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Nitrogen Fertilization and Grafting of Tomato Under High-Tunnel Production in Northern Nevada

By Maria-Sole Bonarota and Felipe Barrios-Masias (Agriculture, Veterinary & Rangeland Sciences), Jill Moe (Desert Farming Initiative), and Heidi Kratsch (University of Nevada, Reno Extension)

Summary

We studied the effects of high and low nitrogen fertilization on grafted and ungrafted tomatoes under high tunnels at three sites in northern Nevada. Yield responses were site-specific and influenced by historical soil conditions at each site prior to nitrogen additions. We found that grafting has the potential to increase tomato crop productivity in northern Nevada by as much as 62%, especially when soil nitrogen availability is not optimal. Farmers using organic methods should time fertilization considering soil temperatures that favor soil microbial decomposition to make sure nitrogen is available during tomato peak demand.

Introduction

Tomato is the main vegetable crop grown under protected environments such as high tunnels in northern Nevada, where it is an important cash crop for direct market. In the challenging environment of the Great Basin High Desert, tomato high tunnel production can extend the harvest season, maximize yields and improve fruit quality (DiGiacomo et al., 2023). Currently, tomato harvested area in northern Nevada is estimated at 15,278 square feet and accounts for $118,000 in annual sales (U.S. Department of Agriculture, 2017). Appropriate nitrogen (N) fertilization can increase tomato productivity by up to 60% and improve the nutritional quality of the fruit (Cheng et al., 2021). High-tunnel vegetable production is intense, as two or more crops per year are planted, resulting in higher plant nutrient demand and the need to better manage soil nutrient availability. In addition, Nevada farmers are seeking alternative methods to build healthy soils while minimizing the use of chemical fertilizers. Yet, it is unclear how N fertilizer level and source may impact crop performance under local soil conditions. Tomato is a heavy N feeder, and its maximal N uptake can reach 400 mg to 500 mg N per square meter per day (1.31 ounces to 1.64 ounces per 1,000 square feet; Jackson and Bloom, 1990). A better estimate of the N requirements for high tunnel tomato production can help farmers adjust fertilization practices to maximize productivity. Moreover, use of grafted tomatoes can improve crop N utilization (Djidonou et al., 2013) and leaf nutrient profile (Bristow et al., 2021) under conditions of low N availability, and some small farms in Nevada have been adopting this technique.

The goals of our study were to:

1. Determine whether grafting tomatoes could result in improved uptake of N, thus improving tomato yield, by using one optimal and one suboptimal level of N fertilizer; and

2. Test the performance of a novel graft rootstock against that of a commercial rootstock, in terms of N uptake and tomato yield.

Materials and Methods

Three trials were performed, one in each of three locations in northern Nevada:

1. Lattin Farms, Fallon (Fallon) in 2022
2. Main Station Field Lab (MSFL) at the University, Reno in 2022
3. Desert Farming Initiative (DFI) at the University, Reno in 2023

In each trial, two tomato (*Solanum lycopersicum*) rootstocks (one commercial rootstock and one novel rootstock) grafted with the scion of tomato cultivar BHN-589 were compared to the ungrafted BHN-589 as a control. The commercial rootstock Beaufort was used in 2022 at both Fallon and MSFL, but Beaufort seed was not available in 2023, so we substituted Maxifort rootstock for Beaufort in the 2023 trial at DFI. Both Maxifort and Beaufort rootstocks are from the same seed company and have similar characteristics (Gioia et al., 2010; Mohamed et al., 2012); they were chosen for their vigor and root system architecture (Bristow et al., 2021; Suchoff et al., 2017). A second comparative rootstock 'OH-SG18-197' was used in all locations. This rootstock was a selection from a cross between the processing tomato variety from Ohio 'OH8245' (Berry et al., 1991) and a wild relative (*S. galapagense* 'LA1141') and has the potential to confer abiotic stress tolerance (more detail in Fenstemaker et al., 2022). The commercial tomato cultivar BHN-589 was selected for use as the scion for grafting based on its performance in research trials at the University and because it is grown by local growers (Bonarota et al., 2021; Bristow et al., 2021).

In 2022, seedlings and grafted plants were prepared by Plug Connections (Vista, Calif.). In 2023, all grafted and ungrafted plants were prepared at the University's Valley Road Greenhouse Experiment Station. Grafted plants were healed in Conviron growth chambers (Winnipeg, Canada) at a relative humidity of 98% and no light for 24 hours. The relative humidity was gradually decreased to ensure a successful acclimation to open-air low humidity of 50% or less. Air temperature was maintained at 28 C.

In all trials, the plants were transplanted into high tunnels the last week of May, with 17-inch spacing between plants. The N fertilization was performed in the first eight weeks after transplanting, and the total N amount was equally split in three applications. Urea (46-0-0 of N-P-K) was used as the N source at MSFL and Fallon (conventional management), while a mixture of blood meal (13-0-0 of N-P-K) and feather meal (13-0-0 of N-P-K) at a ratio of 4:6, respectively, was used at the DFI (organic management). The form of the added N (conventional versus organic) was determined according to the farmer's needs, and the amount of added N was determined in response to the soil N analysis (nitrate, ammonium and organic matter) previous to transplanting and treatment level (low N versus high N) (Table 1).

Table 1. Soil N, in the form of nitrate, ammonium and organic N, and the organic matter content under high tunnels in three locations (DFI, Fallon and MSFL) in northern Nevada (pretreatment) and the added N as treatment (N- and N+).

Location	**DFI**		**Fallon**		**MSFL**	
Production method	Organic		Conventional		Conventional	
Soil depth (in.)	0 to 8	8 to 16	0 to 8	8 to 16	0 to 8	8 to 16
Nitrate (ppm)	10.2	3.8	22.0	9.0	22.5	19.5
Ammonium (ppm)	13.1	6.0	26.0	5.0	5.1	3.9
Organic N (lb/acre)	50	40	120	50	120	60
Organic matter (%)	2.5	1.8	4.2	1.2	2.7	2.5
Treatment	**Added N in the soil (lb/acre)**					
Low N (N-)	67		67		0	
High N (N+)	134		134		67	

Across the three locations, two treatments were applied: (1) a suboptimal N fertilization of 67 pounds per acre at Fallon and DFI and no N addition at MSFL (referred to as N-) and (2) optimal N fertilization of 134 pounds per acre at Fallon and DFI and 67 pounds per acre at MSFL (referred to as N+). Both Fallon and the MSFL high tunnels had been previously managed under organic practices; MSFL was not cultivated for two years prior to this trial.

The experiments were conducted in a randomized complete block design with a split-plot structure. The main plot was N treatment (N+ or N-), and within each, three consecutive subplots (one per rootstock) were randomly assigned. Each subplot contained four plants in DFI, five plants in Fallon and six plants in MSFL, with each subplot having the same type of grafted or ungrafted plants. Treatments (i.e., plots) were replicated six times in Fallon and four times in MSFL and DFI. A total of three plants were added as buffers between the N treatments to avoid affecting the contiguous plot under a different N treatment.

The measurements were taken from the middle two plants in each plot. To study the capacity of the rootstock and the N input to induce plant growth and to increase tomato productivity, total plant dry weight (biomass accumulation) and yield were measured. In order to study the capacity of the rootstock and the N input to influence the amount of N in the leaf, leaf N content was measured using a Micromass Isoprime stable isotope ratio mass spectrometer (Isotopx, N.M., United States) at the University's Stable Isotope Lab. Higher N in the leaf correlates with higher photosynthetic capacity (Nakano et al., 1997) and higher biomass accumulation. As the analysis for leaf N is an expensive procedure, the relative amount of chlorophyll in leaves, an inexpensive and indirect measure of N, was measured (SPAD meter; Debaeke et al., 2006) using the PhotosynQ MultispeQ V1.0 (Kuhlgert et al., 2016). Mixed-effects analysis of variance (ANOVA) followed by unrestricted least discriminant analysis (Bristow et al., 2021) was performed to understand the effect of phenotype (plant type as affected by grafting and rootstock) and N treatment. Statistical analysis was done separately for each individual location on each parameter (R Core Team, 2021). Since there was interaction between location and treatment, the results will be discussed separately for each location.

Results

Fruit yield of marketable tomatoes was affected mainly by plant phenotype (rootstock-scion combination or ungrafted cultivar) and only marginally by N treatment levels in the grafted plants at DFI, with the commercial graft exhibiting greater overall yield (Fig. 1). Fruit yield was not influenced by plant phenotype nor by the level of N fertilization at Fallon and MSFL. At DFI, use of the commercial rootstock improved yield by 62% compared to the novel graft (OH-SG18-197) and the ungrafted cultivar (BHN-589). Across all three sites, the average yield was 5 pounds per plant in the low N treatment, 5.2 pounds in the high N treatment, 4.6 pounds for the novel rootstock, 4.8 pounds for the ungrafted cultivar, and 5.9 pounds for the commercial rootstock.

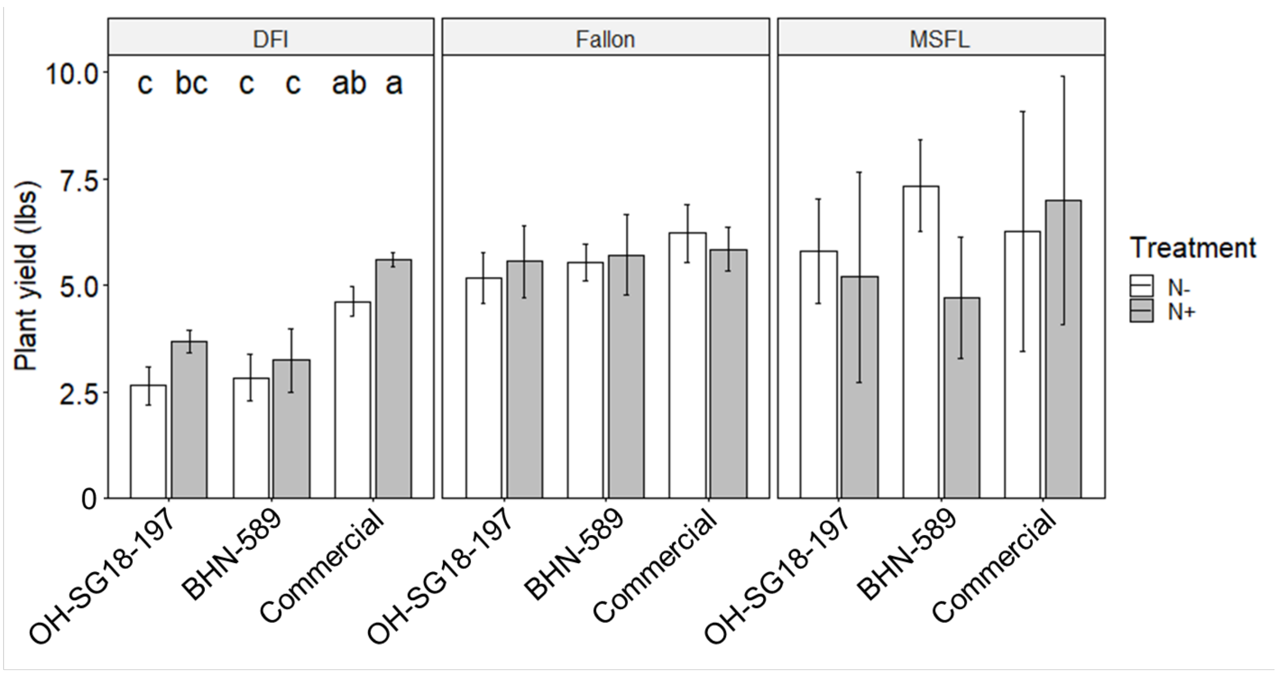

Figure 1. Total fruit yield per plant in the ungrafted tomato cultivar BHN-589 and BHN-589 grafted onto one of two rootstocks (OH-SG18-197 or commercial rootstock) in three locations in northern Nevada (DFI, Fallon, and MSFL) under high-tunnel production. Different letters above the bars indicate statistically different means within location among plant phenotypes and N treatments (p-value < 0.05). Lack of letters above bars indicates no significant difference among means at that site (data analyzed within location and graphs modified from Bonarota and Barrios-Masias, 2024).

At DFI, biomass accumulation of tomato plants, as measured by shoot dry weight, was unaffected by plant phenotype (Fig. 2). Only the ungrafted cultivar (BHN-589) at DFI showed increased shoot biomass accumulation in response to higher N fertilization, while grafted plants at DFI showed only a marginal response to increased N. In Fallon, the ungrafted cultivar (BHN-589) and the commercial graft were only marginally affected by N application; the novel graft (OH-SG18-197) was unaffected by the level of N fertilization. Shoot dry weight was not influenced by plant phenotype nor by the level of N fertilization at MSFL.

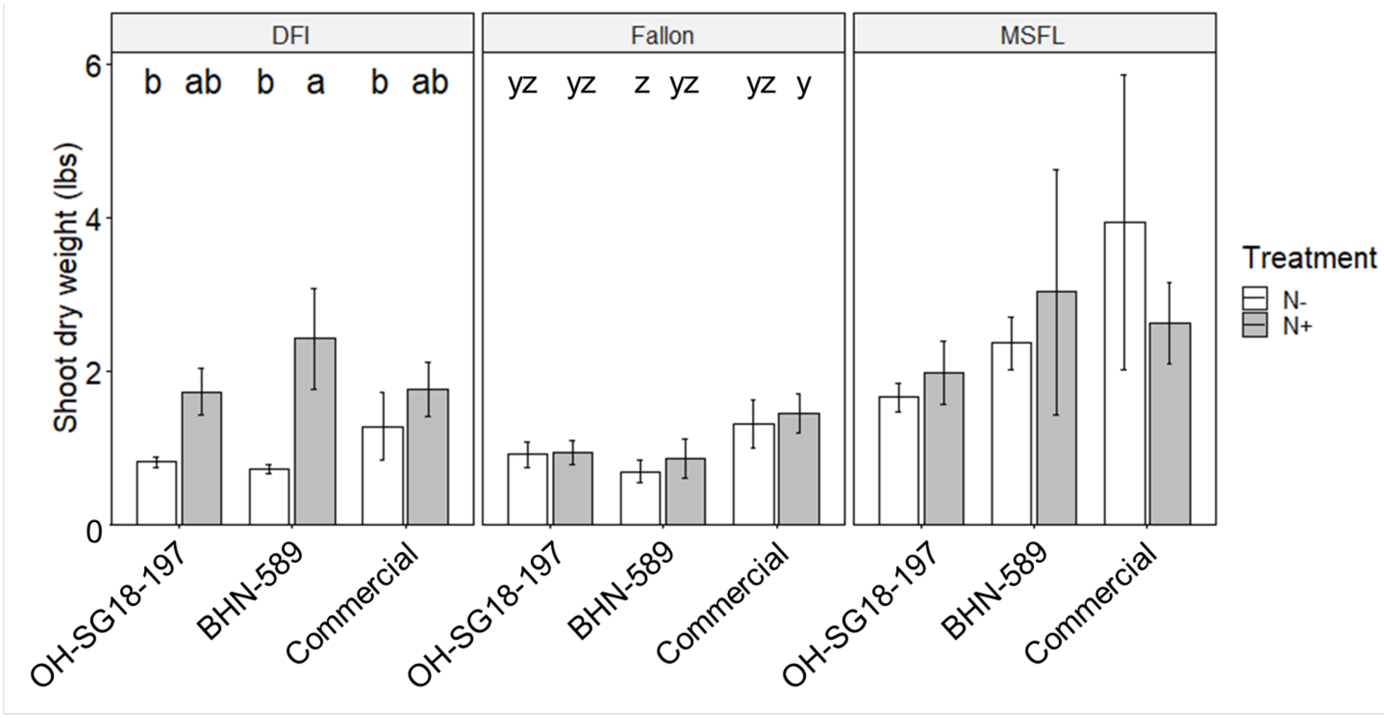

Figure 2. Shoot dry weight of the ungrafted tomato cultivar BHN-589 and BHN-589 grafted onto one of two rootstocks (OH-SG18-197 or commercial rootstock) at the end of the harvest season in three locations in northern Nevada (DFI, Fallon and MSFL) under high-tunnel production. Different letters above bars indicate statistically different means within location among plant phenotypes and N treatments (p-value < 0.05). Lack of letters above bars indicates no significant difference among means at that site (data analyzed within location and graphs modified from Bonarota and Barrios-Masias, 2024).

Leaf N content was significantly affected by N treatment in grafted plants in Fallon; whereas, the leaf N content in the ungrafted cultivar (BHN-589) was only marginally affected by N fertilization level at that site (Fig. 3). At DFI, the ungrafted cultivar had a marginally greater leaf N content due to increased N fertilization, and the commercial rootstock had the highest leaf N content among plant phenotypes, regardless of the N treatment. At MSFL, leaf N content was high regardless of N treatment or plant phenotype.

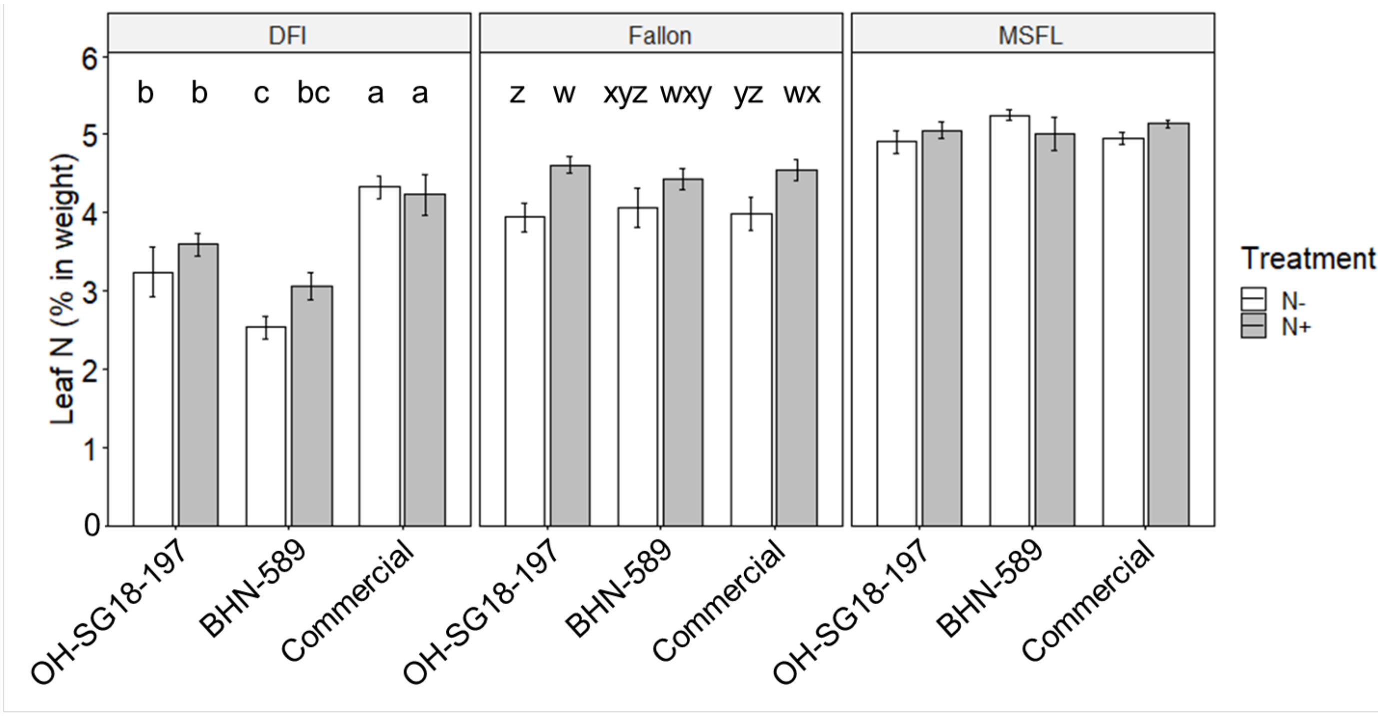

Figure 3. Leaf N content expressed in percent of dry weight in the ungrafted tomato commercial cultivar BHN-589 and BHN-589 grafted onto two rootstocks (OH-SG18-197 and commercial rootstock) at week 13 from transplanting in three locations in northern Nevada (DFI, Fallon and MSFL) under high-tunnel production. Different letters above bars indicate statistically different means within location among plant phenotypes and N treatments (p-value < 0.05). Lack of letters above bars indicates no significant difference among means at that site (data analyzed within location and graphs modified from Bonarota and Barrios-Masias, 2024).

SPAD value is an indirect measure of N content in leaves. SPAD values were significantly higher under N+ fertilization in Fallon, regardless of plant phenotype (Fig. 4). At DFI, SPAD values were significantly greater only under N+ fertilization in the ungrafted cultivar (BHN-589). SPAD values were not affected by plant phenotype nor by N treatment at MSFL.

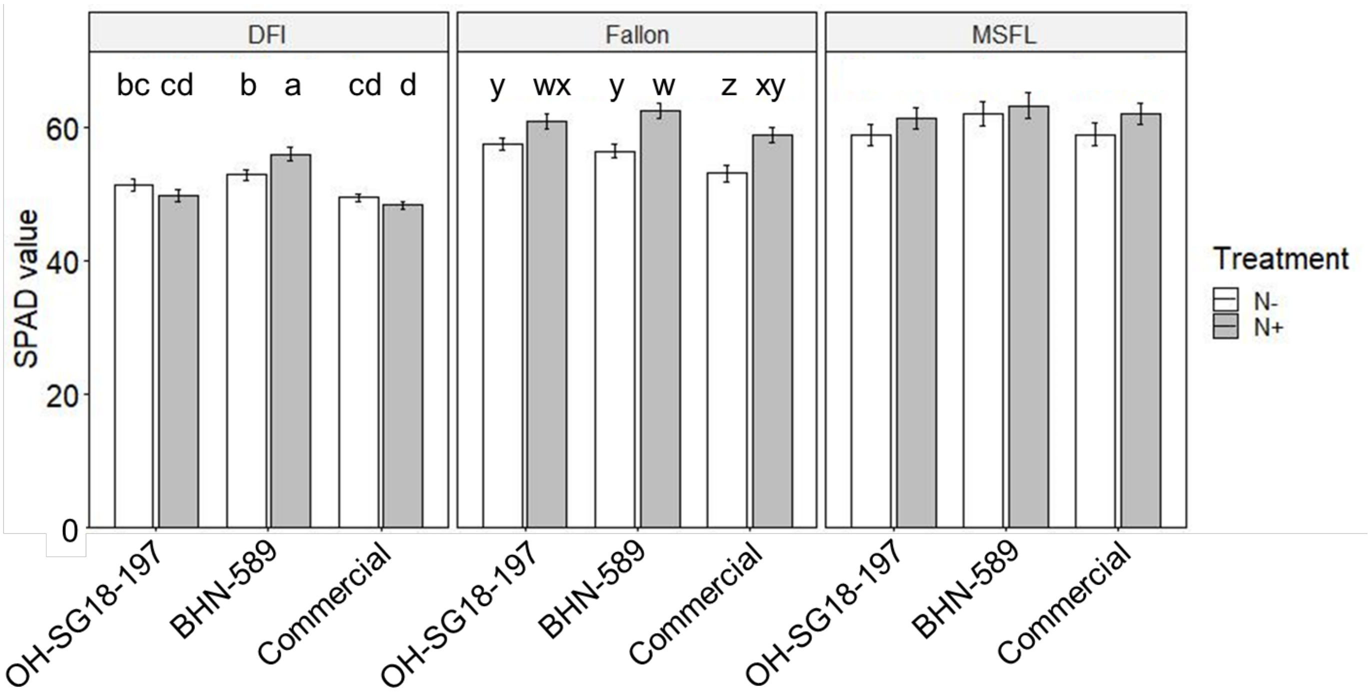

Figure 4. SPAD value in the ungrafted tomato cultivar BHN-589 and BHN-589 grafted onto two rootstocks (OH-SG18-197 and commercial rootstock) from week 12 to week 16 from transplanting in three locations in northern Nevada (DFI, Fallon and MSFL) under high-tunnel production. Different letters indicate statistically different means within location among plant phenotypes and N treatments (p-value < 0.05). Lack of letters indicates no significant differences at that site.

Discussion

Whereas N fertilization at the beginning of the crop establishment has been shown to have low impact in several locations in northern Nevada high-tunnel tomato production (Bonarota and Barrios-Masias, 2024), here we emphasize results per location and aim to clarify the soil-crop N dynamics under different management to support farmers in making informed choices on N fertilization. Our study showed that the effects of plant phenotype and N fertilization on plant growth and yield parameters under high-tunnel production were dependent on trial location; use of grafted tomato plants did not provide a consistent advantage across all three locations where the trials were conducted. Despite these challenges, we found that tomato yield was significantly improved by use of a commercial grafted rootstock at DFI, even when our fertilization treatment was suboptimal (N-) (Fig. 1). DFI was the only site where organic production methods were used during the trial period. Organic production requires use of organic sources of N, which must be decomposed by soil microbes before the N becomes available to plants. Organic production methods improve soil health and reduce pesticide and fertilizer contamination of groundwater. Use of grafted tomatoes during organic production in Nevada has the potential to increase tomato crop yield and meet the growing demand for local, organic produce in the state (Kratsch et al., 2023).

Effect of the pretreatment soil N

Fallon and MSFL had higher initial soil N compared to DFI, and this difference was observed in higher SPAD and leaf N content and yields. SPAD values are influenced by environment and cultivar, and they may not be a good predictor for N management (e.g., Bonarota and Barrios-Masias, 2024). When nitrate to ammonium ratio is 50:50 (as in DFI and Fallon), tomato tends to have lower yield compared to when the ratio is higher (i.e., 75-25) (Hartman et al., 1986; Liu et al., 2017), which can be affected by the type of amendments used. Yet, the higher initial organic and inorganic N in Fallon compared to DFI supported better yields. At DFI, only the commercial rootstock performed well under both optimal and suboptimal N treatments (e.g., similar yield, biomass and leaf N). This highlights the importance of rootstocks in providing a root system capable of scavenging nutrients in soils where N availability is low, and it suggests that soil management and nutrient amendments should be tightly coupled to plant nutrient demands (Bowles et al., 2015).

Soil N availability to plants

For plants to be able to take up N from the organic fertilizers used at DFI, the amendments had to be mineralized to ammonium and nitrate, which are forms of inorganic N more readily available for plant uptake. During organic matter breakdown and mineralization, which is a microbial-driven process, soil microbes can also compete for N, especially if soil organic matter has a high C to N ratio (e.g., wood chips) (Burger and Jackson, 2003). Under this situation, soil microbes can immobilize N and reduce availability for plant uptake (Jackson et al., 2008). In addition, N mineralization is facilitated by environmental conditions, and temperature is an important factor in the mineralization rate. For instance, when the temperature is <60 F, it takes four more weeks to mineralize the same amount of fertilizer compared to when the temperature is between 68 F and 77 F (Hartz and Johnstone, 2006). This is important in northern Nevada, because soil temperature warm-up lags behind air temperatures, even when the average air temperature in June is >57 F (Bristow et al., 2019). In this study, the fertilizer was applied at DFI (June 2023) when air temperatures were between 50 F and 79 F. Lower soil temperatures can also reduce plant establishment and root growth (Bristow et al., 2021), which can reduce overall nutrient uptake at the vegetative stage and result in overall lower yields.

At MSFL, the two years of noncultivation, which is not representative of vegetable production in these systems, may have increased N mineralization, even under high tunnels (see Table 1). Over the long-term, soil N and organic matter under those conditions would be expected to decrease if the soil were not actively cultivated or replenished with organic matter. MSFL has overall better soil quality (soil type: Truckee silt loam and classified as prime farmland) and historically has been used for forage production and grazing, which has helped maintain higher organic matter and soil N levels.

Considerations on rootstocks and tomato management to enhance productivity

Identification of cultivars or rootstocks that can improve early root growth under suboptimal soil temperatures can enhance productivity under low-input environments. The present study and Bristow et al. (2021) used the same tomato cultivar (scion), which corroborates the positive effects of some commercial rootstocks on yield in northern Nevada. Evaluation of the effects of grafting on other cultivars is warranted. Although we did not evaluate how canopy management such as trellising and pruning affects tomato yield, this also could have impacted tomato response to N fertilization and productivity. At DFI, plants were trained in a two-leader trellising system from two weeks after transplanting, and pruning of lateral branches was conducted weekly, starting three weeks after transplanting. Pruning can inhibit plant growth when branches are cut to less than 2 inches in length from the main stem (Xu et al., 2020), and this warrants further evaluation to understand whether, under the short growing season of the high desert, pruning may negatively affect plant performance and yield.

Conclusions

Our study highlights how soil management and root systems (rootstocks) can influence the response of the same cultivar (scion) to different N fertilization levels. If the soil has low N availability, as was observed at DFI, we recommend use of a rootstock with the capacity to scavenge nutrients, for example a vigorous rootstock such as Maxifort. As many farms in northern Nevada adopt practices to enhance soil health over the long term, such as cover cropping and addition of compost and manure, short-term N fertilization with a readily available N source is advised to prevent N deficiency and slow canopy growth. Although the novel rootstock (OH-SG18-197) that was tested for the first time in this study was not as competitive as the commercial rootstock, OH-SG18-197 had comparable performance to the ungrafted BHN-589 and could be used in further studies under more extreme abiotic stress, such as high soil salinity conditions.

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References

Berry, S. Z., Gould, W. A., Wiese, K. L. (1991). ‘Ohio 8245’ processing tomato. HortScience, 26(8), 1093–1093.

Bonarota, M. S., Barrios-Masias, F. H. (2024). Low impact of nitrogen fertilization on grafted tomatoes under high-tunnel production. HortTechnology, 34(6), 761-763.

Bonarota, M. S., Barrios-Masias, F. H., Singletary, L. (2021). Combatting salinity: evaluation of tomato rootstocks under mild and severe salt stress, Extension, University of Nevada, Reno FS-21-08.

Bowles, T. M., Hollander, A. D., Steenwerth, K., Jackson, L. E. (2015). Tightly-coupled plant-soil nitrogen cycling: comparison of organic farms across an agricultural landscape. PloS one, 10(6), e0131888.

Bristow, S. T., Hernandez, L., Barrios-Masias, F. H. (2019). Tomato rootstocks contribute to abiotic stress tolerance: emphasis on root chill tolerance. In II International Symposium on Vegetable Grafting 1302 (pp. 193-200).

Bristow, S. T., Hernandez-Espinoza, L. H., Bonarota, M. S., Barrios-Masias, F. H. (2021). Tomato rootstocks mediate plant-water relations and leaf nutrient profiles of a common scion under suboptimal soil temperatures. Frontiers in Plant Science, 11, 618488.

Burger, M., Jackson, L. E. (2003). Microbial immobilization of ammonium and nitrate in relation to ammonification and nitrification rates in organic and conventional cropping systems. Soil Biology and Biochemistry, 35(1), 29-36.

Cheng, M., Wang, H., Fan, J., Xiang, Y., Tang, Z., Pei, S., Zeng, H., Zhang, C., Dai, Y., Li, Z., Zou, Y., Zhang, F. (2021). Effects of nitrogen supply on tomato yield, water use efficiency and fruit quality: a global meta-analysis. Scientia Horticulturae, 290, 110553.

Debaeke, P., Rouet, P., Justes, E. (2006). Relationship between the normalized SPAD index and the nitrogen nutrition index: application to durum wheat. Journal of Plant Nutrition, 29(1), 75-92.

DiGiacomo, G., Gieske, M., Grossman, J., Jacobsen, K., Peterson, H., Rivard, C. (2023). Economic trade-offs: analysis of hairy vetch (*Vicia villosa*) cover crop use in organic tomato (*Solanum lycopersicum* L.) high tunnel systems across multiple regions. Renewable Agriculture and Food Systems, 38, e10.

Djidonou, D., Zhao, X., Simonne, E. H., Koch, K. E., & Erickson, J. E. (2013). Yield, water-, and nitrogen-use efficiency in field-grown, grafted tomatoes. HortScience, 48(4), 485-492.

Fenstemaker, S., Sim, L., Cooperstone, J., Francis, D. (2022). *Solanum galapagense*-derived purple tomato fruit color is conferred by novel alleles of the anthocyanin fruit and *atroviolacium* loci. Plant Direct 6(4), e394.

Gioia, F. D., Serio, F., Buttaro, D., Ayala, O., Santamaria, P. (2010). Influence of rootstock on vegetative growth, fruit yield and quality in ‘Cuore di Bue’, an heirloom tomato. The Journal of Horticultural Science and Biotechnology, 85(6), 477-482.

Hartman, P. L., Mills, H. A., Jones, J. B. (1986). The influence of nitrate: ammonium ratios on growth, fruit development, and element concentration in ‘Floradel’ tomato plants. Journal of the American Society for Horticultural Science, 111(4), 487-490.

Hartz, T. K., Johnstone, P. R. (2006). Nitrogen availability from high-nitrogen-containing organic fertilizers. HortTechnology, 16(1), 39-42.

Kratsch, H. A., Barrios-Masias, F., Poudel-Ward, B. (2023). Enhancing production of warm-season crops in Nevada using rootstocks: A grower survey. University of Nevada, Reno Extension Special Publication 23-01.

Kuhlgert, S., Austic, G., Zegarac, R., Osei-Bonsu, I., Hoh, D., Chilvers, M. I., Roth, m. G., Bi, K., terAvest, D., Weebadde, P., Kramer, D. M. (2016). MultispeQ Beta: a tool for large-scale plant phenotyping connected to the open PhotosynQ network. Royal Society Open Science, 3(10), 160592.

Jackson, L. E., Bloom, A. J. (1990). Root distribution in relation to soil nitrogen availability in field-grown tomatoes. Plant and Soil, 128, 115-126.

Jackson, L. E., Burger, M., Cavagnaro, T. R. (2008). Roots, nitrogen transformations, and ecosystem services. Annual Review of Plant Biology, 59, 341-363.

Liu, G., Du, Q., Li, J. (2017). Interactive effects of nitrate-ammonium ratios and temperatures on growth, photosynthesis, and nitrogen metabolism of tomato seedlings. Scientia Horticulturae, 214, 41-50.

Mohamed, F. M., Wasfy, M., Elwan, M., El-Sayed, K., El-Hamed, A., Hussien, M. A. N. (2012). Comparative growth, yield and fruit quality of grafted and non-grafted cherry tomato plants under protected cultivation. Agricultural Research Journal, 12, 21-29.

Nakano, H., Makino, A., Mae, T. (1997). The effect of elevated partial pressures of CO_2 on the relationship between photosynthetic capacity and N content in rice leaves. Plant Physiology, 115(1), 191-198.

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Suchoff, D. H., Gunter, C. C., Louws, F. J. (2017). Comparative analysis of root system morphology in tomato rootstocks. HortTechnology, 27(3), 319-324.

U.S. Department of Agriculture. 2017. “United States 2017 Census of Agriculture.” Washington, DC: U.S. Department of Agriculture, National Agriculture Statistics Service. Available online: https://www.nass.usda.gov/AgCensus/.

Xu, Y., Liu, X., Shi, Q., Cheng, F., Zhang, L., Shao, C., Gong, B. (2020). Pruning length of lateral branches affects tomato growth and yields in relation to auxin-cytokinin crosstalk. Plant Growth Regulation, 92(1), 1-13.

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