PROJECT REPORT

This is a final project report submitted
to the Organic Farming Research Foundation.

Project Title:

Grafting tomatoes on disease resistant rootstocks for small-scale organic production

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Summary

Herbaceous grafting is a site-specific management tool that can be tailored to the challenges of individual production systems using rootstock and scion selections. The objectives of this study were to investigate the use of grafting to enhance organic field production of tomatoes at Black River Organic Farm in North Carolina. At this farm, high disease pressure from bacterial wilt (caused by *Ralstonia solanacearum*) has resulted in the grower abandoning open-field fresh-market tomato production. Preliminary studies in 2007 indicated that 'Celebrity' scion grafted onto 'RST-04-105-T' (D. Palmer Seed Co., U.S.A) rootstock and 'Dai Honmei' (Asahi Seed Co., Japan) rootstock demonstrated complete and intermediate levels of resistance, respectively to bacterial wilt. In 2008, the study was duplicated and expanded to include two additional rootstocks and to assist the grower with propagating grafted transplants on-farm.

In 2008, we compared 'Celebrity' scion grafted onto four different rootstocks ('RST-04-105-T,' 'Dai Honmei,' 'BWR,' and 'Sweet Olive') compared to non-grafted and self-grafted (scion grafted back onto itself) controls. In 2008, soilborne disease pressure was very high as anticipated, but southern blight, caused by *Sclerotium rolfsii*, was the dominant disease rather than bacterial wilt. The rootstocks utilized in this study were selected for resistance to bacterial wilt but also demonstrated a range of resistance to southern blight. 'Celebrity'- 'RST-04-105-T' grafts had the lowest incidence of southern blight, and Area Under the Disease Progress Curve (AUDPC) values were significantly lower among the three rootstocks than the self-grafted and non-grafted controls. Grafting effects on leaf nutrient concentrations did not indicate greater nutrient uptake ability of grafted treatments although there were significant differences among

treatments for selected nutrients including phosphorus (P), potassium (K), magnesium (Mg), zinc (Zn), copper (Cu), and boron (B).

The greatest total fruit yields were achieved with 'Celebrity–RST-04-105-T' grafts (19.5 T/A), followed by 'Celebrity–BWR' grafts (14.4 T/A), 'Celebrity-Dai Honmei' grafts (13.9 T/A), 'Celebrity-Sweet Olive' grafts (6.7 T/A), 'Celebrity' non-grafted (5.4 T/A), and 'Celebrity' self-grafted (4.6 T/A). A cost and benefit analysis based on variable costs of grafted transplant production at the 1-acre scale, estimated $2,275 of additional transplant costs when grafted plants were utilized. The per acre net returns of the top yielding scion-rootstock combination, 'Celebrity-RST-04-105-T,' was $59,635. The non-grafted 'Celebrity' crop generated $8,780 per acre. Because the grafted plants were able to maintain production under severe soilborne disease pressure, this cost-benefit analysis reflects the ability of disease resistant rootstock to reduce the risk of pathogen outbreaks and therefore add to on-farm economic stability. Overall, the grower was very pleased with the results of this study and in 2009 continued to propagate and utilize grafted plants on-farm.

Introduction

Organic tomato production is a challenging endeavor in the Southeast due to weathered soil structure, high foliar and soilborne pathogen pressure, and mild winter temperatures. Grafting offers an innovative cultural practice that can be used to manage soilborne disease pressure, achieve greater fruit yields, and increase nutrient uptake efficiency. Grafting has been implemented as an Integrated Pest Management (IPM) tactic in commercial tomato production in Asia, the Mediterranean, and northern Africa (Kubota et al., 2008; Lee, 1994; Oda, 1995, 2002).

This trial was carried out at Black River Organic Farm located in Ivanhoe, North Carolina. Stefan Hartmann, the owner and farm manager of this 16-acre farm, grows a variety of vegetables and small fruits. He has been certified organic since 1989, currently by Quality Certification Services (QCS) based in Florida. Mr. Hartmann is a founding member of the organic marketing cooperative Eastern Carolina Organics and is a featured supplier to Whole Foods Markets in North Carolina. Currently the farm is not able to successfully produce field tomatoes due to heavy soilborne and foliar disease pressures and has resorted to greenhouse tomato production. The goal of this research project was to evaluate the use of tomato grafting in small-scale organic field production for: 1) soilborne disease resistance, 2) fruit yield and quality, and 3) nutrient uptake. Rootstocks were selected based on the dominant soilborne disease profiles. Scions were selected for market fruit preference and early maturation to manage foliar disease pressure.

The evaluation of grafted plant performance in a typical southeastern organic system can strengthen the ability of organic growers to expand and optimize their tomato production practices. Lessons learned from this trial will be applicable to many other small growers, who like Stefan Hartmann, stand to benefit from increased economic security and sustainability by being able to produce their own grafted transplants and to cultivate a profitable tomato crop in challenging growing environments.

Objectives

1) Evaluate disease resistance of commercial rootstock cultivars under organic production in naturally-infested soils.

2) Trial grafted transplant propagation at a small-scale organic farm greenhouse facility.

3) Observe crop productivity and nutrient uptake of grafted heirloom tomatoes in organic field production.

4) Assess the performance of a variety of rootstock/scion combinations in organic field production.

5) Develop cost and benefits analysis on small-scale on-farm grafting transplant production.

6) Develop and disseminate research-based knowledge regarding grafting that can be used by organic growers to successfully and profitably adopt this emerging technology into current growing practices.

Materials and Methods

The trial was located in a certified organic, open-field production system located at Black River Organic Farm. For the replicated research trial, rootstocks were selected to manage bacterial wilt (*Ralstonia solanacearum*), and the scion 'Celebrity' was selected by the grower according to market preferences (farmer's markets, CSA, and Co-op) and early maturation to manage foliar disease pressure. This trial was centrally-located on two rows within a ½-acre tomato block.

Transplant production. Seedlings for the research trial were grafted using the 'Japanese tube-grafting' method at NCSU Southeastern Plant Environment Laboratory (Rivard and Louws, 2006). Self-grafted plants were produced by grafting 'Celebrity' scion back onto its own root system. Self-grafts served as an experimental control for assessing the physical effect of grafting. The average grafting success rate was more than 95%. Once grafting and subsequent healing had taken place, all seedlings were transplanted into 4" pots and allowed to grow in the greenhouse for 10 days prior to planting in the field. Crop yield, disease incidence, and leaf tissue concentrations were recorded over the course of the growing season. A number of response variables were measured over the course of the growing season such as fruit weight, number of fruit, leaf nutrient concentration of the most recently mature leaf tissue (MRML), and disease incidence.

Additional grafted transplants were produced at Black River Organic Farm to determine the feasibility and economic costs associated with grafting tomatoes for a small-scale farming operation. Suzanne O'Connell and Cary Rivard assisted with grafting tutorials and constructing a small healing chamber (30" x 48") located inside the grower's propagation greenhouse. Approximately ~1000 grafted transplants were produced in three batches of ~400 plants with an overall success rate of 50%. The first batch was not successful due to a problem with the cool-mist humidifier. The second batch was highly successful. The third batch was not successful due to difficulties controlling higher than optimum temperatures within the healing chamber when ambient greenhouse temperatures rose above 90°F. Cultivars 'Celebrity,' 'Pink Beauty,' 'Taxi,' 'BHN 444,' and 'Jubilee' were grafted to the rootstock 'RST-04-105-T.' These seedlings were not included in the formal research trial but were planted by the grower and observed over the course of the growing season.

Experimental Design. The study was a randomized complete block design with 7 plants in each plot and 4 replications. Six treatments were evaluated among 4 replications located within two 154'-long rows. Seedlings were transplanted into 21" in-row spacing on raised beds covered in plastic mulch. Drip irrigation was used. Lower leaves were pruned up to 'one leaf below the first fruit' and plants were trellised using the stake-and-weave system. Pre-plant fertilizers and soil amendments included: incorporated dwarf essex rape and crimson clover cover crop residue, feathermeal, sulfate of potash, NatureSafe pellets, and boron. Fruit was harvested over 7 weeks and fruit was graded according to on-farm standards. Fruit number and weight were recorded for marketable and non-marketable grades.

The six treatments were: 1) 'Celebrity' non-grafted controls, 2) 'Celebrity-Celebrity' self-grafted controls, 3) 'Celebrity- RST-04-105-T' grafts, 4) ''Celebrity-Dai Honmei' grafts, 5) 'Celebrity-BWR' grafts, and 6) 'Celebrity-Sweet Olive' grafts. Three of the 4 rootstocks ('RST-04-105-T,' 'BWR,' and 'Dai Honmei') are hybrids developed specifically for use as a tomato grafting rootstock. Both 'RST-04-105-T' and 'Dai Honmei' are commercially available as untreated seed. The DeRuiter line 'BWR' is an unreleased cultivar with bacterial wilt resistance that is under development. 'Sweet Olive' is a small-fruited grape tomato that has been grown at Black River Organic Farm. Previous experience by Mr. Hartmann indicated that it may confer intermediate resistance to bacterial wilt so it was included as a potential rootstock in 2008. A list of scion and rootstock selections with additional information is shown in Table 1.

Statistical Analysis. A linear model was used to compare grafting effects for non-repeated measures such as total cumulative yield and disease incidence (PROC GLM) (SAS Institute, Cary, NC). Repeated measures models were used to evaluate parameters measured over time (such as fruit yield and leaf nutrient concentrations) (PROC MIXED) (SAS Institute, Cary, NC). Linear hypotheses were used to test pairwise differences for fixed factors such as grafted versus non-grafted plants and 'RST-04-105-T' rootstock versus all other grafted treatments ('Estimate

Statements,' SAS Institute, Cary, NC). An alpha level of $P \leq 0.05$ was applied to all analyses along with the Tukey multiple comparison test for means separation.

Economic Analysis. A cost and benefit analysis based on variable costs of non-grafted and grafted organic tomato production at the 1-acre scale was developed using standardized equipment costs, organic practices, and regional labor rates for managerial and hourly staff. The estimated budget does not include fixed costs (i.e. greenhouse infrastructure, land, etc.). Grafted transplant production was estimated by inclusion of additional equipment, labor, seed costs, etc. associated with grafted transplant production. For both grafted and non-grafted plants, an 80% germination rate was assumed and, in the case of the grafted plants, grafting success was estimated at 90%. Seeds were sown into 512-cell seedling trays and transplanted into 50-cell trays before grafting and/or subsequent field planting. Grafting labor costs were estimated at 200 grafts/hour/person. A year-long production budget was developed that followed cultural practices, labor needs, and equipment costs typical of those utilized for organic open-field tomato production at Black River Organic Farm. Harvest returns were calculated based on gross market returns ($2.00/lb) minus harvesting costs (labor, boxes, transportation, and marketing) and used to deduce the net returns for the top performing grafting treatment 'Celebrity-RST-04-105-T' compared to the non-grafted 'Celebrity' control.

Results

Fruit Yield. The 'Celebrity- RST-04-105-T' grafts had the highest total fruit yield of all treatments although it was statistically similar to the 'Celebrity-BWR' and 'Celebrity-Dai Honmei' treatments ($P \leq 0.05$) (Fig. 1). The 'Celebrity- RST-04-105-T' grafts had statistically greater fruit yield than the 'Celebrity-Sweet Olive,' self-grafted, and non-grafted treatments ($P \leq 0.05$) (Fig. 1). During the last 3 weeks of the harvest period, the 'Celebrity- RST-04-105-T' grafts produced more fruit compared to 'Celebrity-Sweet Olive' grafts, non-grafted, and self-grafted controls ($P \leq 0.05$) (Fig. 2). Fruit number and size were affected significantly by grafting for total and marketable yield, but fruit marketability was not affected (Table 2).

Disease Incidence. Although high levels of bacterial wilt were seen in 2007, very few plants were diagnosed with this disease in 2008. The most prevalent soilborne disease in 2008 was southern blight (caused by *Sclerotium rolfsii*). A disease progress curve was plotted using disease incidence (# infected / total plants) (Fig. 3) and an 'Area Under the Disease Progress Curve' (AUDPC) was calculated (Fig. 4). The AUDPC calculation (Campbell and Madden, 1990) assesses the impact of the disease epidemic by multiplying the level of disease by time (% x time). Therefore, disease that occurs earlier in the season results in higher AUDPC values. Disease pressure at Black River Organic Farm was severe and 96-100% of the non- and self-grafted controls were killed by *S. rolfsii*. Furthermore, two weeks after first harvest >80% of the non- and self-grafted plants had been infected. The three rootstock-specific hybrids had lower southern blight incidence (54-64%) than the non- and self-grafted controls (Fig. 3) and the severity of the epidemic was significantly lower among these rootstock as indicated by the

AUDPC ($P \leq 0.05$) (Fig. 4). Early blight (caused by *Alternaria solani*) was also present but no treatment effects were observed.

Nutrient Uptake. Nutrient uptake for certain macro- and micro- nutrients have been reported to be higher in selected combinations of grafted plants (Ruiz et al., 1996: Leonardi and Giuffirda, 2006) as well as better able to tolerate more saline soils by preventing the translocation of Na^+ and Cl^- ions into the shoot (Estan et al., 2005). If grafted plants are able to take up more nutrients this could possibly lead to a fertilizer cost savings for the grower and/or increase plant productivity. Similarly, if grafted plants are able to limit the uptake of potentially toxic nutrients, such as Na, than grafted plants may be more tolerant to poor water or soil quality. The grafting effect on leaf nutrient concentrations in this trial did not indicate greater nutrient uptake ability for grafted plants compared to non-grafted, although significant differences among treatments for selected nutrients were present. Phosphorus (P), potassium (K), magnesium (Mg), zinc (Zn), copper (Cu), and boron (B) concentration in the leaf tissue demonstrated differences among treatments indicating that selection of scion-rootstock pairing may offer site-specific tools for nutrient management ($P \leq 0.05$) (Fig. 5, 6, & 7).

Economics. Grafted tomato transplants have higher associated variable costs compared to non-grafted transplants due to increased seed costs, grafting materials and labor, and the requirements of growing a rootstock and scion crop separately prior to grafting (Table 3). Overall, we estimate that grafted organic transplant production required $2,275 of additional investment. Once the tomato plants were in the ground, non-grafted and grafted production costs were equivalent (Table 4). At a selling price of $2.00/lb., the non-grafted 'Celebrity' plants generated a net profit of ~ $8,880 per acre compared to the top yielding scion-rootstock combination, 'Celebrity-RST-04-105-T' with ~$59,640 per acre (Table 5).

Conclusions/Discussion

The results of this study highlight several important factors related to grafting for small-scale organic tomato production. First, on-farm grafted tomato transplant production can be successful and the results of the economic analysis indicate that grafting tomatoes onto hybrid grafting rootstocks can increase on-farm net returns by approximately $50,000 when soilborne disease pressure is high. In this case-study, Mr. Hartmann faced particularly severe disease pressure from southern blight. The utilization of resistant rootstock enabled fruit production for seven weeks, while >80% of non-grafted plants were killed within the first two weeks of harvest ($P \leq 0.05$) (Fig. 2). Although the three rootstocks utilized in this study were susceptible in varying degrees to southern blight disease, they reduced the incidence and severity of the epidemic through the course of the growing season. While this disease pressure may not be typical, it highlights the potential of grafting to allow for open-field organic tomato production where otherwise it is not cost-effective.

Originally, leaf tissue samples were to be collected on five dates over the course of the growing season. However, we were only able to sample on three dates in 2008 (5/14, 6/11, and 6/25) due to the heavy disease pressure present. The nutrient concentrations of diseased and stressed plants often do not contain predictable values and therefore introduce data interpretation errors. Nutrient sampling was aborted when more than 50% of a treatment group was affected by disease. In this trial more than half of the control treatments were severely diseased just as the harvest period began in the middle of June, resulting in the termination of leaf tissue sampling

(Fig. 3). Additional grafted tomato field trials in NC indicate that there is a positive grafting effect on nutrient uptake including nitrogen when disease pressure is low (O'Connell, 2008; O'Connell unpublished data).

This study highlighted the importance of rootstock selection and the difficulty in predicting disease problems prior to the growing season. The rootstocks used in this study were chosen for resistance to bacterial wilt based on farm history and although this disease was present in the field, southern blight was dominant the year this trial was conducted. The rootstocks we trialed conferred intermediate resistance to southern blight and were capable of maintaining crop productivity under severe disease pressure. Southern blight is an especially difficult disease to manage in organic tomato production. It colonizes and survives on organic matter in the soil, and in North Carolina this disease is more frequent during particularly hot summers. Furthermore, southern blight results in total plant collapse and yield losses can be especially acute. Because no resistance is known in commercial tomato cultivars (McCarter, 1991), all hybrid and heirloom varieties are susceptible to this disease. Therefore, grafting with resistant rootstock for management of southern blight in organic systems will be instrumental.

The dramatic effect that grafting with resistant rootstocks had on the net returns is reliant on the significant impact of southern blight on fruit yield and the high value of certified organic tomatoes. Using grafted plants increased transplant costs by approximately 24% or ~4.5% of the net returns (~$50,000/acre) that can be captured through this management strategy (Table 3). Mr. Hartmann had previously quit growing open-field tomatoes at his farm due to high disease pressure from soilborne diseases. However, by using grafted plants that are resistant to soilborne diseases, Mr. Hartmann has the option to grow certified organic tomatoes and fulfill this important market.

Outreach

In 2008 and 2009, the authors presented more than a dozen tomato grafting workshops and outreach events. The trial conducted at Black River Organic Farm provides an excellent example of what a grower can expect to gain by utilizing grafting technology and the challenges of producing on-farm transplants. In July, 2008, Stefan Hartmann, Suzanne O'Connell, and Cary Rivard gave an invited seminar highlighting our research during a 90-minute lunch at the National Association of County Agriculture Agents Conference held in Greensboro, NC. The audience consisted of more than 100 extension agents from nearly every state. Mr. Hartmann spoke about his experience with grafting as well as collaborating with on-farm research trials.

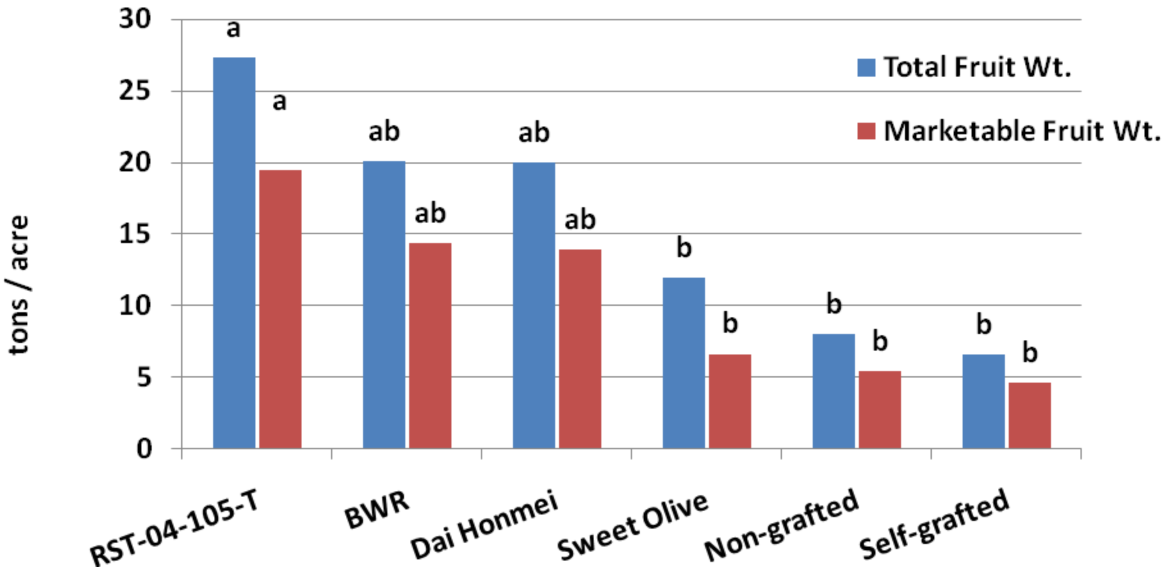

Fig. 1. Fruit yield of grafted and non-grafted 'Celebrity' tomatoes under heavy disease pressure. Columns are marked with the lowercase letters that represent significant differences between treatments based on Tukey's mean separation test at $P \leq 0.05$. Comparison among treatments for total fruit weight is distinct from comparison among treatments for marketable fruit weight. RST-04-105-T = 'Celebrity-RST-04-105-T' grafts; BWR = 'Celebrity-BWR' grafts; Dai Honmei = 'Celebrity-Dai Honmei' grafts; Sweet Olive = 'Celebrity-Sweet Olive' grafts; non-grafted = 'Celebrity'; self-grafted = 'Celebrity'.

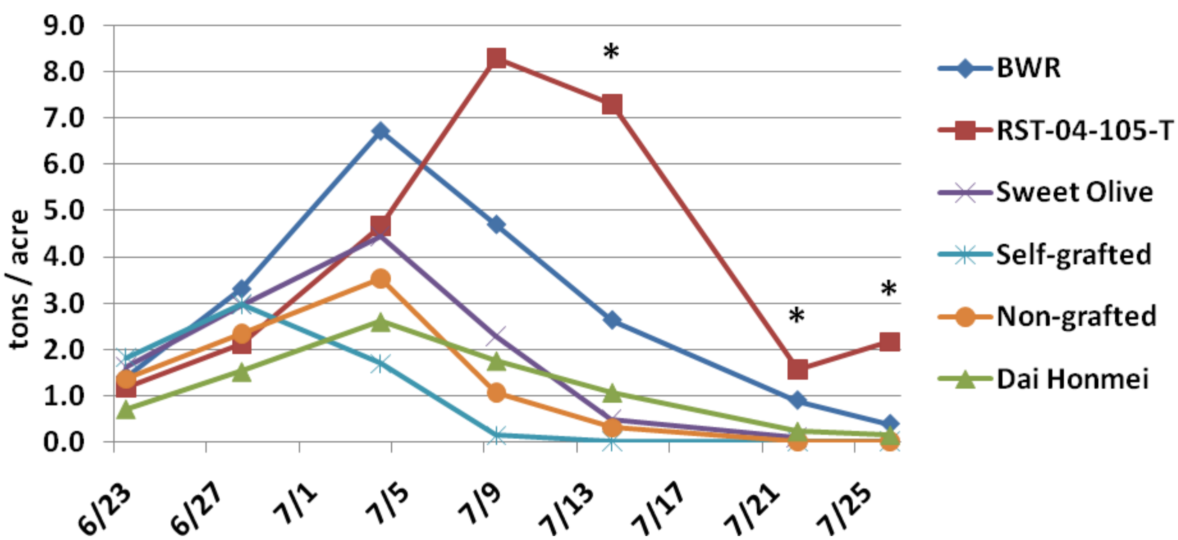

Fig. 2. Total weekly fruit yield for grafted and non-grafted 'Celebrity' tomatoes over time. Points marked with an asterisk indicate that on the corresponding sample date the 'Celebrity-RST-04-105-T' grafts had significantly greater values compared to the 'Celebrity-Sweet Olive' grafts, non-grafted, and self-grafted treatments ($P \leq 0.05$). RST-04-105-T = 'Celebrity-RST-04-105-T' grafts; BWR = 'Celebrity-BWR' grafts; Dai Honmei = 'Celebrity-Dai Honmei' grafts; Sweet Olive = 'Celebrity-Sweet Olive' grafts; non-grafted = 'Celebrity'; self-grafted = 'Celebrity'.

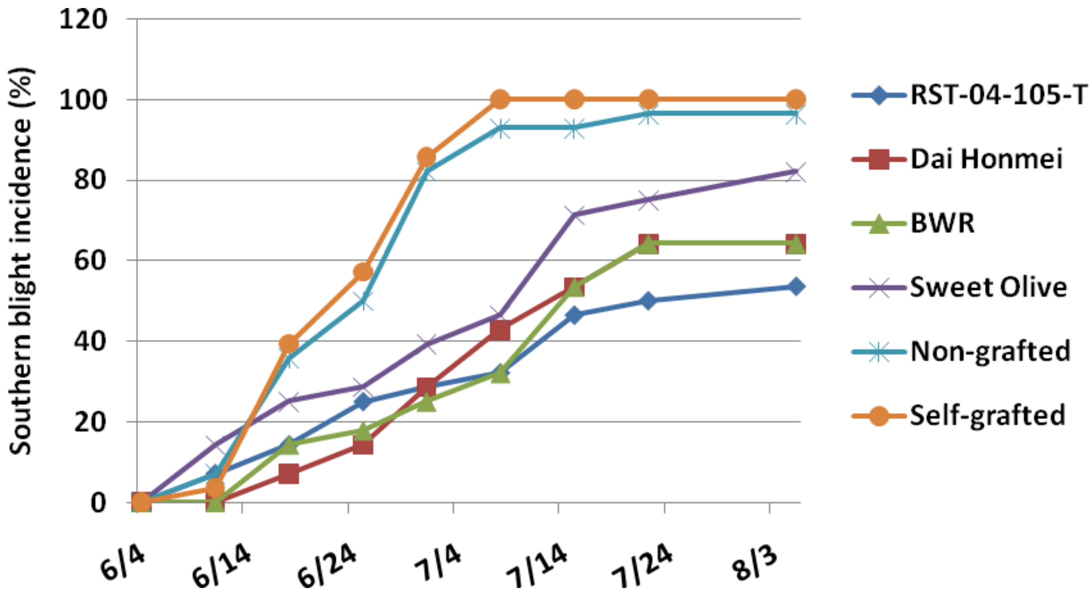

Fig. 3. Southern blight disease progress curve. RST-04-105-T = 'Celebrity-RST-04-105-T' grafts; BWR = 'Celebrity-BWR' grafts; Dai Honmei = 'Celebrity-Dai Honmei' grafts; Sweet Olive = 'Celebrity-Sweet Olive' grafts; non-grafted = 'Celebrity'; self-grafted = 'Celebrity'.

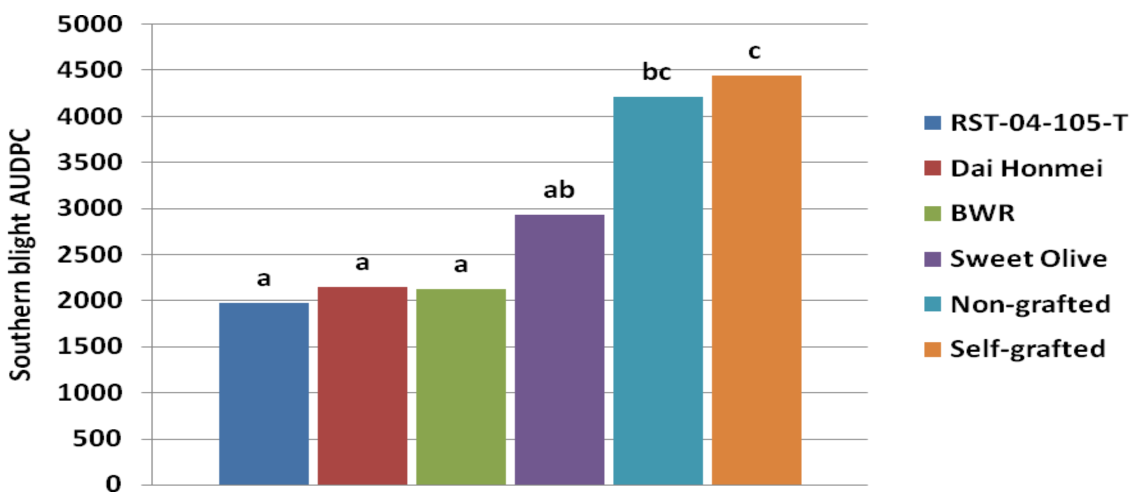

Fig. 4. Southern blight AUDPC. The AUDPC calculation assesses the impact of the disease epidemic by multiplying the level of disease by time (% x time). Columns are marked with the lowercase letters that represent significant differences between treatments based on Tukey's mean separation test at $P \leq 0.05$. RST-04-105-T = 'Celebrity-RST-04-105-T' grafts; BWR = 'Celebrity-BWR' grafts; Dai Honmei = 'Celebrity-Dai Honmei' grafts; Sweet Olive = 'Celebrity-Sweet Olive' grafts; non-grafted = 'Celebrity'; self-grafted = 'Celebrity'.

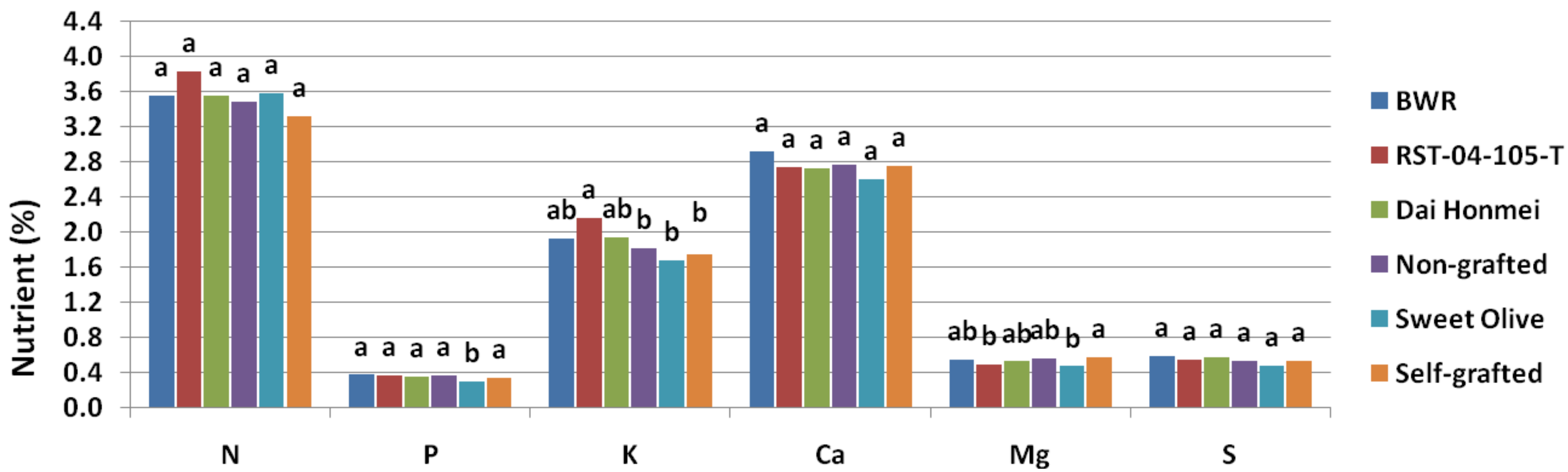

Fig. 5. Mean leaf macro-nutrient concentration. Columns are marked with the lowercase letters that represent significant differences between treatments based on Tukey's mean separation test at *P≤ 0.05*. RST-04-105-T = 'Celebrity-RST-04-105-T' grafts; BWR = 'Celebrity-BWR' grafts; Dai Honmei = 'Celebrity-Dai Honmei' grafts; Sweet Olive = 'Celebrity-Sweet Olive' grafts; non-grafted = 'Celebrity'; self-grafted = 'Celebrity'.

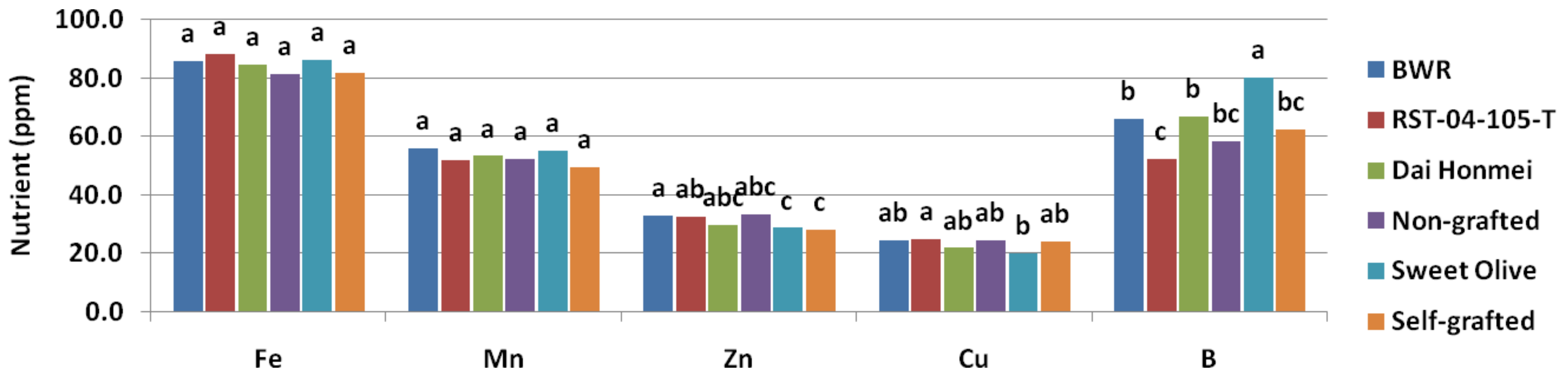

Fig. 6. Mean leaf micro-nutrient concentration. Columns are marked with the lowercase letters that represent significant differences between treatments based on Tukey's mean separation test at *P≤ 0.05*. RST-04-105-T = 'Celebrity-RST-04-105-T' grafts; BWR = 'Celebrity-BWR' grafts; Dai Honmei = 'Celebrity-Dai Honmei' grafts; Sweet Olive = 'Celebrity-Sweet Olive' grafts; non-grafted = 'Celebrity'; self-grafted = 'Celebrity'.

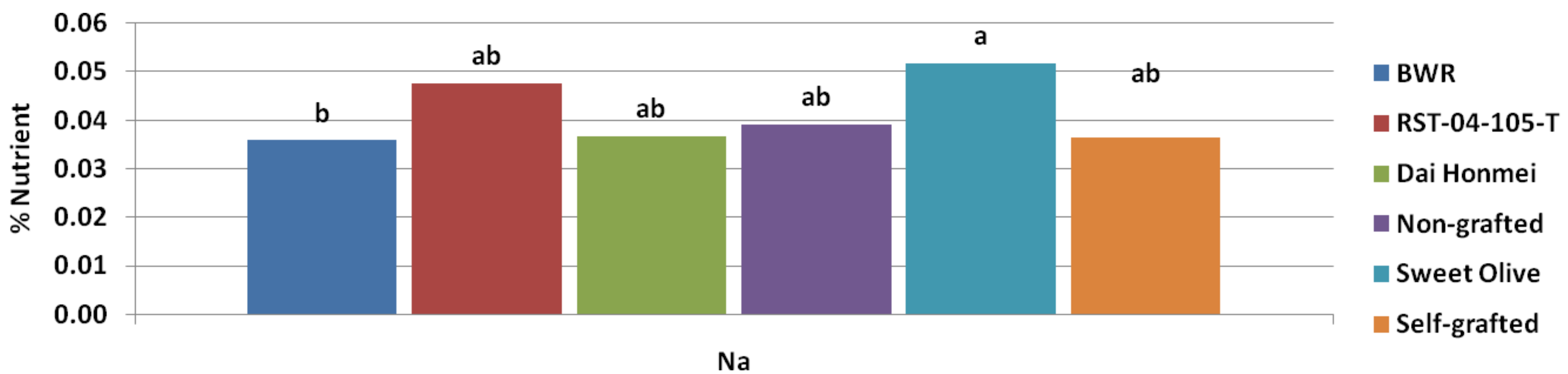

Fig. 7. Mean leaf Na concentration. Columns are marked with the lowercase letters that represent significant differences between treatments based on Tukey's mean separation test at *P≤ 0.05*. RST-04-105-T' = 'Celebrity-RST-04-105-T' grafts; BWR = 'Celebrity-BWR' grafts; Dai Honmei = 'Celebrity-Dai Honmei' grafts; Sweet Olive = 'Celebrity-Sweet Olive' grafts; non-grafted = 'Celebrity'; self-grafted = 'Celebrity'.

Table 1. Scion and rootstock selections[z].

Cultivar	Seed Source	Disease Resistance[y]
'Celebrity'	Johnny's Selected Seeds, U.S.A	F_1, F_2, N, V_1
'RST-04-105-T'	D. Palmer Seed Co., U.S.A	BW, F_1, F_2, F_3, N, Pl, V_1
'Dai Honmei'	Asahi Seed Co., Japan	BW, F_1, F_2, For, V_1
'BWR'	DeRuiter Seeds, U.S.A	BW, F_1, F_2, For, N, Pl, V_1
'Sweet Olive'	Johnny's Selected Seeds, U.S.A	unknown

[z] Organic seeds used when available, otherwise untreated seeds were used.

[y] BW = Bacterial wilt (*R. solanacearum*), F1 = Fusarium wilt (race 1), F2 = Fusarium wilt (race 2), F3 =Fusarium wilt (race 3), For = *Fusarium oxysporum radicis-lycopersici* (crown rot), N = Root-knot nematodes (*Meloidogyne* spp.), Pl = *Pyrenochaeta lycopersici* (corky root), V1 = Verticillium wilt (race 1)

Table 2. Grafting effects on tomato yield.

	Total Yield			Marketable Yield			
Treatment[z]	**Wt. (T/A)**	**# of frt./A**	**Avg. frt. size (lb.)**	**% Marketable**	**Wt. (T/A)**	**# of frt./A**	**Avg. frt. size (lb.)**
Non-grafted	8.02 b[y]	42,668 c	0.38 a	68% a	5.42 b	26,668 b	0.41 a
Self-grafted	6.61 b	34,490 c	0.38 a	70% a	4.63 b	21,512 b	0.43 a
RST-04-105-T	27.34 a	102,404 a	0.53 a	71% a	19.47 a	71,825 a	0.54 a
Dai Honmei	20.00 ab	84,626 ab	0.47 a	70% a	13.94 ab	53,158 ab	0.52 a
BWR	20.06 ab	84,448 ab	0.47 a	72% a	14.38 ab	54,936 ab	0.52 a
Sweet Olive	11.98 b	62,580 bc	0.38 a	56% a	6.65 b	30,224 b	0.44 a

[z] RST-04-105-T = 'Celebrity- RST-04-105-T'' grafts; BWR = 'Celebrity-BWR' grafts; Dai Honmei = 'Celebrity-Dai Honmei' grafts; Sweet Olive = 'Celebrity-Sweet Olive' grafts; non-grafted = 'Celebrity'; self-grafted = 'Celebrity'.
[y] Columns are marked with the lowercase letters that represent significant differences between treatments based on Tukey's mean separation test at $P \leq 0.05$.

Table 3. Summary of variable costs for grafted and non-grafted organic tomato transplant production (per 5000 plants).

Description		Non-grafted		Grafted	
		Materials	**Labor**	**Materials**	**Labor**
Seed Costs[z]	'RST-04-105-T' (D. Palmer Seeds)			$1,166.73	
	'Celebrity' F1	$180.00		$200.01	
Seedling Production[y]	Potting mix and fertilizer inputs	$79.20		$148.80	
	Plug trays	$52.80		$99.20	
	Heating	$160.00		$160.00	
	Transplanting		$108.25		$216.49
	Seedling care		$82.81		$82.81
Grafting[x]	Manual grafting				$325.33
	Grafting clips			$382.25	
	Misc. supplies			$10.00	
Healing chamber[w]	Chamber supplies			$33.35	
	Cool-mist humidifiers			$67.68	
Total		$472.00	$191.06	$2,271.91	$666.03
Grand Total (cost per plant)		**$663.06 ($0.12)**		**$2,937.94 ($0.53)**	

[z] Over-seeding by 20%.
[y] OMRI labeled potting media and fertilizers were used. Organic seeds used when available, otherwise untreated seeds were used. Direct seeding into re-useable 512-cell trays and then transplanted up to 50-cell trays before grafting and/or transplanting to field.
[x] Assuming a 90% grafting success rate and manual grafting rate of 200 grafts/hour/person.
[w] Chamber supplies and humidifiers estimated to last for 3 years.

Table 4. Summary of variable production costs per acre of organic tomatoes[z].

Description	Equipment	Materials	Labor	Total
Off-Season	$20.63	$220.50	$247.32	$488.45
Land Prep / Planting	$154.51	$3,115.30	$482.93	$3,752.74
Irrigation	$949.81	$0.00	$1,100.19	$2,050.00
Pruning	$0.00	$0.00	$851.76	$851.76
Stringing / Staking	$4.82	$62.50	$1,102.56	$1,169.88
IPM scouting/ Pest sprays	$3.96	$321.83	$317.97	$643.75
Total	$1,213.73	$4,112.13	$4334.76	**$9,660.61**

[Z] Summary does not include transplant production, harvesting, or marketing costs.

Table 5. Cost and benefit analysis of grafted tomatoes and non-grafted tomatoes in field with high disease pressure[z].

Treatment	Transplant Costs[y]	Production Costs[x]	Gross Income[w]	Harvest Costs	Net Returns[v]
Non-grafted 'Celebrity'	$663.06	$8,997.55	$21,814.00	$3,239.55	**$8,913.84**
'Celebrity-RST-04-105-T' grafts[u]	$2,937.94	$8,997.55	$77,880.00	$6,308.85	**$59,635.66**

[z] Based on selling price of $2.00/lb.
[y] See Table 3.
[x] See Table 4.
[w] = (Marketable wt. * 2.00/lb).
[v] = Gross income - (transplant costs + production costs + harvesting costs).
[u] = Top performing scion-rootstock graft combination.

References

Campbell, C.L. and Madden, L.V. (1990). Monitoring Epidemics: Environment. In: Plant Disease Epidemiology. John Wiley and Sons, Inc., NY, NY.

Estan, M.T., M.M. Martinez-Rodriguez, F. Perez-Alfocea, T. J. Flowers, and M.C. Bolarin. (2005). Grafting Raises the Salt Tolerance of Tomato Through Limiting the Transport of Sodium and Chloride to the Shoot. Journal of Experimental Botany. 56: 703-712.

Kubota, C., M. A. McClure, N. Kokalis-Burelle, M. G. Bausher, and E. N. Rosskopf. (2008). Vegetable grafting: History, use, and current technology status in North America. HortScience. 43:1664-1669.

Lee, J. M. (1994). Cultivation of grafted vegetables I. Current status, grafting methods, and benefits. HortScience 29:235–239.

Leonardi, C. and F. Giuffirda. (2006). Variation of Plant Growth and Macronutrient Uptake in Grafted Tomatoes and Eggplants on Three Different Rootstocks. European Journal of Horticultural Science. 71: 91-101.

McCarter, S. (1991). Southern blight. Pages 22-23 in: Compendium of tomato diseases, J. B. Jones, J. P. Jones, R. E. Stall and T. Zitter, (eds.) APS Press, St. Paul, MN.

O'Connell, S. (2008). Grafted Tomato Performance in Organic Production Systems: Nutrient Uptake, Plant Growth, and Fruit Yield. M. of Hort. thesis, North Carolina St. Univ., Raleigh, NC. <http://www.lib.ncsu.edu/theses/available/etd-11072008-152636/>.

Oda, M. (1995). New grafting methods for fruit-bearing vegetables in Japan. Japan Agr. Res. Quarterly. 29:187-194.

Oda, M. (2002). Grafting of vegetable crops. Sci. Rep. Agr. & Biol. Sci. Osaka Pref. Univ. 54:49–72.

Rivard, C. and F. Louws. (2006). Grafting for disease resistance in heirloom tomatoes. NC Coop. Ext. Serv. AG-675.

Rivard, C.L. and F.J. Louws. (2008). Grafting to manage soilborne diseases in heirloom tomato production. Hortscience 43 (7):2104-2111.

Ruiz, J.M., A. Belakbir, and L. Romero. (1996). Foliar Levels of Phosphorus and its Bioindicators in Cucumis melo. Journal of Plant Physiology. 149:400-404.

SAS Institute. (2004). SAS/STAT 9.1 user's guide. SAS Institute Inc., Cary, NC.

Presentations/Workshops:

National Association of County Agriculture Agents Conference, 'SARE-funded Research at CEFS: Grafting Heirloom Tomatoes for Disease Resistance in Intensive Farming Systems'. S. O'Connell, C. Rivard, S. Hartmann. Greensboro, NC. July 15, 2008. Pre-registration ~75.

Informational Websites:

<http://www.ces.ncsu.edu/depts/hort/greenhouse_veg/>

<http://www4.ncsu.edu/~soconne/>

< www4.ncsu.edu/~clrivard>

Project photos

Graduate student Suzanne O'Connell and grower
Stefan Hartmann discuss seedling production practices.
Photo by C. Rivard

How to graft tomatoes demonstration.
Photo by C. Rivard

Building a small healing chamber for grafting tomatoes.
Grower Stefan Hartmann and graduate student Suzanne O'Connell.
Photo by C. Rivard

Grower, Stefan Hartmann placing grafted tomato seedlings into a healing chamber with high humidity from a cool-mist vaporizer.
Photo by S. O'Connell

Graduate student Cary Rivard gets a lesson from grower Stefan Hartmann on using a hand-held tobacco transplanter.
Photo by S. O'Connell

Planting the research trial under a threatening sky.
Photo by C. Rivard

Research Trial Planted! Grower Stefan Hartmann, graduate students Cary Rivard and Suzanne O'Connell.
Photo by ?

Summer Intern Seth Avis measuring plant height.
Photo by S. O'Connell

Treatment effects begin to separate.
Photo by S. O'Connell

Southern blight infection (*Sclerotium rolfsii)*.
Photo by S. O'Connell

Southern blight infection (*Sclerotium rolfsii)*.
Photo by S. O'Connell

Control treatment infected with Southern blight.
Photo by S. O'Connell

Celebrity fruit.
Photo by S. O'Connell

End of the season fruit harvest.
Photo by S. O'Connell

Stefan Hartmann with tomato seedlings headed for grafting, 2009.
Photo by S. O'Connell