HortScience 58(8):943–948. 2023. https://doi.org/10.21273/HORTSCI17145-23

# Variable Yield Responses among Grafted and Nongrafted Late blight–resistant Tomato (*Solanum lycopersicum* L.) Hybrids in North Carolina

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*Keywords.* cultivar, late blight, rootstock, Verticillium, ‘Maxifort’

*Abstract.* **Host resistance is an environmentally and economically sustainable disease management strategy that may be especially beneficial to small-scale and organic growers for whom other management tools such as synthetic pesticides are too costly or not permitted. In western North Carolina, the demand for vine-ripened tomatoes (*Solanum lycopersicum* L.) from local and organic farms has led to the development of cultivars bred for resistance to geographically relevant diseases, including late blight of tomato, which causes rapid defoliation and lesions on fruit. Grafting tomato plants has the potential to increase plant vigor and yield; however, this effect is known to be dependent on multiple factors, including scion and geographic location. In this study, we evaluated the yield response of one determinate (‘Mountain Gem’) and four indeterminate (‘Mountain Heritage’, ‘Mountain Girl’, ‘Mountain Rouge’, and ‘NC10291’) late blight–resistant tomato cultivars, grafted on tomato rootstock ‘Maxifort’ or nongrafted, on a commercial farm and at two research facilities in western North Carolina. Yield of marketable fruit from grafted plants was greater than that from nongrafted plants at one location ($P = 0.008$); however, yield response of each cultivar, grafted or not grafted, differed by location. Yield was consistently greater from ‘Mountain Gem’ plants than other cultivars, and grafted ‘Mountain Gem’ plants had greater yields later in the season at two locations than nongrafted plants. Because of the late planting date intended to expose cultivars to the late blight pathogen, the full yield potential of the indeterminate cultivars was not realized at all locations. Disease severity caused by Verticillium wilt (*Verticillium dahliae* Kleb., *Verticillium albo-atrum* Reinke & Berthold) was lowest for cultivar Mountain Heritage at two of three locations. Results from this study emphasize the importance of conducting evaluations of grafted tomato plants at multiple locations, including on farm, to optimize the benefits associated with their use.**

Planting disease-resistant cultivars can be an effective disease management strategy, especially for diseases that are difficult to manage with fungicide applications. Late blight of tomato (*Solanum lycopersicum* L.), caused by *Phytophthora infestans* (Mont.) de Bary, is a foliar and fruit disease of tomato that can cause devastating yield loss if not controlled (Fry et al. 2013). *Phytophthora infestans* spreads via airborne asexual spores that infect aboveground tissues in cool and moist conditions, resulting in necrotic lesions on both leaves and fruit, and eventual plant defoliation. Infection progresses rapidly under favorable environmental conditions and, if untreated, can lead to 50% to 90% yield loss (Kohutek et al. 2023; Meadows et al. 2017). Survival of the pathogen throughout the winter has not been documented in western North Carolina, and it is hypothesized that the pathogen migrates or is transported via infected plant material to this region each year (Fraser et al. 1999). The disease is difficult to control without the use of a robust spray program or durable host resistance and it threatens production of fresh-market tomatoes in western North Carolina annually (Liu et al. 2018; Quesada-Ocampo and Meadows 2019). In response to the consumer demand for specialty and heirloom-type tomato fruit, especially in local farmers’ markets, a focus of the breeding program at NC State University is developing tomatoes that retain their desirable shapes, tastes, and colors while incorporating disease resistance (such as resistance to late blight). In North Carolina, the majority of tomato plantings are less than 5 acres, and nearly all farms report that local farmers’ markets are an important outlet for their product (NC Cooperative Extension 2011). In western North Carolina, improved specialty cultivars with resistance to late blight would allow local, small-scale, and organic farms to produce marketable tomato fruit that otherwise would be limited or not viable as a result of the cost and time requirements of regular fungicide applications.

Grafting of tomato plants can increase yield and fruit size of tomato, and can also be used to manage soil-borne diseases of significance in North Carolina, including Fusarium wilt (*Fusarium oxysporum* f. sp. *lycopersici* races 0, 1, and 2), Verticillium wilt (*Verticillium dahliae* race 1), root-knot nematodes (*Meloidogyne incognita*), and Southern bacterial wilt (*Ralstonia solanacearum* race 1) when disease-resistant rootstocks are available (Grieneisen et al. 2018; Louws et al. 2010). Tomato rootstocks that are resistant to Southern bacterial wilt are probably the most commonly deployed in North Carolina by both small and large farms because of the lack of alternative management strategies for this disease (Louws F, personal communications). Grafting is a cultural practice that can be used by tomato growers as an alternative to fumigants and other synthetic pesticides, and has the sole purpose of increasing plant vigor and yield. This may be especially beneficial for growers who have a small amount of land or limited capacity to fumigate. The ability to graft a scion with desirable traits, such as fruit quality or resistance to foliar disease, onto a desirable rootstock allows growers to obtain the benefits conferred by both in a single plant. Grafted transplants can cost up to 10 times that of nongrafted transplants (Hinson B, personal communications), which may not make them economically feasible in some scenarios. However, the additional cost of grafted tomatoes may not outweigh the yield advantage in the presence of high disease pressure or in small-scale plantings (Barrett et al. 2012). There are limited studies that have evaluated the effect of grafting tomatoes for the organic market or small-scale farms (Barrett et al. 2012; Louws et al. 2010; O’Connell et al. 2012). However, these may be the areas in which they are most practical, as these growers often do not fumigate and have limited acreage. Response to grafting has been shown to differ by scion and geographic location on any given rootstock (Grieneisen et al. 2018). This emphasizes the importance of evaluating specific scion–rootstock combinations at multiple locations, including on farm, to determine potential benefits.

The purpose of this study was to identify potential yield advantages of grafting five improved, specialty, late blight–resistant tomato hybrids from the NC State University tomato breeding program onto the vigorous, but not late blight–resistant, tomato rootstock 'Maxifort' on one farm and at two research stations in western North Carolina.

## Materials and Methods

*Field trials.* Three field trials were conducted in 2019: one at the Mountain Research Station (MRS) in Waynesville, NC, USA; one at the Mountain Horticultural Crops Research and Extension Center (MHCREC) in Mills River, NC, USA; and one at Holly Spring Farm (HSF) in Mills River, NC, USA. The soil type at MRS was a Cullowhee-Nikwasi complex; at MHCREC, an Elsinboro loam; and at HSF, a Fannin silt loam (Soil Survey Staff, Natural Resources Conservation Service, US Department of Agriculture 2019). At each location, Verticillium wilt (*Verticillium dahliae* Kleb., *Verticillium albo-atrum* Reinke & Berthold) had been observed in previous tomato crops, but each field had not been planted with tomatoes for at least two growing seasons, so the soils were not fumigated because disease pressure was expected to be low.

The two determinate tomato treatments were 'Mountain Gem' (Bejo Seeds, Inc., Oceano, CA, USA) grafted onto 'Maxifort' (Bayer Vegetable Seed, St. Louis, MO, USA) rootstock and nongrafted. The eight indeterminate tomato treatments were 'Mountain Heritage', 'Mountain Girl', 'Mountain Rouge', and the experimental hybrid 'NC10291' grafted onto tomato rootstock 'Maxifort' and nongrafted. All of the hybrids were developed as specialty-type, late blight–resistant tomatoes for vine-ripe production; however, none of the indeterminate cultivars are yet commercially available. 'Mountain Girl' and 'Mountain Rouge' are pink-fruited tomatoes, 'Mountain Heritage' is purple-fruited, and 'Mountain Gem' has the crimson gene for improved fruit color and increased lycopene. The rootstock 'Maxifort' was chosen based on evidence of increased vigor conferred by this rootstock, although it does also have resistance to

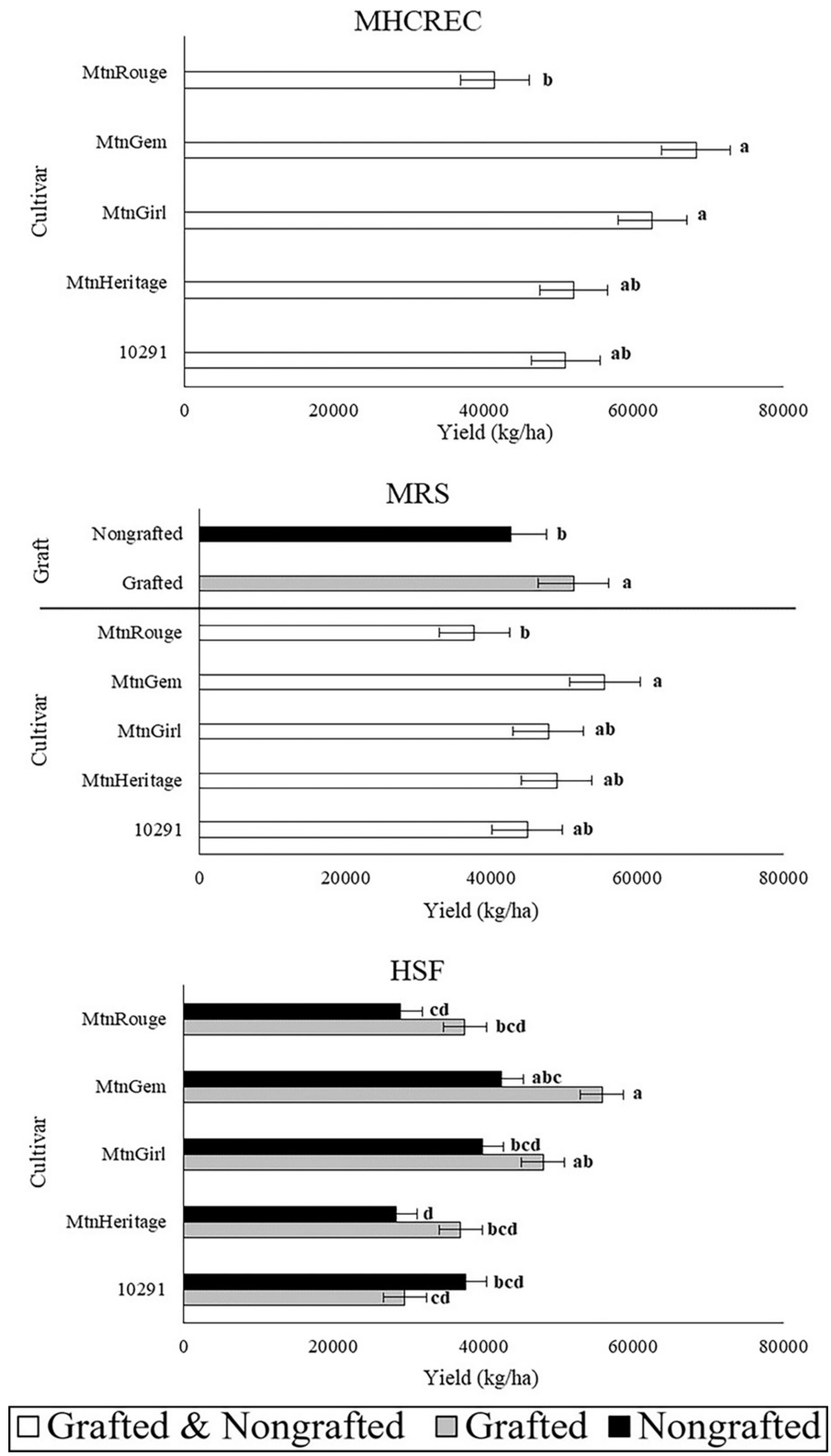


Fig. 1. Total marketable yield in kilograms per hectare by location of grafted (onto rootstock 'Maxifort') and nongrafted cultivars planted at three locations in western North Carolina in 2019. Data for grafted and nongrafted cultivars are combined for the Mountain Horticultural Crops Research and Extension Center (MHCREC; Mills River, NC, USA), while data are presented based on grafting status for the Mountain Research Station (MRS; Waynesville, NC, USA) and Holly Spring Farm (HSF; Mills River, NC, USA). MtnGem = 'Mountain Gem', MtnGirl = 'Mountain Girl', MtnHeritage = 'Mountain Heritage', MtnRouge = 'Mountain Rouge'. Error bars represent the standard error of the mean. Letters following bars indicate grouping by Tukey's honestly significant difference test multiple comparison ($P < 0.05$).


Received for publication 6 Mar 2023. Accepted for publication 16 May 2023.

Published online 28 Jul 2023.

Funding for this project was made possible by the US Department of Agriculture (USDA) Agricultural Marketing Service through grant number 17-182-4012.

The contents of this article are solely the authors' responsibility and do not necessarily represent the official views of the USDA.

Significant contributions to this project were made by Suzette Sharpe, who coordinated and supervised the field trials; staff at the Mountain Research Station and Mountain Horticultural Crops Research Station who grew the plants and helped harvest; Dr. Paul Shoemaker, who is the owner of Holly Spring Farm; Bejo Seeds Inc. which provided seeds; and Tri-Hishtil LLC, which provided the grafted plants.



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Table 1. Mean fruit weight for five cultivars of tomato grafted or nongrafted at three locations in western North Carolina in 2019.

| | | Mean fruit wt (g) | | | |
|---|---|---|---|---|---|
| Location[i] | Cultivar[ii] | Grafted[iii] | Nongrafted[iv] | *P* value | *SEM*[v] |
| MHCREC | NC10291 | 232 | 247 | 0.533 | 17.0 |
| MHCREC | MtnHeritage | 242 | 263 | 0.377 | |
| MHCREC | MtnGirl | 270 | 274 | 0.877 | |
| MHCREC | MtnGem | 307 | 291 | 0.521 | |
| MHCREC | MtnRouge | 256 | 257 | 0.960 | |
| MRS | NC10291 | 236 | 246 | 0.534 | 12.0 |
| MRS | MtnHeritage | 243 | 238 | 0.772 | |
| MRS | MtnGirl | 283 | 286 | 0.856 | |
| MRS | MtnGem | 301 | 307 | 0.723 | |
| MRS | MtnRouge | 270 | 248 | 0.221 | |
| HSF | NC10291 | 328 | 260 | **0.004**[vi] | 12.0 |
| HSF | MtnHeritage | 291 | 257 | 0.055 | |
| HSF | MtnGirl | 301 | 250 | **0.005** | |
| HSF | MtnGem | 298 | 277 | 0.230 | |
| HSF | MtnRouge | 284 | 253 | 0.083 | |

[i] HSF = Holly Spring Farm (Mills River, NC, USA); MHCREC = Mountain Horticultural Crops Research and Extension Center (Mills River, NC, USA); MRS = Mountain Research Station (Waynesville, NC, USA).

[ii] MtnGem = 'Mountain Gem', MtnGirl = 'Mountain Girl', MtnHeritage = 'Mountain Heritage', MtnRouge = 'Mountain Rouge'.

[iii] Mean fruit weight for each cultivar grafted onto rootstock 'Maxifort'.

[iv] Mean fruit weight for each nongrafted cultivar.

[v] *SEM* = standard error of the mean.

[vi] Values in bold type are statistically significant.

soilborne diseases, including corky root rot; Fusarium wilt races 1 and 2; Tomato mosaic virus races 0, 1, and 2; root-knot nematodes; and Verticillium wilt race 1 (Grieneisen et al. 2018; Kleinhenz 2022). At each location, determinate and indeterminate treatments were evaluated in a randomized complete block design with five replicates per treatment at MRS and MHCREC, and four replicates per treatment at HSF. All nongrafted plants were grown in a potting mix containing peatmoss, vermiculite, lime, potassium nitrate (13–0–46), magnesium sulfate, Micromax, boron, and iron in a separate greenhouse but at the same time as the grafted plants. All grafted plants were grown at Tri-Hishtil, LLC (Mills River, NC, USA) under similar conditions as the nongrafted plants and were delivered 3 d before transplant. All plants were maintained outside for 3 d before transplant to harden off. Six-week-old transplants were planted into beds covered with 1.5-mL polyethylene black plastic at MRS and MHCREC, and white plastic at HSF. Transplants were planted on 27 Jun at HSF, 9 Jul at MRS, and 10 Jul at MHCREC. Most fresh-market tomatoes in western North Carolina are planted between May and early July. Planting occurred later in the season to be sure to expose plants to the time period when late blight typically appears in the region (July–September), because the pathogen is not known to survive in western North Carolina from year to year. All plants were watered with drip irrigation. Each treatment plot was separated by a 0.6-m fallow plot and was planted according to the standard recommendation of five or six plants per plot for grafted (in-row spacing of 61 cm) and nongrafted (in-row spacing of 48 cm) plants, respectively. Rows served as blocks at MRS and MHCREC; but at HSF, blocks were split among rows because of space constraints. All rows were established on 1.5-m centers. To avoid any edge effect, buffer rows were planted on the outer sides of each field. Plants were managed for weeds, insects, and diseases; and were pruned, staked, strung, and fertilized according to current conventional tomato production guidelines for the region (Ivors et al. 2010) at all locations except at HSF, where a minimal fungicide spray program was used to minimize the development of foliar disease. At all locations, no fungicides with efficacy against the late blight pathogen were used. Weather data from MHCREC and MRS was accessed from the NC State Climate Office Cardinal Data Retrieval System (2023) (Raleigh, NC, USA). The closest weather station for HSF is located at MHCREC, so the weather data for HSF was not obtained and is assumed to be similar to that at MHCREC.

*Disease severity.* Plants were observed for the incidence of late blight at each location. Because symptoms of Verticillium wilt of tomato were observed, severity ratings for this disease were recorded for each treatment plot at each location. Severity ratings were recorded at MRS on 22 Aug, 29 Aug, 6 Sep, and 13 Sep; at MHCREC on 21 Aug, 28 Aug, 4 Sep, 9 Sep, and 16 Sep; and at HSF on 21 Aug and 28 Aug using a modified Horsfall-Barratt scale. This scale was based on the percentage of leaf are affected per five or six-plant plot: 0 point, 0%; 1 point, < 1%; 2 points, 1% to 3%; 3 points, 3% to 6%; 4 points, 6% to 12%; 5 points, 12% to 25%; 6 points, 25% to 50%; 7 points, 50% to 75%; 8 points, 75% to 87%; 9 points, 87% to 94%; 10 points, 94% to 97%; 11 points, 97% to 100%; and 12 points, 100%. Means were converted to geometric midpoints, and areas under the disease progress curve (AUDPC) were calculated (Madden et al. 2007).

*Yield.* At MRS, fruit were harvested from each treatment plot on 20 Sep, 26 Sep, 4 Oct, and 11 Oct. At MHCREC, fruit were harvested from each treatment plot on 26 Sep, 3 Oct, 10 Oct, and 17 Oct. At HSF, fruit were harvested from each treatment plot on 4 Sep, 9 Sep, 16 Sep, 23 Sep, 30 Sep, and 7 Oct. Only fruit that were ripe or beginning to turn red (breakers) were harvested, except for the final harvest, when plants were stripped of fruit with a diameter greater than 4.3 cm at MHCREC and MRS. The trials were ended at this time at MRS and MHCREC because of the onset of nighttime frost. At HSF, plants were not strip-harvested, so the grower could continue harvesting, although the frost event also ended this trial around the same time. Fruit were graded as marketable or nonmarketable, then were counted and weighed.

*Statistical analyses.* The yield of marketable fruit and AUDPC values from each location were analyzed together and separately with analysis of variance (ANOVA) using the PROC GLM function in SAS ver. 9.4 (SAS Institute, Cary, NC, USA). Means were separated using Tukey's multiple comparison test ($\alpha = 0.05$). Marketable yield for each treatment at each harvest was subjected to multivariate ANOVA using PROC GLM.

## Results

Yield response differed by location ($P < 0.001$); therefore, data collected from each location were analyzed separately. At MHCREC, grafting did not have a significant effect on total marketable yield ($P = 0.750$), but when yield from grafted and nongrafted plants was combined, the 'Mountain Gem' and 'Mountain Girl' yields were significantly greater than 'Mountain Rouge' (Fig. 1). At MRS, grafted plants were, on average, higher yielding than nongrafted plants ($P = 0.008$). When yields of grafted and nongrafted plants were combined, there were no differences in yield among indeterminate cultivars (Fig. 1), but 'Mountain Gem' had a greater yield than 'Mountain Rouge'. At HSF, yield response of

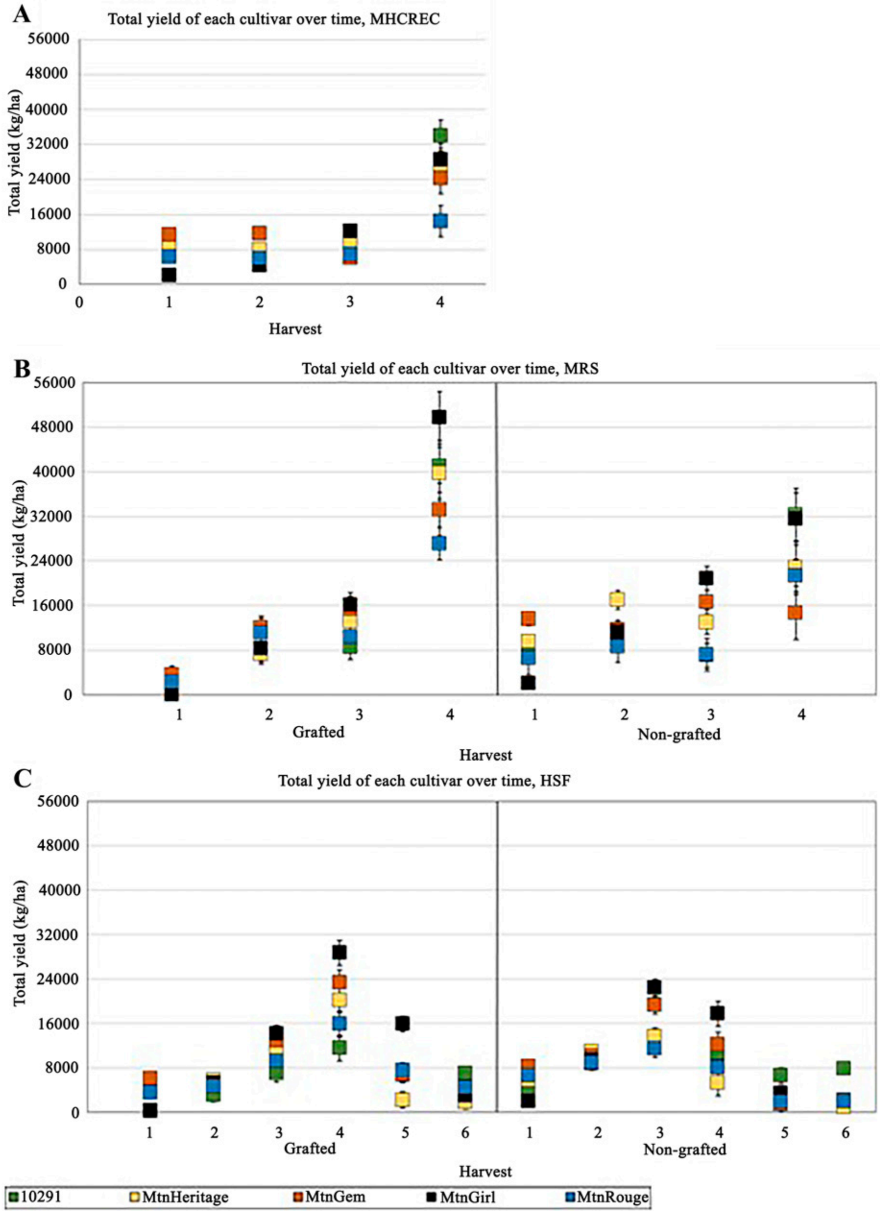


Fig. 2. Total marketable yield in kilograms per hectare over time of grafted (onto rootstock 'Maxifort') or nongrafted tomato cultivars at three locations in western North Carolina in 2019. Data for grafted and nongrafted plants were combined for the Mountain Horticultural Crops Research and Extension Center (MHCREC; Mills River, NC, USA). Locations as follows: MHCREC for each cultivar (**A**), Mountain Research Station (MRS; Waynesville, NC, USA) for each cultivar grafted onto Maxifort rootstock or nongrafted (**B**); and Holly Spring Farm (HSF; Mills River, NC, USA) for each cultivar grafted onto rootstock Maxifort or nongrafted (**C**). MtnGem = 'Mountain Gem', MtnGirl = 'Mountain Girl', MtnHeritage = 'Mountain Heritage', MtnRouge = 'Mountain Rouge'. A multivariate analysis of variance was conducted using the PROC GLM function in SAS ver. 9.4 (SAS Institute, Cary, NC, USA). Error bars represent the standard error of the mean.

grafting differed by cultivar ($P = 0.010$), although yields from nongrafted plants were not statistically different from grafted (Fig. 1). The average fruit weight of fruit harvested from 'NC10291' and 'Mountain Girl' when grafted was greater than the average fruit weight when these cultivars were not grafted at HSF, but this was not observed at any other location (Table 1). The multivariate analysis revealed differences in yield among cultivars regardless of grafting status at each harvest at MHCREC ($P < 0.001$) (Fig. 2). There was an interaction between cultivar and grafting status on yield at harvests 1 and 2 at MRS ($P < 0.014$), where nongrafted 'Mountain Girl' and 'Mountain Heritage' out-yielded all others. However, grafted plants had a greater yield than nongrafted plants at harvest 4 ($P < 0.001$) (Fig. 2). There was not a consistent effect of grafting on yield of each cultivar over time at HSF. Yield from nongrafted plants of each cultivar was greater than that of grafted plants at harvests 1, 2, and 3 ($P < 0.001$), but yield from each cultivar differed based on grafting status at harvests 4 and 5, and there was no effect of grafting at harvest 6 (Fig. 2).

No symptoms of late blight were observed on any of the plants evaluated, although late blight was first diagnosed in the region on 26 Aug and was present on susceptible cultivars at each location. Verticillium wilt disease pressure was low at all locations in 2019. Grafting did not affect the severity of Verticillium wilt at MHCREC ($P = 0.709$); however, severity did differ among cultivars ($P < 0.001$), with 'Mountain Gem' and 'Mountain Heritage' less affected than 'Mountain Rouge' and 'NC10291' (Fig. 3). Symptoms of Verticillium wilt were more severe for nongrafted plants than for grafted plants at MRS ($P = 0.001$), and 'Mountain Heritage' had the lowest severity among cultivars ($P < 0.001$) (Fig. 3). Susceptibility to Verticillium wilt differed by cultivar and grafting status at HSF ($P = 0.046$), with the lowest severity observed for 'Mountain Heritage' regardless of grafting status (Fig. 3). The only cultivar for which disease severity differed depending on grafting at HSF was 'NC10291', where nongrafted plants were more affected than grafted. Because Verticillium wilt pressure was low, we suspect that the effect on yield was marginal.

Average maximum and minimum monthly air temperatures were lower at MRS than at MHCREC, with a difference ranging from 0.2 to 1.6 °C and 1.1 to 1.4 °C, respectively (Table 2). Total precipitation was 39.6 cm at MHCREC and 35.9 cm at MRS (Table 2).

## Discussion

Grafted tomato plants may be an important part of an integrated pest management strategy for organic growers or small-acreage growers who have limited tools to manage soilborne plant pathogens or to increase yields under low disease pressure. Grafting has been shown to increase the yield of tomato plants in both the presence and absence of soilborne plant pathogens in North Carolina (Ingram et al. 2021, 2021; Rivard and Louws 2008; Rivard et al. 2010). In our study, we found inconsistencies in the yield response of late blight–resistant cultivars to grafting at three locations in western North Carolina. The reasons for the inconsistent results are unknown, but because only four harvests were conducted at two locations (MRS and MHCREC), we suspect that the full yield potential of the indeterminate cultivars may not have been realized at these two locations. Variation in yield response among farms using grafted tomatoes is not uncommon (Grieneisen et al. 2018; Kumar et al. 2015; Meyer 2006; O'Connell 2008; Rivard et al. 2010; Sydorovych et al. 2013) and emphasizes the importance of encouraging growers to evaluate a small number of grafted tomatoes on their farm to determine whether this is advantageous under their local conditions and with the cultivars they prefer. Using price data obtained from Tri-Hishtil, LLC, and the Tomato Enterprise Budget published by the North Carolina State University, Department of Agricultural and Resource Economics (2021), a 1-acre field of grafted transplants cost about $5000 more than a

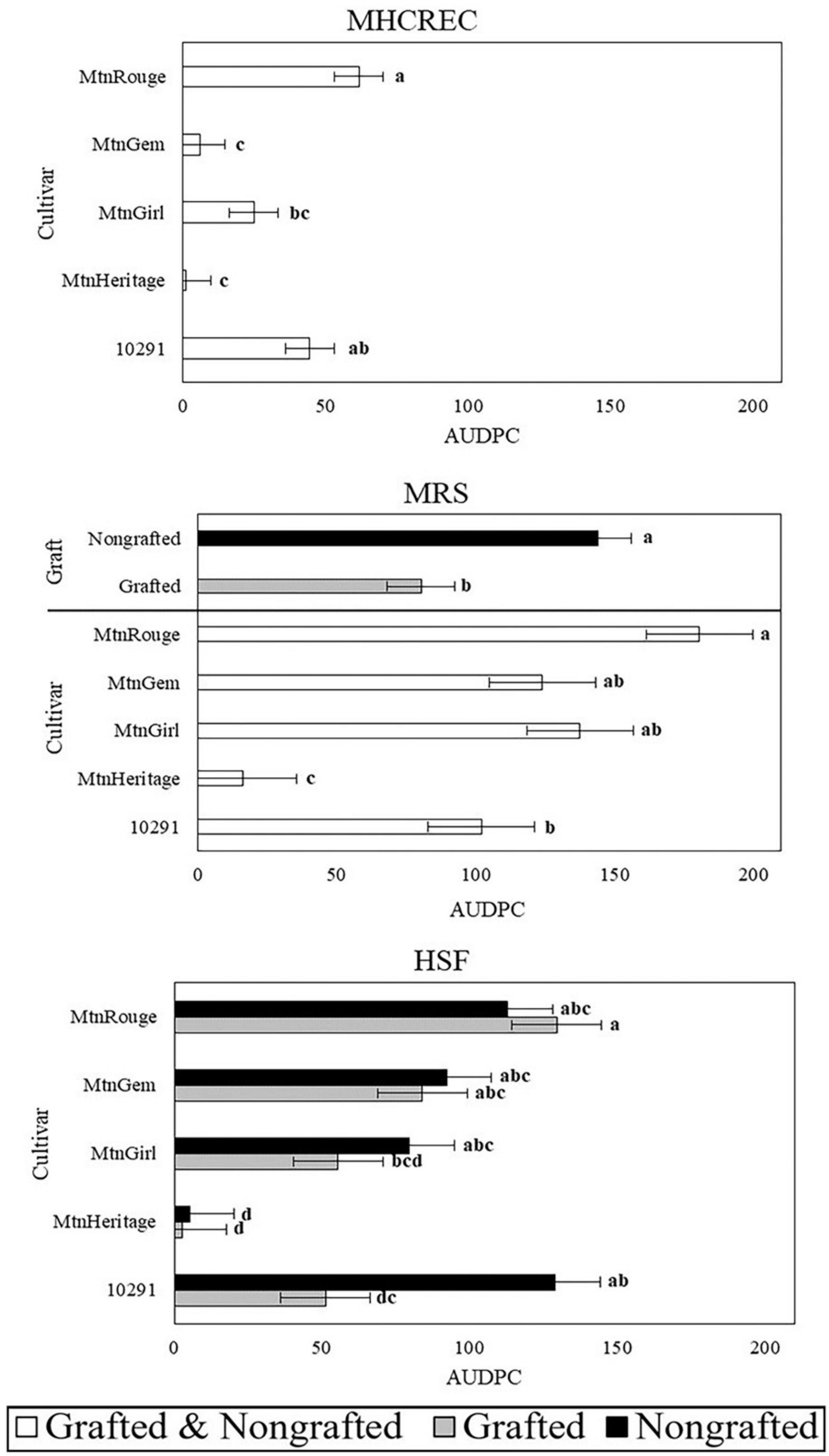


Fig. 3. Area under the disease progress curve (AUDPC) for Verticillium wilt (*Verticillium dahliae* Kleb., *Verticillium albo-atrum* Reinke & Berthold) on five cultivars of tomato, grafted (onto rootstock 'Maxifort') or nongrafted, at three locations in western North Carolina in 2019. HSF = Holly Spring Farm (Mills River, NC, USA); MHCREC = Mountain Horticultural Crops Research and Extension Center (Mills River, NC, USA); MRS = Mountain Research Station (Waynesville, NC, USA); MtnGem = 'Mountain Gem', MtnGirl = 'Mountain Girl', MtnHeritage = 'Mountain Heritage', MtnRouge = 'Mountain Rouge'. Standard error of the mean included for each location. Letters following bars indicate grouping according to Tukey's honestly significant difference multiple comparison ($P < 0.05$).

1-acre field of nongrafted transplants in 2021. This is a substantial investment, further emphasizing the importance of small-scale on-farm evaluations.

Grafting onto 'Maxifort' rootstock did increase yield at two of the three locations, which suggests an increase in plant vigor conferred by this rootstock. Other studies have shown that the effect of grafting onto 'Maxifort' or other rootstocks known to be vigorous, such as 'Beaufort', have the potential to increase yield of determinate cultivars (Ingram et al. 2021, 2022; Kumar et al. 2015; Masterson et al. 2016), but to realize yield increases with indeterminate cultivars may require additional harvests.

The cultivars selected in our study are known to have resistance to late blight of tomato, and no symptoms of late blight were observed on any of the plants or fruit despite susceptible cultivars displaying symptoms on the same farms. Resistance to late blight on tomato is important in regions such as western North Carolina, where late blight occurs each year, small-acreage farms are common, and pesticides are typically applied irregularly or on a reduced schedule (Shoemaker P, personal communications).

Although evaluation of Verticillium wilt on grafted and nongrafted tomato cultivars was unplanned, the occurrence of this disease provided a unique opportunity to identify potential cultivars or rootstocks for resistance. Verticillium wilt of tomato occurs primarily in the western part of the state (Louws et al. 2010). Planting cultivars with resistance to race 1 of this pathogen has led to selection for nonrace 1 strains (Bender and Shoemaker 1984; Ingram et al. 2020). Recent efforts have characterized these nonrace 1 strains into races 2 and 3 (nonrace 2), with race 3 most prevalent in North Carolina (Ingram et al. 2020; Usami et al. 2017). Tomato breeders are working to develop cultivars with resistance to these populations. Because 'Mountain Heritage' consistently showed few symptoms of Verticillium wilt in our study, this cultivar may be a good candidate to evaluate as a rootstock or nongrafted plant for production in fields with high Verticillium wilt pressure.

Our study compared yield differences among four indeterminate cultivars and one determinate cultivar, Mountain Gem, across three locations. Plants were planted late to increase the chance of greater disease pressure caused by the late blight pathogen; however, this resulted in a limited number of harvests that were able to be conducted. A grower would likely not plant indeterminate cultivars late in the season because cool temperatures and frost could limit the potential for an extended harvest. We harvested four times at two locations and six times at one location as a result of the onset of nighttime frost. It is likely that we captured almost all the fruit from the determinate cultivar, but the indeterminate cultivars were likely to continue to produce fruit where they were harvested only four times. Therefore, we may not have captured the full yield potential of the indeterminate cultivars at these locations, and this may be where the benefit of grafting is realized.

Small-scale tomato farmers in western North Carolina may benefit from using vigorous rootstocks on some specialty tomato cultivars, but how and why these benefits are seen are unclear, although they may be dependent on location and cropping history. We

Table 2. Average daily minimum and maximum temperatures and monthly precipitation totals for two on-farm locations (Mills River, NC, USA; and Waynesville, NC, USA) during the 2019 growing season.

| Location[i] | Month | Avg minimum daily temperature (°C)[ii] | Avg maximum daily temp (°C)[ii] | Total precipitation (cm)[iii] |
|---|---|---|---|---|
| MHCREC | July | 17.5 | 29.5 | 10.8 |
| MHCREC | August | 16.6 | 28.6 | 7.8 |
| MHCREC | September | 14.7 | 29.6 | 2.0 |
| MHCREC | October | 9.0 | 21.5 | 19.0 |
| MRS | July | 16.1 | 27.9 | 9.2 |
| MRS | August | 15.4 | 27.8 | 7.7 |
| MRS | September | 13.6 | 28.1 | 3.2 |
| MRS | October | 7.9 | 21.3 | 15.8 |

[i] MHCREC = Mountain Horticultural Crops Research and Extension Center (Mills River, NC, USA); MRS = Mountain Research Station (Waynesville, NC, USA).
[ii] Average minimum and maximum daily temperature retrieved from the North Carolina State Climate Office Cardinal Date Retrieval System (Raleigh, NC, USA).
[iii] Total precipitation (cm) retrieved from North Carolina State Climate Office Cardinal Date Retrieval System (Raleigh, NC, USA).

encourage growers to consult with extension workers in their region to design small-scale on-farm evaluations to maximize yield potentials using grafted tomatoes on their farms.

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