Tomato Grafting for Disease Resistance and Increased Productivity

Cary L. Rivard, Ph.D.
Kansas State University
Horticulture Research and Extension Center

Frank J. Louws, Ph.D.
National Science Foundation
Center for Integrated Pest Management

Photo courtesy C. Rivard

Inside this fact sheet:

• Introduction

• How to Graft

• Economic Advantages of Grafting

• SARE Research Synopsis

• References

• Further Resources

SARE *Agricultural Innovations* are based on knowledge gained from SARE-funded projects. Written for farmers, ranchers, and agricultural educators, these peer-reviewed fact sheets provide practical, hands-on information to integrate well-researched sustainable strategies into farming and ranching systems.

Geographic Applicability:

Grafting provides different advantages in various geographic climates across the United States. Grafting can be especially advantageous for growers using high tunnels or other season extension techniques, no matter the climate.

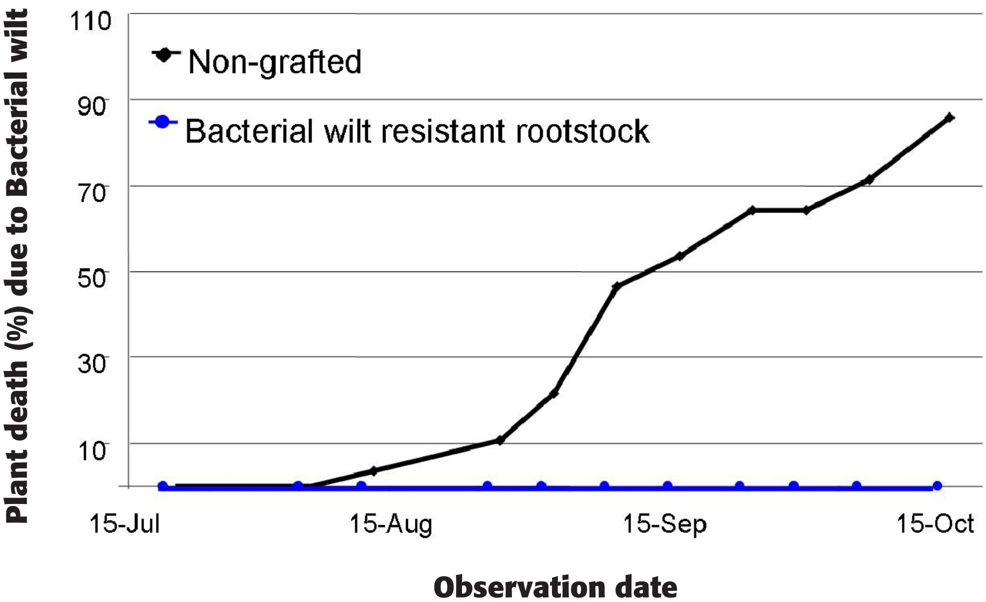
Researchers around the world have demonstrated that grafting—the fusing of a scion (young shoot) onto a resistant rootstock—can protect plants against a variety of soil-borne fungal, bacterial, viral and nematode diseases in various climates and conditions. Grafting has been successfully implemented in Japan, Korea, Greece, Morocco, New Zealand, Brunei and elsewhere to battle Verticillium and Fusarium wilt (FW), corky root rot, root-knot nematodes, bacterial wilt, southern blight and other diseases.

In particular, the worldwide use of grafting with resistant rootstock has been a successful tool for managing bacterial wilt of tomato, even in severely infested soils. In western North Carolina, for example, a resistant rootstock was used to reduce bacterial wilt in tomatoes. At season's end, nearly 90 percent of the control plants died while 100 percent of the grafted plants not only survived—their yield was more than two fold that of the surviving non-grafted plants (Figure 1). In most cases, popular commercial varieties are grafted as scions onto inter-specific hybrids that have been bred specifically for use as rootstocks.

Tomato grafting also offers benefits beyond disease control. Scientists have discovered that it can increase stress tolerance and productivity while maintaining high fruit quality. Using the right rootstock can also help overcome abiotic stressors, such as high salinity, excess moisture and soil temperature extremes, even allowing the extension of the growing season. In addition, grafted plants have produced increased yields and show increased water and nutrient uptake.

Still a relatively uncommon practice in the United States, tomato grafting shows promise for growers who face disease challenges, specifically organic, heirloom and high-

Figure 1. Plant death over time due to bacterial wilt when using a susceptible tomato line or the same tomato cultivar grafted onto rootstock resistant to bacterial wilt.



tunnel growers. With little opportunity for extended crop rotation intervals in a high tunnel, disease pressure can be very high. This is compounded further with organic heirlooms as heirloom varieties are not bred for resistance and other disease management practices are limited in organic systems. Due to the phase-out of methyl bromide in the United States, grafting could become a widespread pest management strategy for a large segment of growers.

Relying on grafting principles that have worked for generations of growers across the globe, researchers from a SARE-funded project at North Carolina State University (NCSU) have shown that tomato grafting has potential as an integrated pest management strategy to increase U.S. crop productivity. This fact sheet provides information on how to graft tomatoes to fight soil-borne disease and improve the health and vigor of tomato crops.

How to Graft

Grafting to manage soil-borne pathogens is a relatively simple process. An above-ground portion of a plant (scion) chosen for high fruit quality is secured to the root system (rootstock) of a disease-resistant seedling.

The researchers at NCSU used "Japanese top-grafting" or "tube grafting," a technique popular for tomato production in commercial greenhouses worldwide, because the process is fast and a large number of seedlings can be propagated

Plant Selection

Step one in the grafting process is to choose rootstock and scion cultivars that will complement each other. There are many tomato varieties, such as heirlooms, that have highly desirable fruiting characteristics, but may have low disease resistance and/or yield. Consider using these cultivars as scions to graft onto rootstocks that offer resistance to soil-borne diseases. Table 1 lists rootstock varieties and their level of disease resistance.

Table 1. Rootstock and Disease Resistance

Rootstocks	TMV	Corky Root	Fusarium Wilt		Verticillium Wilt	Root-knot Nematode	Bacterial Wilt	Southern Blight
			Race 1	Race 2				
Beaufort*	R	R	R	R	R	MR	S	HR
Maxifort*	R	R	R	R	R	MR	S	HR
TMZQ702**	R	S	R	R	R	R	MR	?
Dai Honmei***	R	R	R	S	R	R	HR	?
RST-04-105****	R	R	R	R	R	R	HR	MR
Big Power*****	R	R	R	R	R	R	S	HR
Robusta******	R	R	S	R	R	S	S	?

HR=Highly Resistant **R**=Resistant **MR**=Moderately Resistant **S**=Susceptible

* = De 'Ruiter Seed Co. ** = Sakata Seed Co. *** = Asahi Seed Co. **** = D Palmer Seed Co.
***** = Rijk Zwaan ****** = Bruinsma Seed Co.

Adapted from: Rivard, C.L., 2010. Grafting for Open-field and High Tunnel Tomato Production. PhD Dissertation. pg 171.

Rootstock selection is the single most important step in grafting tomatoes for disease resistance. To choose the right rootstock, first try to identify potential pathogens on the farm through basic diagnostic testing and history of problems (Table 1).

Ideally, you should find rootstock varieties specifically bred for resistance, but typical hybrids or other modern varieties can also be used. Use Table 2 to learn the "tomato code" that breeders use to designate resistance in modern rootstock varieties of rootstock and scion cultivars.

Grafting

Be sure to use good sanitation measures and a sterile, lightweight potting mix to plant seeds. Sow both rootstock and scion seeds two weeks before typical, non-grafted transplant production begins to allow grafted seedlings to spend about one week in a healing chamber, followed by a week of re-acclimation in the greenhouse before planting in the field.

Tips for Successful Grafting

1. Diagnose your soil diseases correctly.
2. Choose the right rootstock for disease resistance.
3. Plan ahead so rootstock and scion grow to the same size on the same day.
4. Provide proper management for the healing chamber.
5. Use appropriate management techniques such as spacing, pruning, suckering, etc. when planting grafted transplants.
6. Ensure the graft union is above the soil line.

The rootstock and scion stems must be the same diameter for grafting to be successful, so alter seeding times to allow different cultivars to grow to the same size. For example, many rootstock varieties take 2-5 days longer to germinate than scion cultivars; however, hybrid rootstock cultivars may germinate faster than the scion. To test the growth rate, do a germination test with 10-15 rootstock seeds after you receive them. If after seedling emergence you find either the rootstock or scion is much larger, decreasing temperature can help slow growth of the faster growing cultivars.

Tube grafting should be done when seedlings have 2-4 true leaves and stems are 2-2.5 millimeters in diameter. The best time of day to graft is early in the morning or just after dark, when there is little water stress on the plants. Moving the seedlings into a shaded area for 2-4 hours prior to grafting will also reduce water stress. Grafting should always be done indoors and under shade.

When making the graft, wash your hands with anti-microbial soap and use latex gloves and sterile tools to reduce exposure of plants to pathogenic bacteria, fungi and viruses. Sever the bottom half of a rootstock seedling from its top at an approximate 45-degree angle, making sure to cut the stem of the scion at the same angle. It makes no difference whether the scion is cut above or below the cotyledon. Be sure to cut the scion in a place where stem diameters of rootstock and scion will best match. Make the graft union below the cotyledon of the rootstock to prevent rootstock suckers that may form later in the crop. Attach the rootstock to the scion with a silicon

Table 2. Traditional and 2005 international resistance codes for tomato cultivars

Scientific Name	Common Name	Traditional Code	2005 International Code
Tomato mosaic virus	Tomato mosaic	Tm	ToMV
Tomato spotted wilt virus	Spotted wilt	TSWV	TSWV
Ralstonia solanacearum	Bacterial wilt	R	Rs
Fusarium f. sp. *lycopersici*	Fusarium wilt (Races 0 & 1)	FF or F2	Fol: 0,1
Fusarium oxysporum f. sp. *radicis-lycopersci*	Fusarium crown and root rot	Fr	For
Pyrenochaeta lycosersici	Corky root rot	K	Pt
Verticillium albo-atrum	Verticillium wilt	V	Va
Verticillium dahliae	Verticillium wilt	V	Vd
Meloidogyne spp.	Root-knot nematodes	N	Mj, Mi, Ma

Adapted from: Rivard, C. L., and Louws, F. J. 2006. Grafting for Disease Resistance in Heirloom Tomatoes. North Carolina Coop. Ext. Serv. Bull. AG - 675.

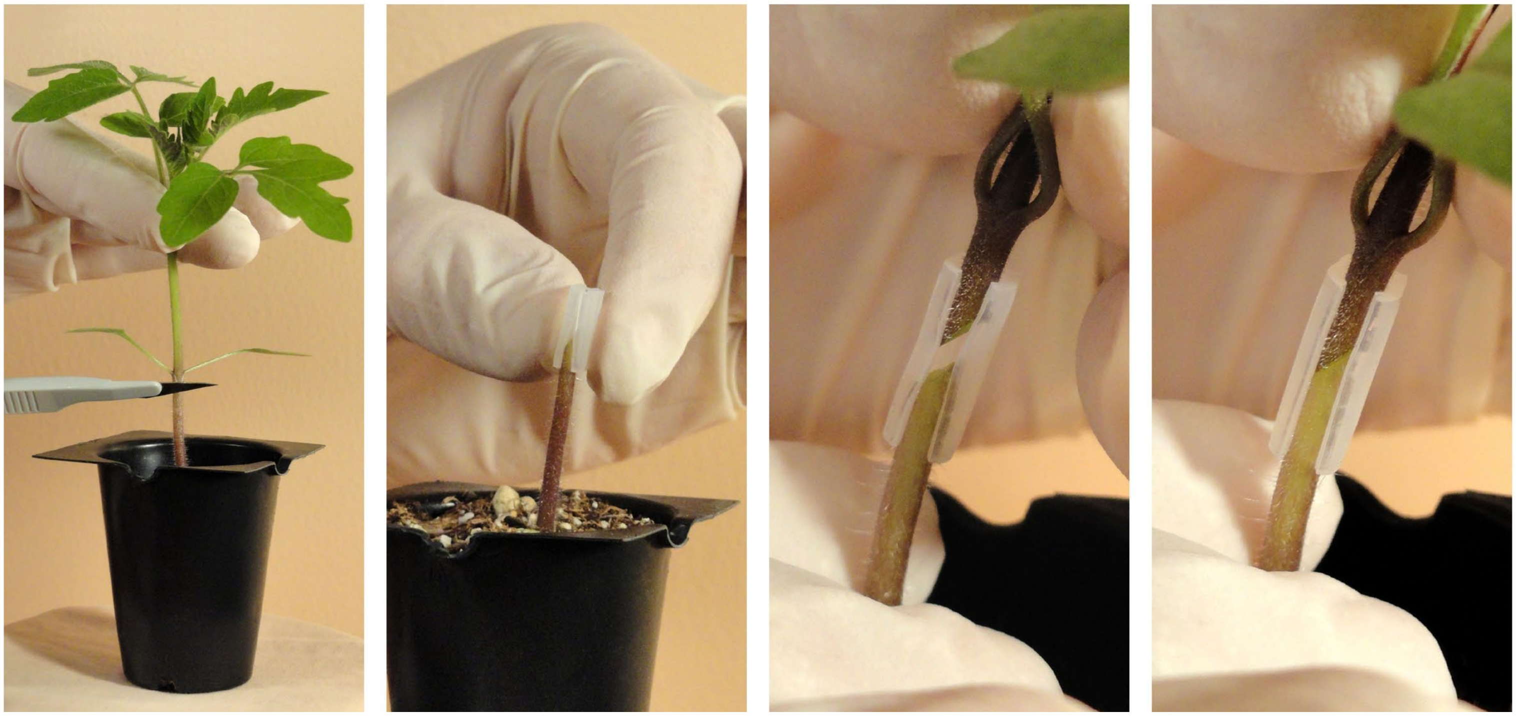


Figure 2. Details of the Grafting Process. Photo courtesy C. Rivard

grafting clip used for tube grafting (Figure 2). The clip will easily slide over the rootstock stem, and the scion stem should be inserted into it so that the cut angles match. See Figure 2.

Caring for Grafted Plants

Immediately after grafting, place the transplants into a healing chamber—a highly regulated area that provides specific amounts of humidity, light and temperature. This will facilitate a reconnection of vascular tissue so water and nutrients can be supplied to the scion. While the grafts are in the chamber, they must receive 80-95 percent humidity, minimal direct sunlight and a temperature of 70-80 degrees F. Be sure that the healing chamber has high humidity levels and is operating properly prior to grafting.

Healing Chamber

Healing chambers generally consist of a frame covered by polyethylene sheeting. The floor of the chamber should be covered with plastic/poly to contain humidity, with a few small holes for drainage. Use an opaque covering on the chamber the first days after grafting to keep out all light, then fluorescent lights or low levels of natural light during the final days of healing. The ideal place for a healing chamber is indoors, in a heated storage area or garage.

Building a Healing Chamber

1. Stretch a tarp or dense shade cloth above a frame or greenhouse bench to reduce sunlight in the area where the healing chamber will reside. Be sure that the shaded area is much larger than the chamber in order to provide reduced light levels throughout the day and reduce the risk of excessive heat building up inside the chamber.
2. Place a layer of plastic sheeting on the surface of the frame or bench, so if the bench has raised edges, a shallow pool of water can be placed on the chamber floor. If a raised lip is not available to help hold water in the chamber, shallow pans of water can be distributed on the bench among the grafts. Cool-water vaporizers are an excellent way to increase chamber humidity as long as they do not also increase the internal temperature.
3. Construct a frame using 1/2" to 1" polyvinyl chloride (PVC) piping or wire hoops as illustrated in Figure 3. The frame should have a peak to keep condensation from dripping onto the newly grafted transplants.
4. Cover the PVC frame with a layer of clear plastic so that the sides and ends can be easily pulled up to check on the grafts.

Make sure humidity, light and temperature levels inside the chamber are constant before beginning the grafting procedure so that the grafts will be placed into a well-functioning chamber. As noted above, the relative humidity level should be high, 80-95 percent, and the temperature should be a constant 70-80 degrees F. Use black plastic to block all available sunlight from entering the chamber until the leaves of the newly grafted transplants attain normal turgor levels, meaning they no longer show signs of moisture stress.

(Instructions adapted from NCSU's Extension Bulletin "Grafting for Disease Resistance in Heirloom Tomatoes").

Transplanting to the Field

Closely monitor the healing process, as well as acclimation of the plants when you remove them from the healing chamber. Typically, the whole process from seeding to grafting to healing to transplanting in the field is five weeks (see Figure 4). However, specific timing of rootstock and scion seeding as well as the total time of propagation will vary based on the greenhouse environment and light intensity within a given propagation area.

Grafted transplants have specific spacing, fertility management, pruning, planting depth and suckering requirements. For example, fruit from rootstock suckers will be poor quality for eating, so be sure to remove rootstock suckers. This will increase production of high-quality fruit and ensure that the scion receives more water and nutrients. Proper planting depth is also very important. The graft union must remain above the soil line when transplanting; otherwise the scion will grow roots into the soil and become infected by the pathogen, losing the advantage of the resistant rootstock.

For more information on how to graft, see "Grafting for Disease Resistance in Heirloom Tomatoes" at http://www4.ncsu.edu/~clrivard/TubeGraftingTechnique.pdf, as well as this instructional video from Ohio State University: http://oardc.osu.edu/graftingtomato/grafting-english.htm.

Figure 3. Healing chamber. Photo courtesy C. Rivard

Economic Advantages of Grafting

As tomato grafting is adopted as an environmentally sound practice to fight soil-borne diseases in the United States, researchers and farmers alike are finding it to be economically viable.

When NCSU researchers developed economic models based on work with growers who produced their own grafted plants, they found that it costs about 43-74 cents more per plant to produce grafted rather than non-grafted plants. These costs reflect additional rootstock and scion seeds, direct costs of grafting (labor, clips, healing chamber, etc.) and indirect costs of growing both a rootstock and scion crop before grafting. (See Table 3).

However, when used in a system where plants generate high-value fruit (such as organics or heirlooms), tomato grafting can provide a net economic gain for tomato fruit growers as well as transplant propagators. In the case of the economic modeling done by NCSU, grafted tomato transplant propagation yielded a

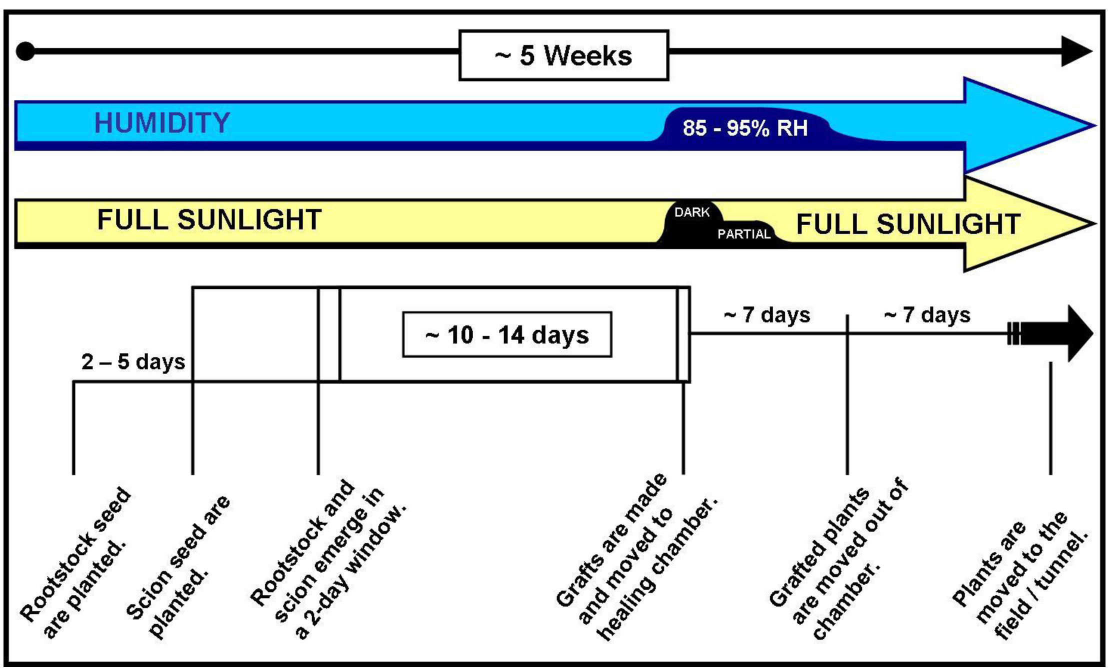


Figure 4. Timeline for Grafting. Taken from Hartmann and Kester's Plant Propagation: Principles and Practices. 8th Edition.

per plant profit that was 38 cents higher than non-grafted plants. Similarly, the grafted plants made better use of greenhouse heating costs which correlate directly with the amount of space used during propagation. On-farm research and other case studies are emerging that demonstrate the profitability of tomato grafting in a wide diversity of tomato production systems.

An analysis of two U.S. farms that successfully produced grafted tomato plants and recorded their costs showed that seeds—not labor—were the highest cost (see Figure 5). This is probably because there are very few rootstock cultivars available to U.S. growers. These seed costs could go down if a larger market develops here.

At both sites, tomato grafting improved per acre profits since deploying resistant rootstocks resulted in healthier plants and increased production. The use of grafting allowed one of the growers to retain organic tomato sales for retail and wholesale markets since the grower did not have to employ non-organic means to keep plants disease-free.

The economics of tomato grafting have also proved positive in high tunnel on-farm trials. In a SARE-funded farmer grant, Pennsylvania grower Steve Groff, collaborating with NCSU scientists, found that grafting with Maxifort rootstock increased yield in his high tunnel, where he faced disease pressure from Verticillium wilt. He also noted that in-row spacing can be manipulated to reduce the economic constraints of grafting. For example, even when plant den-

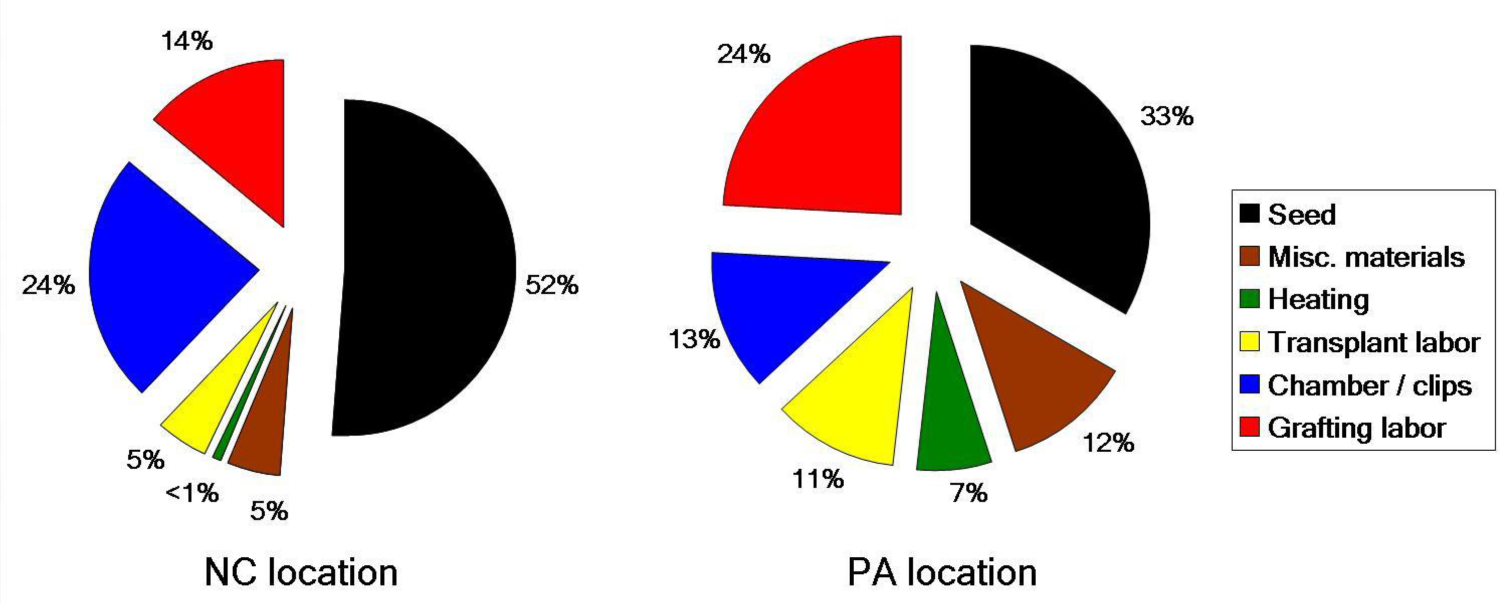
Table 3. Variable costs of tomato transplants at Good Harvest Farms, Strasburg, PA.

Description		Nongrafted		Grafted	
		Materials[Z]	Labor[Y]	Materials[Z]	Labor[Y]
		($/1000 plants)		($/1000 plants)	
Seed costs[X]	Rootstock ('Maxifort')[W]			242.69	
	Scion ('BHN 589')[V]	72.92		78.13	
Transplant production	Custom plug costs[U]	57.60	1.38	124.80	2.95
	Potting mix	30.65		37.37	
	Plastic trays	65.78		76.58	
	Heating	88.41		138.04	
	Transplanting		73.69		104.15
	Transplant care	5.68	112.30	6.96	166.77
Grafting	Manual grafting[T]				180.29
	Grafting clips			46.20	
	Miscellaneous supplies			1.33	
Healing chamber[S]	Chamber supplies			42.11	3.93
Total		321.04	187.36	794.20	458.08
Total (materials & labor)		1525.20		1252.28	
Cost ($/plant)		0.51		1.25	
Selling price (50% mark-up)		0.76		1.88	

[Z]Based on prices during budget development in Fall 2009.
[Y]Based on average hourly agricultural wages (U.S. Department of Agriculture, 2009).
[X]Seed costs were calculated to reflect the total cost required for 20% oversowing and 90% grafting success (where applicable).
[W]Interspecific rootstock (De Ruiter Seeds, Bergschenhoek, The Netherlands).
[V]Determinant fresh-market variety (BHN Seed, Immokalee, FL).
[U]Seedlings were germinated by a local custom plug propagator (York, PA).
[T]Grafting rate was 100 plants/h per worker and grafting wage was $14.00/h. Grafting success was 90%.
[S]Once grafted, tomato transplants were placed in a healing chamber that holds 3300 plants for 7d.

Adapted from: Rivard, C. L., Sydorovych, O., O'Connell, S., Peet, M. M., and Louws, F. J. 2010. An Economic Analysis of Two Grafted Transplant Production Systems in the US. HortTechnology 20:794-803

Figure 5. Distribution of Added Costs. Taken from Rivard, C.L. O. Sydorovych, S. O'Connell, M.M. Peet and F. J. Louws. 2010. An economic analysis of two grafted tomato transplant production systems in the United States. HortTechnology 20:794-803.



sity was reduced 25 percent (from 24" spacing to standard 18" spacing), the Maxifort graft still had significantly higher per acre yields than non-grafted plants at standard spacing.

In Groff's study, grafting allowed for an approximate 20 percent increase in yield, representing 9.4 more tons per acre, or 752 more boxes per acre at $12 per box. According to Groff, the 20 percent yield increase translated into an additional gross income of $9,024 per high tunnel acre, or $1.88 per plant.

SARE Research Synopsis

In 2005, SARE began supporting innovative tomato grafting research at NCSU and continues to fund projects to determine the environmental and economic feasibility for controlling disease and increasing productivity.

The objectives of one project, "Inducing Disease Resistance and Increased Production in Organic Heirloom Tomato Production through Grafting," were to evaluate rootstock/scion combinations through field trials, and to determine the dynamics of induced resistance mechanisms when heirloom scions are grafted onto rootstocks.

Grafted tomatoes were planted in fields where bacterial wilt incidence was historically high, and data was collected on disease incidence, yield and fruit quality. Production techniques were analyzed to increase yield and offset added costs of grafting.

Grafted and non-grafted plants were produced in NCSU greenhouse facilities. The bacterial wilt and organic crop productivity on-farm trials were set up in a randomized complete block design with four replications. Seven plants were used per plot, and typical cultural practices were employed. Other trials were set up in split-plot design with four replications. All results were analyzed using ANOVA, and significant findings were identified using a protected LSD test.

For the induced resistance study, plants were raised and grafted in a growth chamber at the NCSU Phytotron. Tissue from grafted and non-grafted plants was destructively sampled at 24 hours through 24 days after grafting. Plant tissue was frozen in liquid nitrogen and RNA was extracted and reverse-transcribed. Real-time PCR was used to monitor the induction of PIN II, a gene known to be associated with wounding in tomato that is used by the plant to reduce insect herbivory. Grafting was found to elevate the expression of PIN II, although it returned to normal levels 16 days after grafting.

In the bacterial wilt trials, plants grafted with resistant rootstock breeding lines CRA 66 and Hawaii 7996 showed no symptoms of wilt in multiple years. Yield in 2005 was significantly higher in Hawaii 7996 rootstock treatments compared to the non-grafted control. CRA 66 and Hawaii 7996 were highly effective at preventing bacterial wilt from endemic populations of the bacterial pathogen Ralstonia solanacearum in eastern North Carolina.

In organic productivity trials, scientists tested the efficacy of using commercial rootstocks Maxifort and Robusta to increase crop productivity for organic heirloom production. While controls were susceptible to Fusarium wilt, Maxifort rootstock completely controlled incidence of the disease. Robusta offered moderate control. Cumulative marketable and total yields were not impacted by FW incidence or rootstock treatment. In another organic trial, Maxifort showed 50 percent higher yield than controls.

Maxifort rootstock also improved plant growth on land with a history of Verticillium wilt compared to controls, indicating that these vigorous rootstocks provide tolerance to Verticillium wilt. Grafting with vigorous rootstock could help manage Verticillium wilt by giving growth advantage over non-grafted plants. However, further research is warranted to determine if this trend is consistent across locations and growing seasons.

Further Resources

www.extension.org/article/25443
Webinar on tomato grafting

www.hydro-gardens.com
General supplies and rootstocks

www.johnnyseeds.com
General supplies and rootstocks

http://oardc.osu.edu/graftingtomato/grafting-english.htm
Ohio State University instructional video

www.rijkzwaanusa.com
Rootstocks

This fact sheet is based on a SARE-funded project. For more information, please visit www.sare.org > Project Reports > 'Search the database' > Enter text 'GS05-046'. Related projects include GS07-060, LS06-193 and OS09-046.

Prepared with assistance from Lisa Bauer
SARE Publication #12AGI2011

References

Clement, B. 2009. Grafting Tomatoes on Disease Resistant Rootstocks for Small-Scale Organic Production. Tomato Magazine 13 (6): 10-11.

Groff, Steve. Grafting Tomatoes in Multi-Bay High Tunnels as a Way to Overcome Soil-Borne Disease. 2009. USDA SARE program final report for project number FNE08-636.

O'Connell, S. Grafted Tomato Performance in Organic Production Systems: Nutrient Uptake, Plant Growth and Yield. December 2008. North Carolina State University MS thesis.

Rivard, C. Grafting for Disease Resistance in Heirloom Tomatoes. September 2006. North Carolina Cooperative Extension Service.

Rivard, C. and F.J. Louws. 2006. Grafting for Disease Resistance in Heirloom Tomatoes. North Carolina Cooperative Extension Service Bulletin AG-675.

Rivard, C. and F.J. Louws. Inducing Disease Resistance and Increased Production in Organic Heirloom Tomato Production through Grafting. 2007. USDA SARE program final report for project number GS05-046.

Rivard, C.L. and F.J. Louws. 2008. Grafting to Manage Soilborne Diseases in Heirloom Tomato Production. HortScience 43: 2104-2111.

Rivard, C.L., S. O'Connell, M.M. Peet and F.J. Louws. 2010. Grafting Tomato with Inter-Specific Rootstock Provides Effective Management Against Diseases Caused by Sclerotium Rolfsii and Southern Rootknot Nematodes. Plant Disease 94:1015-1021.

Rivard, C.L., O. Sydorovych, S. O'Connell, M.M. Peet and F.J. Louws. 2010. An Economic Analysis of Two Grafted Tomato Transplant Production Systems in the United States. HortTechnology 20:794-803.

This publication was developed by the Sustainable Agriculture Research and Education (SARE) program with funding from National Institute of Food and Agriculture, USDA. Any opinions, findings, conclusions or recommendations expressed here do not necessarily reflect the view of the U.S. Department of Agriculture.

SARE Outreach operates under cooperative agreements with the University of Maryland and the University of Vermont to develop and disseminate information about sustainable agriculture.