**Is Vegetable Grafting Economically Viable in the United States: Evidence from Four Different Tomato Production Systems**

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**Abstract**

Four case studies representing distinct tomato (*Solanum lycopersicum*) production systems were selected, including conventional and organic field production, conventional production in multi-bay tunnels and organic production in high tunnels. Relevant cost and revenue information was collected. On-farm economic impact of grafting technology adoption was evaluated for each system. The primary objective was to use these real-life examples to investigate the forces that should be driving grower adoption decisions. A combination and interaction of multiple factors such as grafting transplant prices, expected yield improvements and sale prices guide adoption decisions. The use of grafted transplants generally resulted in positive net returns; conventional field tomato production and high tunnel organic tomato production were shown to be more sensitive to grafting transplant prices as they generally have lower profit margins. At high selling prices, growers can afford to pay price premiums for grafted transplants because only very modest yield improvements are required to compensate for higher costs of grafted plants. Use of grafted plants has potential economic benefits in all systems but actual outcome is dependent on multiple factors.

**INTRODUCTION**

The use of grafting in fruiting vegetables was first introduced in China in the 5\(^{th}\) century (Lewis et al., 2014), while commercial use of vegetable grafting originated in Japan and Korea about 30 years ago and later expanded to Western countries (Kubota et al., 2008; Lee et al., 2010). Even though, the United States transplant production capacity is growing (Lee et al., 2010), vegetable grafting is still rare in field-based production systems due to the high cost of grafted transplants and lack of reliable information and local infrastructure (Barrett et al., 2012; King et al., 2010; Kubota et al., 2008; Taylor et al., 2008).

The use of grafting is common with various vegetable species in both the *Cucurbitaceae* and *Solanaceae* families. A wide variety of rootstocks is available for specific conditions and environments (Lee et al., 2010). The use of grafted plants is seen primarily as a way to manage various soilborne pathogens in successive cropping systems (King et al., 2010; Kubota et al., 2008; Rivard and Louws, 2008) as there are commercially available rootstocks that exhibit resistance or tolerance to a number of diseases and nematodes. As a result of increased pathogen pressure, adoption of organic and high tunnel production systems, and the loss of methyl bromide as a soil fumigant, grafting is steadily becoming an important part of integrated pest management programs in vegetable crops (Barrett et al., 2012; King et al., 2010; Lee et al., 2010; Louws et al., 2010). In addition, growers may rely on grafting as a way to improve vigor, optimize absorption of water and nutrients, leading to improved use of limited resources (Djidonou et al., 2013a; Lee et al., 2010; Rivard and Louws, 2008), as a tool to manage abiotic...
stress, to reduce the use of agricultural chemicals, and to enhance fruit quality (Lee et al., 2010).

Tomato (Solanum lycopersicum) is the major crop currently grafted in North America (Kubota et al., 2008) primarily for vigor benefits in protected agriculture and for disease resistance (Barrett et al., 2012; King et al., 2010; Kubota et al., 2008; Rivard and Louws, 2008). In tomato production, rootstock selection for disease management, and therefore associated production and economic benefits of grafting, are site-specific and depend on various local pathogens, as well as edaphic, environmental and anthropogenic factors (Barrett et al., 2012; Louws et al., 2010). As a result, it is difficult to generate reliable scientific evidence directly relevant for all growers who seek to determine the benefits of grafting for their situation (Kubota et al., 2008; Rivard and Louws, 2008).

High costs of grafted plants are often viewed as a barrier to adoption of grafted technology in the United States (Rivard et al., 2010). Studies investigating economic viability of grafting typically have a specific focus predetermined by location, crop, production system and issue addressed by the experiment. For example, Barrett et al. (2012) investigated the cost-effectiveness of grafting to overcome root-knot nematodes (Meloidogyne sp.) in the production of organic heirloom tomatoes in Florida’s sandy soils. Grafted plants demonstrated great potential for maintaining fruit yields and reducing economic losses at high levels of infestation but were not economically feasible when used in fields with low nematode pressure. Taylor et al. (2008) arrived to a similar conclusion: it is not economically feasible for farmers growing seedless watermelon (Citrullus lanatus) to use grafted transplants if Fusarium wilt caused by Fusarium oxysporum is not an issue. Djidonou et al. (2013b) evaluated the impact of grafting on fresh-market tomato production under common management practices in North Florida in fumigated fields. They showed that grafting increased production costs considerably compared to the non-grafted system. However, net returns were higher in the grafted system due to yield improvements, but varied considerably depending on seasonal yields and market prices.

A useful tool that could help growers make decisions about grafting is to provide a comparison of economic impacts of grafting across different production systems. We selected four case studies representing different tomato production systems capturing tomato production diversity in eastern United States: conventional field production, organic field heirloom tomato production, organic heirloom tomato production in high tunnels, and conventional heirloom tomato production in large multi-bay tunnels. Our primary objective is to investigate economic impact of grafting in these case studies and the forces that should be driving grower adoption decisions based on their specific economic circumstances.

**MATERIALS AND METHODS**

It was noted earlier that economic benefits of grafting are specific to the site and depend on various local environmental and economic factors. In addition, there exists great variability in the economic circumstances of different tomato production systems and sites. Selected case studies capture some diversity in tomato production in eastern United States. Conventional field production is the predominant system in the Southeast and is often characterized as large scale and orientated towards wholesale markets. Field and high tunnel organic heirloom tomato production systems are typically a part of highly diversified farms and are orientated towards specialized markets and local direct marketing. Finally, production of conventional heirloom tomatoes in multi-bay tunnels varies in scale and could be orientated towards both wholesale and specialty markets. In the case of multi-bay tunnels, frame construction is less expensive compared to high tunnels and can cover larger growing blocks.

For each case study, we collected information on production, transplant and harvesting costs, expected yields and sale prices, and estimated revenues. Production cost models were developed based on customary management practices recommended by extension and research horticultural specialists and practiced by growers. These models
were also reviewed by commercial growers for corroboration. In the production models, we assumed that machinery and equipment expenses reflect machinery components that can be used for other farming enterprises in addition to growing tomatoes on a typical diversified farm, but irrigation equipment was used only for tomato production. Input prices were obtained from growers and local dealers who regularly supply growers. Because land rental rates are variable, a land charge was not considered. It was assumed that hired employees were paid $9.59/h (U.S. Department of Agriculture, 2013) and owner/operator was compensated at $15.72/h which accounts for workers’ compensation, unemployment, taxes and other overhead expenses. It was assumed that tomatoes are harvested by hand at the “vine ripe” stage by seasonal labor paid $3/11-kg box. For the conventional field production, the cost model is based on the production budget developed by Sydorovych et al. (2012). The costs associated with organic heirloom tomato production in the field and high tunnel are based on O’Connell et al. (2012) and Sydorovych et al. (2013). Finally, production costs associated with growing heirloom tomatoes in multi-bay tunnel are based on field trials that were conducted on a commercial farm in Lancaster County, Pennsylvania, USA.

Other assumptions about production costs and revenues for each case study, e.g., quantity of required transplants, transplant prices, expected marketable yields, and sale prices, are summarized in Table 1. These assumptions were based on the research trials mentioned above and our conversations with growers and their suppliers, though actual production practices and economic circumstances vary significantly from grower to grower and from one production season to another. Marketable yield estimates presented in Table 1 assume optimal management and no yield losses due to disease pressure. Economic impact of grafting is expressed in terms of expected net revenues in grafted and non-grafted systems at assumed marketable yields, but also in terms of additional yield needed to compensate for higher transplant prices in the grafted system. This approach enabled to abstract from the specific circumstances of the case studies and develop generally more applicable evidence.

Net revenues in both non-grafted and grafted systems were calculated as follows:

$$ NR = Y \times P - C - T - H $$

where $NR$ – net revenue in the corresponding system; $Y$ – estimated marketable yield per ha; $P$ – sales price per kg; $C$ – annual production costs per ha including annual share of fixed costs associated with tunnel structure, where applicable, and excluding transplant and harvesting costs; $T$ – transplant costs per ha; $H$ – harvesting costs per ha.

In the case of both tunnel systems, net revenue estimates were adjusted for an annual share of associated fixed structure costs. These tunnel structures, used to modify the microclimate to extend the growing season and to protect crops from excessive precipitation, also require additional capital investment (Wells and Loy, 1993). However, the structures are durable and typically last over multiple growing seasons. The initial fixed costs required to construct a 0.03-ha high tunnel with two layers of plastic were estimated. Assuming that the polyethylene plastic needs replacement every 4 years, the total costs associated with high tunnel construction were spread out equally over the period of 10 years to estimate the share of these costs per year of useful life for annual revenue analysis (Sydorovych et al., 2013). In the case of multi-bay tunnels, an estimate of costs associated with construction of a 0.4-ha structure was obtained from a supplier (Haygrove, Inc.; Ledbury, United Kingdom). It was also assumed that the structure would be used for 10 years and that the polyethylene plastic needs replacement every 4 years.

**Calculating Required Additional Marketable Yield in the Grafted System**

As mentioned previously, higher prices of grafted transplants result in increased production costs. For this technology to be economically viable, these extra costs need to be offset by certain yield improvements. Equation 2 could be used to calculate breakeven marketable yield required in the grafted system to make it as profitable as the non-grafted system. It represents the equality of net revenues in the two systems:
\[ Y_g \times P - C_g - T_g - H_g = Y_{ng} \times P - C_{ng} - T_{ng} - H_{ng} \]  

where subscript \( g \) refers to the grafted system and subscript \( ng \) to the non-grafted system.

Solving Equation 2 for \( Y_g \) will give the level of marketable yield in the grafted system required to break even with the non-grafted system:

\[ Y_g = \frac{Y_{ng} \times P + (C_g - C_{ng}) + (T_g - T_{ng}) + (H_g - H_{ng})}{p} \]  

(3)

Alternatively, we can use Equation 2 to express added yield required in the grafted system to break even with the non-grafted system. If we assume that the cost to harvest tomatoes remains constant; \( H = k \times Y \), where \( k \) is harvest cost per kg, then additional yield required in grafted system to break even with non-grafted system could be expressed as:

\[ \Delta Y = \frac{(C_g - C_{ng}) + (T_g - T_{ng})}{p - k} \]  

(4)

where

\[ \Delta Y = Y_g - Y_{ng} \]

RESULTS

Annual tomato production costs (transplant, harvest and marketing excluded) associated with four case studies are reported in Table 1. The data for conventional and organic field production, as well as multi-bay tunnel production, are presented on per 0.4-ha (1 acre) basis. Organic high tunnel production data are presented for a 0.03-ha high tunnel but some variables were converted to the 0.4-ha scale to make the comparison with other case studies possible. The table also reports assumed values for other main impact variables.

Presented variable production costs do not include transplant and harvesting charges as they have direct impact on the analysis and need to be separated. It was assumed the systems needed 130 (organic high tunnel) up to 5800 (conventional field) plants (Table 1).

Transplant prices vary depending on propagator, especially for grafted transplants, as a mature grafted transplant market has not developed yet. The higher costs of rootstock seeds, rather than labor costs, is one of the largest contributor to higher prices (Djidonou et al., 2013b; Rivard et al., 2010). Based on the information from several propagators and farmers and a literature review, grafted tomato transplants can cost anywhere from $0.59 (when produced on-site without markup) to over $2.00 including $0.25-$0.34 for seeds; non-grafted transplants can cost from $0.12 to $0.76 including $0.04-$0.07 for seeds (Barrett et al., 2012; Djidonou et al., 2013b; Rivard et al., 2010). We assumed that non-grafted transplants used for conventional and organic field production cost $0.12 and $0.40 and $0.50, respectively, and conventional and organic grafted transplants cost $1.80 and $1.45, respectively.

Assumed marketable yield in the field conventional system was 34,900 kg per 0.4 ha, 17,150 kg per 0.4 ha in the field organic system, 29,030 kg per 0.4 ha in the multi-bay tunnel and 1,770 kg per 0.03 ha in an organic high tunnel. These values were based on our discussions with farmers and field trial observations and represent yields expected in well-managed systems under no disease pressure. When harvested, tomatoes are packed into 11-kg boxes, and it was assumed that picking labor was paid $3 per box resulting in our harvest labor expense estimates reported in Table 1. Presented sale prices are wholesale under minimal marketing expenses and were obtained from United States Department of Agriculture Agricultural Marketing Services (2013) and directly from growers. Gross revenues were obtained by multiplying marketable yield estimates by
sales price. Net revenue estimates accounted for annual production, transplant and harvesting costs.

To make adjustments in net revenues for the costs of tunnels, we assumed that initial investment of $12,975 was required to construct a 0.03-ha high tunnel (Sydorovych et al., 2013) and $38,014 to construct 0.4-ha multi-bay tunnel. When the 10-year useful life (4 years for plastic) was considered for each tunnel, annual share of tunnel costs was estimated to be $4430 for the high tunnel and $1410 for the multi-bay tunnel (Haygrove, Inc.; Ledbury, United Kingdom). When annual costs of the structure were accounted for, net revenues were calculated to be equal to $22,618 in conventional field production, $48,465 in organic field production, $84,247 in multi-bay tunnel, and $2031 per tunnel in organic high tunnel production in the systems using non-grafted transplants. In the corresponding grafted systems, net revenues were $17,398, $44,460, $80,887, and $1737 per high tunnel.

The last two rows in Table 1 report additional yields required in the grafted system to compensate for higher transplant prices calculated based on Equation 4. These estimates take into account additional harvesting costs resulting from higher yields and assume that other production costs are the same in grafted and non-grafted systems, except for transplant costs. Additional yields are reported on a per 0.4-ha/tunnel and per plant basis. We found that an additional 6,230 kg per 0.4-ha (1.07 kg per plant) are needed to compensate for the higher costs of grafted transplants in conventional field production, 1,230 kg (0.28 kg per plant) are needed in organic field production, 1,030 kg (0.43 kg per plant) are needed in the conventional multi-bay tunnel system, and 90 kg per high tunnel (0.29 kg per plant) are needed in the organic high tunnel production system.

CONCLUSION

High costs of grafted transplants have been identified as barriers to adoption of grafted technology (Rivard et al., 2010). This technology is economically viable under certain circumstances (Barrett et al., 2012; Djidonou et al., 2013b; Taylor et al., 2008). We looked at four case studies intended to reflect the diversity in tomato production in eastern United States. Based on these case studies we assessed whether grafted transplant prices could in fact be detrimental to broad acceptance of grafting technology in the country. What we found is that it is a combination and interaction of multiple factors, such as grafting transplant prices, expected yield improvements and sale prices, which should guide adoption decisions.

Grafted transplants resulted in positive net returns at reported grafted transplant prices, marketable yield levels, and sale prices. The net returns were the lowest for the conventional field production and high tunnel organic production and the highest for the conventional multi-bay tunnel production. Based on these results conventional field tomato production and high tunnel organic tomato production would be more sensitive to grafting transplant prices as they have lower profit margins compared to the other two systems. At higher selling prices, for example possible with organic heirloom tomato cultivars, growers should be able to pay price premiums for grafted transplants because only very modest yield improvements per plant are required to compensate for higher costs of grafted plants. At the same time, at lower selling prices typical for wholesale conventional field tomatoes, yield improvements need to be significant even if grafted plants are acquired at only moderate price premiums. Grafting is economically viable at any grafted transplant price premium if a grower expects considerable yield improvements from using grafted transplants. Still, the price of grafted transplants is extremely important to growers as considerable additional investment is required early in the production season. With further developments in rootstock breeding, grafting techniques and automation and increased use of grafted transplants, future reductions in transplant prices are expected. Such reductions would be desirable by growers as they would improve economic viability of grafting across systems.

This analysis assumed that the use of grafting technology has no impact on production beyond transplant prices and harvesting costs associated with changes in
yields. This might not apply in all real-world circumstances. Grafted systems may differ in terms of nutrient requirements, pest management practices, the number of transplants needed due to different spacing or use of more vigorous rootstock, etc. If this is the case, annual production costs held constant in this analysis will be affected. Potential impact is beyond the scope of this analysis and could be a fruitful area for future research.

While our results indicate that grafted technology is potentially economically viable in various tomato production systems, actual costs and returns will vary from grower to grower and from year to year due to a number of factors such as market situation, weather conditions, managerial skills, etc.

ACKNOWLEDGEMENTS
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Literature Cited
Table 1. Summary of the baseline scenarios for the four tomato production systems.

<table>
<thead>
<tr>
<th></th>
<th>Conventional tomato production in the field (0.4 ha)</th>
<th>Organic heirloom tomato production in the field (0.4 ha)</th>
<th>Conventional heirloom tomato production in multi-bay tunnel (0.4 ha)</th>
<th>Organic heirloom tomato production in high tunnel (0.03 ha)</th>
<th>Organic heirloom tomato production in high tunnel converted (0.4 ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production costs(^z) ($)</td>
<td>5,946</td>
<td>6,945</td>
<td>5,083</td>
<td>2,176</td>
<td>31,086</td>
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<tr>
<td>Number of transplants required(^y)</td>
<td>5,800</td>
<td>4,450</td>
<td>2,400</td>
<td>310</td>
<td>4,450</td>
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<tr>
<td>Price of transplants ($/plant)</td>
<td></td>
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<tr>
<td>Non-grafted</td>
<td>0.12</td>
<td>0.12</td>
<td>0.40</td>
<td>0.50</td>
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<tr>
<td>Grafted</td>
<td>1.02</td>
<td>1.02</td>
<td>1.80</td>
<td>1.45</td>
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<tr>
<td>Marketable base yield (kg)</td>
<td>34,930</td>
<td>17,150</td>
<td>29,030</td>
<td>1,770</td>
<td>25,270</td>
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<tr>
<td>Sale price ($/kg)</td>
<td>1.1</td>
<td>3.53</td>
<td>3.53</td>
<td>3.53</td>
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<tr>
<td>Net revenue ($)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Non-grafted</td>
<td>22,618</td>
<td>48,465</td>
<td>88,677</td>
<td>3,441</td>
<td>49,157</td>
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<td>Grafted</td>
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<td>44,460</td>
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<td>44,950</td>
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<td>Annual cost of structure ($)</td>
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<td>Non-grafted</td>
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<tr>
<td>Grafted</td>
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<td>Net revenue adjusted for structure cost ($)</td>
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<tr>
<td>Additional yield needed to pay for higher transplant price</td>
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<tr>
<td>kg/0.4 ha</td>
<td>6,230</td>
<td>1,230</td>
<td>1,030</td>
<td>90</td>
<td>1,290</td>
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<td>kg/plant</td>
<td>1.07</td>
<td>0.28</td>
<td>0.43</td>
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\(^z\)Production cost estimates do not include transplant, harvest, and marketing expenses.

\(^y\)Including additional 2% required to replant.