Grafting Manual:
How to Produce Grafted Vegetable Plants

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Synopsis:
As grafting is primarily an assembly operation, logistics and workflow in the context of labor management are critical considerations for commercial grafting nurseries. These operations need to be optimized to reduce time spent on each step while assuring quality of the end product.

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USDA United States Department of Agriculture National Institute of Food and Agriculture

Designing Logistics & Workflow of Grafting Nurseries

General information

The grafting process typically involves multiple steps (e.g., cutting scion and rootstock plants, placing a grafting clip on rootstock, etc.) as described in other chapters of this grafting manual. As grafting is primarily an assembly operation, logistics and workflow in the context of labor management are critical considerations for commercial grafting nurseries. Logistics and workflow need to be optimized in order to reduce the time spent for individual grafting operational steps (cutting, placing clips, etc.), while assuring the quality of the end product, grafted plants. Labor is the highest cost constituent in vegetable grafting (e.g., Lewis et al., 2014), and worker performance throughout the whole workflow of the grafting department is a critical control point affecting the costs and quality of the end product. The author visited several commercial grafting operations where grafting was done manually, and following is a summary of typical successful workflows observed in these facilities along with suggested approaches to further improve the efficiency in a given workflow design. This chapter focuses on manual grafting operation design; please refer to the 'Automation' chapter for grafting with machines or robots.

Workflow designs in grafting operations

There are two basic workflow designs employed in manual grafting operations. Each design has pros and cons, and propagation nurseries must select a workflow design that works best for their labor and production conditions.

1.Cellular manufacturing

This workflow design is also known as 'one-person assembly' where each worker performs every step/task of the grafting process. Workers typically sit in front of a work table where trays of scion and rootstock seedlings as well as grafting tools

(knives, cutting boards, a spray bottle of disinfestation solution, etc.) are placed (Fig. 1). A large table could be shared by many workers, or multiple smaller tables shared by a few workers can be used. In either case, each worker needs to have a complete set of tools. This is the most common workflow design observed, and is advantageous for tracing individual worker performance and work quality (e.g., success rate, disease introduction).
Large-scale grafting operations often have a separate supervisory crew, who watch individual's performance and respond to their needs such as providing new trays and replenishing consumable materials as needed so that the grafting worker's work performance is not interrupted. Use of a conveyer system to move the trays in or out of individual workspaces is effective to improve work efficiency.

2. Assembly line

This workflow design is also known as 'line operation' where each worker is assigned to perform one or a few specific tasks of the grafting process (Fig. 2). In the workflow design shown in Fig. 2, rootstock preparation consists of rearranging the plants, cutting the stem at a consistent angle (e.g., 45 degree), and placing a grafting tube (clip) on the cut end of each rootstock plant. The scion preparation process consists of cutting shoots under the cotyledons at the same angle. Excised scion cuttings and trays of rootstock plants are brought to the final stage of assembling, where workers are picking up a scion cutting and inserting it into the tube to join these two plants. An additional worker is assigned to move the finished trays with grafted plants to healing chambers.

This workflow design is more suitable for grafting operations where the order lot size is relatively large, or when a fewer number of scion-rootstock cultivar combinations are used. When the lot size is small and consists of several different scion and/or rootstock graft combinations, there tends to be idle time between switching from one order to the next, which can slow down the whole team's grafting efficiency. This is the reason this workflow design is not used in Asian countries where lot size is typically very small (e.g., sometimes only a few trays) and these propagation nurseries tend to graft a wide range of scion and rootstock combinations.

This assembly line operation is effectively used in Canada where a relatively limited number of scion and rootstock combinations are used. One advantage of this type of workflow is that it allows a worker to be assigned tasks based on his/her skill set, and may be suitable in an operation where the majority of workers are new and un-

Figure 1. An example of a cellular workflow design in a grafting nursery where each worker performs all the steps of "assembling" grafted plants.

trained.

Cutting scion and rootstock seedlings in a consistent sharp angle typically requires some training, while placing grafting tubes on the cut end of rootstock plants is an easy task for beginners. Placing an experienced worker as inspector at the end of the workflow can enhance the quality of grafted plants. Another inspector or an experienced worker in the assembly line can observe the performance of other workers and change work-assignment as needed to improve the whole grafting assembly line efficiency.

Some considerations in grafting workflow design

Horticultural operations consist of individual processes highly dependent on each other. Improving grafting efficiency in a given workflow design often requires optimizing ergonomic time-motion at the individual worker's level. Additionally, the selection of a grafting method that is best suited for a particular grafting propagation nursery should be evaluated in the context of the whole nursery operation. The following are two examples of how to select a grafting method and a workflow design for a grafting propagation nursery.

1. Grafting plants in or out of the tray

Fig. 3 shows two nurseries grafting tomato plants using the splice (tube) grafting method. However, the first nursery (Fig. 3-left) performs grafting by removing the plants from the tray and lining them up to assure an accurate angle cut for rootstock and scion plants. Note that plants are lined up on a cutting board with X-Y grids to assist workers to make consistent, accurate cut angles.

This process might achieve the highest quality of grafted plants by assuring the quality of the cut (correct angle and clean sharp cut) for each plant. However, the extra steps of pulling plants from the tray, laying on the cutting board, and placing the grafted plants back in the tray add time to the grafting process and increase the labor cost per plant. Workers can pull one whole row of plants (8 plants in this case) at a time to minimize the additional motion-time needed in the process, but overall grafting speed still is slower than when plants are not removed from the tray.
Another notable issue is that the work area tends to become messy with substrate materials, and workers need to wipe or clean the work surface regularly, an additional step in the grafting process. In contrast, grafting

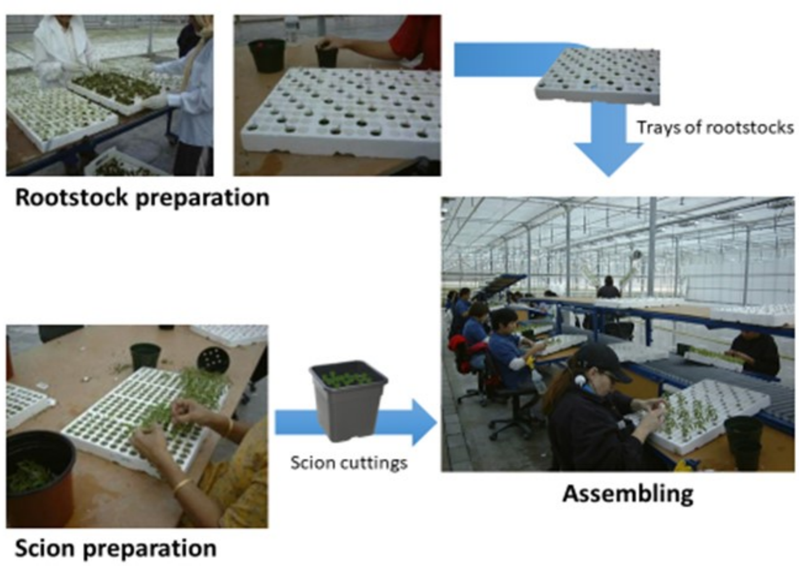

Figure 2. An example of an assembly line workflow design, where rootstock and scion plants are prepared separately by different sets of workers.

Figure 3. Examples of two different cutting methods: pulling out plants and cutting them on a cutting board assures the highest quality and consistency of the cut (left), while cutting plants in the tray reduces the time needed to process scion and rootstock plants for grafting.

plants in the tray is faster because it minimizes the time spent on each grafted plant (Fig. 3-right and Fig. 4). Nurseries that graft plants in the tray typically grow rootstock plants at lower density so that there is ample space around each plant to work. This will increase the costs of producing rootstocks and limit the production capacity, as more space is required for growing the same number of plants at lower densities. Some growers re-space and sort rootstock plants prior to grafting to address the space issue, despite the increase of additional labor. Cutting plants at a consistent angle in the tray without removing the plants requires training, and a simple tool to assist workers to make consistent angle cuts is useful (Fig. 4).

2. Timing to remove rootstock meristems

In cucurbit grafting, one process critical for producing high quality grafted plants is removal of cotyledonary axillary meristems/buds from rootstock seedlings. The cotyledonary axillary buds of most rootstocks used for cucurbit are not visible at the time of grafting but these buds become problematic as they grow after grafting.

There is a need to develop effective methods to completely remove the axillary meristematic tissue from cucurbit rootstocks (Daley et al., 2014; Dabirian and Miles, 2017). One process that is commonly used to prevent rootstock grow-out is to remove the meristematic layer of

Figure 4. A grafting cutter is designed to cut plants in the tray at a consistent angle.

tissue in the axil region using a sharp scalpel or razor blade (Table 1).

This process can be difficult for workers with limited experience. While complete removal of meristematic tissue during grafting will eliminate the grow-out of rootstock axillary shoots, this additional step slows down the grafting speed and increases the grafting costs.

As another approach, in commercial nurseries in China and Taiwan, grafters intentionally leave the invisible axillary buds. These buds grow out when plants are going through the healing and greenhouse finishing processes, and workers remove the extended axillary shoots in the greenhouse (sometimes more than once). At this growth stage, shoots are extended, visible, and easily snapped off. This approach is perhaps more advantageous than trying to remove invisible meristematic tissue with a scalpel or razor blade at the time of grafting, and is a good example of a whole system approach to improve overall efficiency and thereby reduce the overall costs.

Integration of information technology—Smart grafting operation

Workflow design is typically created by trial and error processes driven by an experienced production manager. Successful operation of grafting relies on the skills and experience-based wisdom of such personnel. Recent developments in information technology such as real time data collection for optimization should assist personnel to make decisions regarding labor management and assignment of workers with various skill levels to selected tasks to meet production timelines and demand patterns. In the U.S., while migrant temporary workers are the key workforce during peak production seasons of agricultural and horticultural operations, the costs and regulatory issues relating to migrant workers can be problematic for propagation nurseries. Utilizing computer algorithms to optimize the production process, logistics, and task assignment among workers with different skill sets and wage scales could provide helpful solutions in future horticultural operations as demonstrated by Masoud et al. (2017) and Kubota et al. (2017).

Axil removal methods	Axillary bud extension (%) after 7 days	Note
Non-treated control	92%	
Three light scratches with scalpel over the axil region	25%	The incidence can be further reduced by increasing extent of scratching depth.
Cutting off a cotyledon deep enough to completely remove the remaining axil region	0%	Too deep of cut could damage rootstock plants.

Table 1. Incidence of 'Strong Tosa' interspecific hybrid rootstock axillary bud extension (%) as affected by the method of removing axillary buds at the time of grafting (preliminary unpublished data obtained at the University of Arizona; n=12 per treatment.

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