Economic Analysis of Pruning Grafted Fresh-market Tomato Plants under Field Conditions in North Carolina

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Abstract. Grafted tomato (Solanum lycopersicum L.) plants have the potential to increase yield in the absence of soilborne disease; however, success is dependent on geographic location and rootstock–scion combination. Pruning auxiliary shoots on field-grown tomato plants is a standard practice for fresh-market production in the southeastern United States, although few studies have evaluated the effects of pruning grafted tomato plants. In this study, we evaluated six field grown tomato rootstock–scion combinations and their nongrafted counterparts, pruned or not pruned, over the course of 2 years at one location in North Carolina. Total yield, fruit size, variable cost of inputs, and net return data were analyzed. In both years of the study, cultivars Mountain Gem and Jolene had high yield of jumbo and extra-large fruit when grafted onto ‘Maxifort’ or ‘Beaufort’ rootstock. Yield was higher ($P < 0.0001$) for plants that were grafted and not pruned compared with nongrafted pruned plants (grower standard). Net return from the treatment where plants were grafted onto ‘Maxifort’ rootstock and not pruned was greater than that from the grower standard practice, although this was not the case in both years of the study. The variable cost of growing grafted plants that were not pruned was always greater than that of the grower standard practice due to the greater cost of transplants and labor associated with harvest. The results from this study emphasize the importance of evaluating a small number of prospective rootstock–scion combinations on-farm and considering the balance between higher input costs of the grafted plants and potential increased yields before planting an entire field.

Due to their potential to increase yield, reduce soilborne disease, overcome environmental stress, and minimize the use of fumigants, interest in grafted tomato (Solanum lycopersicum L.) plants has increased over the past decade in the United States (Grieneisen et al. 2018; Kubota et al. 2008; Louws et al. 2010). At present, commercial production of grafted tomatoes in the United States is largely limited to greenhouse operations (Kubota et al. 2008); however, grafted tomatoes have the potential to produce greater yields and to serve as an integrated pest management strategy under field conditions. Fresh-market tomato production is a major industry in the southeastern United States, and North Carolina ranks fifth nationwide in acres harvested [US Department of Agriculture, National Agricultural Statistics Service (USDA NASS 2017)]. Production of fresh-market tomatoes in North Carolina is concentrated in the central and western regions of the state (USDA NASS 2017), where high humidity and moderate temperatures create ideal environments for many bacterial and fungal diseases of tomato, including Verticillium wilt (Verticillium sp.), Fusarium wilt (Fusarium oxysporum f. sp. lycopersici) bacterial wilt (Ralstonia solanacearum), southern blight (Athelia rolfsii), and root-knot nematode (Meloidogyne sp.). Fortunately, some of these diseases can be managed using resistant rootstocks (Louws et al. 2010, 2018; Rivard et al. 2010). Although management solutions for soilborne diseases such as Verticillium wilt and bacterial wilt rank as high importance to tomato producers in this region (Meadows I, unpublished data), grafted tomatoes may also provide a yield advantage in fields with low soilborne disease pressure. Unfortunately, few field trials evaluating the yield of grafted tomato plants in relation to nongrafted plants aside from soilborne disease management have been conducted in the southeastern United States (Djidonou et al. 2013; Grieneisen et al. 2018; Rysin and Louws 2015). In addition to disease resistance, high-yielding varieties are important to a successful commercial operation to offset the variable cost of inputs, including labor, fertilizer, pesticides, plastics, and fuel (Ivors et al. 2010).

Due to geographic variation in growing conditions, disease pressure, cost of production, market opportunities, and accessibility of grafted tomato transplants, it is critical to evaluate the benefits and constraints associated with growing grafted tomatoes for the fresh-market on a local level to provide accurate information to nearby producers (Cohen et al. 2017; Grieneisen et al. 2018; Rysin and Louws 2015). Understanding situations where grafting increases yields to consistently offset added input costs has promise to aid local producers; however, identifying rootstock–scion combinations suitable for producers’ needs in a specific region is complicated due to the large number of possible heterografting (grafting of different varieties) combinations, unknown compatibility, and unknown horticultural practices required for optimal growth of grafted plants. According to rootstock tables produced by the Vegetable Production Systems Laboratory at the Ohio State University, 34 tomato rootstocks are commercially available in the United States (Vegetable Grafting, undated). Scion varieties are often selected from local varieties that perform well and are familiar to growers. Horticultural practices such as pruning, stringing, fertilization, and mulching all contribute to fresh market tomato fruit yield and quality (Ivors et al. 2010). However, optimal practices for grafted tomatoes under field conditions may differ from those of nongrafted tomatoes. Manually removing auxiliary shoots (pruning) is a cultural practice used in the production of many fresh market tomato varieties that is thought to increase fruit size and yield by decreasing vegetative plant growth (Davis and Estes 1993), if timed appropriately. Increased vigor of grafted tomato plants may result in excessive vegetative growth, in which case pruning may be a useful practice to increase yield (Ingram et al. 2021). However, few studies have
evaluated the effect of pruning grafted tomato plants and the effect of pruning may differ based on whether the variety is determinate or indeterminate (Ingram T, personal communications).

The objectives of this study were to 1) evaluate the effects of grafting and pruning of six scion–rootstock combinations and their nongrafted counterparts on the yield and fruit size of fresh-market tomato fruit in North Carolina and 2) conduct a partial budget analysis to determine if planting grafted tomatoes for the fresh market is a profitable practice in North Carolina under low soilborne disease pressure. We hypothesize that 1) grafted plants will yield greater than nongrafted plants regardless of pruning status; 2) pruned, grafted tomatoes will yield greater than the grower standard (nongrafted, pruned); and 3) grafted, nonpruned plants will yield similar to the grower standard.

**Materials and Methods**

*Field trials.* A field trial was conducted in both 2020 and 2021 at the Mountain Research Station in Waynesville, NC. The soils were a Cullowhee–Vikwasi complex. The soils were not fumigated because soilborne disease pressure was low to nonexistent in previous tomato crops, and both fields had been under a rotation of corn and soybeans for the previous 2 years. Sixteen treatments were evaluated in a randomized complete block design with five replications per treatment. Treatments consisted of either two determinate tomato varieties (‘Jolene’ or ‘Mountain Gem’) grafted onto one of three tomato rootstock varieties (‘Beaufort’, ‘Maxifort’, or ‘Shinchonggang’), or nongrafted. Each of the eight variety–rootstock combinations was either pruned or nonpruned for a total of 16 treatments. Grafted transplants were obtained from Tri-Hishtil LLC (Mills River, NC, USA) where they were grown in a potting mix consisting of peatmoss, vermiculite, lime, potassium nitrate (13–0–46), magnesium sulfate, Micromax®, boron, and iron in a greenhouse at Mountain Horticultural Crops Research and Extension Center in Mills River, NC, USA. All plants were watered as needed. Six-week-old transplants (both nongrafted and grafted) were planted into beds covered with 1.5-mL polyethylene black plastic on 2 Jun 2020 and 26 May 2021. Each treatment plot was separated by 1.2-m fallow plot and consisted of 13 and 10 plants per plot for nongrafted (planted 48 cm apart) and grafted plants (planted 61 cm apart), respectively. Rows were served as blocks and were established on 1.5-m centers. A nontreated buffer row was established on the outer sides of the field study and planted with nongrafted plants to avoid any edge effect. All plants were watered with drip irrigation, staked, strung, fertilized, and managed for weeds, insects, and diseases following current tomato production guidelines for the region (Ivors et al. 2010). Pruning was conducted by manually detachment of all axillary shoots (suckers) from the lower portion of the plant once plants began to produce flower clusters. For tomato ‘Jolene’, all suckers except the two immediately underneath

<table>
<thead>
<tr>
<th>Variety × rootstock × prune</th>
<th>F value</th>
<th>P &gt; F</th>
<th>F value</th>
<th>P &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>5.73</td>
<td>0.05</td>
<td>6.61</td>
<td>0.01</td>
</tr>
<tr>
<td>Grafted</td>
<td>1.49</td>
<td>0.21</td>
<td>2.73</td>
<td>0.10</td>
</tr>
<tr>
<td>Rootstock (grafted)</td>
<td>0.92</td>
<td>0.34</td>
<td>0.93</td>
<td>0.34</td>
</tr>
<tr>
<td>Prune</td>
<td>0.58</td>
<td>0.45</td>
<td>0.53</td>
<td>0.46</td>
</tr>
<tr>
<td>Variety × grafted</td>
<td>0.34</td>
<td>0.56</td>
<td>0.37</td>
<td>0.55</td>
</tr>
<tr>
<td>Variety × prune</td>
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<td>0.03</td>
<td>0.90</td>
</tr>
<tr>
<td>Rootstock (grafted) × prune</td>
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<td>0.40</td>
<td>0.73</td>
<td>0.40</td>
</tr>
<tr>
<td>Variety × grafted × prune</td>
<td>2.73</td>
<td>0.01</td>
<td>2.73</td>
<td>0.01</td>
</tr>
</tbody>
</table>

*Mountain Gem* and ‘Jolene’ were either nongrafted or grafted onto rootstocks ‘Shinchonggang’, ‘Maxifort’, or ‘Beaufort’ and either pruned or nonpruned in two field experiments in Waynesville, NC.
Table 2. Mean marketable yield, standard error, and $P$ values for the main effects of variety, rootstock, and pruning practice on marketable yield based on analysis of variance.

| Factor          | Treatment | 2020 Yield (kg/ha)$^a$ | SE | $P > |t|$ | 2021 Yield (kg/ha)$^a$ | SE | $P > |t|$ |
|-----------------|-----------|------------------------|----|-------|-----------------------|----|-------|
| Variety         | Jolene    | 81,364 a 1 1,989       | <0.001 | 92,037 a 2,970 | <0.001 |
| Rootstock       | Mountain Gem | 68,022 b 1 1,989 | 77,407 b 2,986 | 107,956 a 3,757 | <0.001 |
| Prune           | Nonpruned | 83,173 a 1 1,989       | <0.001 | 100,523 a 2,986 | <0.001 |
|                 | Pruned    | 65,673 b 1 1,989       | 71,921 b 2,970 | 79,008 b 3,637 |         |

$^a$ Tomato varieties ‘Mountain Gem’ and ‘Jolene’ were either nongrafted or grafted onto rootstocks ‘Shincheonang’, ‘Maxifort’, or ‘Beaufort’ and either pruned or nonpruned in two field experiments in Waynesville, NC. $^b$ There was an interaction between variety, rootstock, and prune in 2020 ($P = 0.037$) and is presented in Fig. 1.

In 2020, there was an interaction among the main factors of variety, rootstock, and pruning practice ($P = 0.037$) and is presented in Fig. 1.

The first flower cluster was removed by hand. For tomato ‘Mountain Gem’, all suckers except one immediately underneath the first flower cluster were removed by hand. The number of suckers removed was based on information provided by the seed company representatives. Pruning was conducted when plants were nine weeks old on 23 Jun 2020 and on 16 Jun 2021.

Yield analysis. In 2020, fruit were harvested from all plants in each treatment plot on 19 and 27 Aug and on 2 and 10 Sep. In 2021, fruit were harvested from each treatment plot on 9, 23, and 30 Aug and on 8 Sep. All fruit that were ripe or beginning to turn red (breakers) were manually harvested. Fruit were visually assessed to separate marketable from nonmarketable, then marketable fruit were sorted by size, counted, and weighed. Fruit size specifications differed slightly from those of the USDA standard: medium: greater than 2.54 cm and less than or equal to 6.35 cm; large: greater than 6.35 cm and less than or equal to 7.62 cm; extra-large: greater than 7.62 cm and less than or equal to 8.59 cm; jumbo: greater than 8.59 cm. Count and weight of fruit in each size class was recorded to understand differences by rootstock, variety, and pruning practice.

Disease analysis. In 2021, disease severity ratings for bacterial spot of tomato ($Xanthomonas perforans$ Jones et al.) were recorded for each treatment plot on 20 and 27 Aug, and 3 Sep using a modified Horsfall–Barratt scale to assess percentage of leaf area affected ($0 = 0\%$, $1 = <1\%$, $2 = 1\% to 3\%$, $3 = 3\% to 6\%$, $4 = 6\% to 12\%$, $5 = 12\% to 25\%$, $6 = 25\% to 50\%$, $7 = 50\% to 75\%$, $8 = 75\% to 87\%$, $9 = 87\% to 94\%$, $10 = 94\% to 97\%$, $11 = 97\% to 100\%$, and $12 = 100\%$). Means were converted to geometric midpoints and areas under the disease progress curve (AUDPC) were calculated. Bacterial spot was not observed in treatment plots in 2020.

Partial budget analysis. To estimate the effects of the cultural practices identified earlier on net profits, marketable yield composed of large, extra-large, and jumbo fruit was analyzed for each treatment using the enterprise budget for tomato developed at North Carolina State University (https://cals.ncsu.edu/are-extension/wp-content/uploads/sites/27/2021/06/Tomato-Budget-2021.pdf). The enterprise budget used in this analysis was identical for both 2020 and 2021; all input costs, labor costs, and fruit prices were the same. Therefore, this does not accurately reflect the market conditions of each year, but rather provides relative estimates based on the market conditions of 2020. Prune activity was either included or not included in labor costs as calculated in the budget. The budget is designed so that additional costs of labor and supplies are automatically adjusted when yield increases. The cost of the grafted plants was based on prices provided by Tri-Hishtil at the time of the study. The net profit for each treatment in each year was calculated for each rep and used in statistical analyses. The variable cost of inputs, including the additional cost grafted transplants as well as labor associated with pruning activity, picking, packing, and the number of boxes required were calculated using the budget for each rep in each treatment.

Statistical analysis. All analyses were conducted using the statistical software SAS 9.4 (SAS Institute Inc., Cary, NC, USA). Analyses of variance (ANOVAs) were performed to determine the effect of year, variety, grafting, rootstock (nested within grafting), pruning, and their interactions on the total marketable yield (composed of medium, large, extra-large, and jumbo fruit), yield of extra-large and jumbo fruit sizes, and AUDPC of bacterial spot using the PROC GLM function. Means were separated using Tukey’s honestly significant difference multiple comparison ($\alpha = 0.05$). Yields from 2020 and 2021 were significantly different, so data were analyzed separately each year. To answer custom hypotheses of how the yield from 1) grafted plants compared with nongrafted plants regardless of pruning status 2) grafted plants compared with that of the grower standard (nongrafted, nonpruned); and 3) grafted, nonpruned compared with that of the grower standard, linear contrasts were performed using the CONTRAST and ESTIMATE statements. Net return, cost of transplants, cost of labor, and total variable cost of inputs for each treatment in each year were subjected to ANOVA as described earlier, followed by Dunnett’s two-sided test with the standard practice (pruned, nongrafted) as the control.

Results

Main treatment factors. In 2020, there was an interaction among the main factors of variety, rootstock, and pruning practice on mean marketable yield, but there were no interactions in 2021 (Table 1). In 2020, there was an increase in marketable yield when ‘Mountain Gem’ was not pruned and grafted onto ‘Maxifort’ or ‘Beaufort’ compared to when not grafted and not pruned. In contrast, there was an increase in marketable yield and when

Table 3. Mean marketable yield, mean differences in marketable yield and standard error, and $P$ values ($\alpha = 0.05$ in bold) from linear contrasts performed to test the effects of pruning and grafting practices on mean marketable yield of tomato in 2020 and 2021.

| Contrasts between treatments | Yield (kg/ha)$^a$ | Difference $\pm$ SE | $P > |t|$ |
|------------------------------|------------------|---------------------|--------|
| 2020                         |                   |                     |        |
| Grafted vs. nongrafted       | 80,475; 68,911    | 11,564 $\pm$ 4,060 | 0.006  |
| Grafted, pruned vs. nongrafted, pruned (grower standard) | 76,109; 61,247 | 8,853 $\pm$ 5,741 | 0.128  |
| Grafted, nonpruned vs. nongrafted, pruned (grower standard) | 90,850; 61,247 | 29,604 $\pm$ 5,741 | <0.0001 |
| 2021                         |                   |                     |        |
| Grafted vs. nongrafted       | 91,112; 78,080    | 13,032 $\pm$ 5,860 | 0.029  |
| Grafted, pruned vs. nongrafted, pruned (grower standard) | 75,770; 62,073 | 13,697 $\pm$ 8,269 | 0.102  |
| Grafted, nonpruned vs. nongrafted, pruned (grower standard) | 10,6958; 62,073 | 44,885 $\pm$ 8,307 | <0.0001 |

$^a$ Mean yield in kilograms per hectare (kg/ha).
Fig. 2. Percentage of total marketable yield (kg/ha) composed of large and medium (white), extra-large (gray), and jumbo (black) tomato fruit harvested from two varieties ['Jolene' and 'Mountain Gem' (Mountain)] grafted onto one of three rootstocks ('Beaufort', 'Maxifort', 'Shincheonggang') or nongrafted, and pruned or nonpruned in (A and B) 2020 and (C) 2021. Percentage of marketable yield was analyzed within each fruit size, with the exception of large and medium fruit, which were excluded from analysis. There were no main effect interactions on yield of extra-large fruit in 2020 (A), but there was an interaction between variety and rootstock on yield of jumbo fruit (B) and among variety, rootstock, and prune on yield of extra-large and jumbo fruit in 2021 (C). Sections of bars with the same letters are not significantly different according to Tukey’s honestly significant difference multiple comparisons ($P < 0.05$), and sections without letters indicate no effects on percentage of marketable yield.
Fig. 3. Area under the disease progress curve for severity of bacterial spot (Xanthomonas perforans) on tomato in 2021. Disease severity was rated using a modified Horsfall–Barratt scale based on percentage of leaf area affected. Varieties ‘Jolene’ or ‘Mountain Gem’ nongrafted or grafted onto three rootstocks, ‘Shincheonggang’ (Shincheo), ‘Maxifort’, and ‘Beaufort’, and pruned or nonpruned. Rootstock and prune activity were the only significant factors (P = 0.015 and < 0.001, respectively). Horizontal bars with different letters were significantly different based on Tukey’s honestly significantly difference multiple comparisons (P < 0.05).

‘Jolene’ was not pruned grafted onto ‘Shincheonggang’ compared to when pruned and grafted onto the same rootstock, but no increase when ‘Jolene’ was grafted onto ‘Maxifort’, ‘Beaufort’, or nongrafted and not pruned (Fig. 1A). In 2021, the main factors of variety, grafted, rootstock and pruning practice were significant (Table 1; P < 0.001, < 0.001, <0.001, and <0.001, respectively). Marketable yield was greater for ‘Jolene’ than for ‘Mountain Gem’, when plants were grafted onto ‘Beaufort’ or ‘Maxifort’ rootstock than when grafted onto ‘Shincheonggang’ or not grafted (P < 0.001), and when plants were not pruned compared with pruned (Table 2).

To address hypotheses, linear contrasts of mean yields in both years revealed that grafted plants yielded significantly greater than nongrafted plants (P = 0.006 and 0.029, respectively; Table 3). In both 2020 and 2021, yields from grafted, nongrafted plants were significantly greater than the standard grower practice (nongrafted, pruned) (P < 0.001 in 2020 and 2021; Table 3), but not when they were pruned (P = 0.128 and 0.102, respectively).

**Fruit size.** The mean weight of fruit in each size class was 0.1 kg for medium, 0.2 kg for large, 0.3 kg for extra-large, and 0.4 kg for jumbo fruit. We excluded analysis of large and medium-sized fruit due to the lower-marketability of these fruit sizes. In 2020, there was no interaction between the main factors of variety and rootstock in yield of jumbo fruit (F = 2.78; P = 0.048). The percentage of jumbo fruit was greater for ‘Mountain Gem’ compared with ‘Jolene’ when grafted onto ‘Maxifort’, ‘Shincheonggang’, and nongrafted but not when grafted onto ‘Beaufort’ (Fig. 2A). There were no interactions among the main factors for yield of extra-large fruit, but the main factors of prune activity, cultivar, and rootstock were significant (each at P < 0.001). There was a greater percentage of extra-large fruit when plants were nongrafted compared with pruned regardless of grafting status (Fig. 2B). There was a greater percentage of extra-large fruit harvested from ‘Jolene’ compared with ‘Mountain Gem’, and from plants of both varieties grafted onto ‘Shincheonggang’ or nongrafted compared with grafted onto ‘Maxifort’ or ‘Beaufort’ (Fig. 2B). In 2021, there was an interaction among the main factors of variety and rootstock in yield of jumbo and extra-large fruit (P = 0.002 and P = 0.003, respectively). There was a greater percentage of jumbo fruit when plants were pruned compared with nongrafted for each variety and each rootstock but not when plants were not grafted (Fig. 2C). There was a significantly greater percentage of extra-large fruit when plants were not pruned and grafted onto ‘Maxifort’ or ‘Beaufort’ but not when grafted onto ‘Shincheonggang’ or nongrafted (Fig. 2C).

**Disease.** Foliar symptoms of bacterial spot were not observed in plots in 2020, so data were not collected, but in 2021, there were differences in foliar disease severity observed among treatments (P < 0.001). Disease severity was lower for pruned plants compared with nongrafted plants (P < 0.001; Fig. 3), and there were differences in severity among rootstocks (P = 0.015). Plants grafted onto ‘Maxifort’ or ‘Beaufort’ rootstocks had a higher disease severity than when grafted onto ‘Shincheonggang’ or nongrafted.

**Budget.** There was a main effect of variety, rootstock, and prune on net return in each year (P < 0.004), but no interaction effects in either year. Only in 2021, and not in 2020, was there a greater net return when ‘Jolene’ was grafted onto ‘Maxifort’ and not pruned (Fig. 4). The net return for ‘Mountain Gem’ in both years was greater than that from the standard practice when grafted onto ‘Maxifort’ and not pruned and was lower in both years when ‘Mountain Gem’ was grafted onto ‘Shincheonggang’ and pruned. Variable cost of inputs for both ‘Jolene’ and ‘Mountain Gem’ were significantly greater than that of the standard practice (nongrafted, pruned) when not pruned and grafted onto any rootstock (Fig. 5). When total variable cost was separated into cost of transplants, cost of labor, and other variable cost, the cost of transplants and labor for each grafted variety were each greater than that of the grower standard in both years (P < 0.05). Variable cost of inputs for ‘Jolene’ and ‘Mountain Gem’ also were significantly greater when plants were grafted onto ‘Maxifort’ and ‘Beaufort’ and pruned.

**Discussion**

In both years of this study, tomatoes grafted onto certain rootstocks and not pruned had greater yields than when not grafted and pruned in the absence of soilborne disease. Highest yields were observed when the variety ‘Jolene’ was grafted onto ‘Maxifort’ or ‘Beaufort’ and not pruned. The variety ‘Mountain Gem’ had greater yields when grafted onto these same rootstocks than when grafted onto ‘Shincheonggang’ or not grafted, suggesting increased plant vigor associated with these rootstocks. Numerous studies have evaluated the yield response of grafting different varieties onto ‘Maxifort’ rootstock across the United States and Europe, with yield response differing by scion variety and geographic location (Grieneisen et al. 2018; Kumar et al. 2015; Meyer 2016; O’Connell 2008). Trials in the United States have shown that, on average, an increase in yield is observed when plants are grafted onto ‘Maxifort’, ‘Beaufort’, or other rootstocks considered to be vigorous compared with their nongrafted counterpart (Lang and Nair 2019; Louws et al. 2018; Meyer 2016; Suchoff et al. 2018). However, some of these studies were conducted in the presence of soilborne disease, which may disproportionately affect the health of the nongrafted control plants (Grieneisen et al. 2018). In other cases, grafting onto ‘Maxifort’ and ‘Beaufort’ rootstock did not consistently result in a significant yield increase even in the absence of soilborne disease (Carbonell et al. 2022). In one North Carolina study, a yield increase of 43% over the nongrafted controls was observed for ‘German Johnson’ plants grafted onto ‘Maxifort’ at one location, whereas no difference in yield between grafted or nongrafted plants was observed at two additional locations (Rivard and Louws 2008). Similarly, another study found that when tomato ‘Cherokee Purple’ was grafted onto ‘Maxifort’ and ‘Beaufort’, yields were similar to the nongrafted plants (Buller et al. 2013).
Although there was a main effect of grafting on marketable yield observed in this study, yield of plants grafted onto ‘Shincheonggang’ was not different from that of the nongrafted plants, emphasizing the importance of rootstock selection in the absence of bacterial wilt disease pressure. When tomato rootstocks with resistance to the bacterial wilt pathogen, similar to ‘Shincheonggang’, are deployed in fields with heavy disease pressure, grafted tomatoes can significantly and dramatically improve yields over the nongrafted tomato (Louws et al. 2018; Suchoff et al. 2019), but rootstocks that have resistance to bacterial wilt tend not to provide a yield increase outside of this scope (Lang and Nair 2019).

There are a limited number of published studies evaluating the impact of pruning on yield under field conditions, although the impacts under greenhouse conditions are known (Heuvelink et al. 2018). Regardless, pruning is a standard practice on non-grafted plants employed to limit vegetative growth and increase yield and fruit size (Ivors et al. 2010). In our study, pruning decreased total marketable yield of all plants regardless of grafting. Our results are similar to what was found in a similar study of nongrafted plants conducted in North Carolina in which pruning decreased total yield from tomato ‘Mountain Pride’, but fruit from the nonpruned plants was smaller than that from pruned plants, on average (Davis and Estes 1993). In the same study, timing of pruning affected fruit size and total marketable yield, with pruning only beneficial in increasing yield of jumbo and extra-large fruit if conducted early. Ingram et al. (2021) found
that pruning ‘Tasti Lee’ and ‘Mountain Fresh Plus’ decreased yields when these plants were grafted onto ‘Beaufort’ rootstock, with no difference in fruit size between pruned and nonpruned treatments. In our study, ‘Jolene’ and ‘Mountain Gem’ plants were pruned differently based on guidelines given from seed representatives, yet we observed a similar yield response to pruning for each variety. Pruned plants yielded a higher percentage of jumbo fruit than nonpruned plants when grafted onto any rootstock in 2021, but yields of jumbo fruit from pruned plants were not significantly different from nonpruned plants in 2020. Harvesting nonpruned, grafted plants may also be challenging due to the extra foliage and this may factor into the growers’ decision on whether to prune. Regardless, the variation in fruit size in response to pruning should be further investigated to understand how and when to prune to increase fruit size on grafted tomatoes.

We found that nonpruned plants had greater bacterial spot severity in 2021, which may be due to increased vegetative growth and a reduction in air flow throughout the plant canopy. However, even though nonpruned plants experienced greater disease severity, yield from nonpruned plants grafted onto ‘Maxifort’ or ‘Beaufort’ were either numerically or statistically greater than pruned and grafted plants. Regardless, increased vegetative growth associated with plants grafted onto vigorous rootstocks may promote other diseases; therefore, increased disease pressure should be considered when growers wish to use grafted tomatoes on their farm.

Both ‘Maxifort’ and ‘Beaufort’ are considered vigorous rootstocks whereby they produce a larger root system that can extract more nutrients and water from the soil.
(Djidonou et al. 2015; Leonardi and Giuffrida 2006; Suchoff et al. 2018) and potentially result in additional vegetative growth over a nongrafted tomato plant. Plants grafted onto vigorous rootstocks may require less fertilizer input (Djidonou et al. 2015; Leonardi and Giuffrida 2006), but due to our randomized complete block design, we were not able to adjust fertilizer and irrigation rates among treatments. Regardless, irrigation and nutrient requirements for grafted plants ought to be monitored by growers so that they can adjust inputs accordingly during the season.

The partial budget analysis revealed that the greatest net return was achieved when plants were grafted onto ‘Maxifort’ rootstock and not pruned. However, the net return data should be considered with a wide margin due to the high variability associated with input costs, geographic location, market prices among years, and other factors known to affect tomato yield such as pest (insect and weed) and pathogen pressure. Additionally, the budget that we used in this analysis reflected the market conditions of 2020 only. The greatest variable costs tended to occur when plants were grafted and not pruned. These additional costs were due to the additional cost of grafted plants and labor required to harvest the higher yielding plants. Similarly, the lowest variable costs were primarily observed in treatments that were nongrafted, which also yielded the least fruit. Economic analyses of yield from grafted tomatoes under field conditions have also varied, but grafted tomatoes with rootstocks that are resistant to a disease result in profitable production (Barrett et al. 2012; Rysin and Louws 2015).

In the absence of soilborne disease pressure, we found that ‘Jolene’ or ‘Mountain Gem’ grafted onto vigorous rootstocks ‘Maxifort’ or ‘Beaufort’ and not pruned provided high yields of both jumbo and extra-large fruit. Results from this study suggest that grafting and not pruning ‘Jolene’ or ‘Mountain Gem’ results in greater marketable yield than that obtained from the grower standard practice of not grafting and pruning. However, net returns achieved with these practices were not consistently greater than those obtained with the grower standard. Growers are advised to evaluate a small number of grafted plants on their farm to determine if this practice would be economically beneficial under their local conditions.

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