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Discovering Ways To Improve Nursery Practices and Plant Quality

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Working with plants is a process of discovery. Being curious and aware, paying close attention, and staying open and adaptive are important practices. Books and people can help us learn about plants in the nursery, but the very best teachers are the plants themselves. "Research" is simply tracking what is happening, asking questions about what is causing it to happen, and seeking answers. In other words, research is something most growers already do. Astronomer Carl Sagan (1996) said, "Every time we exercise self-criticism, every time we test our ideas against the outside world, we are doing science." Scientific research is simply "the testing (systematic, controlled, empirical, and critical investigation) of ideas (hypothetical propositions about presumed relations among natural phenomena) generated by intuition" (Dumroese and Wenny 2003). If research is done well, the process can yield useful, accurate information. The purpose of this chapter is to provide information about how to design easy trials and experiments to discover useful, meaningful ways to improve crop production and quality.

Some people may be lucky enough to have an elder or mentor pressing them to explore and discover more. Carrying out research, asking questions, and keeping records are ways to self-mentor. Using a systematic approach supports making accurate observations so that discoveries otherwise missed can be made and shared. It is widely acknowledged that working with plants is an art as well as a science: observation, senses, emotions, empathy, and intuition play important roles. When a question arises that is important to answer, it is time to consider conducting a trial or experiment. Growers often work with plants for which minimal literature or outside information is available. Nursery research may be subjective or objective, simple or complex. Learning how to effectively carry out experiments to evaluate new plant production techniques is essential to discovering relevant and applicable practices.

Managing a nursery in the tropics is a profession where you will learn as much or more from your own direct experience than you will learn from readings, classes, and other formal teaching. Some learning comes from experiments; but some comes from experience and reflection. A few tips for reflective practice as a way to continually learn and adapt are provided at the end of this chapter.

Facing Page: *A germination experiment. Photo by Brian F. Daley.*

The Importance of Trying New Things in the Nursery

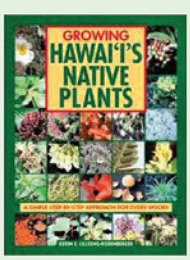
Often, the tendency is to take the path of least resistance and use known or established nursery production techniques. The first propagation technique that was tried and that produced an adequate plant may have become the established protocol. The technique, however, may be more costly or inefficient than alternate methods, and may not produce the best quality plant for the outplanting site. A few modifications could improve production, plant quality, and, ultimately, plant survival and growth after outplanting. Simple experiments enable the nursery to try out new techniques, ideas, and problem-solving strategies (figure 20.1).

The tasks of keeping up with day-to-day nursery management may feel like more than enough to fill your schedule, and time for experimentation may seem a low priority. In truth, however, most growers already engage in investigations on a regular basis. Experimentation happens every time a new idea is tested, a question leads to alternative strategies, or a problem is analyzed and solved. Taking a little care to be systematic and follow a few guidelines will dramatically increase the benefits of these activities and will provide greater confidence in the conclusions you draw from them.

Simple experiments can be carried out simultaneously with filling an order for plants. For example, in most cases, the nursery can produce plants using an established protocol and also grow some additional plants for research at the same time. One variable can be altered for the experimental plants, such as using a different seed treatment, a modified growing medium, a new type of container, or a different mycorrhizal inoculant. Your results for the experimental group can then be compared against those for the established protocol. In this way, each new crop represents an opportunity to try something new on a small scale. The discoveries can greatly improve production efficiency and seedling quality over time. Because of these potential benefits, it is worth putting a little effort into experimenting and trying new things.

The Value of Experimenting

Today's best methods for raising native plants came from growers like you learning through experimentation, then sharing what they learned. For example, Kerin E. Lilleeng-Rosenberger describes her process: [in 1989] "I was hired and put in charge of the new native Hawaiian plant nursery…I was provided with a variety of native seeds, but had neither instructions nor reference guides to follow; the majority of these plants had never been grown in cultivation before… For more than ten years, I experimented with different potting mixes, seeds, and cutting treatments, along with many other types of plant materials. I kept detailed records, which helped identify what had contributed to the successful results. Eventually, the knowledge I had gathered filled fourteen notebooks." Her book, ***Growing Hawai'i's Native Plants***, shares what she learned.



(Lilleeng-Rosenberger 2005)

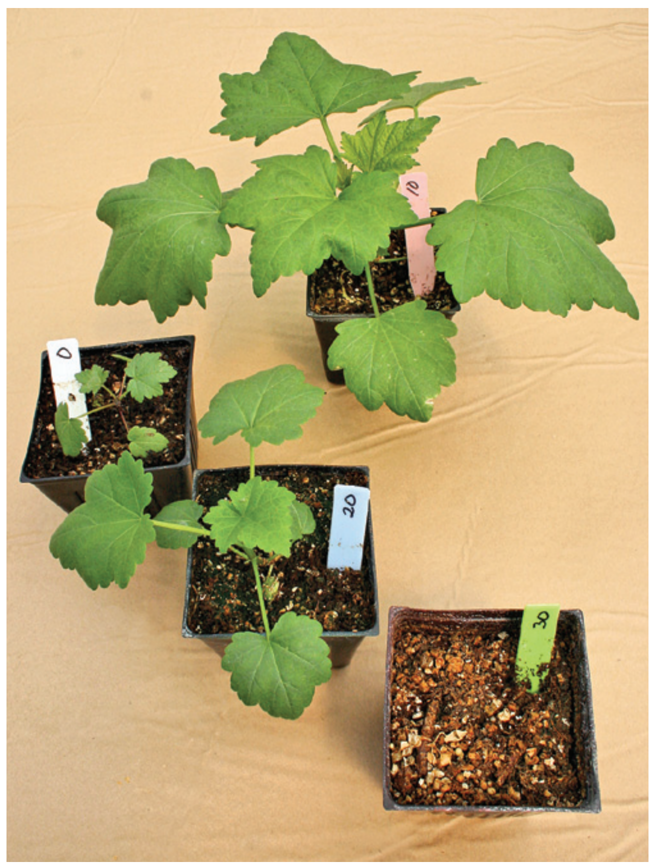


Figure 20.1—*Simple experiments and trials, such as this fertilization trial, can teach us a lot about how to grow plants. Photo by R. Kasten Dumroese.*

Conducting simple experiments and trials in the nursery can accomplish the following—

- Produce better plants.
- Speed up production.
- Save money, labor, seeds, and other materials.
- Improve outplanting survival and performance.
- Refine target plant criteria for outplanting sites.
- Contribute to greater knowledge of the plants.

Making Observations and Keeping Records

A foundation for improving plant health and quality is a good understanding of current production practices and how plants respond to them. The following three basic types of records, as discussed in Chapter 4, Crop Planning: Propagation Protocols, Schedules, and Records, are the foundation of good nursery recordkeeping (figure 20.2):

1. A daily log of general conditions and activities.
2. Development records for each crop that are filled out as the plants develop.
3. Propagation protocols that describe from start to finish how the plants are currently grown.

Additional records may also be enjoyable and valuable, such as an informal, personal journal that documents reflections in growing plants or a photo diary.

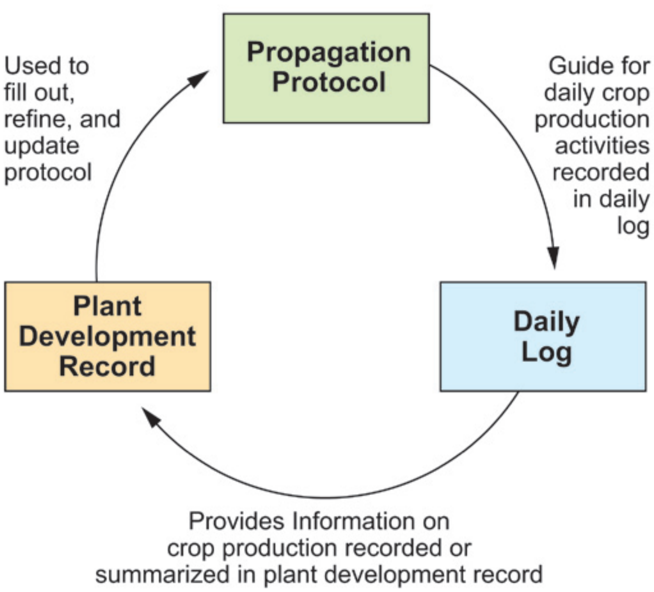


Figure 20.2*—The nursery's daily log, plant development record, and propagation protocol are the three basic kinds of records that form the foundation for learning. Illustration adapted from Dumroese and others (2008) by Jim Marin.*

These records prevent the nursery from wasting time repeating strategies that do not work while providing a plan to help duplicate successful crops. This information also establishes how crops normally perform and can be used to recognize problems or gauge the effect of alternative production methods. Perhaps most important, keeping data and cultural records in a written format creates information that can be passed on to future nursery staff or others in the community. Without these records, valuable information (perhaps gleaned from a lifetime of nursery work) may be lost, and the new grower will have to start over. Knowing in a measurable way what is "normal" helps the nursery experiment with modifications that can improve crops and productivity over time.

Solving Problems Through Collaboration and Questioning Assumptions

In our small research nursery, we had poor results growing the Virgin Islands native tree *Clusia rosea* (in some places known as the "autograph tree"). We kept having low germination rates. I shared this experience with my friend who is the local nursery owner at Cruzan Gardens. He offered to give the seeds a try. When he reported a nearly 100-percent germination, I knew he found "the trick." What had he done differently?

The tiny seeds of *Clusia rosea* are embedded in the flesh of a succulent fruit and often are eaten by bats. My standard protocol for all tree species at the time included removing all fruit and flesh from seeds before germination. My friend, however, found this method too time consuming and simply spread the seeds, still embedded in their fruit pulp, into trays of potting mix, as if he were spreading jam on toast! It turns out that my method was dessicating the tiny seeds that are not normally exposed to air.

Naturally, we revised our protocol to keep the seeds in their pulp during germination, and we were able to get great germination results, too. I learned from this experience to share my challenges with other growers and to question my assumptions.

—Brian F. Daley, U.S. Virgin Islands

Solving Problems Through Observation

We grow an important Hawaiian endemic tree, the ʻōhiʻa tree. This tree is a foundation of many Hawaiian native ecosystems. A problem we had is ʻōhiʻa rust (figure 20.3). ʻŌhiʻa rust is easily spread by the wind, and our nursery in Kamuela, on the north tip of the Island of Hawaiʻi, is always windy.

The disease would get so bad at our nursery that our mortality rate was quite high. So we started observing the ʻōhiʻa plants in different locations around the nursery. Although not fully scientific in our methods, we noticed some things that caused us to rethink the plant locations throughout our nursery.

Figure 20.3*—ʻŌhiʻa rust, shown here on an ʻōhiʻa leaf, is a disease spread by wind. Observations of wind patterns and experiments with plant locations helped staff at the State Tree Nursery in Kamuela, Hawaiʻi, to minimize losses. Photo by J.B. Friday.*

Basically we found that—

- Plants in our greenhouse were very susceptible to the rust disease (which may be because the wind slows down and "circles" in the greenhouse because only one side of the building is open, causing the wind to blow the rust spores gently around in a circular pattern over all the plants in the greenhouse).
- Plants outside exposed directly to the wind (such as on the windward side of a table or pallet) seemed as susceptible as the plants in the greenhouse.
- ʻŌhiʻa seedlings located outside on the leeward side of larger plants were relatively rust free. The larger plants may cause a disruption in the wind pattern, pushing the rust up and away from the smaller plants behind them.

After we observed these three things, we adjusted the locations of our ʻōhiʻa seedlings so they would be protected from the wind, essentially hidden from the rust. It did not totally eliminate the problem, but we experience far lower mortality rates and fewer diseased plants. We can tolerate the amount of loss now. We have tried this approach with limited success with other diseases and problems such as moving plants susceptible to mildew or powdery mold to be surrounded by plants that do not seem nearly as susceptible. So far, however, nothing has been quite as dramatic or successful as "hiding" our ʻōhiʻa seedlings from the ʻōhiʻa rust.

—Jacob Witcraft, Nursery Forester, State Tree Nursery, Kamuela, Hawaiʻi

Step 1: Developing Ideas for Nursery Experiments

Ideas for experiments may come from many places, including the following—

- A casual observation the nursery wishes to verify.
- A pressing question that seems to recur in the daily log or journal.
- An informal trial in which a difference is observed.
- A need to improve something (for example, percentage of germination).
- A need to change practices or materials (for example, the rise in cost of a potting media ingredient requiring use of substitutes).
- A desire to work with a new species.
- A desire to try out a new technique or idea.

Because staff time is limited, ideas for experiments will likely be prioritized in terms of their potential positive effect and importance to production. Nevertheless, it is good to keep a list of any potential experiments or trials that you or other staff believe would be beneficial and keep these ideas on hand to try as time allows. As described earlier, some experiments may be easy and quick to carry out and can be done efficiently as part of crop production.

Many topics lend themselves well to experimentation, including the following—

- Developing seed treatments and germination techniques.
- Testing culturing options for new species or seed sources.
- Researching microsymbiont sources or application methods.
- Altering watering regimes.
- Trying new container types.
- Trying new blends or materials in potting media.
- Changing an aspect of management, such as timing for moving crops from one phase to another.

Step 2: Gathering Information

After you have an idea of what you want to investigate, some background research is in order. Check your existing plant development records, plant protocol, and daily log to review what has happened and has been tried in the past, reflecting on your experiences and observations. Information can also be gathered from nursery staff, specialists, extension agents, and associates from other nurseries. Look up the subject in journals, books, and electronic sources of information. This background research can help narrow the focus of the experiment to a question that can be answered.

Step 3: Specifying a Question and Creating the Hypothesis

The question must be limited in scope, pertaining to only one aspect of production. It would not work to focus on multiple variables at the same time. For example, if more than one aspect of the seed treatment process (such as, season harvested, collection and processing method, sowing times and methods, and medium used during the germination phase) were modified at the same time, how would you know which modification caused a difference?

The hypothesis is the proposed answer to the focused question.

Step 4: Designing the Experiment

A good study design to answer a specific question and test the hypothesis starts with careful selection of the treatments to be evaluated (the independent variable) and the

Example: Step 1—An Idea for an Experiment

A native species consistently has less than a 25-percent germination after sowing. In addition, germination is sporadic, taking place over 4 weeks. These results occur despite good seed sterilization and handling practices. A seed test sent to a laboratory indicated that a higher percentage of the seeds are viable. The nursery wishes to increase the percentage germination. The first step is to look at the options for experimentation. What could be contributing to the low germination for this species in your nursery? And what could increase germination?

Example: Step 2—Gathering Information

An Internet search, along with a review of this manual's Chapter 8, Collecting, Processing, and Storing Seeds, indicates that when viable seeds fail to germinate, the seeds may be dormant and, therefore, may require a treatment to break dormancy. A bit of reading into the natural history of this species reveals that its seeds are often passed through the digestive system of birds, which can be a form of scarification, breaking natural dormancy. According to publications and other nursery growers consulted, several closely related species have a hard seedcoat that is usually scarified before planting. A search on the Native Plant Network (http://www.nativeplantnetwork.org/) may not find your exact species, but it shows that several growers have had success with a few related species when using mechanical scarification.

Example: Step 3—Specifying the Question and Creating the Hypothesis

From your information gathering, it appears that lack of scarification may be causing the poor germination of your species. The question that the experiment will address is now formulated: How does scarifying the seeds of this species affect its germination? The hypothesis might be, "Mechanical scarification of the seeds by hand nicking the seedcoat with a small nail clipper will result in improved germination." If time allows, it may be desirable to pose more than one treatment to answer the same question. Perhaps a second treatment to be tested separately for this example would be, "Hot water scarification for 20 seconds will result in improved germination."

response to be measured (the dependent variables). From there, the experimental design can be decided. The "Three R's" of designing a good experiment are Replication, Randomization, and Representation and are described in the following sections. Even the simplest study design needs to include these important elements to minimize the risk of generating incorrect or meaningless data. The components of the study including the question, hypothesis, plant material, treatments, and experimental design should all be written into a study plan. The study plan needs to read like a recipe so that you know what, why, when, where, and how to conduct your study.

Independent Variable (Treatments)

The independent variable is the one factor purposely changed for the sake of the experiment. It is the factor that is expected to create a response. A factor could be seed source, seed treatment method, growing medium, irrigation frequency, fertilizer rate, and so on. But, only one needs to be used as the independent variable in a simple nursery trial; all other factors must stay the same. This approach enables you to isolate whether or not changes in that factor result in a desired response. The independent variable can be modified one or more ways (treatments) and compared with an unmodified treatment (the control).

The Control

An essential aspect of experimenting is to have a control treatment. For experiments in plant production, the control treatment is simply the way the nursery usually does things according to established protocols. The performance of control plants grown in the usual way will be compared with the performance of plants grown in the modified way. All plants in the experiment need to be started at the same time and kept in the same areas of the nursery to eliminate further variation among them, thereby isolating effects of the independent variable (figure 20.4).

Dependent Variables

The dependent variables are the variables being observed or measured. These are the variables that are hypothesized to be influenced by the independent variable. Although many variables can be affected by specific treatments, you will want to decide ahead of time which dependent variables are most important to measure. For instance, fertilizer rate can change foliar nutrients, growth, survival, media chemistry, and so on. However, you will want to focus on the variable(s) that address your experimental question and hypothesis.

Figure 20.4*—Seed scarification and stratification requirements are often discovered through experimentation and trials. Careful labeling of the control and each treatment is essential. Photo by Tara Luna.*

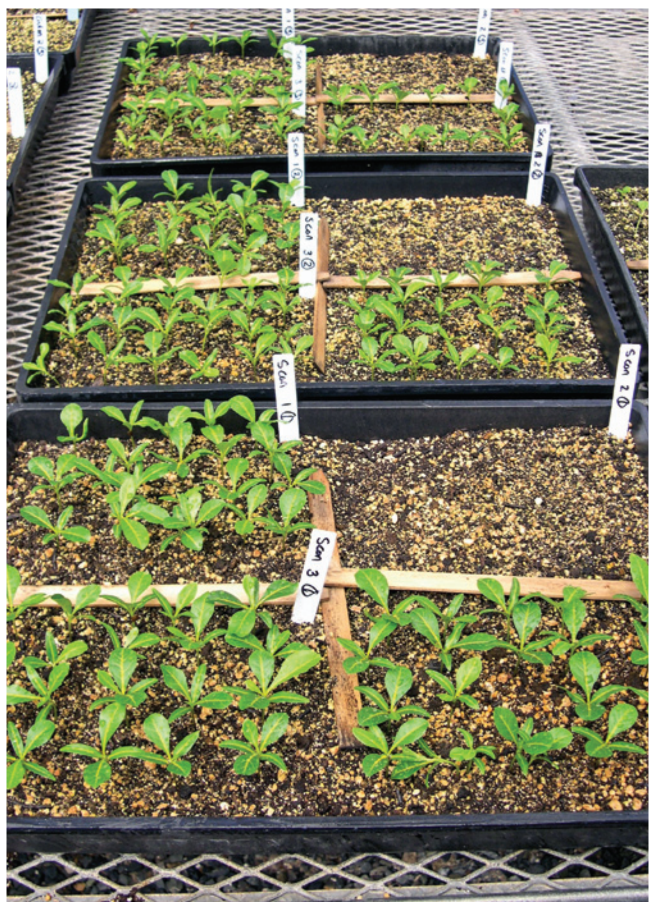


Figure 20.5*—Replications need not be large scale but should consist of at least 30 plants per treatment (including the control). Photo by Brian F. Daley.*

Replication

Research is largely about isolating the independent variable and eliminating the possibility that any other factors could be contributing to observed differences in the dependent variables. Replication is an essential aspect of this process (figure 20.5). Without replication, you cannot confidently conclude that your findings are repeatable. If too few plants are used in the experiment, any differences observed among treatments may simply be a coincidence. For this reason, it is valuable to have as many plants as is reasonable included in the experiment.

Variability in the nursery environment can profoundly affect experiments. For example, two benches may differ in the amount of irrigation or light received. Because of environmental variability, it is best to place plants from all treatments (including the controls) right next to each other, on the same bench or even in the same tray. (Of course, this placement is not possible if the objective of your experiment is to compare different growing environments; in that case, the plants will have to be located separately.) Every effort needs to be made to keep all conditions the same except the one being studied. Otherwise, you might find differences among treatments that are not actually caused by the treatment.

Replications can be individual plants or can be a group (block) of several plants (for example, a tray of seedlings). When blocking, place each of the replications in different parts of the nursery if possible. That way, if the same relative treatment differences are observed within each of the blocks, in spite of variations around the nursery, you can have greater confidence that the results are not a fluke. Each block needs to consist of a similar number of plants from every treatment (including the control). For example, a block might consist of 10 control plants, 10 treatment-1 plants, and 10 treatment-2 plants for a total of 30 plants in each block.

A few tips for having good replication include the following—

- Have at least 30 to 40 plants total per treatment (including the control)
- When blocking, use a minimum of 4 blocks and include at least 10 plants from each treatment in each block.
- For each replication, situate all treatments (including the control) adjacent to each other to reduce variation in microclimate.
- If possible, place replications in three or four different locations within the nursery.
- Because each growing season is different, the experiment may be repeated one or two times on subsequent batches of plants to confirm results.

Example: Step 4—Designing the Experiment

From your research, questions, and hypothesis, you have decided to look at scarification as your independent treatment variable. The study design will include three treatments: (1) hand nicking the seedcoat with a small nail clipper, (2) immersion in hot water (200 °F [93 °C]) for 20 sec, and (3) a nonscarified control (the current method used by the nursery). The dependent variables to be measured will be percent germination and rate of germination. You decide to have four replications; each replication will consist of 25 seeds from each of the three treatments for a total of 100 seeds in each treatment and 300 seeds total in the study. From the total supply of seeds, 25 seeds will be randomly selected and then randomly assigned to a block and treatment. For each replication, all seeds will be treated and sown at the same time into a single seed tray. The four seed trays (replications) will be placed throughout the nursery's germination area to see if results are similar among treatments.

Representation

Another important aspect of experimental design is to make sure the plant materials and treatments used in the experiment are representative of the same plant materials and treatments to which you plan to apply your results. For example, if you want to learn about the effect of fertilizer on seedlings grown in a particular sized container, then you do not want to do your study on seedlings grown in smaller or larger containers.

Randomization

It is important to randomly select the plants to be included in the study from the pool of representative plants (or seeds). It is also important to randomly assign treatments to each replication (plant or group of plants as described previously). Randomization prevents any systematic or personal bias from being introduced into the study and skewing the results; for example, using only the largest seedlings for one of the treatments would lead to the incorrect conclusion that that treatment made the seedlings grow more. Many ways exist to randomize. For example, you can roll a die or draw from a deck of cards to determine which numbered tray of seedlings to use in a study or you can draw slips of paper out of a bag with treatment names: control, treatment 1, and so on.

Step 5: Conducting the Experiment

If you feel unsure about the validity of the proposed elements of an experiment, find an ally in the local university or agricultural extension system to discuss your plan briefly. This investment of time is wise and ensures that the research successfully addresses the question posed.

After the hypothesis is posed and the treatments and experimental design determined, it is time to plan when and how to carry out the experiment. Unless the problem addressed is urgent (that is, interferes with production), it may be most economical to wait until you have an order for the species you wish to investigate. A group of plants from those grown according to the usual protocol will be designated as the control treatment. Extra plants can be planted at the same time from the same seed source and on the same day, with only the independent variable manipulated.

A few tips for starting and carrying out the experiment include the following—

- Have one person in charge of setting up the experiment, making observations, and collecting all data. Having one person in charge helps eliminate unnecessary variations in the data.
- If special materials are needed for the experiment (for example, a different microbial inoculant, a new seed source, a special growing medium ingredient), be sure to have them on hand before the experiment starts.
- Mark treatments (including the control) clearly with durable, easy-to-read labels. Nothing is worse than discovering a group of plants performing outstandingly but with no record of what was done differently.
- Do not count on experimental treatments to produce marketable plants. Use established protocols to meet client requirements. Plants devoted to research need to be above the count required for the order. If the experimental subjects turn out to be of high quality and saleable, that will be a side benefit. If growing on contract, the client may be interested in accepting research plants and to continue the trial in the field. Agreements need to be clarified in advance regarding experimental plants.
- Take careful notes and keep a journal documenting every step of the experiment as it is carried out. Changes may occur rapidly and go unnoticed if care is not taken to record them. Sometimes the independent variable will affect one brief but important stage of plant development. Keep data organized, ideally entered into a computer spreadsheet soon after taking measurements and observations.
- Be prepared to carry out the experiment more than once.

Example: Step 5—Conducting the Experiment

The experiment on seed scarification will be carried out simultaneously with growing an order of plants for that species. Do not expect to be able to use any of the seeds from the experiment (the new method may increase, decrease, or have no effect on germination percentages). So, the procedures to produce the correct number of seedlings to meet the order need to be carried out as described in your usual protocol for that species. If an order for 100 plants of the species with the usual expected 25-percent germination is received, according to the established protocol, the nursery will need to sow about 450 seeds to compensate for the low germination and other losses. A portion of those seeds (100) are designated to be part of the experiment as the control. At the same time, 100 additional seeds from the same seedlot would be scarified using mechanical scarification and 100 seeds would be subjected to the hot water treatment according to the experimental design. The four experimental seed trays (replications) and the group of 25 seeds of each treatment within each tray are clearly marked. All seeds will be treated identically otherwise. Because germination usually takes place sporadically over a 4-week period to achieve a 25-percent germination, the experiment will run 4 weeks.

Step 6: Making Observations and Collecting Data

When gathering data, keep the process as simple and straightforward as possible, and reduce risks of nonappli-

Example: Step 6—Observations and Data Collection

Each of the three seed treatments in the four seed trays (replications) in the experiment is monitored daily for 4 weeks and the number of germinants recorded. (If the emergents are to be transplanted into larger containers before the end of the experiment, it is critical to ensure the counts are accurate before transplanting. Germinants from each treatment are transplanted in separate trays and carefully marked, even in their new containers.) The percent and rate of germination are calculated from the collected data.

cable or meaningless results. For example, the wet weight of live plants will vary considerably depending on irrigation and time of day; therefore, weighing live plants does not usually generate meaningful data for experiments. For small experiments, have only one person take measurements and gather hard data (such as plant height or stem diameter) to reduce variations in the way data are collected. For larger experiments, however, it may be necessary for several people to collect data. If several people will be collecting data, make sure each person is trained to measure using the same procedures. In these cases, it is a good idea for the different people to take data on all treatments, including the control, to cancel out bias in data collection (instead of having one person collect all the data for the control and a different person collecting the data for the experimental plants).

Data collection for the experiment needs to focus on the dependent variable for that experiment. Other data and observations, if available, however, may be collected as well if time allows. Even if they are not quantified, observations about the appearance and vitality of plants can be especially useful for many experiments. Taking several photos of the experiment is another way to document your findings. Remember, by doing this type of work, you are gaining expertise; your observations are meaningful.

The best timing for data collection varies depending on what is being studied. Although any period of rapid change for the crop can be a useful time to gather data, in general, the most meaningful results tend to be gathered—

- During germination (as in the example in this chapter).
- At the beginning and end of the rapid growth phase.
- At the end of the hardening phase (just before shipping).
- After outplanting (usually after the first 3 to 12 months in the field, up to 5 years).

Stick to simple measurements and observations that are meaningful and relevant to your study. Depending on the subject of your experiment, your data collection may include one (or sometimes more) of the measurements described below.

Germination Rate and Percentages

A percentage of germination can be determined by comparing the total number of seeds planted versus the number of healthy germinants that emerge for each seed treatment.

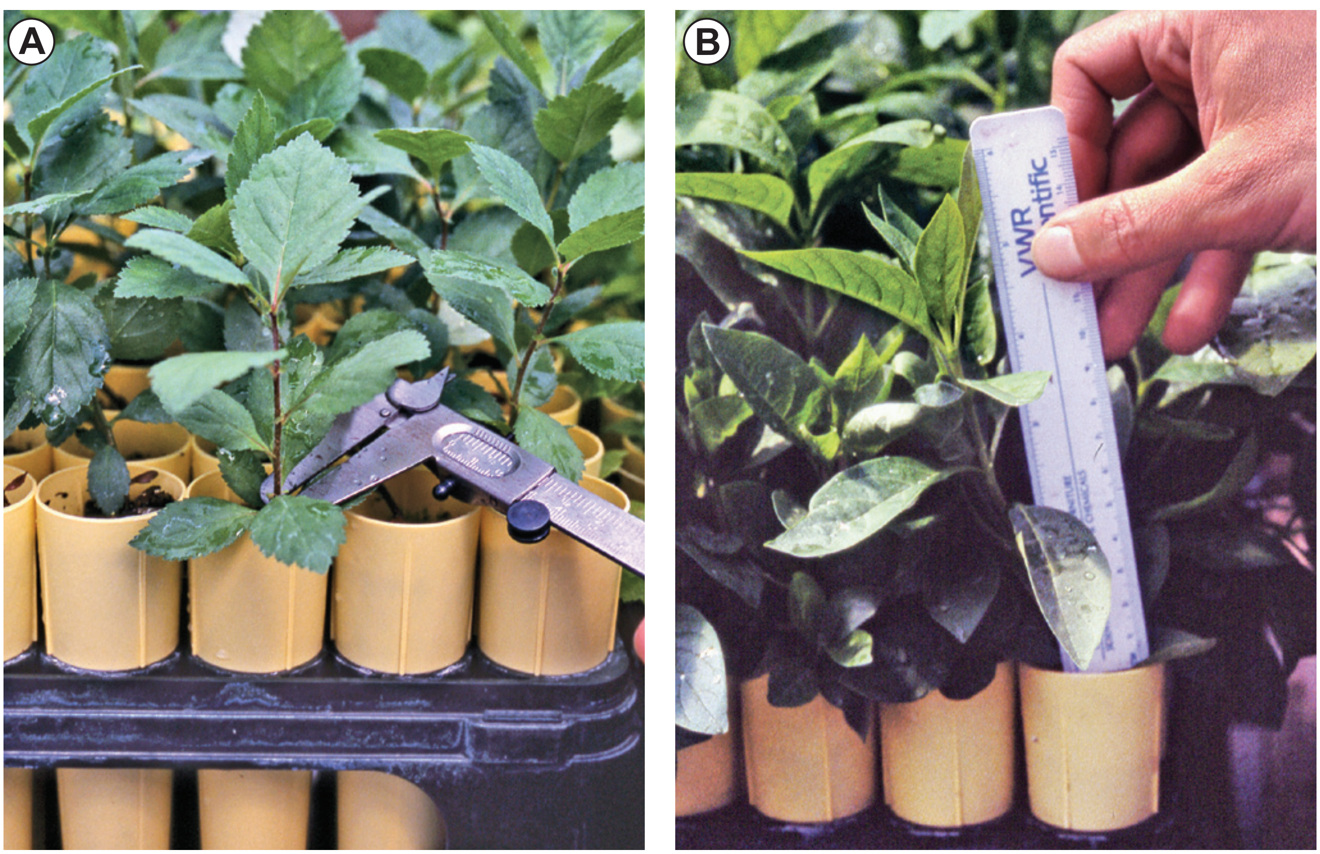


Figure 20.6*—Stem diameter measurements are usually taken just above the medium line or on the stem (A). Height can be measured from the medium surface to the top of the growing point on the stem (not the top of the leaf) (B). Photos by Tara Luna.*

Germination rate is also important to monitor: sometimes the percentage of germination will ultimately be the same but one treatment may result in uniform and rapid germination while another treatment may be uneven or delayed. Daily or weekly measurements will capture differences in germination rate.

Plant Height and Stem Diameter

These measurements are useful to compare changes in plant development among the treatments and to previous crops described in the plant development records and propagation protocol. Stem diameter measurements are often taken about 0.25 in (0.5 cm) above the medium (figure 20.6A). Height can be measured from the growing medium surface to the top of the growing point on the stem (not the top of the leaf) (figure 20.6B).

Shoot-to-Root Ratios

Shoot-to-root ratios are taken only periodically and usually only as small samples, because these measurements destroy the plants sampled. They are based on oven-dry weight. Carefully remove any medium from the roots and dry the plant samples for 72 hours at 150 °F (66 °C). A convenient way to handle plants is to put them into paper lunch bags labeled by treatment and then place them into a drying oven. After the plants are dry, cut the sample at the place where the stem meets the roots (the root collar; often a change of color occurs here) and weigh the shoots and roots separately to calculate the ratio.

Plant Survival and Vigor

Plants can be subjectively rated at the beginning and end of each of the growth phases using a numeric rating system,

Experiments Provide Opportunities To Learn More and Improve Nursery Practices

Figure 20.7 illustrates an innovative trial that resulted in a modest improvement in seed germination.

***Figure 20.7**—The small seeds of* Guazuma ulmifolia, *native to Puerto Rico and the U.S. Virgin Islands, are embedded in a hard, sweet smelling woody capsule (A). In a preliminary trial, standard treatments and a control treatment all resulted in less than 2 percent germination. Treatment with a mild acid solution caused each seed to produce a clear protective gel around itself, but the seeds still did not germinate. It was hypothesized that the seeds may benefit from passing through an animal's digestive tract. Students at the University of the Virgin Islands weighed fruit, calculated seed numbers, and mixed the fruit in with feed for sheep in pens (B). Students then collected the sheep feces from the pens daily, removed debris with screens (C), soaked the sheep pellets in water and transferred the material to germination trays (D). Germination rates were higher than the control, but variable, and averaged 20 percent. Although the students did not completely solve the problem, they obtained images of the seeds' development stages, and improved the original germination rate from 2 to 20 percent. Photos by Brian F. Daley.*

such as 0 to 5. Clear guidelines must be developed for the numerical scale to give a consistent relative estimate of plant vigor. For example, 0 = dead; 1 = no vigor, plant appears on verge of death; 2 = poor and slow growth; 3 = some growth, some vigor; 4 = plant looking vigorous; 5 = plant appears to be thriving and very vigorous.

Insect and Disease Analysis

The start and end of the rapid growth phase and the end of the hardening phase are good times to inspect for pests and disease. Some types of diseases, such as root rots, are easy to quantify and you can know what percent of your crop you lose to the disease. For other types of pests and diseases, the damage may be more subtle and you may only make qualitative observations. Samples of pests or diseases can be sent to the local agricultural extension office for identification, if necessary.

Outplanting Survival and Growth

Field performance after outplanting can also be evaluated by measuring height, stem diameter, survival, vigor, or other measures of interest (for example, amount of animal damage). See Chapter 17, Outplanting for details about ways to monitor performance after outplanting.

Step 7: Assessing, Recording, and Sharing Results

Keeping detailed records is a key part of successful experimentation. Entering observations and measurements into a computer or project journal is a very good practice (figure 20.8). A simple tabular format is fine for most types of data and makes capturing and assessing the data easier.

While only one person is recording the data, others may contribute to subjective evaluations. Also, the person in charge of the research project may solicit the observations of other staff members and enter these observations in the journal as well.

Some experiments may focus on only one phase of growth, such as the germination phase. Many others will follow plants through all phases. Regardless, when the final phase is complete, it is important to assess the data and observations collected. Data must be organized to be interpreted. In many cases, data can be graphed to visually show differences among the controls. Any results should be shared with other staff and entered into the records. If the experiment focused on producing one species, the results need to be entered into the protocol notes for that species, even if no difference was observed. If a difference was observed, and one or more of the treatments resulted in better germination, survival, or quality than the control, the experiment needs to be repeated at least once or twice more to verify the results. In the interim, however, the new production technique can tentatively become the new protocol. If, after a few repetitions, the same results are found, the new technique can be adopted as the official protocol.

Figure 20.8*—Keeping good records is a key part of successful experimentation. Photo by Tara Luna.*

If no difference was observed, or if the control treatment performed the best, that is still very valuable information. Keep good records in the plant protocol notes of what was tried, even if it failed. Otherwise, someone might think to try it again, wasting time, resources, and energy. In addition, noting ideas for future experiments is an important part of concluding the experiment.

Consider sharing your experimental results at nursery meetings, by submitting short papers to professional publications such as *Native Plants Journal*, or by uploading the information into the Native Plant Network (http://www.nativeplantnetwork.org).

Requesting Assistance When Needed

The ability to carry out your own experiments as described in this chapter is an empowering tool for improving plant growth, quality, and survival in your nursery. Experimenting can also help save you and your clients money and time over the years. Sometimes, however, an idea arises for a much-needed experiment that is beyond the scope of what you are comfortable exploring by yourself. Perhaps the idea is too complex, costly, or time-consuming or requires more intensive statistical analyses. If you believe your idea would benefit you and other growers like you, discuss the problem you are facing and the ideas for possible solutions with an extension specialist or someone at your local university. Often, researchers are interested in conducting research to help native plant growers

Example: Step 7—Assessing, Recording, and Sharing Results

The final count of germinants from each replication of the control treatment is counted, and 26 out of 100 seeds germinated (table 20.1). For the seeds that were mechanically scarified, 79 of the 100 seeds germinated (79 percent) but there were no germinants for seeds treated with hot water at the end of the 4 weeks (table 20.1). A graph can be drawn to show cumulative germination on each day for each treatment (figure 20.9). For control seeds, cumulative germination increased at a constant rate throughout the 4 weeks of the trial and it appeared germination would continue to occur although the experiment had concluded. For seeds that were mechanically scarified, however, the graph indicates that most of the germinants emerged 3 to 8 days after sowing, with germination rates tapering off after the eighth day. This small trial showed that mechanical scarification yielded higher germination percentages and faster germination rates than the control. Although some variation existed from block to block, the differences among treatments within each block were similar indicating that the treatment results were not an isolated, chance event. As a result, the germination protocol for this species can be revised to include mechanical scarification as the seed treatment method.

The hot water treatment will also be noted in the protocol notes. Although a closely related species is known to respond well to hot water, the 20-sec treatment in 200 °F (93 °C) water on these seeds resulted in a 0-percent germination. It is likely that the 20-sec exposure was too long for this species—perhaps this species is smaller seeded than the related species described in the other protocol. A shorter time in the same temperature water or a lower water temperature could be tested to see if those treatments scarify the seeds effectively without harming them. A future experiment could include only 10 sec in 200 °F (93 °C) water or 20 sec in 170 °F (77 °C) water. If a large order for this species is received in the future, scarification will be very labor-intensive to do mechanically by hand. The notes about the hot water option, what did not work and what might work, will be a key piece of information for future discoveries.

In addition to the nursery's records, the manager publishes the experimental findings on the Native Plant Network (http://www.nativeplantnetwork.org) to help other growers who are learning to produce this species.

Table 20.1—*Example experiment results.*

Treatment	Seeds treated	Germinated
Control		
Block 1	25	8
Block 2	25	6
Block 3	25	5
Block 4	25	7
Total	100	26 (26%)
Mechanical nick		
Block 1	25	22
Block 2	25	19
Block 3	25	16
Block 4	25	21
Total	100	79 (79%)
Hot water		
Block 1	25	0
Block 2	25	0
Block 3	25	0
Block 4	25	0
Total	100	0 (0%)

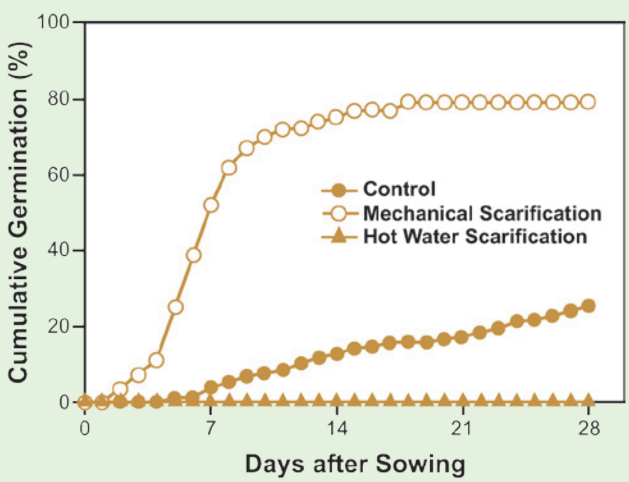


Figure 20.9—*After the final germination count, a graph can be drawn from the table to show cumulative germination on each day. Illustration by Jim Marin.*

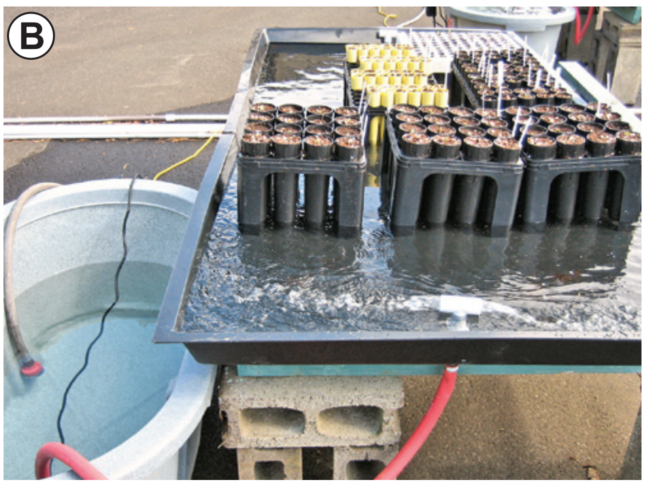


Figure 20.10—If an idea for an experiment is beyond the scope of what you are comfortable exploring yourself, get in touch with an extension agent or researcher. A nursery manager discussed the drawbacks of overhead irrigation of broad-leaved tropical plants—for example, these mahogany seedlings in Palau (A)—with a Forest Service nursery specialist. The specialist communicated the issue to researchers, who took up the challenge of testing and developing subirrigation systems for tropical nurseries (B). Photo A by Tara Luna and photo B by Douglass F. Jacobs.

and may be glad to receive suggestions from a practitioner about what would be a useful study. For example, the subirrigation techniques for tropical plants described in Chapter 11, Water Quality and Irrigation, came about after a nursery manager discussed the challenges and drawbacks of overhead irrigation of broad-leaved tropical plants with a Forest Service nursery specialist. The grower suggested that it would be useful to have a way to water plants from below instead of from above to improve water-use efficiency for tropical nurseries. The nursery specialist was aware of subirrigation practices, but not of applications for tropical seedlings, and so he passed the idea along to researchers at Purdue University and in the Forest Service. The researchers developed and tested some uses of subirrigation with tropical tree seedlings (figure 20.10). The methods are promising and are being shared at nursery and native plant conferences and in publications (Dumroese and others 2007). This type of cooperation between practitioners and researchers benefits growers and researchers and their nursery plants. Because many researchers work to serve the public interest, make sure you mention how the study would be helpful not only for your nursery, but also for other growers of native plants.

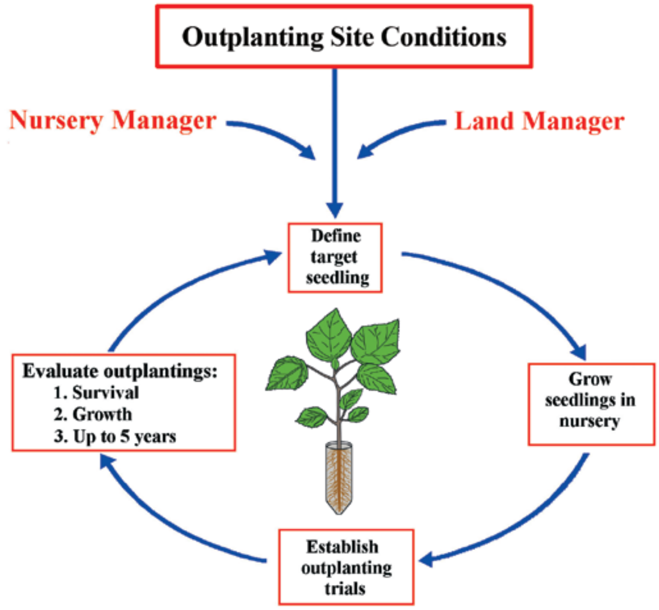


Figure 20.11—Field testing and refining the target plant criteria for various sites and objectives is an important part of nursery management. Illustration by Jim Marin.

Field Testing To Refine the Target Plant

Beyond experiments to improve nursery production, field testing, and improving the target plant criteria for various sites and objectives is an important part of nursery management. This testing was described in Chapter 3, Defining the Target Plant. At the beginning of a planting project, the land manager and the nursery manager agree on certain target morphological and physiological specifications for the plants the nursery will grow. These specifications are based on the eight-step assessment of site conditions, limiting factors, outplanting windows, and so on. After this prototype target plant is grown in the nursery, it is outplanted and monitored for survival and growth to assess its suitability for the site conditions. Both the nursery manager and the land manager learn from field monitoring (figure 20.11).

***Figure 20.12**—The most useful measurements and observations after outplanting include plant growth rates (A,* Cedrela odorata *in Costa Rica) and survival (B,* Acacia koa *in Hawai'i). Photos by Douglass F. Jacobs.*

Plots need to be monitored during the first month or two after outplanting and again at the end of the first year for initial survival (figure 20.12). Subsequent checks after 3 and 5 years will give a good indication of plant growth and survival rates. The client and the nursery manager then use this performance information to refine the target plant specifications for the next crop. The client may also alter their outplanting practices to achieve better survival and growth based on this information.

Beyond Experiments: Learning Through Reflective Practice

Managing a nursery is a profession in which you will learn as much or more from your own experience as you will learn from books, classes, and other formal teaching. In addition, managing a nursery is both an art and a science. Much of this book has been about the science. This chapter's focus has been on learning from, and experimenting with, plants. Some types of learning, however, cannot come from controlled experiments; some learning comes from experience and reflection. The social, economic, and ecological context in which your nursery operates will change and shift over the years; your own motivations, values, and strategies will also evolve as you grow personally and professionally. Making room in your schedule to reflect on larger experiences, observations, and questions allows you to learn from and adapt to these inner and outer changes; this is called "Reflective Practice" (Schön 1983).

Reflective practice is gaining use within many professions where learning from direct experience is as important as formal learning; the educational and medical professions are two examples (Wikipedia 2011). Reflective practice is valuable for nursery management and other environmental professions, providing time and space to question and refine beliefs, values, strategies, and practices and to reflect on the changes happening locally and globally. Reflective time enables the practitioner to improve results and to align work more fully over time with personal values and interests.

The question of how to continually learn from experience is an important one for nursery managers. Reading on the subject of reflective practice or taking a training can help you cultivate a reflective practice. The most important thing is to simply be aware of the value of reflection and make time to reflect regularly. Setting aside even 1 hour per week or month for uninterrupted reflection time can be invaluable. Taking this time can actually save time in the

Learning and Adapting Through Reflective Practice

With the different hats I wear at the nursery and in my community, I am busy. But I know the time I take to sit and reflect has helped me to adapt to the changing needs of the land and people on this island. Here are some ways I have adapted over the years:

I noticed that when many people came to visit the nursery, they wished to connect with the serene environment and the forest nearby, to simply enjoy the land and see native plants growing. I'm probably not the only nursery manager in the tropics who's had people come to visit and want to stay all day! I also enjoy sharing with my visitors. So, the question I contemplated was, how to share this environment yet still make a living? After a while, I found my solution. Right on the nursery grounds, I set up a retreat cottage for overnight stays, stocking it with all the creature comforts including local Kona coffee, plus field guides about our native birds and forests. I also began to offer guided forest walks to guests. This cottage has been a source of side income and given me a chance to share with visitors a deeper experience of the forest and the native plants growing in the nursery.

Most local restoration efforts 20 years ago, including mine, focused on our upland and cloud forests. Somehow we as a society were blind to the critical value of our endangered tropical dryland ecosystems. As the importance of dryland forests came on our radar, I did my research and learned ways to help restore these forests and to grow their plants. I now provide endemic dryland species including mamane, ulei, naio, lama, aweoweo, and many others that were not available commercially a decade ago. I also took on coordinating the Native Hawaiian Seed Bank Cooperative to help protect these and other native species by saving seed. This shift has been a good match between society's changing priorities, my conservation interests, and the needs of the land.

Although my passion is growing plants, I've long been concerned about helping the native wildlife that depend on these plants. I have taken time over the years to sit in observation in the local forests and watch the ways plants and birds associate with each other. I know birds that eat the manono with dark purple fruit, pilo with orange fruit, akala, the Hawaiian raspberry (figure 20.13A), and naio with white fruit. Observing the birds taught me to prioritize learning to grow their important habitat plants in my nursery. The observation and reflection also helps me to better understand processes and interactions in a diverse and healthy forest, to better mimic them in restoration of disturbed lands.

I don't know what the future will bring. But I know as I take time to reflect, learn, and stay aware of what is going on around me as well as within, my nursery will be able to evolve with the changing times.

—Jill Wagner, Forestry Consultant, Kailua Kona, HI
Owner, Future Forests Nursery, LLC
Coordinator, Hawai'i Island Native Seed Bank Cooperative

***Figure 20.13**—Ripe fruits of 'akala, the native Hawaiian raspberry (*Rubus hawaiensis*), observed to be an important food source for native birds (A). Jill Wagner at a dryland forest outplanting site (B). Photo A by J.B. Friday, and photo B by Yvonne Yarber Carter.*

long run by raising awareness of inefficiencies and helping prioritize where to focus energy and resources. Examples of reflective practices include—

- Keeping a journal and reviewing it from time to time.
- Revisiting your nursery's vision statement, guiding principles, roles, and goals.
- Interacting with clients a few years after planting to follow up on the experience.
- Contemplating your own practices and beliefs, the results you are currently achieving, and your own dreams or ideas.
- Considering the changing community needs and public concerns, and how these criteria may align with your own values and the nursery's vision.
- Sitting and observing interactions in healthy ecosystems similar to the ecosystems you work to restore, and making notes of what you learned.
- Reviewing photos of your plants, projects, and nursery operations and reflecting on your thoughts and feelings.
- Taking time after a meeting or conference to sum up what you learned and what it might mean for you and your work.
- Sharing your insights with colleagues or friends.

Whether your nursery is large or small, for-profit, nonprofit, or public, reflective practice will help you continually learn, adapt, and evolve.

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