Economic Analysis of Grafted Organic Tomato Production in High Tunnels

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KEYWORDS. net return, partial budget analysis, protected culture, revenue, sensitivity analysis, Solanum lycopersicum, vegetable grafting

SUMMARY. With the phase-out of methyl bromide because of its impact on ozone depletion and the shift to a more protected culture system in organic vegetable production, grafting practice has gained greater attention in the United States because it may be considered a viable disease control method in organic vegetable production. However, there is a lack of information on the economic feasibility of using grafting in organic tomato (Solanum lycopersicum) production in a protected culture system such as a high-tunnel system. Using 2-year on-station trial data collected in Citra, FL, we examined the effect of using grafting on the economic returns of organic tomato production in high tunnels. Our analysis suggests that grafting tends to increase the marketable yield of organic tomato production in high tunnels. However, the enhanced yield does not necessarily increase the net return, depending on market conditions and the relative performance of grafted transplants. In addition, our results indicate that the net return of grafted production is highly sensitive to the tomato selling price. Obtaining a price premium is essential for increasing the profitability of grafted organic tomato production in high tunnels.

Vegetable growers in the United States have relied heavily on methyl bromides to conduct soil fumigation. However, because of the phase-out of methyl bromides under the Montréal Protocol, vegetable grafting is gaining great attention as a viable disease control method in the United States. Increasing numbers of studies have shown that using grafting could benefit vegetable production (e.g., Lee et al. 2010). Grafting could provide resistance or tolerance to soilborne pathogens as a way of integrated pest management practices to replace soil fumigation, especially for tomato (Solanum lycopersicum) production (King et al. 2008). Grafting could also help plants deal with abiotic stresses (Colla et al. 2010, 2013), such as temperature (Abdelmageed and Gruda 2009; Venema et al. 1999) and water (Aftunlu and Gul 2012; Bhatt et al. 2015; Sanchez-Rodriguez et al. 2013) stress, and could enhance plant drought resistance and water use efficiency (Kumar et al. 2017). Despite the many benefits of grafting, the use of grafted transplants is still limited in the United States. Two major barriers contribute to the low adoption rate of grafting. First, high grafted transplant costs resulting from increased labor and material costs could lead to economic infeasibility for tomato production. Second, the revenue generated by grafted transplants may not be enough to make tomato production profitable.

To date, most studies on the economic analysis of grafting vegetable production have focused on open-field production (e.g., Barrett et al. 2012; Dijonou et al. 2013; Donahoo et al. 2021; Rivard et al. 2010b; Rysin et al. 2015). For example, Barrett et al. (2012) found that vegetable grafting can increase the profitability of open-field organic farms significantly, especially under severe root-knot nematode [RKN (Meloidogyne incognita)] pressure, because the grafting could effectively control pests and increase crop yield. Rysin et al. (2015) suggested that although grafting might add additional costs to farmers’ budgets, the increase in marketable fruit yield tends to generate significant gross returns to offset such costs. Vegetable production becomes more profitable when farmers use a resistant rootstock in grafting. Donahoo et al. (2021) found that grafting transplants combined with anaerobic soil disinfestation in tomato production could generate either a higher or a lower net return than nongrafted tomato production, depending on the types of scions and rootstocks that producers may use.

Because of the recent shift toward more protected culture systems, such as high-tunnel systems among tomato growers, farms using grafted transplants may gain additional economic benefits from improving yield and crop quality in high-tunnel systems (Carey et al. 2009). Farmers using high tunnels may produce these high-value products during the time that an open-field environment cannot produce to obtain greater profits. Studies have shown that tomatoes produced in high tunnels can be planted 1 to 2 months earlier in the spring, grown faster during the summer, and harvested earlier than tomatoes produced in an open-
field environment in Tennessee, Texas, and Washington in the United States (Miles et al. 2012). Also, tomato production in high tunnels tends to have a more extended harvesting season, and high tunnels can be considered an important tool to reduce production risks, such as flooding, mainly by controlling the tomato growing environment (Carey et al. 2009).

In addition, with the development of the organic product market, grafting may provide an emerging niche for US tomato growers. The price premium of organic products could increase the profitability of tomato farms that use grafted transplants by increasing the gross return of crops. Grafting could also help organic tomato growers control RKN (Kubota 2008; Rivard et al. 2010a), a major issue in sandy soils such as those in Florida (Roberts et al. 2005). Previous studies have shown that RKN-resistant tomato rootstocks effectively reduce RKN galling while maintaining yield (Bausher 2009; López-Pérez et al. 2006; Louws et al. 2010). Therefore, a combination of grafting and high-tunnel production systems may provide more economic benefits to organic growers. Organic production is usually constrained by not allowing synthetic chemicals in production, yet organic production can gain more economic return from increased yield with higher prices of organic crops.

To the best of our knowledge, no study has explored the economic feasibility of grafted organic vegetable production in protected culture systems. Izaba et al. (2021) conducted an economic analysis of nonorganic grafted cucumber (*Cucumis sativus*) production in high tunnels. They only consider the partial cost of cucumber production and do not account for the high-tunnel establishment cost in their economic analysis. Ignoring such costs may overestimate the profitability of vegetable production in high tunnels. To fill the gap in the literature, we evaluated the economic feasibility of using grafted transplants for organic tomato production in high tunnels, and compared the economic returns of grafted and nongrafted tomato production in high tunnels in Florida. Such knowledge could be crucial to Florida organic tomato growers interested in using grafting in protected culture systems. Furthermore, with ~25,000 acres under cultivation and the total value of tomato production at about $463 million in 2020, Florida ranks in the top three states in the production value of tomatoes in the United States [US Department of Agriculture (USDA) 2021b]. The results of our analysis could provide valuable information to the US tomato industry about the use of grafting in organic tomato production under protected agriculture systems.

**Materials and methods**

**Experimental site and field production of organic tomato.** Organic field experiments were carried out during the 2019 and 2020 growing seasons in the high tunnels at the University of Florida, Institute of Food and Agriculture Sciences, Plant Science Research and Education Unit in Citra, FL. The three-bay high tunnel (each bay, 30 × 84 ft) was installed in Fall 2017.

In the first year, tomato plants were grown from late January to mid-June and harvested between April and June. In the second year, tomato plants were grown from mid-December to early June and harvested between March and June. The determinate ‘Skyway’ beefsteak tomato cultivar (Johnny’s Selected Seeds, Winslow, ME) was used as the scion and was grafted onto the commercially available ‘Estamino’ interspecific tomato rootstock (*S. lycopersicum × S. habrochaites*), Johnny’s Selected Seeds). Grafted and nongrafted plants were transplanted in ground beds with plastic mulch and drip irrigation on 30 Jan 2019 and 19 Dec 2019, respectively, in high tunnels. Beds were 36 inches wide and spaced 6 ft apart with 18-inch in-row spacing for high-tunnel tomato production, resulting in about 4840 plants/acre. In 2019, the total nitrogen fertilization rate was 280 lb/acre, whereas the total nitrogen fertilization rates for the 2020 season were 300 lb/acre. Plants were trained using the standard Florida stake-and-weave system. Tomato fruit that reached the breaker or more advanced ripening stages were harvested multiple times 75 d after transplanting in 2019 and 80 d after transplanting in 2020. All tomatoes were sorted into marketable and unmarketable grades before being counted and weighed.

**Cost of high-tunnel construction and maintenance.** Baseline budget assumptions were established to account for variable costs and returns of the high-tunnel operation systems (e.g., crop yield, input costs, commodity price, capital, labor). The construction cost of a high tunnel is the initial cost of building a new high tunnel. It usually contains the material and labor costs. The construction cost only occurs once during the entire life span of a high tunnel. The maintenance cost, which always occurs for a regular period, is the amount of money that vegetable growers pay for maintaining and promoting the daily operation of the high-tunnel system.

To compute the annual average cost of high tunnels, US Internal Revenue Service (2012) guidelines were used first to calculate the typical “useful life” of high tunnels. For example, the life span of the poly covering system is 4 years, so the cost of replacing the plastic cover will occur every 4 years. We assume a life span of 20 years for the construction cost of a high-tunnel structure, with a salvage value of $0.00. To compute the annual-high tunnel cost, we followed the method used by Lewis et al. (2014). Using the 10-year interest rate of Index of Prices Paid by Farmers over the years 2011–20 provided by the USDA National Agricultural Statistics Service (NASS) (2022) we computed the annual interest rate as 2.7% and the annual high-tunnel cost as follows:

\[
\text{Annual high tunnel cost} = \left( \frac{\text{Structural cost} + \text{Maintenance cost}}{20} \right) \times (1 + 2.7%). \tag{1}
\]

**Cost of grafted and nongrafted transplant production.** The costs of grafted and nongrafted transplants were estimated by following the procedure described by Djidonou et al. (2013). All the materials, supplies, and labor associated with the production of grafted and nongrafted transplants were estimated to calculate the costs of nongrafted ‘Skyway’ plants and grafted ‘Skyway’ plants with ‘Estamino’ rootstock.

**Partial budget analysis.** First, a base cost model for growing, harvesting, and marketing tomato in a 1-acre high tunnel with a ground-bed polyethylene mulch production system
was established. Itemized costs of production inputs, including transplants and fertilizers during the 2019 and 2020 trials, were estimated and used in developing the actual production budget in this study. The variable costs of production and harvest were calculated based on information provided by Wade et al. (2020). We adjusted the price by inflation rate from USDA, National Agricultural Statistics Service NASS Index of Prices Paid by Farmers [USDA National Agricultural Statistics Service (NASS) 2022]. The costs in the preplanting stage included the expenses related to transplants and land preparation. The production costs included irrigation, materials, services, and labor costs. The harvesting costs included the costs related to containers, harvesting and hauling, packing, marketing, and organization fees.

A partial budget analysis compares the negative and positive effects of applying a new treatment relative to a base or standard treatment (Sydorovych et al. 2008). It can provide a brief overview of the possible economic advantage to growers adopting the new production practice. In this study, using grafted transplants is the new practice, whereas using non-grafted transplants is the standard practice. The added expenses of grafted transplants are the negative effects, whereas the added gross returns of grafted transplants are the positive effects. Whether the increased tomato yield can offset the additional costs associated with grafted transplants is determined by the increased gross return associated with the yield increase in grafted tomato production.

The principal formulas used in the budget analysis are as follows. First, we calculated the total cost of tomato production:

$$TC = \text{Preplanting cost} + \text{Producing cost}$$

+ Harvesting cost + Fixed cost, \[2\]

where \(TC\) (measured in dollars per acre) stands for the total cost of tomato production. The four types of costs include material and labor costs during the entire tomato growing season. The labor price used in the analysis is $11.35/h, the average labor wage rate for crop workers in Florida between 2015 and 2020 from the Farm Labor Survey (US Department of Agriculture 2021a).

After we recorded the number of tomatoes \((Q)\) at harvested dates, we used the daily tomato shipping point price \((P)\) collected from the USDA Agricultural Marketing Services (2022) to calculate the gross returns of tomato production. To consider the fluctuation of the selling price of organic tomatoes, we first calculated the average crop selling price during each harvest period; then, we calculated the gross returns for each harvest period. Total gross returns of the entire harvest season were the sum of the gross returns of all harvest periods in that production season. According to our data, the average tomato market price was between $5.95 and $17.95 per 25-lb carton in 2019 and between $6.45 and $27.95 per 25-lb carton in 2020 during the harvesting season.

Hence, the gross return during the entire production season is

$$TR = \sum_{t=1}^{T} P_t \times Q_t,$$ \[3\]

where \(TR\) (measured in dollars per acre) represents the total revenue, also known as a gross return; \(P_t\) (measured in dollars per 25-lb carton) is the average daily shipping point price for tomatoes in Florida at harvesting period; \(Q_t\) (measured in 25-lb cartons per acre) is the tomato yield at harvesting period; and \(T\) is the total number of harvest times during the production season. Because the coronavirus disease 2019 (COVID-19) pandemic, which started in Feb 2020, caused a significant labor shortage for tomato harvesting for our trials, our trials resulted in a low marketable yield during the 2020 production season. Hence, we conducted our analysis using both total yield and marketable yield to provide a better estimate of the gross return of organic tomato production in high tunnels.

The net return or profit of tomato production was calculated as follows:

$$Profit = TR - TC.$$ \[4\]

**Sensitivity analysis.** Sensitivity analysis is an important tool to determine how net return changes under various scenarios in relation to a factor. It can indicate the relative importance of the investigated factors (Shi et al. 2019). Low-selling tomato prices and high grafting transplant costs may lead to an enormous reduction in the net return of grafted tomato production. Therefore, in this study, we conducted a sensitivity analysis to evaluate the effects of changes in tomato selling prices and grafted transplant costs on the difference between the net return of grafted and non-grafted tomatoes. The analysis was performed for grafted tomatoes involving variations in tomato prices (i.e., $11.20, $12.60, $14.00, $15.40, and $16.80/25-lb carton) and grafted transplant costs (i.e., $0.71, $0.80, $0.89, $0.98, and $1.07/plant). Tomato selling prices were selected from the reported shipping point prices of mature green organic tomatoes grown in the adapted environment per 25-lb carton in Spring 2019 and 2020. Sensitivity analysis helps determine the economic feasibility of using grafted transplants for organic tomato production in high tunnels under different market scenarios.

**Results and discussion**

**High-tunnel construction cost.** Table 1 reports the estimation of total high-tunnel construction and maintenance costs. The total cost to build a three-bay high tunnel (2520 ft² each bay, or 7560 ft² in total) is $50,785.02. The initial installation cost of the high-tunnel main structure is the major contributor to the cost of using high tunnels. It costs $48,436.02 in total. The detailed breakdown of this cost is presented in Table 1. Among different parts of the high-tunnel main structure, the frame of the main structure is the most expensive part, followed by the ventilation system, controls, and locking system. The miscellaneous costs, such as shipping and labor, are crucial to installing high tunnels. We estimated the maintenance cost as $2349.00 for the three-bay high tunnel every 4 years. Maintenance consists of replacing plastic covers and doors of the high tunnel every 4 years. Assuming the salvage value of the high tunnel is $0.00, the main structure has a life span of 20 years, and the plastic covers and doors need to be replaced every 4 years. The annual cost of using a high tunnel is estimated as $18,030.36/acre (Table 1).

**Comparison of grafted and non-grafted tomato production cost, yield, and net return.** Table 2 shows the comparison of the estimated grafted and non-grafted transplants cost. Because grafting involves
combining two plants to form a new plant, the use of grafted tomato transplants leads to an additional cost associated with materials and labor for grafting transplants. Our results suggest that the cost of grafted and nongrafted transplants was $0.89 and $0.27/transplant, respectively. Grafting increases the transplant cost by 230% per transplant. Our estimated grafted transplant cost is consistent with the findings of Rivard et al. (2010b), who estimated that grafted transplants are more expensive than nongrafted transplants (145% to 354% per transplant of the nongrafted).

Figure 1 compares the 2-year average yield per acre between grafted and nongrafted organic tomato production in high tunnels. Although grafted tomato production generated a greater total yield and marketable yield than nongrafted tomato production, the difference in net return between grafted and the nongrafted tomato production is inconsistent. On the one hand, the net return of grafted tomato production was greater than that of nongrafted tomato production if using the total yield to calculate the gross return. On the other hand, the net return of grafted tomato production was less than that of nongrafted tomato production if using the marketable yield to calculate the gross return. The difference in net returns using marketable yield and total yield implies that the additional yield from grafted tomato production may or may not increase the profitability of organic tomato production, depending on the magnitude of the gap in yield between grafted and nongrafted tomato production. When grafted tomato production does not increase the yield significantly compared with nongrafted tomato production (i.e., the case of using the marketable yield to estimate the net return), grafted tomato production may result in lower profitability, possibly resulting from the high grafted transplant price.

We also compared the average yield per acre and net return per acre between grafted and nongrafted organic tomato production in high tunnels by year (Figs. 3 and 4). The results from 2020 were like the results of using 2-year data. Grafted tomato production can be less or more profitable than nongrafted tomato production, depending on whether one uses marketable yield or total yield to compute the gross return. However, the
The net return of grafted tomato production was greater than that of non-grafted tomato production in 2019, regardless of whether we used the marketable yield or the total yield to calculate the gross return. This is because the total yield gap and the marketable yield gap between grafted and non-grafted tomato production were very high in 2019, so the additional gross return generated by grafted tomato production was high enough to make grafted tomato production more profitable in 2019. More interesting, the net return of tomato production in 2020 was greater than that in 2019 in general if using marketable yield to compute the gross return, although the marketable yield of tomato production in 2020 was reduced. In fact, the net return of both grafted and non-grafted tomato production, if using marketable yield to calculate the gross return in 2019, was negative. The negative net return in 2019 suggests that tomato production might not be profitable in 2019 for both grafted and non-grafted tomato production if only considering the marketable yield. The main reason is that the average crop selling price in 2019 was only $11.30/25-lb carton, whereas it was $16.69/25-lb carton in 2020. The significant change in net return between 2019 and 2020 implies that the net return of tomato production was highly sensitive to the selling price of the crop. Tomato farms might not be profitable unless the market selling price enables farms to generate high enough revenues.

**PARTIAL BUDGET ANALYSIS.** To explore more fully the reasons behind the various effects of grafting on the net return of organic tomato production in high tunnels, we conducted a partial budget analysis. The partial budget analysis describes the cost, gross return, and net return related to alternative inputs and outputs. In our study, the

<table>
<thead>
<tr>
<th>Variable</th>
<th>Grafted ($/1,000 plants)</th>
<th>Nongrafted ($/1,000 plants)</th>
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</thead>
<tbody>
<tr>
<td>Seeds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scion (‘Skyway’)</td>
<td>ND 143.98</td>
<td>ND 143.98</td>
</tr>
<tr>
<td>Rootstock (‘Estamino’)</td>
<td>ND 305.75</td>
<td>ND ND</td>
</tr>
<tr>
<td>Seeding production</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grafting</td>
<td>ND 19.00</td>
<td>ND 9.50</td>
</tr>
<tr>
<td>Flats</td>
<td>ND 27.76</td>
<td>ND 12.49</td>
</tr>
<tr>
<td>Seed sowing and care</td>
<td>92.95 ND</td>
<td>59.15 ND</td>
</tr>
<tr>
<td>Liquid fertilizer</td>
<td>ND 91.00</td>
<td>ND 45.50</td>
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<tr>
<td>Grafted transplant production</td>
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<td></td>
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<tr>
<td>Grafting</td>
<td>52.81 ND</td>
<td>ND ND</td>
</tr>
<tr>
<td>Silicone clips</td>
<td>ND 46.66</td>
<td>ND ND</td>
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<tr>
<td>Miscellaneous supplies</td>
<td>ND 8.00</td>
<td>ND ND</td>
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<tr>
<td>Postgrafting care</td>
<td>21.13 ND</td>
<td>ND ND</td>
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<tr>
<td>Healing chamber</td>
<td></td>
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<tr>
<td>Humidifier</td>
<td>ND 5.49</td>
<td>ND ND</td>
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<tr>
<td>Air conditioner</td>
<td>ND 31.80</td>
<td>ND ND</td>
</tr>
<tr>
<td>Building supplies</td>
<td>ND 26.86</td>
<td>ND ND</td>
</tr>
<tr>
<td>Assembly</td>
<td>16.90 ND</td>
<td>ND ND</td>
</tr>
<tr>
<td>Subtotal</td>
<td>183.79 706.30</td>
<td>59.15 211.47</td>
</tr>
<tr>
<td>Total</td>
<td>890.09 270.62</td>
<td></td>
</tr>
<tr>
<td>Cost/plant ($/plant)</td>
<td>0.89 0.27</td>
<td></td>
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<tr>
<td>Labor cost ($/acre)</td>
<td>900.57 289.84</td>
<td></td>
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<tr>
<td>Material cost ($/acre)</td>
<td>3,460.87</td>
<td>1,086.20</td>
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<tr>
<td>Total transplant cost ($/acre)</td>
<td>4,361.44</td>
<td>1,326.04</td>
</tr>
<tr>
<td>Added cost of using grafted transplants relative to non-grafted plants ($/acre)</td>
<td>3,035.40</td>
<td>ND</td>
</tr>
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</table>

1 $1.00/acre = $2.4711/ha.

ND = no data.
added costs of grafted tomato production were associated with extra material and labor costs of graft transplants, and material and labor costs to harvest tomatoes. The additional gross return was associated with increased yield and price. The effects of grafted organic tomato production in high tunnels on farm profitability are shown in two ways: 1) the difference between the total positive effects and the total negative effects of grafting (Table 3) and 2) the difference between the gross return and the partial costs (Figs. 5 and 6).

As shown in Table 3, the total negative effects incurred with grafting are defined as the added cost plus reduced gross return, and the total positive effects are the reduced cost plus the added gross return. The total effects are the total positive effects minus the total negative effects. The total effects of grafting on the net return were both positive in 2019 and 2020 if using total yield to calculate the gross return. However, the total effects of grafting on the net return were positive in 2019 yet negative in 2020 if using marketable yield to calculate the gross return. The various total effects of grafting on the net return suggest that grafting was uncertain to increase farm profitability, depending on the performance of grafted production and market conditions. When total yield was used to conduct the analysis, grafted tomato production increased the cost by $5162.00/acre and $4947.32/acre in 2019 and 2020, respectively. Meanwhile, it increased the gross return by $6885.41/acre and $9151.39/acre in 2019 and 2020, respectively, resulting in a positive effect on the profit of tomato production.

When marketable yield was used to conduct the analysis, grafted tomato production increased the costs by $4731.09/acre and $3350.37/acre in 2019 and 2020, respectively. The gross return resulting from the greater marketable yield in grafted tomato production increased significantly in 2019, by $5512.56/acre. Because it was high enough to offset the added cost, grafted tomato production increased farm total profitability by $781.47/acre in 2019 compared with nongrafted tomato pro-

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**Fig. 2.** Comparison of average net return from total yield (A) and from marketable yield (B) between grafted and nongrafted organic high-tunnel tomato production for 2 years (2019 and 2020) in Citra, FL; $1.00/acre = $2.4711/ha.

**Fig. 3.** Comparison of total yield (A) and marketable yield (B) between grafted and nongrafted organic high-tunnel tomato production for 2 years (2019 and 2020) in Citra, FL; 1 lb/acre = 1.1209 kg ha⁻¹.
duction. However, the gross return from grafted tomato production was only $1643.49/acre greater than non-grafted tomato production in 2020. It is too low to offset the significant cost increase in 2020.

A more detailed summary of the costs and gross return associated with grafted organic tomato production in high tunnels is presented in Figs. 5 and 6. The total costs included preplanting stage costs (including land preparation costs and costs associated with grafting tomato transplants), production stage costs (including the cost to grow crops, such as applying fertilizer), harvesting stage costs (including harvest costs and organic amendment cost), and fixed costs (including land rent fee, high-tunnel installation, and maintenance fees). The additional costs of grafted tomato production were from the preplanting stage and harvesting stage in both 2019 and 2020. The most significant cost gap between grafted and non-grafted tomato production occurred in the preplanting stage for both years—at about $3000.00/acre. In addition, grafted tomato production also required more costs during the harvesting stage because of the additional harvest cost associated with extra yield from grafted tomato production. On the one hand, the total cost gap between grafted and non-grafted tomato production was similar when comparing data collected from 2019 to 2020 (Fig. 6). On the other hand, the gross return gap between grafted and non-grafted tomato production when using total yield (in both 2019 and 2020) and marketable yield (in 2019) was greater than when using the 2020 marketable yield to conduct the analysis. The different gross return gaps between grafted and non-grafted tomato production when using different yields to conduct analysis is because there was a significant increase in yields from grafted tomato production than nongrafted tomato production (Fig. 5). Consequently, grafted tomato production was more profitable than nongrafted tomato production in 2019, regardless of whether total yield or marketable yield was used to conduct the analysis, but grafted tomato production was only more profitable when using total yield to conduct the analysis in 2020.

Previous studies conducting partial budget analysis to compare grafted and nongrafted tomato production, such as that by Djidonou et al. (2013), found that grafting generally incurred more added costs and generated significant added returns compared with nongrafted tomato production. Hence, using grafting tends to be more profitable. However, our partial budget analysis suggests that the profitability of grafting could vary by year, possibly because of the relative yield performance of grafted organic tomatoes vs. nongrafted organic tomatoes and market conditions such as crop selling price, which varies across years. Another reason is that the COVID-19 pandemic that started in Feb 2020 and caused a significant labor shortage for tomato harvesting for our trials. As a result, the potential yield

<table>
<thead>
<tr>
<th>Table 3. Added and reduced costs and returns, and total negative and positive effects incurred by grafted organic tomato production in high tunnels in Citra, FL.</th>
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<tbody>
<tr>
<td>Year</td>
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<tr>
<td>---------</td>
</tr>
<tr>
<td>2019</td>
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<tr>
<td>2020</td>
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<tr>
<td>2019</td>
</tr>
<tr>
<td>2020</td>
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</table>

$1.00/acre = $2.4711/ha.
increase of grafted tomatoes could not be transformed into marketable yield for greater revenue to offset the additional cost of grafted transplants, thus resulting in a lower net income than nongrafted tomatoes in 2020.

**Sensitivity Analysis.** Table 4 illustrates how net returns associated with grafted organic tomato production in high tunnels change with two market factors: the grafted tomato transplant cost and the tomato selling price. Our results suggest that the economic benefit of grafted organic tomato production in high tunnels was highly sensitive to the selling price of tomatoes. Holding tomato yield constant, decreasing/increasing the tomato prices would decrease/increase significantly the profit of grafted organic tomato production in high tunnels. When the tomato selling price was $11.20/25-lb carton, both grafted and non-grafted tomato production resulted in a negative net return when using marketable yield to conduct the analysis. This result suggests that the financial competitiveness of organic tomato production in high tunnels could be at risk if the tomato selling price is $11.20/25-lb carton, regardless of the type of transplants used. The significant impact of the selling price of tomatoes on net returns in our analysis is consistent with previous findings, such as those of Barrett et al. (2012) and Djidjou et al. (2013), which demonstrated that tomato selling price was a major factor affecting the profitability of grafted tomato production. In addition, grafted organic tomato production would be consistently less profitable than nongrafted organic tomato production when the tomato selling price was $12.60/25-lb carton, regardless of how much grafted transplants cost when using marketable yield to conduct the analysis. Grafted organic tomato production became more profitable than nongrafted organic tomato production under different grafted transplant price scenarios when the tomato selling price increased. For instance, if we used marketable yield to conduct the analysis, grafted organic tomato production generated a greater net return than nongrafted organic tomato production.

![Fig. 5. Comparison of cost from total yield (A) and from marketable yield (B) between grafted and nongrafted organic high-tunnel tomato production for 2 years (2019 and 2020) in Citra, FL; $1.00/acre = $2.4711/ha.](image)

![Fig. 6. Comparison of revenue from total yield (A) and from marketable yield (B) between grafted and nongrafted organic high-tunnel tomato production for 2 years (2019 and 2020) in Citra, FL; $1.00/acre = $2.4711/ha.](image)
when the tomato selling price was $14.00/25-lb carton and the grafted transplant cost was $0.71/transplant. However, when the tomato selling price was $15.40/25-lb carton, grafted tomato production was more profitable in two scenarios: when the grafted transplant cost was $0.80 and $0.71/transplant. It is also noted that the difference between grafted tomato production and nongrafted tomato production became more substantial as tomato prices increased if grafted tomato production was more profitable. These results imply that additional yield is the primary factor that affects the profitability of grafted tomato production positively. At the same time, high transplant cost is the primary factor that affects the profitability of grafted tomato production negatively. Only when the tomato selling price is high enough is the additional yield associated with grafted tomato production enough to offset the higher grafted transplant costs and make grafted organic tomato production more profitable than nongrafted tomato production in high tunnels.

In Table 5, we estimate the break-even crop selling price for grafted and nongrafted tomatoes when facing various transplant costs and yields. The break-even crop selling price is the minimum selling price that makes grafted tomatoes or nongrafted tomatoes profitable. The results show that when tomato yield is 69,108.61 lb/acre, grafted tomatoes need to sell at $14.31 to $14.94/25-lb carton to break even, whereas nongrafted tomatoes need to sell at $13.93 to $14.56/25-lb carton to break even. Compared with the average annual tomato selling price between 2011 and 2020 in Florida (Fig. 7), growers can only make a profit in 1 year out of 10 for both grafted and nongrafted tomatoes. When tomato yield increases, the break-even price for grafted and nongrafted tomatoes decreases. Growers are likely to make a profit in more years. For example, growers are likely to make a profit in 4 years out of 10 years when the grafted tomato transplant cost is $0.71 each.

Table 4. The estimated net return of grafted and nongrafted organic tomato production in high tunnels at varying tomato sales prices and transplant costs in Citra, FL.

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<tr>
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<td>21,713.63</td>
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<tr>
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<td>16.80</td>
<td>7,343.17</td>
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<td>26,840.94</td>
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<td>26,840.94</td>
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</tr>
</tbody>
</table>

![Image](https://via.placeholder.com/150)

\*$1.00/25-lb (11.34-kg) carton = $0.0882/kg, $1.00/acre = $2.4711/ha.
grafted tomato yield is 77,747.07 lb/acre. And growers are likely to make a profit in 5 years out of 10 when the non-grafted tomato transplant cost is $0.22 each and nongrafted tomato yield is 77,747.07 lb/acre.

**Conclusion**

Previous studies have suggested that grafting may increase organic vegetable production’s performance in more protected culture systems such as high-tunnels systems by controlling RKN, increasing yield, and improving crop quality (Carey et al. 2009; Kubota 2008). However, there is little research on the impact of grafting on the economic benefits of organic vegetable production in high tunnels. Using 2-year field trial data in Citra, FL, we drew a similar conclusion to previous research that grafting tends to increase organic tomato yield in high tunnels. However, higher grafted transplant costs increase organic tomato production costs at the preplanning stage. In addition, grafted tomato production has a higher harvesting cost because of the increased yield of grafted production.

Contrary to some previous findings suggesting that the significant increase in the gross return of the grafted vegetables associated with improving yield tends to offset the adverse effects of grafting on the production cost [e.g., Djidonou et al. (2013) for tomatoes and Izaba et al. (2021) for cucumbers], we found that the increased yield of grafted organic tomato production in high tunnels does not necessarily mean an increase in profit. The profitability of grafted organic tomato production depends highly on market conditions, especially on tomato selling price. Grafted organic tomato production was more likely to be more profitable than nongrafted organic tomato production in high tunnels when the tomato selling price was high. Given the high sensitivity of grafted tomato production to crop selling price, finding ways to obtain a price premium for organic tomatoes in the market could be significant to make grafting profitable.

Indeed, the net return of organic tomato production is highly volatile when we compare 2 years of organic tomato production in our analysis. This volatility in price may have been caused by the COVID-19 pandemic, which resulted in a significant labor shortage along the agricultural supply chain, causing a substantial price surge in 2020. The farm labor shortage in 2020 during the harvest season also limited the yield advantage of grafting with an extended production season.
With only 2 years of data, we may not draw solid conclusions on the impact of grafting practice on the economic feasibility of organic tomato production in high tunnels in the long run. Future research needs to collect tomato production data in more years to investigate more completely the economic performance of grafted and nongrafted organic tomato production in high tunnels. In addition, more investigation into the impact of the COVID-19 pandemic on the economic performance of grafted tomatoes is needed when more data are available. Also, one of the major benefits of tomato grafting is to offset the adverse effects of soilborne diseases under protected production systems (Singh et al. 2017). However, our tomato production did not experience severe soilborne diseases in either grafted or nongrafted tomato production. The economic benefits of the grafting practice could be underestimated. Future research could estimate the economic benefits of grafting when there is a severe soilborne disease in crop production. Last but not least, the high tunnel we used in the experiment is a multiple-bay high tunnel with an automation system, which makes it more expensive than many tunnels on the market. Our study is more likely to overestimate the cost of vegetable production under high tunnels. Future research could analyze the economic outcomes of crop production using less-expensive high tunnels.

References


