Proc. Fla. State Hort. Soc. 130:140–144. 2017.

Optimization of Heat Stress Mitigation Measures for Strawberry Plug Transplant Establishment

Prosanta K. Dash[1], Carlene A. Chase[1]*, Shinsuke Agehara[2], and Lincoln Zotarelli[1]

[1]*Horticultural Sciences Department, University of Florida, IFAS, P.O. Box 110690, Gainesville, FL 32611*

[2]*Gulf Coast Research and Education Center, University of Florida, IFAS, 14625 CR 672, Wimauma, FL 33598*

Additional index words. *Fragaria ×ananassa*, s-abscisic acid, kaolin

The Florida strawberry (*Fragaria ×ananassa* Duch.) industry continues to experience competition for the winter market from California; but of particular concern has been Mexico where strawberry acreage has been expanding. Moving Florida strawberry production to earlier in the season to take advantage of the higher prices for early yield may improve the state's economic sustainability. Early planting in Florida, however, exposes strawberry transplants to heat stress. In order to address the problem of heat stress in a system designed to eliminate the use of overhead irrigation for strawberry transplant establishment, the utility of s-ABA and kaolin on 'Florida Radiance' strawberry plugs was assessed. In the first year s-ABA was applied at 250, 500, 750, and 1000 mg/L as a five-second root dip just prior to transplanting. Because of adverse outcomes, which were worse at the higher rates, s-ABA application rates were decreased to 100, 150, 200, and 250 mg/L in the second year. Kaolin (56 kg/ha) was applied in both years as either a single spray shortly after transplanting or as two consecutive sprays—the first at the same time as the single spray application and the second at seven days after transplanting. The results indicate that plug transplants treated with either 100 mg/L s-ABA treatment or with single or double kaolin sprays exhibited better survival, vigor, vegetative growth, and early marketable yield than untreated transplants.

Fresh-market strawberries are an important crop in the United States, with a farm-gate value of $2.2 billion in 2012, more than twice that of fresh tomatoes. Florida and California produce about 99% of U.S. strawberries (USDA, 2015). Florida is the leading producer of winter strawberries, with a production area of approximately 10,800 acres and a production value of $450 million in 2016 (USDA/NASS, 2017). In recent years the Florida strawberry industry has faced a growing challenge for the winter strawberry market from Mexico and California that threatens the economic sustainability of the industry (Wu et al., 2015). Initiating strawberry production earlier in the season has been proposed as a means to enhance early yields during November and December when strawberry prices are highest (Wu et al., 2015).

The Florida strawberry industry utilizes the annual hill system of production with bare-root strawberry transplants from California and Canada. The impaired root systems require the use of sprinkler irrigation for transplant establishment during the first 10–14 days after transplanting to maintain a cool microclimate around the strawberry crowns in order to promote crown survival and new root growth. Strawberry establishment from bare-root transplants can utilize as much as 20 inches (equivalent to 540,000 gallons/acre with sprinkler irrigation) of water, which is one-third of the total water required for strawberry production (Albregts and Howard, 1985). The use of containerized transplants facilitates faster strawberry establishment (Styer and Koranski, 1997) with a much lower water requirement (Santos et al., 2012). However, containerized transplants cost twice as much as bare-root transplants and increase the cost of production (Hochmuth et al., 2006) and is the second reason for adapting the cropping system to enhance early yields.

The black plastic mulch used with the crop to warm the winter soil, combined with early planting in Florida will expose strawberry transplants to higher air and soil temperatures, which can cause stunting and even death of strawberry transplants from heat stress. Heat tolerant cultivars adapted to Florida are not currently available (Wu et al., 2015). In recent years, unusually warm weather in Florida during the normal strawberry establishment period (late September to mid-October) has exposed strawberry plants to heat stress that adversely affected early yields. Further, there has been an increase of 1 to 2 °C in the early part of September for the last few years in Florida [Florida Automated Weather Network (FAWN), 2015]. It is anticipated that mean global temperature will increase by 1.5 to 4.5 °C, within the next century, with local differences (Houghton et al., 1992; IPCC, 2007).

Approaches to mitigating heat stress that may have applicability to strawberry transplant establishment can be direct and involve treating the plant to affect its susceptibility to heat stress or indirect by modifying the microclimate of the plant. The plant growth regulator, s-abscisic acid (s-ABA), has been shown to reduce transplant shock, increase heat stress tolerance, and enhance crop

This research was supported in part by the Southwest Florida Water Management District and by a fellowship to P.K. Dash from the Borlaug Higher Education for Agricultural Research and Development program.

*Corresponding author. Email: cachase@ufl.edu

establishment for many types of transplants (Racsko et al., 2014). Leafy vegetable plants (*Brassica*) treated with s-ABA exhibit greater stress tolerance capacity and less heat stress (Davies and Jones, 1991). Mitigation of water usage may be possible with s-ABA due to its effects of decreasing leaf expansion rate and causing stomatal closure (Agehara and Leskovar, 2012).

Another substance, kaolin, an organic mineral compound rich in kaolinite, is used for mitigating heat and drought stress in various crops. In addition, the white film formed on the leaf surface 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). Kaolin is thought to act as an antitranspirant to mitigate against transplant shock and to improve water use effciency (Boari et al., 2015; El-Khawaga, 2013).

It is hypothesized that s-ABA and kaolin can be used to mitigate heat stress that accompanies earlier planting of strawberry, resulting in enhanced early yield. The objective was to evaluate the effects of varying rates of s-ABA and 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 2015–16 and 2016–17 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 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. Abscisic acid (ProTone®, Valent USA Corp., Walnut Creek, CA) was applied at 250, 500, 750, and 1000 mg/L, respectively, as a 5-second root dip just prior to transplanting during the 2015–16 season and at 100, 150, 200, and 250 mg/L during 2016–17. In both seasons, kaolin (Surround®, NovaSource, Phoenix, AZ) treatments (56 kg/ha, 59.9 g/L kaolin) 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 an untreated control.

Management. Runners were removed periodically to enhance the reproductive capacity of the strawberry crowns. Supplemental weed management was performed as needed to manage weeds that emerged in the planting holes and row middles between the beds. Drip irrigation was used to maintain optimal soil moisture content for strawberry growth and yield. Fertilizer was provided along with drip irrigation according to University of Florida IFAS (IFAS) recommendations. Other crop management practices such as pest management and frost protection were performed as needed.

Data collection. Data were collected from inner plants within each row to avoid border effect.

Net CO_2 assimilation rate was measured with a portable photosynthesis system (LI-6400XT, LI-COR Inc., Lincoln, NE). A fully expanded trifoliate leaf sample was placed in the leaf chamber (6.0 cm^2) and exposed to 500 μmol m^{-2}s^{-1} PPFD and a CO_2 concentration of 400 μL·L^{-1}. The number of surviving transplants was assessed at 2 weeks after transplanting and those data were used to calculate the percentage of strawberry transplant survival. Days to first flowering was measured as the number of days from planting to the first flower opening in each plot.

Strawberries were harvested by hand early in the day (while the air temperatures were cool) every 3–4 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 during the period from first to final harvest. An appropriate electronic balance was used to take the weight of fruits and data were recorded in kilograms (kg)/plot and finally converted into t/ha. The fruit yields were divided into two categories: early yield and total yield. The first eight weeks yield was considered as early yield among the total sixteen weeks yield.

Statistical analysis. Recorded data were analyzed statistically by SAS GLIMMIX procedure. Linear and quadratic models were fit to the responses to s-ABA rates. Tukey's HSD test was used to compare the control to the kaolin treatments.

Results and Discussion

Effects of s-ABA application

Plant survival. In 2015–16 all rates of s-ABA resulted in significant transplant mortality that increased as s-ABA rate increased (data not shown). As a result, rates were reduced to the 100 to 250 mg/L range during the 2016–17 season and only data for this season are reported. However, even these lower rates resulted in a quadratic decline in plant survival as s-ABA rates increased (Fig. 1).

Photosynthesis. Photosynthesis was expected to decline with s-ABA treatment due to its effects on stomatal closure (Agehara and Leskovar, 2012) and this was the observed response. The photosynthesis rates decreased as s-ABA rates increased providing a significant quadratic response (Fig. 2).

Days to first flower. Transplants treated with s-ABA flowered earlier than untreated transplants with the highest s-ABA rate resulting in the earliest flowering (Fig. 3). This is an encouraging

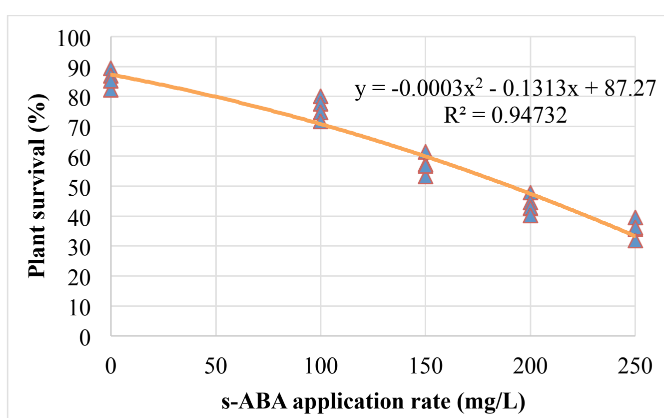

Fig. 1. Effect of s-abscisic acid (s-ABA) on strawberry plant survival (2016–17).

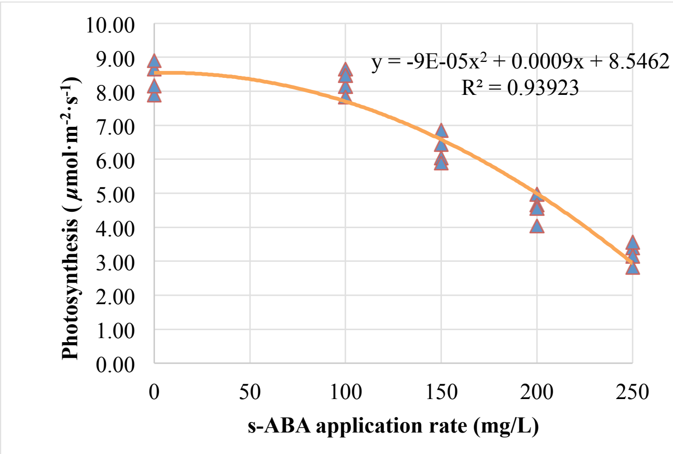

Fig. 2. Effect of s-abscisic acid (s-ABA) on transplant photosynthesis (2016–17).

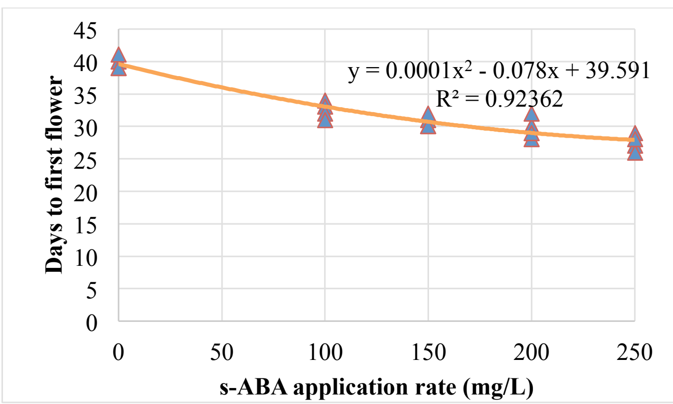

Fig. 3. Effect of s-abscisic acid (s-ABA) on days to first flower (2016–17).

result if a rate can be found that promotes earliness but does not induce plant mortality or other nonlethal injury.

Yield. The response of fruit yield to s-ABA was quadratic with a more pronounced effect on total marketable yield than on early yield (Fig. 4). No stimulation of early and total strawberry marketable yields was obtained with the s-ABA treatment, and rates of s-ABA higher than 100 mg/L reduced fruit yield significantly. Agehara and Leskovar (2014) reported that growth modification by exogenous application of abscisic acid had no harmful effect on fruit yield of two field grown pepper cultivars. Racsko et al.

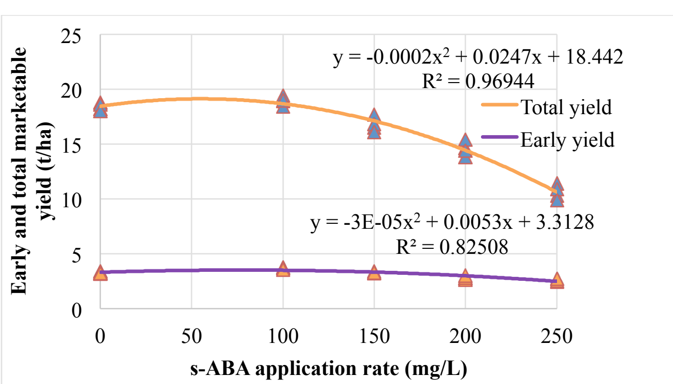

Fig. 4. Effect of s-abscisic acid (s-ABA) on marketable strawberry yield (2016–17).

(2014) found that abscisic acid-treated leafy vegetable transplants withstood post-transplanting shock and performed better even in hot field conditions with high solar radiation than an untreated control. Therefore, it is likely that the rates employed in the current study are still too high.

Effects of kaolin application

Plant survival. Unlike s-ABA, kaolin application improved strawberry transplant survival. In 2015–16, both single and double sprays resulted in better transplant survival than the untreated control (Table 1). However, plant survival was improved by only the double application in 2016–17. Improved survival of kaolin-treated strawberry transplants is consistent with previous reports that kaolin can protect plants against heat stress. Application of a kaolin clay suspension was reported to have resulted in a white coating that reflected light and maintained cooler temperatures on treated as opposed to untreated leaves on 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. 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 would have reflected the incoming solar radiation and kept the plants cool. It is likely that transpiration was 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.

Photosynthesis. Photosynthesis was measured within three days of application prior to application of the second kaolin spray. This explains why there is no difference in the response shown in Table 2. The results in Table 2 indicate that untreated transplants during the three days after transplanting exhibited a lower rate

Table 1. Effect of kaolin on strawberry transplant survival (%) at 2 weeks after transplanting

Treatment	2015–16	2016–17
Control	91.4 b[y]	85.0 b
Kaolin 1X[z]	99.4 a	90.6 ab
Kaolin 2X[z]	100.0 a	95.0 a
P value	0.03	0.01

[z]Kaolin 1X = 50 lb/A kaolin at planting or kaolin 2X = 50 lb/A kaolin at planting and at seven days after planting.
[y]Means in columns followed by the same letters do not differ significantly as per Tukey's HSD test at $P \leq 0.05$.

Table 2. Effect of kaolin on transplant photosynthesis

	Photosynthesis (μmol·m^{-2}·s^{-1})			
Treatment	Sept. 16	Sept. 17	Sept. 18	Oct. 10
Control	8.6 b[y]	9.3 b	9.9 b	14.7
Kaolin 1X[z]	10.3 a	11.3 a	11.7 a	15.3
Kaolin 2X[z]	10.3 a	11.8 a	12.1 a	15.6
P value	0.01	0.04	0.03	0.88

[z]Kaolin 1X = 50 lb/A kaolin at planting or kaolin 2X = 50 lb/A kaolin at planting and at seven days after planting.
[y]Means in columns followed by the same letters do not differ significantly as per Tukey's HSD test at $P \leq 0.05$.

of photosynthesis than kaolin-treated plants. This may be due to greater heat stress occurring in the untreated transplants since by 10 Oct., after the transplants could be considered full established, the difference in photosynthesis was no longer apparent. The white film formed on the leaf surface 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 and improving photosynthesis (Glenn, 2012; Rosati et al., 2006). High temperatures can damage thylakoid membranes and reduce the activity of PS II and finally hampered the photosynthetic activity of plants (Berry and Björkman, 1980). Protection by kaolin from high temperature injury may explain the higher photosynthesis rate of kaolin-treated plants compared to the untreated control.

Days to first flower. Flowering occurred earlier in kaolin-treated plants by 6–7 days in 2015–16 and by 5–6 days in 2016-2017 (Table 3). No significant difference in flowering occurred due to the second application of kaolin.

Yield. Kaolin significantly affected early and total strawberry marketable yields (Fig. 5). Early marketable yield in 2015–16 was higher with kaolin than with the untreated control with both kaolin treatments. However, in 2016–17 early marketable yield was significantly increased only with the double application. In both years total yield was highest with the double application of kaolin and intermediate with the single application, and lowest for the untreated control. Consistent with our results, 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). Kaolin also does not appear to have any recorded negative effects on horticultural crops. Kaolin-treated grape vines exhibited no negative impacts from kaolin with respect to cluster size and weight of clusters (Shellie and Glenn, 2010).

Table 3. Effect of kaolin on days to first flower.

Treatment	2015–16	2016–17
Control	33 a[y]	38 a
Kaolin 1X[z]	26 b	33 b
Kaolin 2X[z]	27 b	32 b
P value	0.01	0.001

[z]Kaolin 1X = 50 lb/A kaolin at planting or kaolin 2X = 50 lb/A kaolin at planting and at seven days after planting.
[y]Means in columns followed by the same letters do not differ significantly as per Tukey HSD test at $P \leq 0.05$.

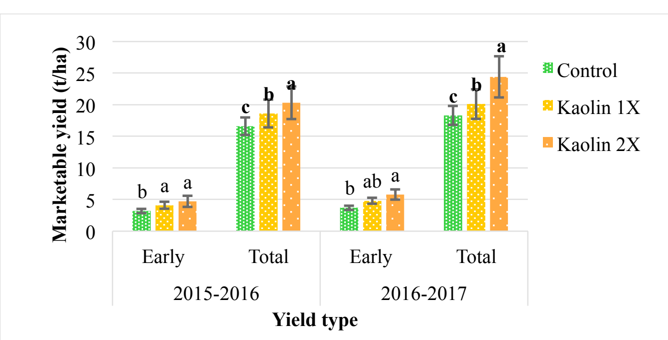

Fig. 5. Effect of kaolin on early and total marketable yields. Kaolin 1X = 50 lb/A kaolin (at planting), kaolin 2X = 50 lb/A kaolin (at planting and at seven days after planting). Bars represent means with standard errors. Bars grouped by yield type and season with the same letters do not differ significantly as per Tukey's HSD test ($P \leq 0.05$).

Conclusions

High temperature is the main constraint of early establishment of strawberry transplants. Retardation of normal growth and development and injury to specific plant parameters are the main effects of heat stress on strawberry plants. This study sought to evaluate the use of s-ABA and kaolin to mitigate heat stress. Strawberry growth and development characteristics such as plant survival, photosynthesis, days to first flower, and yield were adversely affected by abscisic acid rates greater than 100 mg/L. The double application of kaolin consistently protected strawberry transplants from heat stress, promoted early flowering, and enhanced early and total yields. Therefore, the double application of kaolin appears to have the best potential for mitigating heat stress during strawberry plug transplant establishment. Future investigations should evaluate rates of s-ABA lower than 100 mg/L. Evaluation of s-ABA and kaolin with more cultivars will be needed for a broader understanding of applicability for heat stress mitigation in early planted strawberry plug transplants.

Literature Cited

Agehara, S. and D.I. Leskovar. 2012. Characterizing concentration effects of exogenous abscisic acid on gas exchange, water relations, and growth of muskmelon seedlings during water stress and rehydration. J. Amer. Soc. Hort. Sci. 137(6):400–410.

Agehara, S. and D.I. Leskovar. 2014. Age-dependent effectiveness of exogenous abscisic acid in height control of bell pepper and jalapeno transplant. Scientia Hort. 175:193–200.

Albregts, E.E. and C.M. Howard. 1985. Effect of intermittent sprinkler irrigation on establishment of strawberry transplants. Soil Crop Sci. Soc. Fla. Proc. 44:197–199.

Berry J. and O. Björkman. 1980. Photosynthetic response and adaptation to temperature of higher plants. Ann. Rev. Plant Physiol. 31:492–543.

Boari, F., A. Donadio, M.I. Schiattone, and V. Cantore. 2015. Particle film technology: A supplemental tool to save water. Agr. Water Mgt. 147:154–162.

Cantore, V., P. Bernardo, and R. Albrizio. 2009. Kaolin-based particle film technology affects tomato physiology, yield and quality. Environ. Expt. Bot. 66:279–288.

Davies, W.J. and H.G. Jones. 1991. Abscisic Acid: Physiology and biochemistry. BIOS Scientific Publishers, Oxford, UK.

El-Khawaga, A.S. 2013. Response of Grand Naine banana plants grown under different soil moisture levels to antitranspirants application. Asian J. Crop Sci. 5(3):238–250.

Florida Automated Weather Network (FAWN). 2015. <http://fawn.ifas.ufl.edu/>

Glenn, D.M. 2012. The mechanisms of plant stress mitigation by kaolin-based particle films and applications in horticultural and agricultural crops. HortScience 47(6):710–711.

Hochmuth, G., D. Cantliffe, C. Chandler, C. Stanley, E. Bish, E. Waldo, D. Legard, and J. Duval. 2006. Fruiting responses and economics of containerized and bare-root strawberry transplants established with different irrigation methods. HortTechnology 16:205–210.

Houghton, J.T., B.A. Callander, and S.K. Varney. 1992. Climate change 1992. The supplementary report to the IPCC scientific assessment. Press Syndicate of the University of Cambridge.

Intergovernmental Panel Climate Change (IPCC). 2007. Climate Change 2007: Impacts, adaptation and vulnerability: Contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K. and New York, NY.

Makus, D.J. 2005. Effect of kaolin (Surround™) on pepper fruit and seed mineral nutrients. Subtropical Plant Sci. 57:5–9.

Racsko, J., F. Marmor, C.R. Hopkins, P. Petracek, F.P. Silverman, R. Fritts Jr., X. Liu, D. Woodlard, J. Lopez, D. Leep, and J. Pienaar. 2014. Use of *s*-abscisic acid (ConTego™ SL) in vegetable production. Acta Hort. 1042:243–253.

Rosati, A., S.G Metcalf, R.P. Buchner, A.E. Fulton, and B.D. Lampinen. 2006. Effects of kaolin application on light absorption and distribution, radiation use efficiency and photosynthesis of almond and walnut canopies. Ann. Bot. 99:255–263.

Santos, B. M., T.P. Salame-Donoso, and A.J. Whidden. 2012. Reducing sprinkler irrigation volumes for strawberry transplant establishment in Florida. HortTechnology 22(2):224–227.

Shellie, K. and D.M. Glenn. 2010. Wine grape response to kaolin particle film under deficit and well-watered conditions. Acta Hort. 792:587–591.

Styer, R.C. and D.S. Koranski. 1997. Plug and transplant production: A grower's guide. Ball Publ., Batavia, Ill.

U.S. Dept. of Agriculture. 2015. Quick Stats 2.0. U.S. Department of Agriculture (USDA), National Agricultural Statistics Service, Washington, D.C.

U.S. Dept. of Agriculture/NASS. 2017. State agriculture overview for Florida. 2016. <https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=FLORIDA>

Wu F., Z. Guan, and V. Whitaker. 2015. Optimizing yield distribution under biological and economic constraints: Florida strawberries as a model for perishable commodities. Agr. Sys. 141:113–120.