Cost Analysis of Using Cover Crops in Citrus Production

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Abstract. **Florida has a long association with citrus (*Citrus* sp.) production. However, the citrus industry in Florida has been devastated by Huanglongbing (HLB) or citrus greening disease (*Candidatus* Liberibacter asiaticus). HLB affects the citrus tree phloem and eventually causes tree death. Cover crops, or noncash crops, have traditionally been used in row crop production to improve soil organic matter, for nitrogen fixing, and for weed control. Citrus growers may benefit from adopting cover crops because healthier soils could improve yields and fruit quality of citrus trees. However, growers are uncertain about the costs and benefits associated with cover crop investments. The objective of our study was to analyze whether cover crops represent an economically feasible option for Florida citrus growers. We calculated the break-even prices for 'Valencia' and non-'Valencia' oranges (*Citrus sinensis*) in terms of price per box (equivalent to 90 lb of oranges in Florida) and price per pound solids per box (amount of soluble solids per box of oranges) by considering additional costs and short-term savings from using cover crops across various yield and quality scenarios based on the past 10 years of data. Considering the short-term savings from adopting cover crops, the per-acre cost of production increased by $107.3/acre or by 5.73% and constituted 5.42% of the total production cost during the first year of adoption. After the 2018–19 peak, the yield and quality for both 'Valencia' and non-'Valencia' oranges have decreased steadily. Adopting cover crops in the current yield–quality scenario will not be profitable for either 'Valencia' or non-'Valencia' oranges. However, for 'Valencia' oranges, at the median yield and quality levels of 193.5 boxes/acre and 6.08 lb solids/box, respectively, cover crop adoption would be profitable because the break-even price of $2.25/lb solids would be comparable to the market prices of the past 5 years.**

Florida has long been associated with citrus (*Citrus* sp.), which had a total production value of more than $800 million in 2019. However, since the first detection of HLB or citrus greening disease [*Candidatus* Liberibacter asiaticus (*C*Las)] in the state in Aug 2005, both the acreage and production value of citrus have declined consistently. From 2006 through 2020, total citrus acreage decreased from 621,373 to 419,542 acres, whereas the total orange (*Citrus sinensis*) growing acreage decreased by almost 28% during the same period. The total value of production for oranges has more than halved from the peak of $1.33 billion in 2006–07 to $659 million in 2019–20.

Significant research of HLB in citrus is being performed. For example, regarding the development of HLB-resistant cultivars of citrus (Dutt et al. 2015), adopting technologies such as reflective mulch that repel the bacterium carrying Asian citrus psyllid (*Diaphorina citri*) (Croxton and Stansly 2014), finding physical barriers to control pest infestation, and improving citrus best management practices, are among the solutions. Concurrent to the research being undertaken, growers can adopt agricultural practices that can improve the growing conditions that benefit soil quality and contribute to tree health. Cover crops, or noncash crops, have been used by farmers, especially in row crops, to improve soil organic matter, to improve nitrogen fixing, and for weed control. Because the prevalent sandy soils of Florida are low in organic matter, citrus growers who adopt cover crops would benefit from beneficial soil microbial activity and diversity, which positively affect soil organic carbon and total nitrogen (Castellano-Hinojosa et al. 2022; Strauss and Albrecht 2018). However, adopting an agricultural practice such as cover crops would require initial investments and waiting periods before seeing any noticeable impact on tree health.

In this study, we conducted a static 1-year cost-benefit analysis of adopting cover crops in a typical Florida citrus grove. The key question that we analyzed is whether adopting cover crops is an economically feasible option for citrus growers. We calculated the break-even prices for oranges in terms of price per box (equivalent to 90 lb of oranges in Florida) and price per pound solids (amount of soluble solids per box of oranges). We accomplished this by considering additional net costs from using cover crops in citrus groves for various yield and quality scenarios that are based on historical data from the US Department of Agriculture, National Agricultural Statistical Service and Florida Department of Citrus. We also considered short-term savings in terms of reduced cultural costs that are induced from using cover crops. We found that, given the low yields and quality observed in the 2020–21 and 2021–22 growing seasons, it will not be profitable to adopt cover crops in 'Valencia' orange production. However, at yield and quality levels of the pre-COVID era, it will be profitable to adopt cover crops in 'Valencia' orange production. For non-'Valencia' oranges, however, it will not be profitable to adopt cover crops at the yield and quality levels of the last 5 years.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
3.7854	gal	L	0.2642
0.4536	lb	kg	2.2046

Infection with HLB is caused by the *C*Las bacterium, which is vectored by Asian citrus psyllid. The CLas bacterium resides in the infected tree phloem, disrupts its function, and travels through the entire tree, including the roots (Johnson and Graham 2015). Furthermore, HLB infection results in inefficient and decreased nutrient absorption by trees and is responsible for sour and bitter fruits that are inedible (Brodersen et al. 2014). Therefore, in addition to direct measures to reduce incidents of HLB, such as applying foliar supplements to trees, improving and maintaining soil quality would be important indirect steps toward improving tree health. Recent research has found that cover crops planted in row middles of an experimental citrus grove in south Florida increased carbon and nitrogen availability through improvements in the soil microbiome within 1 year of incorporating them in citrus groves (Castellano-Hinojosa and Strauss 2020). Moreover, because Florida soils have low nitrogen levels, organic matter, and water holding capacity, various mixes of cover crops can provide grove-specific benefits depending on the local soil and ecological conditions. For example, mixing both legume (Fabaceae) and nonlegume cover crops was found to improve nitrogen fixing and reduce nitrous oxide emissions from soil (Castellano-Hinojosa et al. 2022). Cover crops have also been found to reduce weed density by outcompeting weeds in absorbing nutrients, light, and moisture (Linares et al. 2008; Strauss et al. 2019). Therefore, adopting cover crops would benefit citrus production by providing improved growing conditions that potentially and partially mitigate the adverse effects that HLB infections have on citrus tree health.

Growers might be hesitant to adopt cover crops because of concerns about costs of establishment and management, as well as time taken for benefits to accrue (Clark 2007). Labor, seed, fuel, and machinery rentals are some of the cover crops inputs that could increase citrus production costs. However, decreased costs due to reductions in fertilizers or foliar supplements, which are to some extent substitutes for using cover crops, would make cover crops more profitable. Some other barriers to adoption could be the growers' limited experience using cover crops, their risk perceptions, the limited information available about cover crops in citrus production, and lacking ownership of specialized machinery such as a no-till drill for planting cover crop seeds. Moreover, improper management of cover crops could increase their chances of becoming weeds or increase pest population (Bugg and Waddington 1994). However, use of cover crops has increased over the past few decades with the continued growth of research and experience among farmers (Myers and Weber 2019). Previous cost estimates of cover crops are primarily based on their use in the midwestern United States where row crops such as corn (*Zea mays*), soybean (*Glycine max*), and common wheat (*Triticum aestivum*) are grown. Our study is the first of its kind to estimate costs of using cover crops in citrus, specifically for 'Valencia' and non-'Valencia' oranges. Our study used primary data gathered from growers, data from published studies, and secondary data to compare and discuss possible scenarios in terms of break-even prices for using cover crops in Florida citrus production.

Materials and methods

Our analysis started with the estimated per-acre costs of planting cover crops in a typical Florida orange grove. We added these costs to the baseline costs of production for a 10-year-old orange grove and calculated break-even prices in dollars per box and dollars per pound solids per box for 'Valencia' and non-'Valencia' oranges. We obtained the baseline costs for an orange grove from Singerman (2022a, 2022b). Next, we considered historical levels of yields (boxes per acre) and quality (pound solids per box) from the US Department of Agriculture, National Agricultural Statistical Service and Florida Department of Citrus and calculated break-even prices in dollars per box and dollars per pound solids for 'Valencia' and non-'Valencia' oranges for three quartiles of yields and quality and their minima and maxima. We based our analysis on plausible yield–quality scenarios. A snapshot of the costs of citrus production for a 10-year-old grove is given in Table 1.

There are approximately 400,000 acres of orange groves in Florida. Of these, approximately 250,000 acres, or more than 60% of the total citrus acreage, is in southwest Florida. The southwest Florida region includes Charlotte, Collier, DeSoto, Glades, Hendry, Lee, Manatee, and Sarasota counties. The costs of production estimates provided by Singerman (2022a, 2022b) are based on reports from growers with groves representing 11% and 18% of the total acres in southwest Florida in 2020 and 2021, respectively. The production cost estimates for the central Florida (Ridge) region (consisting of Highlands, Lake, Osceola, Orange, and Polk counties) were not considered in our study because the recent estimates were not available, whereas for the Indian River region (consisting of Brevard, Indian River, Palm Beach, Martin, St. Lucie, and Volusia counties), the numbers are available only for grapefruit (*Citrus paradisi*). The production costs for the central region are available up to the 2015–16 growing season, and the production costs for both the central and the southwest regions were comparable at \$1864.07/acre and \$1910.25/acre during that growing season. Therefore, we can safely assume that the production costs for southwest Florida are representative of the costs of production for the entire state. We used an average of the costs of the 2020–21 and the 2021–22 growing seasons because both growing seasons were marked by the COVID pandemic-induced market conditions, and because the cost structure has changed since COVID emerged.

Table 1 provides a breakdown of cost estimates by the types of production and management practice as reported by Singerman (2022a, 2022b). The costs included cultural costs such as those for weed management, foliar sprays, fertilizers, pruning, and irrigation, tree replacement costs, and other costs, such as interest on operating costs, management cost, property tax, and water management assessment, and interest on average capital investment. As Table 1 shows, costs in 2021–22 were marginally lower than those in 2020–21. The overall proportions of the primary cost items were comparable. However, regarding foliar sprays, although fungicides contributed to 9% of the total costs in 2020–21 and 6% in 2021–22, nutritional supplements contributed to 4% and 7% of the total costs of foliar sprays in 2020–21 and 2021–22, respectively. The total cost per acre with tree replacement was \$1882.43/acre in 2020–21, and in

Table 1. Total per acre production costs for a typical 10-year-old orange grove in Florida.

Cost items	2020–21 Applications (no./yr)	2020–21 Materials cost ($/acre)[i]	2020–21 Application cost ($/acre)	2020–21 Total cost ($/acre)	2021–22 Applications (no./yr)	2021–22 Materials cost ($/acre)	2021–22 Application cost ($/acre)	2021–22 Total cost ($/acre)	Avg total cost 2020–22 ($/acre)
Cultural costs									
Weed management									
Mowing (chemicals and mechanical)	6	1.49	77.75	79.24	8	0.57	125.58	126.16	102.70
Herbicides	4	83.65	52.75	136.4	3	112.51	48.77	161.28	148.84
Total weed management costs				215.64				287.43	251.54
Foliar sprays									
Insecticides		160.53		160.53		185.54		185.54	173.04
Fungicides		131.95		131.95		96.28		96.28	114.12
Nutritionals		59.04		59.04		103.32		103.32	81.18
Bactericides									
Ground application	4		116.58	116.58	5		105.97	105.97	111.28
Aerial application	1		11.61	11.61					
Total foliar sprays costs				479.71				491.1	485.41
Fertilizer									
Ground/dry fertilizer	3	215.42	25.8	241.21	3	225.06	22.23	247.29	244.25
Fertigation/liquid fertilizer	6	143.51	3.23	146.75	10	175.68	1.4	177.08	161.92
Total fertilizer costs				387.96				424.37	406.17
Pruning									
Topping and hedging	1		33.28	33.28	1		29.71	29.71	31.50
Chop/mow brush	1		0.3	0.3	1		0.32	0.32	0.31
Total pruning costs				33.58				30.04	31.81
Irrigation									
Irrigation system				76.36				72.9	74.63
Fuel for pump				120.8				59.12	89.96
Total irrigation costs				197.15				132.03	164.59
Total cultural production costs without tree replacement				1314.04				1364.98	1339.51
Tree replacement (six trees)									
Tree removal (clip-shear; use front-end loader)				32				20	26.00
Site preparation and plant tree (includes reset trees)				62				30	46.00
Supplemental fertilizer, sprays, sprout, etc. (trees 1–3 years old)				99.75				98.66	99.21
Total tree replacement costs				193.75				148.66	171.21
Total cultural costs with tree replacement				1507.79				1513.64	1510.72
Other costs									
Interest on operating (cultural) costs				75.39				75.68	75.54
Management cost				144				115.33	129.67
Property tax/water management assessment				28.73				28.73	28.73
Interest on average capital investment				126.52				126.52	126.52
Total other costs				374.64				346.27	360.46
Total costs				1882.43				1859.9	1871.17

[i] $1/acre = $2.4711/ha (Singerman 2022a, 2022b).

Table 2. Partial budget of the costs of incorporating cover crops in orange production in Florida.

Costs	Applications (no./yr)	Materials cost ($/acre)[i]	Total cost ($/acre)
Total cost of orange production (no cover crops)[ii]			1871.17
Cover crop cost items			
Seeds	2	80	160
Fuel costs	2	2	4
Labor	2	5.5	11
Drill	2	15	30
Other			5
Total cost of cover crops			210
Total production costs and cover crops costs			2081.17
Savings from cover crops (no mowing)			102.7
Net cost (total production costs + cover crops costs − savings)			1978.47

[i] $1/acre = $2.4711/ha.

[ii] The total cost of orange production is the average of the total costs of production for the 2020–21 and the 2021–22 seasons obtained from Singerman (2022a, 2022b).

2021–22 it was $1859.9/acre. During our study, we considered the average of the two total cost figures, which was $1871.17/acre per year.

Our cost figures for incorporating cover crops into citrus groves were based on discussions with two commercial growers in southwest Florida; one had less than 50 acres under citrus production, and the other had between 150 and 200 acres, with groves in Charlotte County and Polk County. We also discussed optimum practices for cover crop use in citrus with Sarah Strauss, a faculty member at University of Florida, Institute of Food and Agricultural Sciences, Southwest Florida Research and Education Center, in Immokalee, FL, USA, and her team. In this region, cover crops should be planted in June and November. Table 2 provides the breakdown of cover crop costs per acre.

To grow cover crops, 50 to 80 lb/acre of cover crop seeds, or an average of 65 lb/acre, were required. We included costs for four common types of cover crops: common sunflower (*Helianthus annuus*), daikon radish (*Raphanus sativus*), buckwheat (*Fagopyrum esculentum*), and the legume sunn hemp (*Crotalaria juncea*). Seed prices are the average prices available online from seed companies and are calculated at $1.225/lb, or $80/acre per application. Because cover crop seeds were planted twice per year, our total cost was $160/acre per year. We also gave equal weight to all seeds. This is in keeping with creating a budget that represents a typical farm and keeping in mind that seed availability will change over time and by location. Therefore, our cost figures were based on an average of several types of cover crop seeds. The experiments that were conducted at Southwest Florida Research and Education Center focused on 'Valencia' oranges, but we applied cost estimate and analysis to both 'Valencia' and non-'Valencia' oranges because both have similar production practices and costs.

Our estimate of $20/h for the cost of labor was based on the "Central Florida (Ridge) and Indian River-Southwest Florida Citrus Custom Rate Charges" reports published online by Ariel Singerman and Faith Aiya from the Citrus Research and Education Center of the University of Florida, Institute of Food and Agricultural Sciences in Lake Alfred, FL, USA. We used an average of the hourly wage rates given for "general labor" for the central Florida (Ridge), Indian River, and southwest Florida regions for 2020–21 and 2021–22 (Singerman and Aiya 2021, 2022). This translated to $5.33/acre based on discussions with the growers about time required by an agricultural worker to cover an acre of farmland. We assumed this cost to be $5.50/acre per application or $11/acre per year.

Regarding fuel costs, we averaged the retail prices of "diesel ultra-low sulfur" for the lower Atlantic region from Mar 2020 through Feb 2022, which we obtained from the US Energy Information Administration website (2022). Because our orange production costs were averages of values for 2 years, 2020–21 and 2021–22, and also because we spoke to the growers in Feb 2022, we used the average of 24 months of diesel prices until Feb 2022. Therefore, the average diesel price calculated was $3/gal. This cost was comparable to the grower-reported costs of fuel. The growers who we spoke to provided an estimate of 0.6667 gal of fuel (diesel) required per acre of citrus grove. This translated to approximately $2/acre per use, or $4/acre per year.

There are multiple methods of planting cover crop seeds. However, experts in citrus production and growers we interviewed indicated that using a no-till drill significantly improved the seeding rate of cover crops. Therefore, we included the costs of using a no-till drill seeder in our budget for planting cover crops. A no-till drill is a significant investment for most Florida farms. Because a grower will plant cover crops twice per year, and because this is a new management practice for most citrus growers, we assumed a grower will likely rent this equipment during the early years of adoption. Therefore, although information is available about the purchase cost and interest rates, we opted to use the rental rates. Information about rental rates of no-till drills in Florida is not publicly available. Therefore, we have used rental rates that are available online for Georgia Conservation Districts (Georgia Association of Conservation Districts 2022). The rental of $15/acre per use or $30/acre per year that we considered in our budget was the upper ceiling of the rates found for equipment rental companies in Georgia. We believe that this rental rate is acceptable because the equipment costs in Georgia are similar to those in Florida, with those in Florida being marginally more expensive on average. We also added a $5/acre miscellaneous cost to account for the learning curve associated with growers adopting a new practice such as cover crops in citrus production. For example, growers might accrue additional costs before determining the right mix of cover crop species for their grove-specific soil type or might not plant when there is adequate precipitation. Therefore, we obtained a total cost of \$210/acre per year for using cover crops in citrus. Adding this to the total costs, we calculated \$2081.17/acre per year as the total cost of production for both cultivars of oranges when cover crops were used (Table 2).

We considered the short-term benefits in terms of savings that cover crops provided. Savings would be primarily in the form of reduced mowing of citrus row middles where cover crops were planted. Not mowing cover crops reduces soil disturbance and keeps the ground covered (Strauss and Albrecht 2018). Moreover, because cover crops suppress weeds, chemical mowing, which is used for weeding, also would not be required. We did not consider cost savings from reduced fertilizer and herbicide use from using cover crops in citrus groves because the current research of citrus has yet to estimate exact savings from these inputs. Moreover, herbicides for weed management have been used primarily under the trees, where cover crops are not usually grown. Including the \$102.70 in savings from not mowing, the total production cost of citrus while using cover crops was \$1978.47/acre, or the net cost of cover crops was \$107.3/acre for citrus. This translated to a 5.73% increase from the original production cost and 5.42% of the total production cost.

We calculated yields in terms of boxes per acre from citrus acreage and production data obtained from "Citrus Fruits Summary" reports for 10 years, from 2012–13 through 2021–22 (USDA-NASS 2022a, 2022b). For quality in terms of pound solids and price per box and price per pound solids from 2012–13 through 2021–22, we used "Early Season Field Box Reports" for non-'Valencia' oranges (Florida Department of Citrus 2022a) and "Final Orange Field Box Reports" for 'Valencia' oranges (Florida Department of Citrus 2022b). Figures 1 and 2 plot the changes in yield and quality over time for 'Valencia' and non-'Valencia' oranges, respectively. Yields have been steadily decreasing for both types of oranges since the 2012–13 season. However, although yields improved significantly during the post-Hurricane Irma season of 2018–19, their trends have been negative since then, especially for 'Valencia' oranges. Quality in terms of pound solids per box show similar trends (Figs. 1 and 2). In fact, there was a strong correlation between yields and quality. The correlation coefficient between the two was 0.83

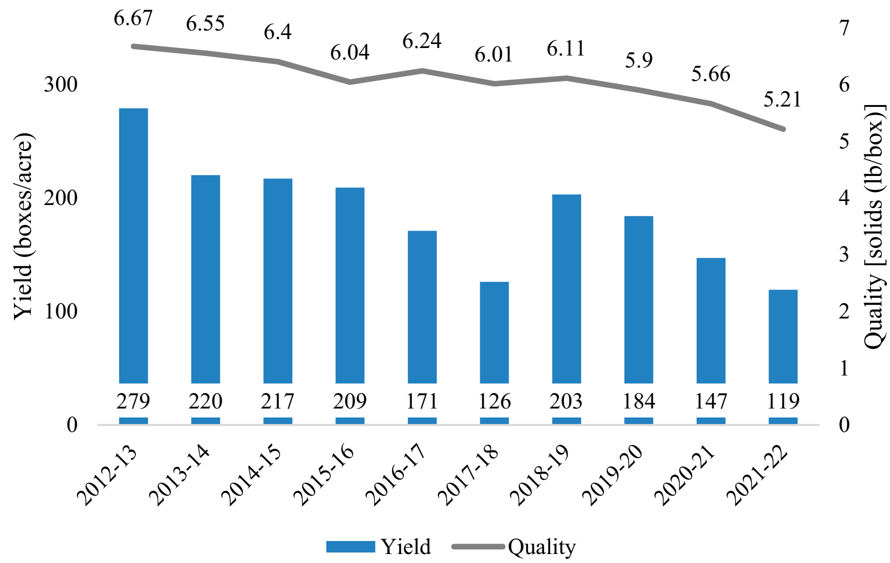

Fig. 1. Historical yields and quality figures for 'Valencia' oranges in Florida from the 2012–13 through 2021–22 seasons. Yield data are from the US Department of Agriculture, National Agricultural Statistical Service (USDA-NASS 2022b), and quality data are from the Florida Department of Citrus (2022b). Pound solids per box are defined as "the amount of soluble solids (sugars and acid) contained in 1 box of citrus fruit" (USDA-NASS 2022b); one 90-lb (40.8 kg) box/acre = 100.8766 kg·ha^{-1}; 1 lb/90-lb box = 0.0111 kg·kg^{-1}.

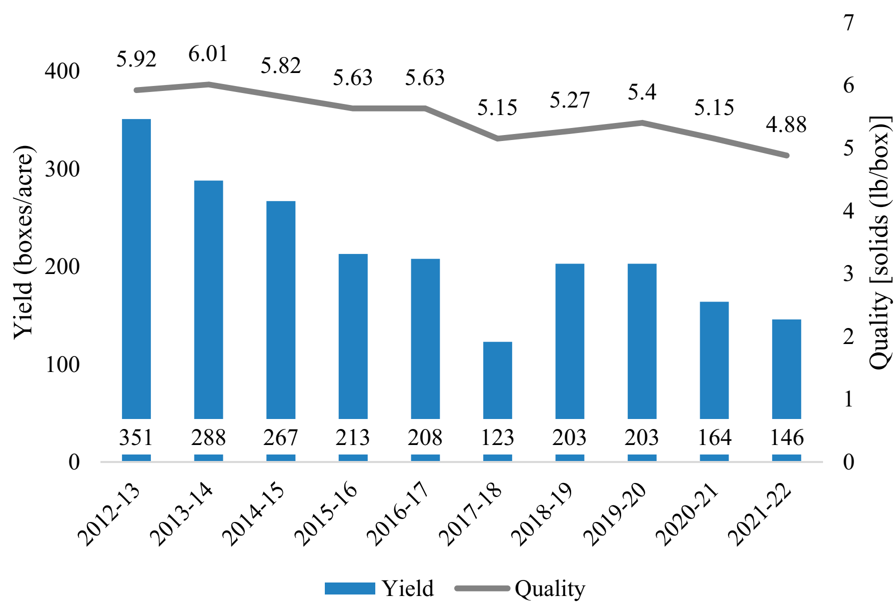

Fig. 2. Historical yields and quality estimates for non-'Valencia' oranges in Florida from 2012–13 through 2021–22 seasons. Yield data are from the US Department of Agriculture, National Agricultural Statistical Service (USDA-NASS 2022b), and quality data are from the Florida Department of Citrus (2022a). Pound solids per box are defined as "the amount of soluble solids (sugars and acid) contained in 1 box of citrus fruit" (USDA-NASS 2022b); one 90-lb (40.8 kg) box/acre = 100.8766 kg·ha^{-1}; 1 lb/90-lb box = 0.0111 kg·kg^{-1}.

Table 3. Break-even prices for 'Valencia' oranges for yield–quality quartile scenarios in Florida.

Yield quartiles[i]	Minimum	Quartile 1	Median	Quartile 3	Maximum		
Yield (boxes/acre)[ii]	119	153	193.5	215	279	Quality quartiles (lb solids/box)[iii]	
Total delivered-in cost ($/acre)[ii]	2389.0	2506.3	2646.0	2720.2	2941.0		
	Break-even prices						
Break-even delivered-in price ($/box)[iv]	20.08	16.38	13.67	12.65	10.54		
Break-even delivered-in price per pound solids ($/lb solids)[v]	3.85	3.14	2.62	2.43	2.02	5.21	Minimum
	3.39	2.76	2.31	2.13	1.78	5.93	Quartile 1
	3.30	2.70	2.25	2.08	1.74	6.08	Median
	3.16	2.58	2.15	1.99	1.66	6.36	Quartile 3
	3.01	2.46	2.05	1.90	1.58	6.67	Maximum

[i] Yield quartiles are based on yield data from 2012–13 through 2021–22 growing seasons obtained from the US Department of Agriculture, National Agricultural Statistical Service (USDA-NASS 2022b).
[ii] One 90-lb (40.8 kg) box/acre = 100.8766 kg·ha^{-1}, $1/acre = $2.4711/ha.
[iii] Quality quartiles are based on quality data from 2012–13 through 2021–22 growing seasons obtained from Florida Department of Citrus (2022b); lb solids per box = "the amount of soluble solids (sugars and acid) contained in one box of citrus fruit" (USDA-NASS 2022b); 1 lb/90-lb box = 0.0111 kg·kg^{-1}.
[iv] Break-even delivered-in price ($/box) = total delivered-in-cost ($/acre) ÷ yield (boxes/acre); $1/90-lb box = $0.0245/kg.
[v] Break-even delivered-in price per pound solids ($/lb solids) = break-even delivered-in-price per box ($/box) ÷ quality per box (lb solids/box); $1/lb = $2.2046/kg.

for 'Valencia' oranges, and it was 0.89 for 'Valencia' oranges, implying a strong positive correlation. However, peaks and troughs are more prominent for yields. For example, for 'Valencia' oranges, the highest yield value was 279 boxes/acre in 2012–13, and the lowest yield was 119 boxes/acre in 2021–22. The quality peaked in 2012–13, at 6.67 lb solids/box, and its lowest level was 5.21 lb solids/box in 2021–22. Therefore, yields have more variability relative to their average as compared with quality. Moreover, variability in yields is higher for non-'Valencia' oranges than for 'Valencia' oranges. We constructed our yield–quality scenarios by using the following values for both yield and quality–minimum, first quartile, median/second quartile, third quartile, and maximum/highest.

Results and discussion

During this analysis, we estimated the break-even delivered-in prices, which include the pick and haul charges of $3.33 and $3.22/box for 'Valencia' and non-'Valencia' oranges, respectively, and the Florida Department of Citrus assessment charge of $0.12/box of oranges (Singerman 2022a).

Tables 3 and 4 show the estimates of break-even prices for 'Valencia' and non-'Valencia' oranges, respectively, across all yield–quality scenarios. The break-even price per box does not directly depend on quality. However, prices per pound solids depend on quality, and the higher the quality, the lower the break-even prices will be. Figures 3 and 4 plot the historical prices in dollars per box and dollars per pound solids for 'Valencia' and non-'Valencia' oranges from "Field Box Reports" (Florida Department of Citrus 2022a, 2022b). Prices have been increasing and peaked in 2018 to 2019 for 'Valencia' and in 2016 to 2017 for non-'Valencia' oranges, respectively.

For 'Valencia' oranges, break-even prices varied from $20.08/box for the minimum historical yield to $10.54/box for the maximum historical yield (Table 3). Yields for 'Valencia' oranges decreased significantly since the peak of 203 boxes/acre during the 2018 to 2019 season. Although the season-to-season decrease in yields averaged 16.17%, yield decreased by 41.3% between 2018–19 and 2021–22. The prevalence of HLB along with damages caused by the recent freezes were primarily responsible for the decreasing

Table 4. Break-even prices for non-'Valencia' oranges for yield–quality quartile scenarios in Florida.

Yield quartiles[i]	Minimum	Quartile 1	Median	Quartile 3	Maximum		
Yield (boxes/acre)[ii]	123	173.8	205.5	253.5	351	Quality quartiles (lb solids/box)[iii]	
Total delivered-in cost ($/acre)[ii]	2389.3	2558.8	2664.8	2825.2	3150.8		
	Break-even prices						
Break-even delivered-in price ($/box)[iv]	19.43	14.73	12.97	11.14	8.98		
Break-even delivered-in price per pound solids ($/lb solids)[v]	3.98	3.02	2.66	2.28	1.84	4.88	Minimum
	3.75	2.84	2.50	2.15	1.73	5.18	Quartile 1
	3.52	2.67	2.35	2.02	1.63	5.52	Median
	3.37	2.55	2.25	1.93	1.56	5.77	Quartile 3
	3.23	2.45	2.16	1.85	1.49	6.01	Maximum

[i] Yield quartiles are based on yield data from 2012–13 through 2021–22 growing seasons obtained from the US Department of Agriculture, National Agricultural Statistical Service (USDA-NASS 2022b).
[ii] One 90-lb (40.8 kg) box/acre = 100.8766 kg·ha^{-1}, $1/acre = $2.4711/ha.
[iii] Quality quartiles are based on quality data from 2012–13 through 2021–22 growing seasons obtained from Florida Department of Citrus (2022a); lb solids per box = "the amount of soluble solids (sugars and acid) contained in 1 box of citrus fruit" (USDA-NASS 2022b); 1 lb/90-lb box = 0.0111 kg·kg^{-1}.
[iv] Break-even delivered-in price ($/box) = total delivered-in-cost ($/acre) ÷ yield (boxes/acre); $1/90-lb box = $0.0245/kg.
[v] Break-even delivered-in price per pound solids ($/lb solids) = break-even delivered-in-price per box ($/box) ÷ quality per box (lb solids/box); $1/lb = $2.2046/kg.

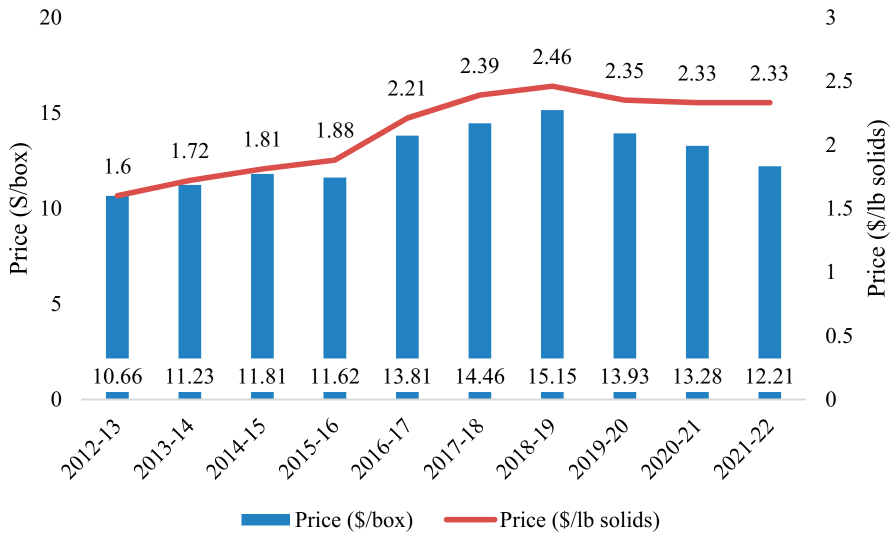

Fig. 3. 'Valencia' orange prices per box and per pound solids in Florida from 2012–13 through 2021–22 seasons. Prices data are from the Florida Department of Citrus (2022b); $1/90-lb (40.8 kg) box = $0.0245/kg, $1/lb = $2.2046/kg.

yields (Giles 2022). Because the weather induced exogenous shock on yields, it could be expected that possible yields are between 119 boxes/acre (the minimum) and 153 boxes/acre (first quartile). The corresponding break-even prices were $20.08 and $16.38/box, which were higher than the highest per-box prices reported by the Florida Department of Citrus (Fig. 3). However, cover crops are expected to increase both yields and quality after 3 to 5 years of continuous use. At the median yield of 193.5 boxes/acre, the break-even price of $13.67/box was lower than the per-box prices received between the 2016 to 2017 through the 2019 to 2020 growing seasons. Quality in terms of pound solids per box decreased for 'Valencia' oranges since the post-Irma peak of 6.11 lb solids/box in 2018 to 2019. The 2021 to 2022 season recorded the lowest quality, with 5.21 lb solids/box. At the minimum quality, break-even prices at yields that are equal to or below the median were higher than the maximum recorded price of $2.46/lb solids, which was observed during the 2018 to 2019 growing season.

Therefore, at the yield and quality levels of the last two growing seasons, adopting cover crops in 'Valencia' orange production will not be profitable. Because yield and quality are strongly positively correlated, the positive effects of using cover crops would be reflected in both increased yield and quality. At the median yield–quality scenario, that approximately corresponds to the yield and quality levels of the 2018–19 season, and the break-even price of $2.25/lb solids is lower than the market prices of the last 5 years (Fig. 3). Therefore, although adopting cover crops in 'Valencia' orange production may not be profitable at the yield and quality levels of the post-COVID pandemic seasons of 2020–21 and 2021–22, it will be profitable at the yield and quality levels observed during the seasons before the postpandemic seasons.

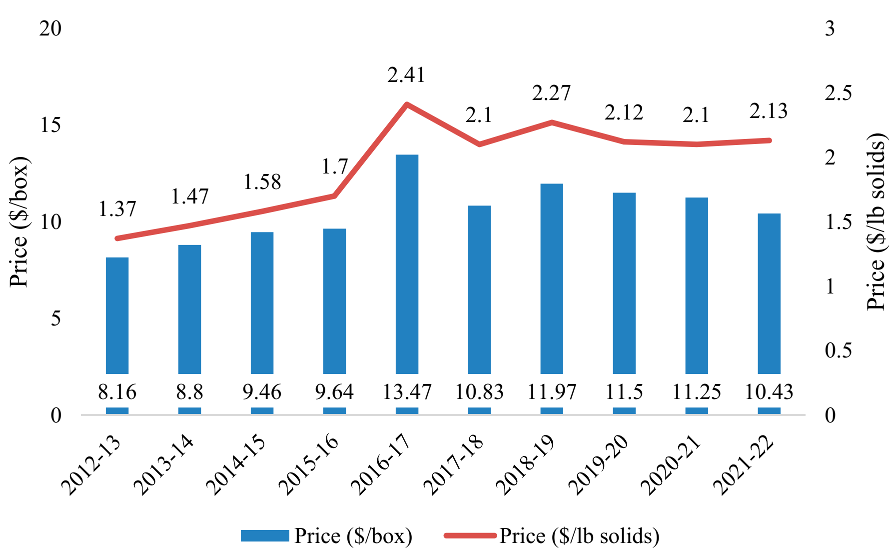

Fig. 4. Non-'Valencia' orange prices per box and per pound solids in Florida from 2012–13 through 2021–22 seasons. Prices data are from the Florida Department of Citrus (2022a); $1/90-lb (40.8 kg) box = $0.0245/kg, $1/lb = $2.2046/kg.

For non-'Valencia' oranges, break-even prices per box varies from $19.43/box for the minimum yield to $8.98/box for the maximum yield. For the most recent growing seasons of 2021–22 and 2020–21, the yields were 146 and 164 boxes/acre, respectively, which were between the minimum and the first yield quartiles (Table 4). The corresponding break-even prices were higher than the peak historical price that was recorded during the 2016–17 growing season. Quality levels have also been at their lowest levels during the postpandemic seasons, and the lowest quality level was recorded in 2021–22, at 4.88 lb solids/box. For any yield and quality levels recorded since 2016–17, the corresponding break-even prices were higher than the highest recorded price of $2.41/lb solids. Therefore, it will not be profitable to incorporate cover crops in non-'Valencia' orange production at the yield and quality levels of the past 5 years. At the median yield–quality scenario, the break-even price of $2.35/lb solids was lower than the peak market price. At the higher yield and quality quartiles, however, break-even prices were comparable to those of the pre-2016–17 season.

Conclusions

The primary objective of a citrus grower is to maintain sustainable yield and quality as HLB continues to adversely impact the citrus industry in Florida. Cover crops provide significant benefits to tree health through their effects on soil quality. Although the benefits of cover crop adoption on fruit yield and quality are not immediate, the benefits on soil health and quality are well-documented. Therefore, cover crops would indirectly benefit citrus trees by providing improved growing conditions. Including cover crops in citrus production could be a feasible option in the long term, even though in the short term it would increase the costs of production. Cover crops increase the per-acre cost of production by 5.73% and constitutes 5.42% of the total production cost during the first year of adoption.

Yields and quality for both 'Valencia' and non-'Valencia' oranges have been at the lowest levels in the postpandemic seasons of 2020–21 and 2021–22. Because of recent trends in yield and quality, it will not be profitable to adopt cover crops in these commodities. However, because cover crop adoption could increase yield and quality, it could be profitable to adopt cover crops in 'Valencia' orange production because the break-even prices corresponding to prepandemic levels of yield and quality would be lower than the market prices of the last few years.

Our study provided an upper ceiling of the costs of using cover crops in citrus. We expect that the results will be helpful for growers who would like to benefit from this practice because citrus production has been severely affected by HLB in Florida. As part of our future research, we plan to include the exact estimates of long-term savings induced by using cover crops and the plausible yield and quality estimates from the experiments that are currently underway.

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