mulch color (M)	NS		**	**
Transplant type (T)	*		***	***
Application type (A)	NS		NS	NS
S x M	NS		NS	NS
S x T	*		NS	NS
S x A	NS		NS	NS
M x T	NS		NS	NS
M x A	NS		NS	NS
T x A	NS		NS	NS
S x M x T	NS		NS	NS
S x M x A	NS		NS	NS
S x T x A	NS		NS	NS
M x T x A	NS		NS	NS
S x M x T x A	NS		NS	NS

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 $lb.acre^{-1}$. s-ABA applied at 150 $mg.L^{-1}$ (2016-2017) and at 75 $mg.L^{-1}$ (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4-34. Effect of mulch color, transplant type, and application type on yield of unmarketable fruit weight at Balm

Treatments	Unmarketable yield (t.ha^{-1})			
	JAN		FEB	Season total
Mulch color (M)	S_1	S_2		
White	2.3 a	1.6 a	3.5 a	6.5 a
Black	2.2 a	0.8 b	2.5 b	4.7 b
Transplant type (T)				
Jiffy	1.8		3.0	5.9
Tray	1.7		3.0	5.3
Application type (A)				
Control	1.9		3.1	5.8
s-ABA	1.6		2.8	5.4
Kaolin	1.8		3.2	5.7
Significance				
Season (S)	NS		***	**
Mulch color (M)	**		*	***
Transplant type (T)	NS		NS	NS
Application type (A)	NS		NS	NS
S x M	*		NS	NS
S x T	NS		NS	NS
S x A	NS		NS	NS
M x T	NS		NS	NS
M x A	NS		NS	NS
T x A	NS		NS	NS
S x M x T	NS		NS	NS
S x M x A	NS		NS	NS
S x T x A	NS		NS	NS
M x T x A	NS		NS	NS
S x M x T x A	NS		NS	NS

Means followed by the same letters within each month do not differ significantly whereas means having dissimilar letters differ significantly as per Tukey HSD test. S_1- 2016-2017 growing season and S_2- 2017-2018 growing season. Kaolin applied at 50 lb.acre^{-1}. s-ABA apply at 150 mg.L^{-1} (2016-2017) and at 75 mg.L^{-1} (2017-2018). NS, *, **, ***. Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

5. A STRAWBERRY CROPPING SYSTEM DESIGN FOR IMPROVING EARLY YIELD AND WATER CONSERVATION AND ITS ECONOMIC EFFECT

The objectives of the present study were to evaluate a strawberry production system resulting heat-stress mitigation, improved early yield and water conservation and to determine whether the net returns justify the higher costs of plug transplants and heat-stress mitigation measures.

Materials and Methods

In order to determine a potential management combination for early yield and water conservation in the strawberry production system, two experiments were conducted at the Plant Science Research and Education Unit (PSREU) in Citra, and Gulf Coast Research and Education Center (GCREC) in Balm, during the 2016- 2017 and 2017-2018 growing season. 'Florida Radiance' (Production Lareault Inc, Lavaltrie, Quebec, Canada) strawberry transplants grown in Jiffy peat pellets and bare-root transplants were used as the planting material. The experiments were conducted using a split-plot design in which main plot treatments were either white-on-black mulch or black mulch; and a factorial arrangement of strawberry transplant type and stress-prevention application was randomly assigned to the subplots. The strawberry transplants were set on September 13, 2016 and September 6, 2017 in Citra and on September 28, 2017 and September 29, 2017 in Balm. For comparison with conventional strawberry production, bare-root 'Florida Radiance' strawberry transplants were also set in adjacent plots on October 14, 2016 and October 9, 2017 in Citra and October 14, 2016 and October 13 in Balm. The best treatment under split plot design in two years, and locations study is compared with conventional bare-root system in this article. Establishment of the bare-root transplants with standard sprinkler irrigation (at 50 PSI with 120 $gal.h^{-1}$; 8 $h.day^{-1}$ for 12 days) was estimated. Water requirement for strawberry was measured by a DLJ water meter. Three weeks prior to transplanting, the soil was fumigated (Pic Clor 60 at 300 $lb.ac^{-1}$) and the beds were prepared. Beds are 8 in height and 30 inches wide on 5-ft centers at Citra but 8 in height and 32 in base and 28 in top wide om 4-ft centers at Balm. Black and white-on-black polyethylene mulch were applied immediately after soil fumigation. Strawberry transplants within beds were set in two offset rows spaced a foot apart. Forty transplants per plot at Citra and twenty-four transplants per plot at Balm were used with 15-inch within-row plant spacing. Soil fumigation manages soil borne pests, and the mulch conserves soil moisture, suppresses weeds, and provides healthy conditions for the fruits. Crop maintenance included periodic runner removal, management of weeds emerging through the mulch and planting holes, and within the row middles. Drip irrigation (0.25 gal $min^{-1}.emitter^{-1}$) was used to maintain optimal soil moisture content for strawberry growth and yield. Fertilizers (6-2-8: % N-P-K) were provided along with drip irrigation. Ridomil Gold (16 $oz.ac^{-1}$) was applied 1 and 2 months after transplanting to control soil-borne fungal diseases. Acaramite (2.5-4 $lb.ac^{-1}$) was applied to control two-spotted spider mite at Citra. Captan 50 WP (4-5 $lb.ac^{-1}$) was used to control botrytis fruit rot and anthracnose. Spical predatory mites (Koppert biological system) were applied (2.5 $mites.ft^{-2}$) as a preventive measure for two-spotted spider mite at Citra.

Data were collected from inner plants within each row to avoid border effect. Photosynthesis, chlorophyll content, plant vigor, plant survival, days to flower, canopy and soil temperature and biomass were measured (data not shown). Water requirements for strawberry production and early and total marketable yields were assessed. Strawberries were harvested by hand early in the day while air temperatures were cool, every 3 to 4 days. The fruit was harvested at commercial maturity after >80% of the fruit surface turned a uniform red color. Immediately after harvest, strawberries were sorted into marketable and cull fruits. Marketable fruit size merited at least a grade of U.S. No. 1. The number and fresh weight of marketable and unmarketable fruits were determined. Total weight of fruits from 15 sample plants was measured separately from each plot. The fruit yields were divided into two categories: early yield and total yield. Up to December was considered as early yield among the total six months. Yield was expressed as the number of 8-lbs flat fruit per acre. Recorded data were calculated by Microsoft Excel 2016.

A partial budget analysis was conducted summarizing the changes in revenue and expenses between production using a combination of white-on-black mulch, plug transplants and kaolin with no sprinkler at establishment and production using a combination of black mulch and bare-root transplants with standard sprinkler irrigation. In Florida, farm workers are usually paid by the hour. In 2016, mean hourly wages for farm workers were $10.38 (BLS). Strawberry pickers are paid by an individual flat rate and the rate differs within the season depending upon the time of harvest. During early season (November to December), the fruit yield is lower, but a higher harvesting price must be paid to meet the minimum wage rate. In 2017, strawberry pickers were paid an average of $2.5 per flat (8 lbs of fruit) in the early part of the season (Wu et al., 2017). As the season advances, yield increases gradually, and less time is required to harvest a flat, and labor cost per flat reduces significantly. However, in 2017 the price per packed box, with clamshells and the unit cost of cooling was a constant $2.49 (Guan et al., 2017).

For the purposes of this study, the weekly weighted average price from 2013-2017 were used to analyze revenue. The early (November to December) grower weekly weighted average price per flat varied from $11.07 to $23.50, whereas later in the season (January to February) the grower weekly weighted average price per flat was $8.59 to $13.20 (USDA-AMS, 2017). The cost per acre with black mulch was $360 whereas white-on-black mulch was $80 per acre more than the black mulch.

Irrigation cost includes pumping, operating, maintaining, and repairing system per inch was $22.5 (Bolda et al., 2016). The bare-root system irrigation cost per acre was $983 (43.7 $in.ac^{-1}$) at Citra and $970 (43.06 $in.ac^{-1}$) at Balm, which was $364 (27.51 $in.ac^{-1}$) at Citra and $ 428 (23.91 $in.ac^{-1}$) higher than the irrigation for the WP system.

The transplant cost per acre was $2,646 for bare-root (at $147 per 1000 plants), whereas $3,816 more was required to purchase plug transplants (at $359 per 1000 plants if buying >10,000-24,999 plants) (Production Lareault Inc, Lavaltrie, Quebec, Canada). Labor cost for transplanting reduced $102 in the WP system than the bare-root system. Equipment, materials and labor cost for disease and pest control are reduced $376 in total in WP system than the bare-root system.

Results and Discussion

Early and total yield

Early fruit receives the highest prices and contributes the most to the income of strawberry growers in Florida. Early fruit can be worth as much as $11.08 to $23.50 per flat of strawberries. Fruit response from the early (November to December) harvest period in Citra and Balm was affected by the WP system and bare-root system (Table 5-1). Average early marketable yield was lower in bare-root system compared to the WP system, because bare-root transplants were planted one month later while the plugs transplants established and started fruiting. Hochmuth et al. (2006) reported that strawberry plug transplants facilitate earlier flowering than bare-root transplants that required a longer time to flower. Thus, plug transplants may have the potential to provide greater early yield of the strawberry and thus more profit to the producer.

Consistency in early fruit production is vital for the WP system to be economically viable. Mohamed (2000) reported that early yield was increased by plug transplants compared to bare-root transplants in Egypt. In addition, mulching also improves plant growth, berry weight, fruit yield and quality in the strawberry. White-on-black mulch helps to mitigate heat stress in vegetable industry (Tarara, 2000). Mulching has a large impact on soil temperature and moisture content and it enhances yield quality of crops (Ham et al., 1993). However, total season yield was also higher in the WP system compared to bare-root system in both locations (Citra and Balm) (Table 5-1). The yield of bare-root transplants was considerably lower than with the WP system especially in the 2016-2017 growing season at Balm because significant portion of bare-root transplants died due to *Phytophthora* infestation. Since bare-root transplants also succumbed to this disease at Citra it is likely that the transplants were infected from the nursery. At Balm, production cost was calculated based on a 2-year average whereas yield was calculated based on the 2017-2018 growing season only.

Economic evaluation

Irrigation water use at both Citra and Balm continued to be lower with WP system than bare-root system even though the former were transplanted earlier (Table 5-2). This is because no overhead irrigation was used to establish the WP system. Since one-third of the water used in a strawberry production season is used during plant establishment, it suggests that, with white-on-black mulch and plugs (WP) system, the pumping cost would be condensed by one-third. This cost ($364 ac^{-1}) denotes about 7.2 % at Citra and ($428 ac^{-1}) signifies about 8.4 % at Balm of the total operating costs for strawberry production. The money conserved in pumping, operating, maintaining, and repairing cost through the WP system would influence a small portion of the overall strawberry production costs. However, if farmers ever need to pay for all or a portion of their irrigation water, then the economic savings in production costs with the WP system could be significant.

Table 5-1. Effect of white-on-black mulch and Jiffy plug (WP) system and bare-root system on early and total yield of strawberry at Citra and Balm, Florida[z]

System	October ($flat.ac^{-1}$)	November ($flat.ac^{-1}$)	December ($flat.ac^{-1}$)	January ($flat.ac^{-1}$)	February ($flat.ac^{-1}$)	Early yield ($flat.ac^{-1}$)	Total yield ($flat.ac^{-1}$)
				Citra (2016-2017)			
WP	-	325.8	587.3	1933.1	1600.3	913.2	4446.6
Bare-root	-	0.0	124.9	384.7	1414.6	125.0	1924.3
Difference	-	325.8	462.4	1548.4	185.7	788.2	2522.3
				Citra (2017-2018)			
WP	53.4	451.3	525.9	1108.3	1431.3	1030.6	3570.2
Bare-root	0.0	3.1	449.9	625.2	890.1	452.9	1968.3
Difference	53.4	448.2	76.0	483.1	541.2	577.7	1601.9
				Balm (2016-2017)			
WP	-	184.0	877.9	674.4	1188.0	1061.9	2924.3
Bare-root	-	0.0	258.0	205.0	500.0	258.0	963.0
Difference	-	184.0	619.9	469.4	688.0	803.9	1961.3
				Balm (2017-2018)			
WP	-	227.4	584.2	1362.5	2095.3	811.6	4269.4
Bare-root	-	0.0	465.4	635.9	1250.9	465.4	2352.3
Difference	-	227.4	118.8	726.6	844.4	346.2	1917.1

[z]Early yield (October to December); total yield (November to February); 1 flat=8 lbs (3.63 kg); $flat.ac^{-1}$ means flats per acre. N.B. Significant portion bare-root transplants died at Balm due to *Phytophthora* infestation during 2016-2017 growing season.

Table 5-2. Irrigation water use in the Plant Science Research and Education Unit (PSREU) and Gulf Cost Research and Education Centre (GCREC) at Citra and Balm (2-year average)

System	Overhead irrigation			Drip irrigation		Total irrigation	
	Duration	GPA[z]	($in.ac^{-1}$)[z]	Duration	GPA	(GPA)	($in.ac^{-1}$)
				Citra			
WP system	--[y]	--	--	Sep. – Feb.	747,000	747,000	27.51
Bare-root system	Oct. (12 days)	610,280	22.47	Oct. – Feb.	576,264	1,186,544	43.70
Difference	--	610,280	22.47	--	170,736	439,544	16.19
				Balm			
WP system	--[y]	--	--	Sep. – Feb.	649,182	649,182	23.91
Bare-root system	Oct. (12 days)	612,563	22.56	Oct. – Feb.	556,700	1,169,263	43.06
Difference	--	612,563	22.56	--	92,482	520,081	19.15

[z] GPA and $in.ac^{-1}$ are gallons per acre and inches per acre, respectively.
[y] No overhead irrigation was used for establishment of containerized transplants.

The use of the WP system increases the amount of input costs for the strawberry grower because plug transplants are approximately twice the cost of bare-root transplants, and the white-on-black mulch also cost more. Inputs most affected by using the WP system are plant establishment irrigation operating costs. Using current 2017 bare-root transplant prices of $147 per 1000 plants and plug prices of $359 per >10,000-24,999 plants (Production Lareault Inc, Lavaltrie, Quebec, Canada), the transplants cost rise from $2,646 to $6,462 ac^{-1} with plugs, mulch cost increase $360 to $440 ac^{-1} with white-on-black mulch, but the costs of pumping water, transplanting, and disease and pest control equipment and materials decreased. The overall cost increase from WP system use combined is $6,734 ac^{-1} (early cost) and $14,304 ac^{-1} (total cost), and $5,067 ac^{-1} (early cost) and $11,262 ac^{-1} (total cost) at Citra and Balm, respectively, including savings in machinery cost due to conservative irrigation needs, labor, disease and pest control (Tables 5-3 and 5-4).

Table 5-3. Cost comparison between strawberries using bare-root system and white-on-black mulch and Jiffy plug (WP) system for Citra, Florida (2-year average)[z]

Cost category	Cost items	Early cost due to use of bare-root system ($.ac^{-1})	Early cost changes due to use of WP system ($.ac^{-1})	Total cost due to use of bare-root system ($.ac^{-1})	Total cost changes due to use of WP system ($.ac^{-1})
Operating	Transplants[y]	2,646	3,816	2,646	3,816
	Labor for transplanting[x]	413	-102	413	-102
	Mulch[w]	360	80	360	80
	Irrigation[v]	983	-364	983	-364
	Equipment, materials and labor cost for diseases and pests control[u]	684	-104	1,184	-376
Total operating		5,086	3,326	5,586	3,054
Total harvesting	Labor for harvesting[x]	722	1,707	4,385	5,636
Total marketing	Price of packing boxes and clamshells and cooling[x]	720	1,701	4,367	5,614
Total		6,528	6,734	14,338	14,304
Additional costs of using WP system			6,734		14,304

[z]Costs based on early yield of 971.89 flats.ac^{-1} (flats per acre) and 288.95 flats.ac^{-1}, and total yield of 4008.37 flats.ac^{-1} and 1946.27 flats.ac^{-1}, respectively (2-year average) _8-lbs (3.63 kg) flats.ac^{-1}, $1.00 acre^{-1}=$2.47 ha^{-1}, $2.50 flat^{-1}_harvesting, $2.49 flat^{-1}_marketing

[y]Bare-root transplants are $147 per 1000 plants and plug prices of $359 per 1000 plants if buying >10,000-24,999 plants, 18,000 plants.ac^{-1}

[x]Mean hourly wage for farm workers in Florida ($10.38)

[w]Cost based on black mulch at $360 and white-on-black mulch at $440 per acre

[v]Irrigation costs based on $22.5 in^{-1} for 43.70 in.ac^{-1}_bare-root system and 27.51 in.ac^{-1}_white-on-black and plugs system (in.ac^{-1} is inches per acre)

[u]Disease and pest control cost for materials, equipment and labor

Table 5-4. Cost comparison between strawberries using bare-root system and white-on-black mulch and Jiffy plug (WP) system for Balm, Florida (2-year average)[z]

Cost category	Cost items	Early cost due to use of bare-root system ($.ac^{-1})	Early cost changes due to use of WP system ($.ac^{-1})	Total cost due to use of bare-root system ($.ac^{-1})	Total cost changes due to use of WP system ($.ac^{-1})
Operating	Transplants[y]	2,646	3,816	2,646	3,816
	Labor for transplanting[x]	413	-102	413	-102
	Mulch[w]	360	80	360	80
	Irrigation[v]	970	-428	970	-428
	Equipment, materials and labor cost for diseases and pests control[u]	684	-104	1,184	-376
Total operating		5,073	3,262	5,573	2,990
Total harvesting	Labor for harvesting[x]	1,438	904	4,848	4,144
Total marketing	Price of packing boxes and clamshells and cooling[x]	1,432	901	4,829	4,128
Total		7,943	5,067	15,250	11,262
Additional costs of using WP system			5,067		11,262

[z]Costs based on early yield of 971.89 flats.ac^{-1} (flats per acre) and 288.95 flats.ac^{-1}, and total yield of 4008.37 flats.ac^{-1} and 1946.27 flats.ac^{-1}, respectively (2-year average) _8-lbs (3.63 kg) flats.ac^{-1}, $1.00 acre^{-1}=$2.47 ha^{-1}, $2.50 flat^{-1}_harvesting, $2.49 flat^{-1}_marketing

[y]Bare-root transplants are $147 per 1000 plants and plug prices of $359 per 1000 plants if buying >10,000-24,999 plants, 18,000 plants.ac^{-1}

[x]Mean hourly wage for farm workers in Florida ($10.38)

[w]Cost based on black mulch at $360 and white-on-black mulch at $440 per acre

[v]Irrigation costs based on $22.5 in^{-1} for 43.70 in.ac^{-1}_bare-root system and 27.51 in.ac^{-1}_white-on-black and plugs system (in.ac^{-1} is inches per acre)

[u]Disease and pest control cost for materials, equipment and labor

There must be a revenue reward in addition to the water conservation for the WP system use to be cost-effective for current strawberry growers. That revenue reward is provided by price premiums from earlier strawberry yield. Earlier strawberry production with the WP system use occurred in both locations (Tables 5-5 to 5-8). Average early yield (up to December) was increased by 683 flats.ac^{-1} at Citra and 346 flats.ac^{-1} at Balm for the WP system over sprinkler-irrigated bare-root system (Table 5-9). Early strawberries in Florida typically command prices of $11.08 to $23.50 and $8.59 to $13.20 for late, estimated from 2013-2017 weekly weighted average prices (USDA-AMS, 2017). The increase in early yield with the WP system use would pay for the amplified input costs compared to bare-root system. For instance, the additional cost for using the WP system amounts to \$6,734 ac^{-1} (early cost) and \$14,304 ac^{-1} (total cost) at Citra and \$5,067 ac^{-1} (early cost) and \$11,262 ac^{-1} (total cost) at Balm (Tables 5-3 and 5-4) and the income for the rise in early yield in Citra at \$11.08 to \$23.50 per flat would be \$5,450 (early) and \$14,657 (total) and in Balm would be \$2,075 (early) and \$13,765 (total) (Table 5-9). The savings in water used in establishment with the WP system would add more to this cost-effectiveness. The capacity to establish plants with less water would be particularly vital in potential future conditions where farmers are required to cut farm water consumption.

Table 5-9 is a partial budget analysis specifying the differences in revenue and expenses between the WP system and the bare-root system. Costs not directly mentioned in the partial budget are expected to be alike. Additional income from early production is based on the Citra and Balm yield data (Tables 5-5 to 5-8). There is a reduction in irrigation variable costs associated with using the WP system compared to bare-root system. The WP system does not require overhead sprinkler irrigation for transplant establishment. The decrease in irrigation operating costs is a natural result of not having to pay for supplies, repairs, maintenance, and energy costs for operating a pump for an overhead sprinkler system distributing 16.19 $in.ac^{-1}$at Citra and 19.15 $in.ac^{-1}$at Balm water to plants within 96 h during the 12 days establishment period. These savings are \$364 ac^{-1} at Citra and \$428 ac^{-1} at Balm (Tables 5-3 and 5-4). Operating cost includes pumping, maintaining, and repairing system for irrigation per inch is conventionally \$22.5 (Bolda et al., 2016).

Additional expenses of \$6,734 ac^{-1} (early) and \$14,304 ac^{-1} (total) at Citra and \$5,067 ac^{-1} (early) and \$11,262 ac^{-1} (total) at Balm (Tables 5-3 and 5-4) were experienced due to the use of the WP system rather than the bare-root system. There is loss of revenue related to the lower price of strawberry especially in the end of season (\$8.59 to \$13.20 $flat^{-1}$). The expected net effect from using the WP system is \$5,450 (early) and \$14,657 (total) in Citra and in Balm would be \$2,075 (early) and \$13,765 (total) greater than using the bare-root system, signifying increased effectiveness potential under this specific set of assumptions. The findings agreed with Hochmuth et al. (2006). They conducted a partial budget analysis that indicated that although plug transplant costs were higher by \$1,853 ac^{-1}, higher earlier yield offset the higher cost of production and resulted in net returns that were higher by \$1,142 ac^{-1} than with bare-root transplants in one year of the two-year study.

Table 5-5. Early (Nov. to Dec.) and total (Nov. to Feb.) yield and price variation of using white-on-black mulch and Jiffy plug (WP) system relative to bare-root system at Citra (2016-2017) [z]

Treatments	**Week 1**			**Week 2**			**Week 3**			**Week 4**			**Total**	
	Yield ($flat.ac^{-1}$)	Price ($\$.flat^{-1}$)	Value ($\$.ac^{-1}$)	Yield ($flat.ac^{-1}$)	Price ($\$.flat^{-1}$)	Value ($\$.ac^{-1}$)	Yield ($flat.ac^{-1}$)	Price ($\$.flat^{-1}$)	Value ($\$.ac^{-1}$)	Yield ($flat.ac^{-1}$)	Price ($\$.flat^{-1}$)	Value ($\$.ac^{-1}$)	Yield ($flat.ac^{-1}$)	Value ($\$.ac^{-1}$)
							November						**November**	
WP system	8.2	13.78	113.0	82.3	16.21	1334.1	105.33	20.42	2150.8	130.0	20.77	2700.1	325.83	6298.0
Bare-root system	0	13.78	0.0	0	16.21	0.0	0	20.42	0.0	0	20.77	0.0	0.00	0.0
Difference	8.2	0	113.0	82.3	0	1334.1	105.33	0	2150.8	130.0	0	2700.1	325.83	6298.0
							December						**December**	
WP system	55.86	23.50	1312.7	43.64	20.90	912.1	65.80	20.64	1358.1	422.02	16.02	6760.8	587.32	10343.7
Bare-root system	17.25	23.50	405.4	28.96	20.90	605.3	35.52	20.64	733.1	43.23	16.02	692.5	124.96	2436.3
Difference	38.61	0	907.3	14.68	0	306.8	30.28	0	625.0	378.79	0	6068.2	462.36	7907.4
							January						**January**	
WP system	627.5	13.20	8283.0	411.6	12.59	5182.0	508.5	12.08	6142.7	385.5	13.10	5050.0	1933.1	24657.8
Bare-root system	117.4	13.20	1549.7	41.3	12.59	520.0	108.7	12.08	1313.1	117.3	13.10	1536.6	384.7	4919.4
Difference	510.1	0	6733.3	370.3	0	4662.0	399.8	0	4829.6	268.2	0	3513.4	1548.4	19738.4
							February						**February**	
WP system	206.9	11.33	2344.2	238.9	10.45	2496.5	358.4	10.62	3806.2	796.1	8.59	6838.5	1600.3	15485.4
Bare-root system	95.6	11.33	1083.1	199.5	10.45	2084.8	348.6	10.62	3702.1	770.9	8.59	6622.0	1414.6	13492.1
Difference	111.3	0	1261.1	39.4	0	411.7	9.8	0	104.1	25.2	0	216.5	185.7	1993.3

[z]Grower weekly weighted average price per flat $11.08 to $23.50 (early) and $8.59 to $13.20 (late) (USDA-AMS, 2013-2017)

Table 5-6. Early (Nov. to Dec.) and total (Nov. to Feb.) yield and price variation of using white-on-black mulch and Jiffy plug (WP) system relative to bare-root system at Citra (2017-2018)[z]

Treatments	Week 1			Week 2			Week 3			Week 4			Total	
	Yield ($flat.ac^{-1}$)	Price ($\$.flat^{-1}$)	Value ($\$.ac^{-1}$)	Yield ($flat.ac^{-1}$)	Price ($\$.flat^{-1}$)	Value ($\$.ac^{-1}$)	Yield ($flat.ac^{-1}$)	Price ($\$.flat^{-1}$)	Value ($\$.ac^{-1}$)	Yield ($flat.ac^{-1}$)	Price ($\$.flat^{-1}$)	Value ($\$.ac^{-1}$)	Yield ($flat.ac^{-1}$)	Value ($\$.ac^{-1}$)
							October						**October**	
WP system	-	-	-	-	-	-	4.76	11.07	52.7	48.64	12.53	609.5	53.4	662.2
Bare-root system	-	-	-	-	-	-	0	11.07	0	0	12.53	0	0	0
Difference	-	-	-	-	-	-	4.76	0	52.7	48.64	0	609.5	53.4	662.2
							November						**November**	
WP system	113.3	13.78	1561.3	125.55	16.21	2035.2	105.58	20.42	2155.9	106.91	20.77	2220.5	451.34	7972.9
Bare-root system	0	13.78	0.00	0	16.21	0.00	0	20.42	0	3.08	20.77	64.0	3.08	64.0
Difference	113.3	0	1561.3	125.55	0	2035.2	105.58	0	2155.9	103.83	0	2156.5	448.26	7908.9
							December						**December**	
WP system	54.54	23.50	1281.7	31.37	20.90	655.6	231.07	20.64	4769.3	208.91	16.02	3346.7	525.89	10053.4
Bare-root system	17.09	23.50	401.6	25.54	20.90	533.8	217.05	20.64	4479.9	190.18	16.02	3046.7	449.86	8462.0
Difference	37.45	0	880.1	5.83	0	121.8	14.02	0	289.4	18.73	0	300.0	76.03	1591.4
							January						**January**	
WP system	182.89	13.20	2414.1	354.36	12.59	4461.4	162.02	12.08	1957.2	408.99	13.10	5357.8	1108.26	14190.5
Bare-root system	160.42	13.20	2117.5	200.89	12.59	2529.2	45.49	12.08	549.5	218.41	13.10	2861.2	625.21	8057.4
Difference	22.47	0	296.6	153.47	0	1932.2	116.53	0	1407.7	190.58	0	2496.6	483.05	6133.1
							February						**February**	
WP system	260.26	11.33	2948.7	262.62	10.45	2744.4	210.49	10.62	2235.4	697.94	8.59	5995.3	1431.31	13923.8
Bare-root system	73.59	11.33	833.8	87.91	10.45	918.7	109.70	10.62	1165.0	618.93	8.59	5316.6	890.13	8234.1
Difference	186.67	0	2114.9	174.71	0	1825.7	100.79	0	1070.4	79.01	0	678.7	541.18	5689.7

[z]Grower weekly weighted average price per flat \$11.08 to \$23.50 (early) and \$8.59 to \$13.20 (late) (USDA-AMS, 2013-2017)

Table 5-7. Early (Nov. to Dec.) and total (Nov. to Feb.) yield and price variation of using white-on-black mulch and Jiffy plug (WP) system relative to bare-root system at Balm (2016-2017) [z]

Treatments	Week 1			Week 2			Week 3			Week 4			Total	
	Yield (flat.ac^{-1})	Price (\$.flat^{-1})	Value (\$.ac^{-1})	Yield (flat.ac^{-1})	Price (\$.flat^{-1})	Value (\$.ac^{-1})	Yield (flat.ac^{-1})	Price (\$.flat^{-1})	Value (\$.ac^{-1})	Yield (flat.ac^{-1})	Price (\$.flat^{-1})	Value (\$.ac^{-1})	Yield (flat.ac^{-1})	Value (\$.ac^{-1})
							November						**November**	
WP system	-	-	-	-	-	-	23.56	20.42	481.1	160.47	20.77	3332.9	184.03	3814.1
Bare-root system	-	-	-	-	-	-	0	20.42	0	0	20.77	0	0	0
Difference	-	-	-	-	-	-	23.56	0	481.1	160.47	0	3332.9	184.03	3814.1
							December						**December**	
WP system	178.17	23.50	4187.0	110.13	20.90	2301.7	140.87	20.64	2907.6	448.72	16.02	7188.5	877.89	16584.8
Bare-root system	5.74	23.50	134.9	25.77	20.90	538.6	93.32	20.64	1926.1	133.17	16.02	2133.4	258.00	4733.0
Difference	172.43	0	4052.1	84.36	0	1763.1	47.55	0	981.5	315.55	0	5055.1	619.89	11851.8
							January						**January**	
WP system	269.92	13.20	3562.9	128.89	12.59	1622.7	131.94	12.08	1593.8	143.63	13.10	1881.6	674.38	8661.1
Bare-root system	60.18	13.20	794.4	50.73	12.59	638.7	59.13	12.08	714.3	34.97	13.10	458.1	205.01	2605.5
Difference	209.74	0	2768.5	78.16	0	984.0	72.81	0	879.5	108.66	0	1423.5	469.37	6055.6
							February						**February**	
WP system	157.97	11.33	1789.8	242.72	10.45	2536.4	364.96	10.62	3875.9	422.36	8.59	3628.1	1188.01	11830.2
Bare-root system	62.34	11.33	706.3	120.41	10.45	1258.3	134.19	10.62	1425.1	183.05	8.59	1572.4	499.99	4962.1
Difference	95.63	0	1083.5	122.31	0	1278.1	230.77	0	2450.8	239.31	0	2055.7	688.02	6868.1

[z]Grower weekly weighted average price per flat \$11.08 to \$23.50 (early) and \$8.59 to \$13.20 (late) (USDA-AMS, 2013-2017)

Table 5-8. Early (Nov. to Dec.) and total (Nov. to Feb.) yield and price variation of using white-on-black mulch and jiffy plug (WP) system relative to bare-root system at Balm (2017-2018)[z]

Treatments	Week 1			Week 2			Week 3			Week 4			Total	
	Yield (flat.ac^{-1})	Price ($.flat^{-1})	Value ($.ac^{-1})	Yield (flat.ac^{-1})	Price ($.flat^{-1})	Value ($.ac^{-1})	Yield (flat.ac^{-1})	Price ($.flat^{-1})	Value ($.ac^{-1})	Yield (flat.ac^{-1})	Price ($.flat^{-1})	Value ($.ac^{-1})	Yield (flat.ac^{-1})	Value ($.ac^{-1})
						November							**November**	
WP system	-	-	-	29.46	16.21	477.6	94.24	20.42	1924.4	103.68	20.77	2153.4	227.38	4555.4
Bare-root system	-	-	-	0	16.21	0	0	20.42	0	0	20.77	0.0	0	0
Difference	-	-	-	29.46	0	477.6	94.24	0	1924.4	103.68	0	2153.4	227.38	4555.4
						December							**December**	
WP system	104.98	23.50	2467.0	78.87	20.90	1648.4	255.1	20.64	5265.3	145.27	16.02	2327.2	584.22	11707.9
Bare-root system	43.97	23.50	1033.3	53.10	20.90	1109.8	233.1	20.64	4811.2	135.27	16.02	2167.0	465.44	9121.3
Difference	61.01	0	1433.7	25.77	0	538.6	22.0	0	454.1	10	0	160.2	118.78	2586.6
						January							**January**	
WP system	240.56	13.20	3175.4	572.20	12.59	7203.9	288.55	12.08	3485.7	261.17	13.10	3421.3	1362.48	17286.4
Bare-root system	225.06	13.20	2970.8	239.17	12.59	3011.1	76.81	12.08	927.9	94.85	13.10	1242.5	635.89	8152.3
Difference	15.50	0	204.6	333.03	0	4192.8	211.74	0	2557.8	166.32	0	2178.8	726.59	9134.1
						February							**February**	
WP system	306.44	11.33	3471.9	477.88	10.45	4993.8	470.31	10.62	4994.7	840.71	8.59	7221.7	2095.34	20682.2
Bare-root system	86.03	11.33	974.7	126.53	10.45	1322.2	351.90	10.62	3737.2	686.48	8.59	5896.9	1250.94	11931.0
Difference	220.41	0	2497.2	351.35	0	3671.6	118.41	0	1257.5	154.23	0	1324.8	844.40	8751.2

[z]Grower weekly weighted average price per flat $11.08 to $23.50 (early) and $8.59 to $13.20 (late) (USDA-AMS, 2013-2017)

Table 5-9. Net effect of using white-on-black mulch and Jiffy plug (WP) system relative to bare-root system at Citra and Balm (2-year average)

Budget variable	Early Fruit yield changes (flats.ac^{-1})^{z}	Value changes (\$.acre^{-1})^{y}	Total fruit yield changes (flats.ac^{-1})^{z}	Value changes (\$.acre^{-1})^{y}	Value (\$.100 acres^{-1})
			Citra		
Yield or Revenue changes	683	12,184	2,062	28,961	2,896,100
Cost changes	-	6,734	-	14,304	1,430,400
Net effect	-	5,450	-	14,657	1,465,700
			Balm		
Yield or Revenue changes	346	7,142	1,917	2,5027	2,502,700
Cost changes	-	5,067	-	11,262	1,126,200
Net effect	-	2,075	-	13,765	1,376,500

^{z}1 flat=8 lbs (3.63 kg), increased early yield 683 flats.ac^{-1}, and total yield 2,062 flats.ac^{-1} (2-year average) at Citra and increased early yield flats.ac^{-1}, and total yield 1,917 flats.ac^{-1} (Based on 2017-2018 season yield only) at Balm and \$1.00 ac^{-1}=\$2.47 ha^{-1}
^{y}Grower weekly weighted average price per flat \$11.08 to \$23.50 (early) and \$8.59 to \$13.20 (late) (USDA-AMS, 2013-2017)

Conclusions

Our results show that WP system use has the potential for decreasing irrigation water use as well as improving revenues on strawberry farms. The bare-root system resulted in a total water use (sprinkler + drip) for the season of 1,186,544 gallons per acre at Citra and 1,169,263 gallons per acre at Balm. The WP system, which used only drip irrigation, accounted for 747,000 gallons per acre at Citra and 649,182 gallons at Balm. Thus the elimination of sprinkler irrigation resulted in decreases in water use of 439,544 gallons per acre at Citra and 520,081 gallons per acre at Balm. The WP system provided higher early and total fruit yields than the bare-root system at both locations (Citra and Balm). The total profitability of strawberry production was elevated by \$14,657 acre^{-1} at Citra and \$13,765 acre^{-1} at Balm. The results can be used to inform the decision-making about cropping system modification that can considerably increase profitability while reducing water use. More research is required to establish consistency in earliness with the WP system with strawberry cultivars other than ‘Florida Radiance’.

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