



Growers' Guide to Grafted Tomatoes

First Edition

**Michael Grieneisen¹, Brenna Aegerter²,
Scott Stoddard³, Minghua Zhang¹**

¹Department of Land, Air & Water Resources, University of California, Davis

²University of California Cooperative Extension, San Joaquin County, Stockton, CA

³University of California Cooperative Extension, Merced County, Merced, CA





Cover image sources: (top) <http://www.horticulturablog.com/2012/06/en-tomates-las-variedades-si-que.html>; (bottom) Scott Stoddard performing the tomato plant grafting for our field trials.

Note: The Department of Pesticide Regulation (DPR) provided partial funding for this project but does not necessarily agree with any opinions expressed, nor endorse any commercial product or trade name mentioned. In addition, this project was supported by the Specialty Crop Block Grant Program at the U.S. Department of Agriculture (USDA) through Grant 14-SCBGP-CA-0006. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the USDA.

This Guide

- Introduces the reader to grafted tomatoes
- Describes a commonly used method for producing grafted tomato plants
- Describes the potential benefits of using grafted tomatoes
- Summarizes the data from 2016-2017 field trials with grafted tomatoes in commercial California fields

1. Grafted tomato basics

1.1 What are grafted tomatoes?

Grafting of tomato plants involves the splicing together of two seedlings of different cultivars, with one serving as the rootstock and the other as the scion (Fig. 1). Grafting allows the grower to benefit from traits of both plant cultivars. In many countries in Latin America, Europe and Asia, grafted plants represent a large percentage of the tomato industry. For example, in Spain 50 to 70 million grafted plants are grown annually (Miguel, et al., 2011; Raymond, 2013).

Optimal production requires meeting the horticultural needs of both rootstock and scion cultivars. Due to the physiological interactions between the rootstock and scion, the only way to know how well a particular combination will perform, in terms of yield, is through field trials. Fresh market tomato production in California differs from that in other regions, including the use of unique cultivars. Therefore, despite the recent grafted tomato research in states such as Florida, North Carolina, and Kansas, it is necessary to conduct field trials under California conditions.

1.2. Grafting process

- For non-woody plants like tomatoes, several different methods of grafting exist (see: http://aggie-horticulture.tamu.edu/faculty/davies/pdf%20stuff/ph%20final%20galley/M12_DAVI4493_00_SE_C1_2.pdf)
- The use of fully- or semi-automated grafting robots is emerging as a way to reduce labor costs and improve the survival rate of grafted plants. This of course requires significant capital investment.
- Two main sources of grafted transplants in California are Plug Connection (Vista, CA) and Growers Transplanting, Inc. (Salinas, CA). Other companies produce grafted plants for their own use.
- About 20 companies offer rootstock seeds (see page 5). However, building a healing chamber may be a hurdle for operations wanting to do their own grafting. There is research underway on conducting healing inside the greenhouse.

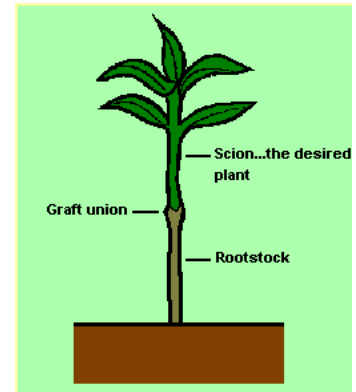


Figure 1. Schematic of a grafted plant. From: <http://anpsa.org.au/grafting.html>

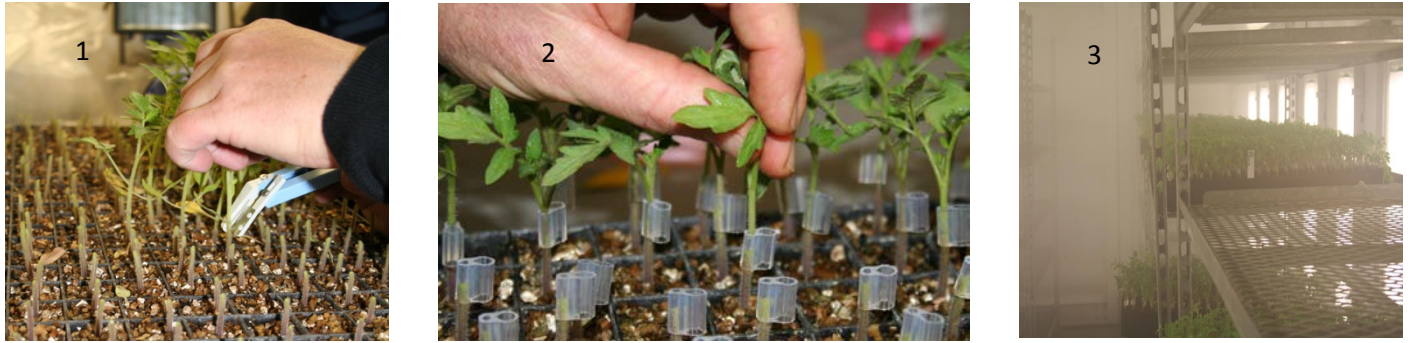


Figure 2. Production of clip-grafted tomato plants for our field trials.

- **Step 1.** Scion and rootstock shoots, with stems of about the same diameter, are cut at 45° angles.
- **Step 2.** The scions are placed onto the rootstocks, aligning the 45° angle cuts, and secured with a soft plastic clip. Plant survival rates are highest when the diameters of the two stems to be joined are similar.
- **Step 3.** The plants are then transferred to a healing chamber with high humidity, low light and moderate temperatures for about a week to allow the graft union to heal. The plants are then transferred back to finish growing in the greenhouse.

1.3. Potential benefits of grafted tomatoes: Higher vigor, pathogen resistance and reduced pesticide use

- 1.3.1. Rootstock vigor.** One benefit of grafted tomatoes is a characteristic typically described as “vigor”. The commercial rootstocks produce a larger root system than typical commercial tomato varieties (Fig. 3), improving water and nutrient uptake. Some studies have found increased yields at lower-than-normal planting densities, and suggested that the larger root structures of grafted plants need more space to avoid competing with each other.



Figure 3. Tomato plant root structures of varieties that are optimized for both biomass production (B) and water usage efficiency (W), a non-optimized variety (bw), and their grafted combinations. The non-grafted optimized “BW” variety clearly shows a more robust root structure than the others. Source: Cantero-Navarro, et al., 2016.

1.3.2. Pathogen resistance

Rootstocks may be resistant to some of the most serious soil pathogens.

- Many rootstocks are interspecific hybrids between the commercial tomato and a wild tomato species, the latter being adapted to a wide range of environmental conditions. Some are resistant to six to eight different soil-borne pathogens, such as Fusarium wilt and corky root rot. Unfortunately, resistance to Fusarium wilt race 3 and Verticillium wilt race 2 is not common among the commercially available rootstocks.
- Plants with rootstocks that are “highly resistant” (“HR” in Fig. 4) can be used as “non-host” rotation crops, rather than the small grains or corn, which are currently recommended by UC as rotation crops for limiting the proliferation of soil-borne pathogens in tomato fields across multiple years.

Rootstock Variety	Product URL	Developer	Bacterial Wilt	Corky Root Rot	Fusarium Wilt Race 1	Fusarium Wilt Race 2	Fusarium Wilt Race 3	Fusarium Crown and Root Rot	Southern Blight	Verticillium Wilt
Aegis F1	Click Here	Takii	IR	IR	HR	HR		HR		HR
Aibou	Click Here	Asahi Industries	R		R	R		R		R
Akaoni	Click Here	Asahi Industries								
Anchor-T F1	Click Here	Takii	IR		HR	HR				HR
Aooni	Click Here	Asahi Industries			R	R				R
Armada F1	Click Here	Takii	IR	IR	HR	HR		HR		HR
Arnold	Click Here	Syngenta		HR	HR	HR		HR		HR
B.B. F1	Click Here	Takii	IR	IR	HR	HR		HR		HR
Beaufort	Click Here	DeRuiter Seeds		R	R	R		R		R
Bettercrop MTR-013 F1	Click Here	Osbourne Seed			R	R	R			R
BHN 1087		BHN Seed	R		R	R	R	R		R
BHN 1088	Click Here	BHN Seed		R	R	R	R	R		R
Block	Click Here	Sakata Seed			R	R				

Figure 4. Small portion of an alphabetical list of 48 commercial tomato rootstocks and some of the pathogens to which they are resistant. Source: <http://www.vegetablegrafting.org/tomato-rootstock-table/>

1.3.3. Reduced pesticide use. Grafted plants using highly resistant (HR) rootstocks may be used in fields infested with diseases or nematodes without the need for additional management practices, such as fumigation.

1.4. Economics of grafting

- **Grafted plants cost more than non-grafted plants** due to increased seed costs and the labor required to do the grafting. Several studies have tracked the total life-cycle costs of grafted and non-grafted tomato plants in actual field trials.
- **The amount of yield increase required to pay for the extra expense of grafted plants depends on two things: The cost of the grafted plants and crop value.** A Florida study (Djidonou, et al., 2013) found grafted plants to be economically advantageous based on costs of \$0.67 per grafted plant and \$0.15 for non-grafted plants, and a crop value of \$10.95-\$11.95 per 25-lb carton of tomatoes.
- **In California the value per 25-lb carton is typically much lower, in the range of \$6-\$9.** Thus far, grafted tomato plants are only available from a few sources in California, and we won't know what the cost for grafted plants will be until they are being produced in larger volumes here, perhaps with automation of the grafting process.
- **Using figures from the Fresh Market Tomato Production Cost Study published by University of California Cooperative Extension** (Stoddard et al., 2007), we can consider a hypothetical economic analysis of grafted plants using figures more appropriate for our production system. Assuming a hypothetical 23% yield increase with grafting (from 1,300 to 1,600 25-lb boxes/acre) and a grafted plant price of \$0.40 each, an increase in net revenue with grafting could be achieved when the price per box is between \$8 and \$9 (Table 1). If the grafted plants are more expensive (e.g., \$0.60 versus \$0.40) or the price per box is lower, then an increase in net revenue with grafting would be much harder to achieve.

Table 1. Impact of grafted plant cost and crop value on potential profitability of grafted tomato plants in CA.

	Conventional	Cost per grafted plant			Net revenue difference		Net revenue difference
		\$0.60 each	\$0.40 each				
Yield 25 lb boxes/A	1,300	1,600	1,600				
Cultural \$/A	\$1,600	\$3,784	\$2,912				
Pick/haul/pack \$/box	\$5,200	\$6,400	\$6,400				
Total \$/A	\$6,800	\$10,184	\$9,312				

Box \$	Conventional		Grafted	\$0.60 each	Net revenue difference	\$0.40 each	Net revenue difference
	Gross \$/A	Net \$/A	Gross \$/A	Net \$/A		Net \$/A	
\$5.00	\$6,500	-\$300	\$8,000	-\$2,184	-\$1,884	-\$1,312	-\$1,012
\$6.00	\$7,800	\$1,000	\$9,600	-\$584	-\$1,584	\$288	-\$712
\$7.00	\$9,100	\$2,300	\$11,200	\$1,016	-\$1,284	\$1,888	-\$412
\$8.00	\$10,400	\$3,600	\$12,800	\$2,616	-\$984	\$3,488	-\$112
\$9.00	\$11,700	\$4,900	\$14,400	\$4,216	-\$684	\$5,088	\$188

All dollar amounts are rounded to the nearest dollar. Estimates are based on plant densities of 5,808 per acre for conventional (18" spacing), and 4,356 per acre for grafted (24" spacing), and the conventional cost of establishment (materials only): plants \$31 per 1000, seed \$43 per 1000 = \$74 per 1000.

2. Grafted tomato trials in commercial California tomato fields. Fresh market tomato production in the Central Valley of California differs from other regions in several respects:

- Fields are typically harvested only once, when fruit are mature-green
- The commercial cultivars are generally not grown elsewhere
- Plants are grown in open fields without staking or other support. In other regions, more intensive production systems are the norm; plants are staked or trellised and are protected in high tunnels, greenhouses, or shadehouses.

2.1 Description of our field trials

The treatments included all combinations of the scions and rootstocks listed in Table 2. These cultivars were selected based on the performance of various rootstocks in the published literature as well as conversations with seed companies and our grower-cooperators. The trials were conducted in commercial fields at four locations: near Vernalis (2016) and Farmington (2017) in San Joaquin County, and two sites near Le Grand, Merced County (one each year).

Scion cultivars	Rootstock cultivars
'Bobcat' (2016)	'DRO137TX'
'Dixie Red' (2016)	'Maxifort'
*'Galilea' (2016)	Non-grafted control
'HM 1794' (both years)	
'QualiT-27' (2017)	
'QualiT-47' (2017)	
'QualiT-99' (2017)	

Table 2. Scion and rootstock cultivars used in our field trials. We evaluated all combinations of the scion cultivars with three rootstocks, in addition to non-grafted scion cultivars.

*Note: Galilea is a roma/saladette type, while the other seven cultivars are round types; all but Dixie Red were developed for the Western U.S. mature green production system.

The plots were laid out in a randomized complete-block design with four replicate blocks. The cooperating growers managed the experimental plots similarly to the rest of their field with respect to pest control, fertilization, irrigation, and other management practices. Plants were mechanically transplanted into prepared beds at a 4- to 5-inch depth per normal practice; the graft union ended up well below the soil surface. In staked or trellised production systems, the graft union is typically kept above ground to realize the full benefit of the rootstock pathogen resistance. With graft union buried below the soil surface, soilborne pathogens may attack the scion crown tissues or adventitious roots arising from the scion. Due to the lack of significant pathogen pressure in our fields, we believe this was not an issue for these trials.

2.1. Field trial results from San Joaquin and Merced counties.

Table 3. 2016 yield data

Scion	-----Vernalis, San Joaquin County, 2016-----				-----Le Grand, Merced County, 2016-----								
	<i>Rootstock</i>	Total yield ^u		Market yield ^v		N	Total yield ^u		Market yield ^v				
	(tons/ac)	% diff ^w	boxes/ac	% diff ^w		(tons/ac)	% diff ^w	(boxes/ac)	% diff ^w				
Bobcat													
<i>Maxifort</i>	35.2	abc	51%	2,240	a	60%	3	43.4	cd	ns	2,512	d	ns
<i>DRO138TX</i>	31.1	cd	33%	1,902	abc	36%	4	48.2	bcd	ns	2,655	d	ns
<i>Non-grafted</i>	23.4	ef		1,402	d		4	46.1	cd		2,687	cd	
HM 1794													
<i>Maxifort</i>	41.0	a	31%	2,224	a	ns	3	47.1	bcd	ns	2,893	bcd	ns
<i>DRO138TX</i>	34.0	bc	ns	2,124	ab	ns	4	45.4	cd	ns	2,615	d	-24%
<i>Non-grafted</i>	31.4	cd		1,904	abc		4	58.3	abc		3,428	abc	
Dixie Red													
<i>Maxifort</i>	34.7	abc	28%	1,967	ab	28%	3	36.9	d	-45%	2,158	d	-44%
<i>DRO138TX</i>	38.0	ab	40%	2,002	ab	31%	3	62.7	ab	ns	3,569	ab	ns
<i>Non-grafted</i>	27.1	de		1,533	cd		4	66.4	a		3,864	a	
Galilea													
<i>Maxifort</i>	25.8	def	ns	1,715	bcd	ns	4	46.6	bcd	ns	2,281	d	ns
<i>DR0138TX</i>	19.7	f	ns	1,414	d	ns	4	40.9	d	ns	2,099	d	ns
<i>Non-grafted</i>	20.8	f		1,399	d		4	43.4	d		2,516	d	

Values represent the means of 4 observations in San Joaquin trial and either 3 or 4 in Merced trial (as indicated in column "N"). Means in the same column followed by the same letter are not significantly different according to Fisher's Least Significant Difference test.

^u Total yield includes marketable, plus culls and immature and undersized fruit.

^v Marketable yield reported as number of 25-lb boxes per acre.

^w Percentage difference in yield of grafted plants compared to the non-grafted controls for the same scion cultivar.

Table 4. 2017 yield data

Scion	-----Farmington, San Joaquin County, 2017 trial-----						N	-----Le Grand, Merced County, 2017 trial-----					
	Total yield ^u		% diff ^w	Market yield ^v		% diff ^w		Total yield ^u		% diff ^w	Market yield ^v		% diff ^w
Rootstock	(tons/acre)			(boxes/acre)			(tons/acre)		(tons/acre)			(boxes/acre)	
QualiT-27													
Maxifort	45.6	abc	25%	2,933	abcde	ns	3	67.2	abc	ns	4,157	ab	ns
DRO138TX	45.0	abc	24%	3,131	abc	30%	4	66.1	abc	ns	3,896	abc	ns
Non-grafted	36.4	de		2,411	def		4	62.2	bc		3,608	bc	
QualiT-47													
Maxifort	51.5	a	38%	3,433	a	47%	4	66.8	abc	ns	3,872	abc	ns
DRO138TX	40.0	bcd	ns	2,803	abcde	ns	4	68.4	ab	ns	3,947	ab	ns
Non-grafted	37.3	cd		2,332	ef		4	65.5	abc		3,962	ab	
QualiT-99													
Maxifort	47.7	ab	ns	3,014	abcd	ns	4	63.2	abc	ns	3,394	cd	ns
DRO138TX	48.1	ab	ns	3,302	ab	25%	3	72.3	a	ns	4,251	a	ns
Non-grafted	41.4	bcd		2,638	cde		4	66.8	abc		3,739	abc	
HM 1794													
Maxifort	41.1	bcd	44%	2,775	bcde	47%	3	58.5	cd	ns	3,742	abc	32%
DRO138TX	38.4	cd	35%	2,765	bcde	46%	4	46.7	e	ns	2,973	de	ns
Non-grafted	28.6	e		1,894	f		4	53.9	de		2,833	e	

Values represent the means of 4 observations in San Joaquin trial and either 3 or 4 in Merced trial (as indicated in column "N"). Means in the same column followed by the same letter are not significantly different according to Fisher's Least Significant Difference test.

^u Total yield includes marketable, plus culls and immature and undersized fruit.

^v Marketable yields reported as number of 25-lb boxes per acre.

^w Percentage difference in yield of grafted plants compared to the non-grafted controls for the same scion cultivar.

Marketable yields in the San Joaquin trial, 2016 & 2017.

In 2016, marketable yields ranged from 1,399 to 2,240 boxes per acre, and half of the grafted combinations provided significantly higher marketable yields than the corresponding non-grafted plants at the 2016 San Joaquin site (Table 3). Grafting increased marketable yield 28 to 31 percent for the grafted Dixie Red combinations, 36 percent for Bobcat on DR0138TX, and 60 percent for Bobcat on Maxifort. Averaged over all the combinations, grafting increased marketable yield by 25 percent.

In 2017, marketable yield of the treatments ranged from 1,894 to 3,433 boxes per acre. More than half of the grafted combinations significantly out-yielded the non-grafted controls. Averaged over all the combinations, grafting increased marketable yield by 30 percent.

Marketable yields in the Merced trial, 2016 & 2017.

In 2016, marketable yields were much higher than in the San Joaquin trial, ranging from 2,099 to 3,864 boxes per acre (Table 3). In many cases, grafted plants produced lower marketable yields than the corresponding non-grafted cultivars. Overall, grafted plants yielded 17 percent less than non-grafted plants.

In 2017, marketable yields of the treatments ranged from 2,833 to 4,157 boxes per acre. Only HM 1794 on Maxifort resulted in an increased yield over the non-grafted control. Averaged over all the combinations, grafting increased yield by only 7 percent.

Vine decline in the Merced trials, 2016 & 2017.

In the 2016 and 2017 Merced trials, some of the plots were lost to a rapid vine decline or collapse. In particular, the vine decline occurred with grafted plants which were in the drive row which was straddled by the tractor during a late-season field operation. No pathogens could be isolated from the collapsed plants, so the cause is not known. Collapsed plots were not included in the yield analysis.

Combined marketable yield data for both trial locations, and economic considerations.

Averaged across all four trials, marketable yield increased 20 percent when grafting with Maxifort or DR0138TX as the rootstock, although the results were better in some individual trials. Based on the economic analysis presented in Table 1, an average yield increase of 20 percent would only become economically viable when the crop price exceeds about \$9 per 25-lb carton and grafted plant cost is no more than around \$0.40 per plant.

Many published field trials indicate that the yield advantages of grafted plants are greatest under sub-optimal growing conditions. Field sites with heavy soilborne disease pressure, or abiotic stresses may be the best candidates to see improvements with grafting.

Fruit size. Many published studies have found that grafted plants produce a higher percentage of fruit in larger size classes than those produced by the non-grafted scion varieties. Averaged over all four trials, the differences in fruit size distribution between grafted and non-grafted were small (see below). In some trials, however, plants on vigorous rootstocks did have larger fruit.

Table 5. Size distribution of marketable fruit based on USDA sizing standards. Average of all round-type scion cultivars, 2016 & 2017.

Rootstock	Percent fruit by weight^z		
	<u>Medium</u>	<u>Large</u>	<u>X-large</u>
Maxifort	19	32	47
DR0138TX	20	31	48
non-grafted	26	35	43

Maturity. The maturity index (percentage of red fruit by weight at harvest) did not differ between the grafted and non-grafted plants in either trial (data not shown).

Plant vigor. In the San Joaquin trial, plant vigor was assessed using a subjective scale from 1 to 5 based on visual inspection of plant size and fruit coverage. The rootstocks Maxifort and DR0138TX produced slightly higher plant vigor than the non-grafted plants for all 4 scion varieties. The hand-held NDVI meter measures how much of the crop row is occupied by actively photosynthesizing foliage. NDVI values were higher for the grafted plants.

Table 6. Normalized difference vegetation index (NDVI).

Rootstock	NDVI	
	<u>2016</u>	<u>2017</u>
Maxifort	0.778	0.809
DR0138TX	0.794	0.810
non-grafted	0.731	0.791

Fruit quality. Some published studies provide measures of fruit quality, such as dissolved sugars, pH, total dissolved solids, vitamin C, lycopene, or even “taste-test” data. Those studies indicate that the quality of fruit from grafted plants seems to be slightly inferior to fruit from the non-grafted plants, though still commercially acceptable. Our field trials focused on yields, and we did not measure any fruit quality data.

2.2. Additional trials will be conducted in 2018

A study in Florida with determinant type cultivars has shown yield increases of 25 to 42 percent using certain rootstocks, but year-to-year variability also increased as compared to non-grafted plants (Djidonou et al., 2013). This variation underscores the importance of considering multiple years’ data to determine the feasibility of grafted tomatoes here. Field trial performance is always subject to the prevailing conditions, which make results variable from year-to-year. We have funding to perform additional trials in 2018.

3. Acknowledgements

The California Department of Pesticide Regulation provided partial funding for this project but does not necessarily agree with any opinions expressed, nor endorse any commercial product or trade name mentioned. In addition, this project and report was supported by the Specialty Crop Block Grant Program at the U.S. Department of Agriculture (USDA) through Grant 14-SCBGP-CA-0006. The contents of this report are solely the responsibility of the authors and do not necessarily represent the official views of the

USDA. We also thank our grower-cooperators (Live Oak Farms and Pacific Triple E), Growers Transplanting Inc., and the following companies that supplied the seeds: De Ruiters Seeds, Gowan Seed Company, Harris Moran Seed Company, and Syngenta Vegetable Seeds.

4. References

- Cantero-Navarro, E.; et al. (2016) Improving agronomic water use efficiency in tomato by rootstock-mediated hormonal regulation of leaf biomass. *Plant Science* 251: 90-100.
- Djidonou, D.; et al. (2013) Economic analysis of grafted tomato production in sandy soils in northern Florida. *HortTechnology* 23: 613-621.
- Miguel, A.; et al. (2011) Improving the affinity of tomato grafted on *Solanum torvum* using an intermediate rootstock. *Acta Horticulturae* 898: 291-296.
- Raymond, G. (2013) Grafting market developments. Rijk Zwaan USA, Salinas, CA, 26 pp. Available at: <http://www.vegetablegrafting.org/wp/wp-content/uploads/2013/11/session-4-raymond-scri-vege-grftg-symp-nov13.pdf>.
- Rivard, C.L.; et al. (2010) An economic analysis of two grafted tomato transplant production systems in the United States. *HortTechnology* 20: 795-803.
- Stoddard, C.S.; et al. (2007) Sample Costs to Produce Fresh Market Tomatoes, San Joaquin Valley, 2007. UCCE Publication TM-SJ-07.