Grafting Manual:
How to Produce Grafted Vegetable Plants

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Synopsis:
Technologies for nursery automation have been developed to address high labor cost issues in commercial operations. Types of automation include machines to handle most aspects of plant production.

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

Automation in vegetable grafting nurseries

Technologies for nursery automation have been developed to address high labor cost issues in commercial operations. Attempt to automate vegetable grafting has been made since the 1990s (Kurata, 1994) to contribute to efficiencies in labor at various stages of the grafting nursery operations. This article summarizes currently available automation technologies specific to vegetable grafting nurseries.

Types of automation

In the U.S. commercial vegetable nursery industry, various types of automation have been used for many years. These include machines that mix substrate, fill trays, seed trays, transport trays within the facility, irrigate trays, and control environmental conditions throughout the various stages of seed germination and plant growth. Grafting nurseries may consider additional automation in two categories: 1) sorting plants for uniformity prior to grafting, and 2) grafting (cutting and joining together scion and rootstock).

Sorting machines rearrange seedlings to create trays with uniform stands (Fig. 1). Having uniform seedlings improves grafting speed especially when the grafting method requires matching stem size between scion and rootstock. Uniformity of seedling growth is largely affected by the uniformities of seed germination and cotyledon emergence. Therefore, sorting is typically done when seedlings have fully expanded cotyledons and are about to develop the first true leaf. A sorting machine developed in the Netherlands can sort as many as 7,000-8,000 tomato seedlings per hour into three classes (Table 1). After sorting, nursery growers would manage irrigation, temperature and/or light to accelerate growth of small plants and restrain growth of large plants so that all plants would, ideally, be about the same size at grafting time. One major drawback of sorting machines is that types of substrate (media) and trays compatible with machines are currently limited to specific products. More flexible sorting machines need to be developed to accommodate the variety of trays and substrates used by the nursery industry. Machines or tools that would sort a smaller number of trays would also be useful for small to mid-size nurseries.

Grafting machines have been developed over the years by several manufacturers. Initially automation was targeted mainly towards grafting cucurbit seedlings as the manual grafting speed for these crops is relatively slow (K. Kobayashi, personal communication). For example, an experienced grafter with good work logistics may reach up to only 150 grafts per hour for cucurbits, while 300 grafts per hour can be achieved for tomato.

Recent efforts, however, focus on developing the automated grafting capacity for tomato in addition to cucurbit plants, presumably due to the large increase in the demand for grafted tomato plants compared with 20-30 years ago. Most widely used type of grafting machines are 'semi-automated' machines that typically require at least one worker to manage the operation of each machine (Fig. 2). The specifications for plant size, tray type, and substrate type are less restrictive for semi-automated machines and therefore they are relatively easier to be managed in nurseries than fully automated machines. This specification of the materials compatible with grafting machines was shown as a significant cost factor in an economic sensitivity analysis (Lewis et al., 2014). Table 1 summarizes the grafting machines currently available in the North American market.

Use of automation

The level of automation that is considered adequate for each nursery depends on the size of the individual nursery as well as availability of labor. Grafting machines appear to take a vital role for nurseries that are quickly developing their grafting capacity with limited experience in grafted seedling production. One of the largest operations of automated grafting is now located in the U.S. and it utilizes five semi-automated grafting machines with two shifts of assisting workers (Rootility, 2015).

However, nurseries need to be aware that effective use of automation always requires a foundation of good nursery practices that includes the ability to grow uniform plants of specified size. Quality control by well experienced nursery personnel is essential to achieve the expected plant quality with automated operations. For

Figure 1. A sorting machine that creates uniform stands of seedlings in each tray. (*Photo by Chieri Kubota*)

this reason, most automated grafting nursery operations have at least one or more quality control personnel who examine the quality of each graft. A unique effort being developed recently is the combination of automated grafting with a highly controlled environment for growing scion and rootstock seedlings (Zhao and Kubota, 2015). Indoor transplant production technologies with vertically stacked multi-tiered growing systems and electric lighting such as LEDs were developed in the late 1990s (Kozai et al., 2000; Ohyama et al., 2000) and recently introduced to the U.S. (Hortalizas, 2015) to produce high quality uniform transplants with efficient resource use. Because of the high seedling density that can be produced in indoor growing systems, the increased production cost due to the electricity necessary for lighting and cooling was reportedly only 1.2 U.S. cents per plant as compared to traditional greenhouse nursery seedling production (Kozai, 2016). Indoor transplant production technology can fulfill the need for highly uniform scion and root-

Table 1. Grafting automation available in North America.

Model, make	Type	Usage[1] as of July, 2016
Sorting (grading) machines		
ISO Grade 7000, ISO Group, The Netherlands (http://www.isogroepmachinebouw.nl)	Fully automated grading machine that sorts young tomato seedlings into 3 different sizes with preset spacing between plants. Hourly operation capacity is 7,000 plants.	One machine used in North America; 9 machines used in other regions (Europe and Asia)
Select-O-Mat series, Visser Horti Systems (https://www.visser.eu)	Fully automated grading machine that sorts young tomato seedlings by size. Hourly operation capacity is 4,000-8,000 plants, depending on the model.	Three machines used commercially in North America; 9 machines used in other regions (Europe etc.)
Grafting machines		
ISO Graft series, ISO Group, The Netherlands (http://www.isogroepmachinebouw.nl)	Semi-automated grafting machines for tomato with 1-2 workers assisting each machine, depending on the model. Speed is adjustable and up to 1,050 grafts per hour.	Six machines used in North America; 14 machines used in other regions (Europe and Asia)
GR-series, Helper Robotech, Korea (http://www.helpersys.co.kr/)	Semi-automated grafting machines compatible with both tomato and cucurbit seedlings; 2 workers needed per machine to feed scion and rootstock seedlings. Speed with 2 workers with good coordination is up to 800 grafts per hour, but average is 625 grafts per hour.	Ten machines used in North America; 73 used in other regions (Europe, Asia, and Middle East)
EMP-300, Conic System, Spain (http://www.conic-system.com)	Semi-automated grafting machine for tomato or other solanaceous plants. One machine assists each worker to achieve 400-600 grafts per hour.	Four machines used in North America; 14 used in other regions (Europe, Asia, and Middle East)

[1] Each manufacturer provided information for their machines.

stock seedlings consistently throughout the year, which is needed for automated grafting (Zhao and Kubota, 2015).

These technologies enable nursery operations to address the increasing difficulty of securing the needed number of grafting workers. However, while both technologies reduce labor costs and loss of plants, they both require large capital investments.

Synergistic automation—New concept sought for future nursery automation

Increasing uncertainty regarding agricultural labor availability during the production peak has created a pressing need to develop sustainable solutions. Automation and mechanization are traditional solutions to increase production efficiency for industries where large numbers of workers are needed. One common approach has been to develop reliable automation that can conduct routine tasks currently done by humans. This is by far the exact approach that most efforts towards grafting automation took.

An alternative approach while providing more skilled job opportunities is to develop tools, logistics and automation that can significantly increase worker efficiency. The key concept of this alternative approach is to assist humans instead of replacing them. For example, a machine developed for tomato grafting in Spain (Conic System, Table 1) is designed to make unskilled workers achieve the grafting speed of skilled workers.

A similar type of approach is being pursued for grafting cucurbit plants as the grafting methods most commonly used for these crops is generally more complex and therefore slower than methods used for tomato grafting. Another approach may be to develop a tool or an expert system to enhance the work efficiency of a team of many workers, rather than of each individual. Computational optimization may assist managers of a grafting department to develop a weekly plan of efficient use of machines as well as task distribution among available workers according to their skill levels. A team of scientists and engineers are currently working in the area of expert system development at the University of Arizona.

Figure 2. A grafting operation in Mexico with semi-automated grafting machines. (*Photo by Helper Robotech, Korea*)

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