Principles of Tomato Grafting

Science based, grower informed

WESTERN SARE
Sustainable Agriculture Research & Education

Oregon State University
Dept. of Horticulture Vegetable Program

Panelist: Alice Doyle

- Log House Plants
- Twelve years of tomato grafting experience

Panelist: Beth Satterwhite

- Even Pull Farm
- Three years of tomato grafting experience

Panelist: Leanna Eklund

- Oregon State University Organic Growers Club
- One year of tomato grafting experience

Panelist: Paula House

- Gathering Together Farm
- Thirteen years of tomato grafting experience

Panel Discussion

- Sometimes the panelists will offer different or even opposing advice. That doesn’t necessarily mean that anyone is wrong.
  - There are different ways of having grafting success
  - Sometimes these differences may illustrate important Principles of Grafting

Why graft tomatoes?

- Resistance to soil borne disease and nematodes
- Resistance to abiotic stress
  - Drought stress
  - Salinity
  - Others
- Improved growth and vigor

Beth: We graft primarily as a preventative measure against disease since we are growing repeatedly in the same greenhouse beds year after year. We also graft to improve vigor and yield, as we want to pick many high quality fruit for as long a season as possible.

Paula: We graft to control soil borne disease and to improve plant vigor. Recently, I have been interested in grafting because of how it improves dry farmed tomato performance.

Principle 1: Rootstock and Scion Selection

- Rootstock considerations:
  - Disease resistance
  - Abiotic stress resistance
    - For dry farming, we have found that Fortamino rootstock can reduce drought stress
  - Growth and vigor
    - For dry farming, we have found the Fortamino, DRO141TX, Emperador, and Maxifort improve fruit yield and quality, while Shin Cheong Gang does not
    - https://tinyurl.com/dryfarmtomato
- Scion considerations:
  - Quality of the fruit
  - Disease resistance of the scion
  - Cost of seed

Description of Commercial Tomato Rootstocks as of February 5, 2015

Common Tomato Diseases and Pests and Susceptibility Characteristics

Rating rootstock (RS) characteristics is complex because strains of pathogens differ and plant responses to them are rarely "yes" or "no." Therefore, approaches to and outcomes of rating RSs differ. This table was compiled using only publicly available information provided by seed companies in catalogs and at websites. Companies refer to RSs generically as "resistant" (R below). Others describe RS resistance to a disease or pest as high, full or complete (HR below) or partial or intermediate (IR below). Others use numerical scales which have been converted to R, HR and IR below.

Rootstock	Bacterial Wilt	Corky Root Rot	Fusarium Wilt Race 1	Fusarium Wilt Race 2	Fusarium Crown and Root Rot	Southern Blight	Verticillium Wilt	Nematode	Tomato Mosaic Virus	Tomato Spotted Wilt Virus	Developer
Cheong Gang	IR		HR	HR	HR			IR	HR		Seminis Vegetable Seeds
Colosus RZ		HR	HR	HR	HR		HR	IR	HR		Rijk Zwaan
Dai Honmei	R	R	R			R	R	R	R		Asahi Industries
DRO138TX				R	R		R		R		DeRuiter Seeds
DRO141TX			R	R	R		R		R		DeRuiter Seeds
E28.34679			HR	HR	HR		HR	IR	HR	IR	Enza Zaden
EG203	R		R	R				R			Asian Vegetable Research and Development Center
Eldorado			R	R	R		R	R	R	R	Enza Zaden
Emperador RZ		HR	HR	HR	HR		HR	IR	HR		Rijk Zwaan
Enforcer		R	R	R	R		R	R	R	R	Nunhems Seeds
Enhancer		R	R	R	R		R	R	R	R	Nunhems Seeds
Enpower		R	R	R	R		R	R	R	R	Nunhems Seeds
Estamino			HR	HR	HR		HR	IR	HR	IR	Enza Zaden
Fortamino		IR	HR	HR	HR		HR	IR	HR	IR	Enza Zaden
GCR 66											Glass House Crops Research Institute
Groundforce			R	R	R		R	R	R		Sakata Seed

For additional information on rootstocks, contact the developer and Cooperative Extension and visit a compilation of related technical resources (www.vegetablegrafting.org/reference-database/).

Complete Table at vegetablegrafting.org

Beth: Because we grow for greenhouse production, we mostly grow scions bred for indoor production. For rootstocks we have used Maxifort for the past two years but this year we are trialing Fortamino and DRO141TX.

Principle 2: Preparing to graft, how much seed to sow

- You need to sow more seed than you will have final plants
  - You will need to sow at least 1 rootstock seed and 1 scion seed for every grafted plant. However…
    - Not every seed will germinate; some rootstocks can have particularly bad/uneven germination
    - Seedlings may be different sizes at the time of grafting. You want to have a diversity of sizes so that the right size is present.
    - Not every grafted plant will survive.

Alice: I think it depends on the volume of grafted plants you want to produce. If you are just starting out, you may want to seed a lot more (around 150%). For commercial nurseries, we seed 1.3 scions and 1.4 rootstock for each [grafted plant we aim to produce]. We can also sell ungrafted starts so we’re able to pot-up and sell the extra scion materials.

Beth: In general, for any type of propagation I overseed by around 25%. My first season grafting I had around 40 to 50% loss of grafted plants. I wasn’t very good at it, a lot of my grafts didn’t take, so if it is your first season grafting I would recommend overseeding quite a lot. This may get expensive, but you just have to think of it as paying for your education. Now I just overseed both scion and rootstock by my regular 25%.

Principle 3: Preparing to graft, tools and materials

- There are a bunch of materials that you need to have before you start grafting. Here are some…
  - Rootstock and scion seedlings
  - Razor blades/scalpels
  - Spray bottles
    - One with water and one with 10% bleach solution
  - Grafting clips (1.2 or 1.5 mm work best)
  - Healing chamber/humidity domes (test prior to use)
  - Gloves
  - Straw/sticks to hold plants up

Image from Miles et al., “Guide for Hosting a Vegetable Grafting Workshop”

Humidity Domes; photo by Beth Satterwhite

Grafting clips and support stakes
Johnnyseeds.com

Beth: I use seeding trays for my rootstock and scions. Typically, I use 144 cell trays, and for the rootstocks, I seed every other cell to get a checkerboard. I don’t free hand my cuts I use a miter cut grafting knife tool from Johnny’s. I keep this stuff all together so I never have to look for it and I order new supplies well in advance.

Johnnyseeds.com

Leanna: We used a heat mat in the healing chamber to encourage root growth and regulate the temperature in the healing chamber.

Paula: We start the rootstock in 2” pots and keep them in those pots until planting. It is good to have multiple sizes of clips; we use 1 mm and 1.5 mm clips.

Container size

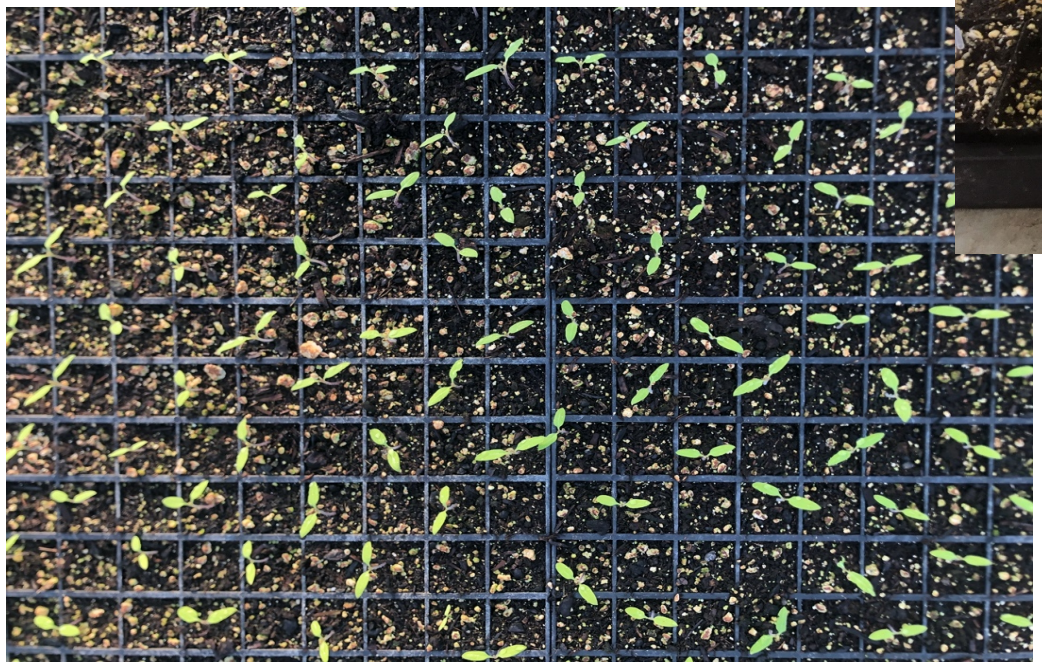


Photo from Beth Satterwhite

144 cell trays -> 5” pots

2” pots

Ellepots (102/tray)
Ellepot.com

Principle 4: Preparing to graft, timing and flexibility

- Start seeds for grafted plants around 2 weeks before standard transplants for the same plant/ship date
  - It will take 7-14 days for plants to recover from grafting
- Rootstock and scion can have different growth rates
  - Growers often sow the rootstock and scions on different days so that they are both the same size on the day that they are ready to graft
- When in doubt, conduct a seedling growth test prior to grafting to evaluate how long the scions and rootstocks will take to reach the optimum size for grafting

Table 4. Seedling vigor values calculated for 18 tomato rootstock and five scion cultivars in a greenhouse in Wooster, OH, using a formula including four plant and two environmental variables and one constant.

Cultivar[z]	Vigor[y] Run 1 (27 Feb.–17 Mar. 2014)		Run 2 (28 Mar.–15 Apr. 2014)	
Aiboh	106	f–h[x]	401	c
Akaoni	72	gh	2,292	bc
Aooni	102	f–h	878	bc
Armada	198	e–h	3,554	bc
Arnold	1,727	a	4,008	bc
B.B.	230	e–h	2,218	bc
Beaufort	1,024	b	2,437	bc
Better Boy	154	e–h	1,593	bc
Brandywine	130	e–h	1,134	bc
Celebrity	141	e–h	1,316	bc
Cheong Gang	190	e–h	2,256	bc
Cherokee Purple	234	e–h	393	c
Estamino	65	h	606	c
Kaiser	513	cd	11,504	a
Maxifort	610	c	5,244	b
Resistar	315	d–f	956	bc
RST-04–105	99	f–h	1,557	bc
RST-04–106	191	e–h	1,844	bc
San Marzano 2	305	d–g	3,751	bc
Shield	73	gh	391	c
Stallone	357	de	4,189	bc
Supernatural	154	e–h	544	c
Trooper	3	h	145	c
P value	<0.0001		0.017	

Table from Hu et al., 2016; “Relative Seedling Vigor Values of Twenty-Three Tomato Varieties”

Alice: We sow some of the scion seeds before we sow the rootstock and some after we sow the rootstock. The point is to seed extra scion materials in staggered sow dates... This gives us a variety of sizes to choose from so we can match the rootstock and scion diameters when we graft. Also, know your scion varieties: skinny stems, thick stems, and quick growing; tomatoes have a variety of sizes and growth habits.

We grow our rootstock seed in Ellepots, which we can move around easily in the holding strip, and we start sorting them as soon as the rootstock seed start germinating. We germinate in the dark at 80 degrees. As soon as the sprouts emerge we sort the flats to move the sprouted plants under lights. There’s always a lot of sorting required.

Alice: You want the rootstock and scion stem to be purple when you graft, not light green. If it is purple then the tissue is thicker and more firm and sturdy. Bright light and cooler conditions make the stems turn purple. This is true for both the rootstocks and the scions. Green stems are from growing too fast, either because of too much fertilizer or heat.

Use the conditions of your site to your advantage, hot and sunny corners of the greenhouse or cooler areas to manipulate the growth needed for matching the stems. We often move flats outside to more sun with a dome just for the day. There's a sensitive balance you'll learn. Too much cold or strong light can make both scions and rootstocks too short.

If the rootstock gets too big, or starts growing out of control, you can remove the stem's growing tip above the cotyledons and that will slow down its growth. Do not cut under the cotyledons because that will kill the plant, but if you cut above the cotyledons that will slow down its growth and later when you have a scion match, you'll be able to graft it.

Beth: We start seeding in January. We sow the scions three days before we sow the rootstocks. We grow them up indoors (in our house) under heat and lights. After 4-5 weeks the plants have two nice size true leaves, the stems are girthy, and they are ready to graft. If one is growing faster than the other I will mess with the number of hours of light that they are getting and moving plants on and off of heat mats. Last year I did a terrible job of getting them to the same size but I grafted them anyways and was able to make it a success (through some strategic cutting).

Paula: We generally sow our rootstock a couple of days before our scion materials because the rootstocks take longer to germinate. We sow our rootstocks in 2” pots so we can move them around and sort them by size. This way we could have trays of rootstock materials that were all the same size. We start our scions in 200 cell trays. We also move materials on and off a heated table to try to regulate their growth, if some material is growing faster than the rest.

Table 4. Seedling vigor values calculated for 18 tomato rootstock and five scion cultivars in a greenhouse in Wooster, OH, using a formula including four plant and two environmental variables and one constant.

Cultivar[z]	Vigor[y] Run 1 (27 Feb.–17 Mar. 2014)		Run 2 (28 Mar.–15 Apr. 2014)	
Aiboh	106	f–h[x]	401	c
Akaoni	72	gh	2,292	bc
Aooni	102	f–h	878	bc
Armada	198	e–h	3,554	bc
Arnold	1,727	a	4,008	bc
B.B.	230	e–h	2,218	bc
Beaufort	1,024	b	2,437	bc
Better Boy	154	e–h	1,593	bc
Brandywine	130	e–h	1,134	bc
Celebrity	141	e–h	1,316	bc
Cheong Gang	190	e–h	2,256	bc
Cherokee Purple	234	e–h	393	c
Estamino	65	h	606	c
Kaiser	513	cd	11,504	a
Maxifort	610	c	5,244	b
Resistar	315	d–f	956	bc
RST-04–105	99	f–h	1,557	bc
RST-04–106	191	e–h	1,844	bc
San Marzano 2	305	d–g	3,751	bc
Shield	73	gh	391	c
Stallone	357	de	4,189	bc
Supernatural	154	e–h	544	c
Trooper	3	h	145	c
P value	<0.0001		0.017	

Table from Hu et al., 2016; "Relative Seedling Vigor Values of Twenty-Three Tomato Varieties

Principle 5: Preparing to graft, prepping plants

- Seedling management prior to grafting can improve success.
  - Growers often withhold or reduce irrigation 1-2 days before grafting.
  - Excess soil moisture prior to grafting may cause water to push up out of the cut surface of the rootstock, potentially interfering with grafting.

Figure 1. A squash (left) and tomato (right) rootstock seedling containing a sap droplet at the cut surface immediately before grafting due to high root pressure. *(Photos by P. Devi, WSU and K. Chamberlain, OSU-OARDC, respectively)*

Photos from Kleinhenz, “Preparing Seedlings and Rootstocks to Graft”

Alice: We water the day before we graft, but one thing I should be sure to mention is that we always subirrigate rather than overhead water. If you overhead water it will make the plants lie down and then the plants will send out adventitious roots, which get in the way of grafting. Also overhead watering can splash soil ingredients up onto the stems.

Beth: I will water heavily the morning before I graft and I will turn off their lights. They are not in full dark but this gets them to calm down. You want their media to be wet because they are going to sit without being irrigated for a number of days. I graft on an overcast day, and if it gets too hot and sunny I stop.

Leanna: Right before we graft and while we graft we mist the leaves with a spray bottle to keep the humidity high right around the plant.

Paula: We irrigate either the night before or the day of grafting, but we irrigate lightly, we do not get them soaking wet. This is because they stay in the healing chamber without being irrigated for a while. We also like that when they have had plenty of water they stand up straight we find that makes them easier to graft.

We keep the scion in the dark starting the evening before we graft so that they are not photosynthesizing. We put the rootstocks under the lights in the warm grafting chamber to get them both plumped up from the water as well as standing up straighter under the lighting, which leaves them much easier to graft. Where you graft is important, you need to be out of the sunshine, out of the wind, you can have light but not too bright.

Principle 6: Good Sanitation

- Grafting requires the wounding of the plant, and this offers a route for pathogens to infect plants.
  - Bacterial canker (*Clavibacter michiganensis*) is a seed borne disease that can be spread during grafting.
  - Botrytis *(Botrytis cinerea)* thrives in the healing chamber environment: high humidity and low light levels.
- Consider all potential disease sources:
  - *Seeds*
  - *Soil mix*
  - *Containers*
  - *Growing environment*
  - *Healing chamber*
  - *Razor blades*
  - *Grafting clips*

Table 1. Some Common Horticultural Disinfectants

Disinfectant	Trade Names	Exposure time	Notes:
Ammonium Chloride	Green Shield, Triathlon, Physan 20	10 minutes	Must be kept wet for 10 minutes
Chlorine Dioxide	Selectrocide	contact	Gas for cleaning GH surfaces
Ethanol	95% or 70% rubbing alcohol	contact	Do not use near open flames
Hydrogen Peroxide	Zerotol, Oxidate	contact	Does not penetrate wood well
Sodium Hypochlorite	Bleach	10 minutes	Use 10% bleach, rinse after use

(Adapted from Kleczewski and Egel, 2011)

Table from Rivard, “GAP and Pathogen Control during Propagation”

Organic Farmers will want to be sure and use materials allowed for use on organic farms

Alice: We use ZeroTol to sanitize surfaces and 10% bleach to clean the blade after every 50 or so cuts. We use a paper towel to dry off the blade after sanitizing because we don’t want to get bleach on the cut. We wear latex gloves always, and you should too, especially if you are a smoker. Tobacco smokers can spread tobacco mosaic virus through residue on their hands.

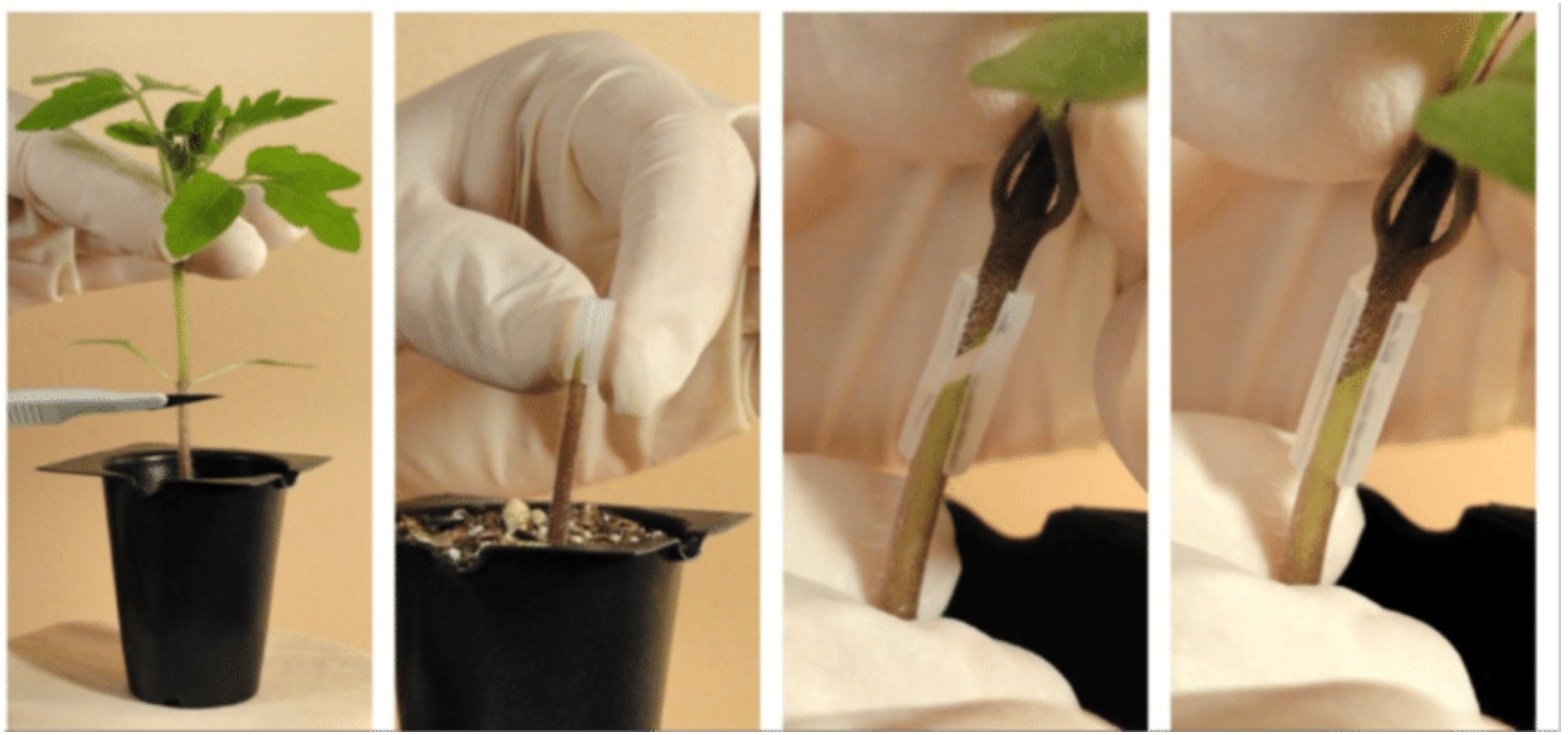
Beth: We graft in the prop house and I try to get it as clean as I can before grafting. I use a paper towel as the landing pad for my scions after I cut them and I switch that out pretty regularly. I use a spray bottle to sanitize my cutting tool.

Leanna: We made sure to sanitize all surfaces, razor blades, all of the tools that we were using and we selected disease free rootstock seed (free from *Cmm* and *Acidovorax avenae)*.

Paula: We change our razor blades out for every flat (32 grafts). You will want to do this anyways as the blades get dull with time. We also sanitize the domes prior to use.

Principle 7: Splice Grafting

- Splice grafting requires that you cut the top off of a rootstock and then attach the top of a scion to the rootstock using a grafting clip
  - Stem diameters should match and should be wide enough that the stem pushes the clip out.
  - Cut angle can vary from 45º to 60º but the rootstock and scion should be cut at the same angle.
  - Cut rootstock below the cotyledon



Splice grafting tomato. (Photos by Cary Rivard Kansas State University)

Alice: We lay down a row of sorted for stem size rootstock “Ellepots” flat on a raised pane of glass and then we cut a scion top off and set it down next to one of the rootstock seedlings to match the stems. We then cut both the scion and rootstock with a single sliced cut. One of the main things though when you are making the cut you never want to hear a crunch, you should just be able to slide the blade through cleanly. If you hear a crunch you are doing damage to the plant, it may be caused by the razor blade being pushed down rather than sliding or maybe it’s too dull. The cut should be around 60 to 70 degrees to give more surface for connecting and the clip should be oriented so that the angle is shown in the opening. This way the clip is pressing in on the narrowest parts of the cut, at the top and bottom. The graft will fail if the scion is wider [in diameter] than rootstock.

Beth: When I graft I do a row at a time, starting with the rootstock. I make sure the orientation is the same for every cut. Then put the clip on cut end of the rootstock and make the same cut on the scion. When I am making the connection, I press them together quite firmly. I twist it gently to make sure the connection is good. The silicone grafting clips are great because you can see what is going on.

Paula: The way I like to do it is I take a rootstock seedling (in a 2” pot) and I slice it at a 45^{o} angle. Then I dispose of the top (you don’t want to accidently regraft the rootstock top onto the rootstock) and turn the pot so that the cut side of the rootstock is facing away from me. I slide the grafting clip on. Then I cut the scion top off and slide it into the grafting clip with the cut side facing me. I just do them one at a time.

Principle 8: Healing Chamber

- Plants need to heal for 3-5 days after grafting. During this time
  - Relative humidity must be between 80-95% (the higher the better)
  - Temperature must be between 70-80^{o}F
  - Light levels must be low (if not completely dark)
- After 3-5 days of healing, plants need to be gradually reacclimated to the prop house/greenhouse environment.

WASHINGTON STATE UNIVERSITY EXTENSION

VEGETABLE GRAFTING: THE HEALING CHAMBER

Humidity Domes; photo by Beth Satterwhite

Alice: You want to site your healing chamber in a heated greenhouse or environment; you do not want to put it in an unheated greenhouse. We use a heater with a thermostat to keep the heat at 78-82°F. To maintain the humidity we use domes on solid flats (with no holes), and we spray the inside of the domes with water after we graft to get the humidity up to 90-95%. It is better to not spray the plants because that is how you get botrytis. We keep them in healing conditions (78-82°F, 95% humidity, and no light) for three days. We check on them every day to make sure that there is condensation on the inside of the dome, as this indicates good humidity. The moisture in the ellepots helps keep the humidity in the chamber at 90-95% for the 3 days.

If you don't have much in the flat, just a few grafted pots, for instance, it's harder to keep the humidity up.

Beth: We use a germination chamber as our healing chamber and it works really well. It is completely dark and has temperature and humidity control so we set it at 90% humidity and 84-85°F. Because it isn't 100% humidity we use the domes too, we mist the inside of the domes. On the second day, I open vents on the domes to let air flow around the plants. On the third day I prop the domes open by an inch or two.

Leanna: I built a makeshift healing chamber out of PVC pipes, plastic, and shade cloth to keep the light out. I used Styrofoam to insulate it and had a heat mat underneath and kept the domes inside there as well and misted the inside of the domes twice a day.

Paula: We are sure to keep the whole flat full of plants, and if there are any gaps in a tray we will fill those with pots with media. This helps to keep the humidity in the chamber.

We use humidity domes and keep it warm in there. It takes 3-4 days to heal. We keep them in the dark until we start reacclimating them.

Principle 9: Reacclimation after healing

- Start reacclimating 3-5 days after grafting.
  - Plants require at least two days of medium light and relative humidity before they are ready for the greenhouse environment with its high light and low relative humidty.
  - Gradually increase light levels
  - Gradually decrease relative humidity
- If plants spend too much time in low light and high humidity they can develop physiological problems and also are susceptible to disease.

Alice: On the fourth day [after grafting] we take them out of the dark room and we open the vents to wean them under artificial lights for a day (if you don’t open the vents, even under florescent lights, they’ll fry). The fifth day we prop the domes open. On the sixth day, no dome. The next day or soon after we move them to a heated greenhouse. We do continue to subirrigate until we sell them. Stainless steel trays for subirrigating are available at any hardware store that sells water heaters.

Beth: On the end of the fourth day [after grafting] I will move the trays underneath our prop house tables so they get a couple hours of indirect sunlight. At the end of the fifth day I move them up onto the prop house tables and gently water the trays (don’t shower the plants). I let them grow under the humidity domes, using the heat mats, until there is a full new set of leaves on the plants.

Paula: In each of our chambers, we have florescent lights with two layers of shade-cloth; once they have healed, I turn on the light with the shade cloth so it is dim light. I also open the vents on the domes so that the humidity starts to drop. We take the layers of shade-cloth off and eventually put them back in the sun.

Principle 10: Maintaining seedlings after healing

- After the plants are fully acclimated to the greenhouse environment, it may still take 5-6 days for the graft to fully heal.
  - Leave the grafting clips on, they will fall off naturally
  - Do not jostle or be rough with the plants.
  - Subirrigate (water from below) to prevent damage to plants.
- About 14 days after grafting, plants are ready to be “hardened off” and planted.

Principle 11: Transplanting

- When the tomatoes are ready to transplant, be sure to plant them with the graft union above the soil. If you bury part of the scion, it will produce adventitious roots that will be susceptible to whatever soil borne disease you are trying to prevent.
- For dry farming we have found that there is still a yield, vigor, and fruit quality benefit even if you do bury the graft union.

Photo by Xin Zhao;
from vegetablegrafting.org

Principle 12: Growing

- Grafting with determinate scions will require one to two suckering events
- Grafting with indeterminate scions will require lots of pruning

Beth: Grafted plants grow very quickly, so you will need to be proactive in keeping them under control. We prune our tomatoes weekly, and it generally takes us an hour a bed.

- For more information on grafting visit vegetablegrafting.org
- For more information on dry farmed tomatoes visit tinyurl.com/dryfarmtomato
- Thank you:
  - Western SARE
  - Alice Doyle
  - Beth Satterwhite
  - Leanna Eklund
  - Paula House

WESTERN SARE
Sustainable Agriculture Research & Education

Oregon State University
Dept. of Horticulture Vegetable Program