Discovering Ways To Improve Crop Production 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 paying close attention, tracking what is happening and what is causing it to happen, asking questions, and seeking answers. In other words, research is something many growers already do. 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." If research is done well, the process can yield useful, accurate information. If done ineffectively, the process can waste time or yield meaningless or inaccurate conclusions (Dumroese and Wenny 2003). The purpose of this chapter is to help design easy trials and experiments to discover useful, meaningful ways to improve crop production and quality.

Asking questions and finding answers is the essence of learning. Some people may be lucky enough to have an elder or mentor in their life who is always asking them questions and pressing them to explore and discover more. Carrying out research, asking questions, and keeping records are ways to "self-mentor." A systematic approach supports the making of accurate observations, honing senses and awareness 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

Fertilizer experiment by R. Kasten Dumroese.

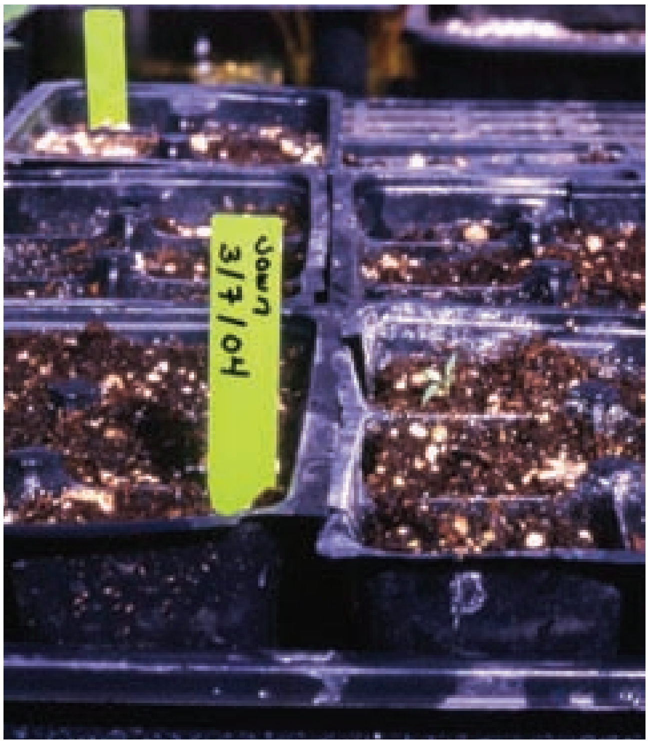


Figure 17.1—*Even simple experiments, such as this seed treatment trial for penstemon, can teach us a lot about how to grow plants.* Photo by Tara Luna.

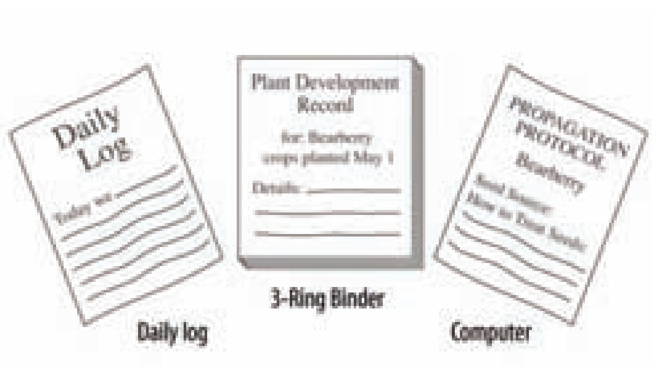


Figure 17.2—*The daily log, plant development record, and propagation protocol are the three basic kinds of records that form the foundation for learning more.* Illustration by Jim Marin.

play important roles. When a question comes up that is important to try to answer, it is time to think about doing a trial or experiment. Because growers are often working with plants for which minimal literature or outside information is available, many questions about optimal techniques will come up. The observations may be subjective or objective; research projects can be simple or complex. Learning how to effectively carry out experiments to evaluate new plant production techniques is essential to discovering relevant and applicable answers.

WHY TRY NEW THINGS IN THE NURSERY?

Often, the tendency is to take the "path of least resistance" and use known or established production techniques. Especially for species that are new to the nursery, the first technique that was tried and that produced an adequate plant may have become the established protocol. The original 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 go a long way to improve production, plant quality, and, ultimately, plant survival and growth after outplanting. Simple experiments allow the nursery to try out new techniques, ideas, and problem solving strategies (figure 17.1).

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

Often, simple evaluations can be carried out simultaneously with producing an order for plants. For example, in most cases, if the nursery has an order for plants, it can produce them using established methods as described in the protocol and also grow some additional plants for research at the same time. One variable can be altered for the additional plants, such as using a modified growing medium, a new type of container, or a different mycorrhizal inoculant. In this way, each new crop represents an opportunity to try something new on a small scale. The discoveries could greatly improve production efficiency and seedling quality over time. Because of these potential benefits, it is worth putting a little effort into trying new things.

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

- Produce better plants.
- Speed up production.
- Save money, labor, and materials.
- Improve outplanting survival and performance.
- 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 basic recordkeeping discussed in Chapter 3, *Crop Planning and Developing Propagation Protocols*, provides this foundation. The following three types of records are most important:

- A daily log of general conditions and activities.
- Development records for each crop that are filled out as the plants develop.
- Propagation protocols that describe from start to finish how the plants are currently grown (figure 17.2).

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 it can be used to recognize problems or gauge the impact of production methods and alternatives. 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 manager 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 OBSERVATION

"Seeds of candle yucca did not germinate well the first year we tried growing it in the nursery. After spending time in the habitat and observing the plants in their natural setting, I observed that yucca seedlings germinated in the crown of the mother plant within the dried cane stalks. I collected a dried cane stalk and cut it into a block, and inserted seeds into it. The seeds germinated very well…

Photos by William Pink

…Next, I applied this natural germination pattern on a larger scale by cutting yucca cane blocks into small pieces, inserting one seed into each and placing them in a plug tray.

The sugars in the cane blocks must help with the germination of the seeds, and I transplant them into individual containers once the root and shoot is well developed."

William Pink, Pechanga Band of the Luiseno Indians

WHERE DO IDEAS FOR EXPERIMENTS AND TRIALS COME FROM?

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.
- An informal trial in which a difference is observed.
- Something that can be improved (for example, percentage of germination).
- A desire to work with a new species or a new seed source.
- A desire to try out a new technique or idea.

Because staff time is limited, ideas for experiments will need to be prioritized in terms of their potential positive impact and importance to production. Nevertheless, it is good to keep a list of any potential experiments or trials that staff think would be beneficial, and keep these ideas on hand to try out as time allows. Some types of experiments may be easy and fast to set up and conclude, and they can be done efficiently as part of crop production.

Experiments and trials can be conducted to improve nursery production, learn about new species, or to try out different strategies for growing plants. Many topics lend themselves well to experimentation, including the following:

- Developing seed treatments and germination techniques.
- Researching microsymbiont sources or application methods.
- Testing out new seed sources.
- Altering watering regimes.
- Trying new container types.
- Changing an aspect of management, such as timing for moving crops from one environment to another.

GATHERING INFORMATION AND SPECIFYING A QUESTION

At this point, some background research is in order. The person initiating the experiment may look back on their own experiences and observations to search for ideas. Checking the existing plant development records, plant protocol, and daily log is essential to track what has happened and what has been tried in the past. 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. A little background research like this can help narrow the focus of the experiment to a question that can be answered.

Note that the question must be limited in scope, pertaining to just one aspect of production. It would not work to focus on multiple variables at the same time. For example, if many aspects of the seed treatment process (for example, season harvested, collection and processing method, sowing times and methods, and media used during the germination

EXAMPLE: STEP 1— AN IDEA FOR AN EXPERIMENT

For example, perhaps one native species that is grown in the nursery consistently has low percentage germination. Less than 25 percent of the seeds germinate after they are planted, and germination is sporadic, taking place over 4 weeks. These results occur despite good seed sterilization and handling practices, and a seed test sent to a laboratory indicated that a higher percentage of the seeds are viable. The nursery wishes to try to increase the percentage germination. The first step is to look at the options for experimentation. What could be contributing to the low germination?

EXAMPLE: STEP 2— GATHERING INFORMATION

Perhaps not much information is available in the literature that discusses this particular species directly. According to publications and other nursery growers consulted, however, several closely related species have a hard seedcoat that is usually scarified prior to planting. According to literature and other growers, mechanical scarification (nicking by hand with a nail clipper) is sometimes used, and other nurseries use a 20-second hot water treatment to scarify their seeds. Perhaps lack of proper scarification is causing the poor germination. The question that the experiment will address is formulated: How does scarifying the seeds affect germination?

phase) were all modified at the same time, how would the experimenter know which modification caused a difference? Pose a focused question that can be answered by experimentation.

THE HYPOTHESIS

The hypothesis is the proposed answer to the focused question or problem posed.

EXAMPLE: STEP 3—THE HYPOTHESIS

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." These two treatments (mechanical and hot water scarification) will be compared against a third treatment that is not modified in any way. In other words, if the seeds are usually not scarified according to the protocol and the plant development records, the third set of seeds will not be scarified. This third treatment is the control for the experiment.

THE VARIABLES OF THE EXPERIMENT

All experiments have the following three essential parts:

- The control (the way things are usually done).
- The independent variable (the one thing that is changed for the experiment).
- The dependent variable (the thing being observed as it is affected by manipulating the independent variable).

The Control

An essential aspect of experimenting is to have a control. For experiments in plant production, the control is simply the way the nursery usually does things according to established protocols. Nothing is changed. For the scarification example, growing medium, seed source, fertilizer, watering regime, light, container type, spacing, and all other factors would be carried out as usual. The performance of control plants grown in the usual way will be measured against the performance of plants grown in a modified way. Plants in the control and the experiment should be started at the same time and kept in the same areas of the nursery to eliminate other potential differences between them, thereby isolating the factor being evaluated (figure 17.3). If possible, it is a good idea to have several identical controls.

Figure 17.3—*Seed scarification and/or stratification requirements are often discovered through experimentation and trials. Careful labeling of the control and each treatment is essential.* Photo by Tara Luna.

The Independent Variable

The independent variable is the one factor purposely changed for the sake of the experiment. In the example, the scarification of seeds is the only aspect of production that is manipulated. Everything else must stay the same. The seed source, collection, and cleaning; growing medium; light and watering regime during germination; and all other factors would not be modified. Only the independent variable is altered. If more than one variable is manipulated, isolating which variable caused a change is impossible.

The Dependent Variable

The dependent variable is the variable being observed. In the example, the percentage germination is being observed.

Repetition and Blocks

Research is largely about isolating the independent variable and eliminating the possibility that any other factors could be contributing to observed differences.

Repetition is an essential aspect of this process (figure 17.4). If too few plants are used for the control or the treatment, any differences observed may simply be a coincidence. For this reason, it is valuable to have as many control and treatment plants as is reasonable for the experiment.

Variability in the nursery environment can affect experiments, and this variability may go unnoticed. For example, two benches thought to be equal may have subtle differences in irrigation or light received. Because of environmental variability, it is best to place treatments and controls right next to each other, on the same bench or even in the same tray. When repetitions are carried out (with multiple blocks), have the block of each kind of treatment (including the control) grouped together, but place each of the repetitions in several different parts of the nursery if possible. In other words, if you have four blocks, each with a control, treatment 1, and treatment 2, place each of these blocks in a different part of the nursery. That way, if a difference is observed, the researcher can be more confident in the results because the possibility of a fluke is reduced.

A few tips for having good repetition include the following:

- Have at least 30 plants per treatment and 30 plants per control, or grow at least three trays each of treatment and control.

Figure 17.4—*Repetition need not be large-scale, but it is important to reduce the possibility that outside factors could be affecting observed differences in the experiment.* Photo by Tara Luna.

- If possible, replicate treatments in three or four different locations within the nursery.
- Situate treatments and the control immediately adjacent to each other to reduce variation in microclimate (also consider splitting the block or tray [half treatment and half control]).

Because each growing season is different, the experiment may be repeated one or two more times on subsequent batches of plants. After the first experiment, however, the results may indicate strongly that the new method led to better germination or higher quality plants. If so, for subsequent crops, this new way can become the protocol (the way plants are grown at the next production time), and, if desired, a small batch of seedlings using the "old" method can also be grown for comparison purposes and to verify that the new method works better.

CARRYING OUT THE EXPERIMENT

If the researcher feels unsure about the validity of the proposed elements of an experiment, find an ally in the local university or agricultural extension system to discuss the plan briefly. It usually takes only a few minutes to have someone verify that the experiment is soundly designed. This is a wise investment of time, saving the trouble of investing in research that does not succeed in answering the question posed.

After the hypothesis is posed and the treatments and repetitions decided on, it is time to plan when and how the experiment will actually be carried out. Unless the problem addressed is urgent (that is, interferes with production), it may be most economical to wait until the nursery has an order to produce the species that is part of the research. The production of these plants carried out according to the usual protocol will be the control. 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 the experiment, making observations and collecting all data. This person should be involved in the research from start to finish. Having one person collect data eliminates the possibility that two people are measuring or making observations in different ways. It also ensures that one person is responsible for keeping records.

- 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 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. Mark the control group as well.
- Do not count on experimental treatments to produce marketable plants. Use established protocols to meet client requirements. Plants devoted to research should 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. Experimental plants, however, will likely be different in size or performance from the bulk of the order. If growing on contract, the client may be interested in accepting research plants to continue the trial in the field. Agreements should 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 just after taking measurements and observations.
- Be prepared to carry out the experiment more than once.

MAKING OBSERVATIONS AND COLLECTING DATA

The focus of the experiment dictates the types of information to be collected and observations to be made. When gathering data, keep the process as simple and straightforward as possible, and reduce risks of non-applicable 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 just one person take measurements and gather "hard" data in order to reduce variations in the way data are collected. For larger exper-

EXAMPLE: STEP 4—CONDUCTING THE EXPERIMENT

Let's say this experiment on seed scarification will be carried out simultaneously with growing an order of plants for that species. The nursery should not count on being 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 produce the correct number of seedlings to meet the order should be carried out as usual. Seeds should be collected and processed as described in the protocol and records 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 probably need to sow about 450 seeds to compensate for the low germination and other losses. At the same time, additional seeds from the same seedlot would be scarified using mechanical scarification. A minimum of 30 seeds should be treated and sown, although, if the supply of seeds is abundant, the researcher might choose to treat more seeds with the new method for a good-sized sample. All these seeds are planted on the same day and placed in the same environment as the control treatment. If they are in separate trays, they should be placed side by side to eliminate any other variables (such as differences in light or humidity) that might affect the germination rate. For a larger experiment, replicating the trial in three or four different locations in the nursery helps eliminate outside variables. The experimental set is clearly marked with exactly what is different about it. All seeds will be treated identically otherwise. If a third treatment (20 seconds with hot-water scarification) is used on a third set of seeds, it, too, should be handled identically otherwise and clearly marked. The control, scarified, and hot-water treated seeds are placed side by side in the same environment or in replicated blocks, as the control. Now, it is time to watch, observe, and collect data.

iments, however, it is a good idea for several people to take data on all treatments, including the control, in order to cancel out bias in data collection. If several people will be collecting data, make sure each person is trained to measure using the same procedures.

Although information on how to keep records of crop progress is provided in Chapter 3, *Planning Crops and Developing Propagation Protocols*, data collection for the experiment should focus on the dependent variable for that experiment (in the example, percentage of germination). 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.

The best timing for data collection also 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).

Measurements may include the following but not every experiment will require all these measurements—only the ones relevant to the study. Stick to simple measurements and observations that are meaningful.

Germination Timing and Percentages. A percentage of germination can be determined by comparing the total number of seeds planted with the number of healthy germinants that emerge for each seed treatment. Timing is very important to monitor: sometimes the percentage of germination will ultimately be the same but one treatment may facilitate uniform and rapid germination while another treatment may be uneven or delayed. Encourage daily or weekly measurements to capture differences in rate of germination.

Plant Height and Root-Collar Diameter. These measurements are useful to compare changes to the timing and development of plants to the control and to previous crops described in the plant development records and propagation protocol. Root-collar diameter measurements are often taken about 0.25 in (0.5 cm) above the medium (figure 17.5A). 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 17.5B).

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 before placing them into an oven. The treatment can be written directly on the bag to avoid confusion. 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 get the ratio.

Plant Vigor. Plants can be subjectively rated at the beginning and end of each of the growth phases using a numeric rating system, such as 1 to 5. Clear guidelines must be developed for the numerical scale to give a relative estimate of plant vigor. For example, 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. Noting, and perhaps quantifying, the presence of disease or insects can be done regularly. Good times to make notes are during emergence and at the ends of the establishment, rapid growth, and hardening phases. Samples of pests or diseases can be sent to the local agricultural extension office for identification, if necessary.

Outplanting Survival and Growth. Field survival and performance after outplanting can also be evaluated using most of the previously described techniques.

RECORDING, ASSESSING, AND SHARING FINDINGS

Keeping good records is a key part of successful experimentation. Entering observations and measurements into a computer or project journal is a very good practice (figure 17.6). A simple tabular format is fine for most types of data and makes capturing and assessing the data easier. If feasible, only one person should be taking measurements and recording data in the journal in order to eliminate variable styles of measurements (figure 17.7). Others may contribute to subjective evaluations, however, and 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 types of experiments may focus on just 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 time to step back and assess the data and observations collected. Data must be organized to be interpreted. If percentages were used, the data can be converted into a graph or chart to visually show differences between the control and the experiment. Any results should be shared with other staff and entered into the records. If the experiment was focused on producing one species, the results should be entered into the protocol for that species, even if no difference was observed. If a difference was observed, and the experimental seedlings had better germination, survival, or quality than the control, the experiment should 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, with the old technique repeated on the smaller scale for comparison purposes. If, after a few repetitions, the same results are found, the old method can be retired and the new one adopted as the official protocol.

If no difference was observed, or if the experimental treatment performed more poorly than the control, that is still very valuable information. As Thomas Edison said, "Every wrong attempt discarded is another step forward." The observation should be entered in the plant protocol notes. (That is, "A trial to scarify this species using a 20-second hot-water (200 °F [93 °C]) treatment resulted in 0 percent germination.") Now that it is known that 20 seconds in 200 °F hot water decreased germination (and likely killed the seeds with too much heat), other scarification techniques (lower temperature, shorter time in hot water, or mechanical methods) can be tried. Noting ideas for future experiments is an important part of concluding the experiment.

Figure 17.5—*(A) Root-collar diameter measurements can be taken at the medium line or elsewhere along the stem as long as the place where the measurements are taken is consistent from plant to plant. (B) Height can be measured from the medium surface to the top of the growing point on the stem (not the top of the leaf).* Photos by Tara Luna.

EXAMPLE: STEP 5— OBSERVATION AND DATA COLLECTION

According to the protocol, germination usually takes place sporadically over a period of 4 weeks in order to achieve 25 percent germination. Therefore, the experiment will run 4 weeks. Each tray of seeds is monitored daily 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 make sure the counts are accurate prior to transplanting. Ideally, germinants from each treatment are transplanted in separate trays and/or carefully marked, even in their new containers. At the end of the 4 weeks, the experiment will be complete.

In the early years of the nursery, especially one growing native and culturally important plants, the improvement rate resulting from experiments and trials can be very high. Many new techniques that are tried will lead to better quality plants and more efficient production. As the nursery gains expertise in the most effective strategies for each species, the focus of experiments may shift in later years to bring about more subtle improvements.

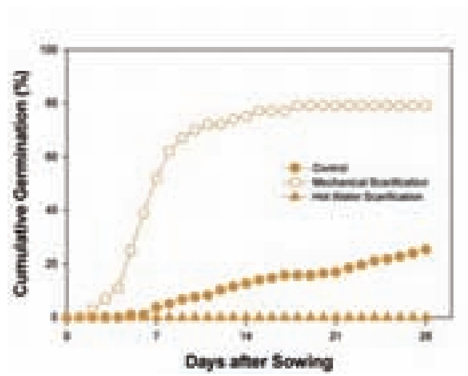
Again, keeping good records and making brief notes of experimental results in the protocols have tremendous long-term value. For example, perhaps the example species will be mechanically scarified by hand using a small nail clipper for some years after this experiment. Then, one day, the nursery receives a very large order for that species and the staff begins to wonder if they can save the labor of hand scarification by using hot water instead. They will be very glad to find results and suggestions from the first experiment, and they will be able to build on that knowledge. Also, consider sharing 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).

SUMMARY

When a nursery is just starting out, many aspects of plant production are waiting to be discovered. Being aware and "connected" to plants will make nursery employees better observers and better growers. Having a "green thumb" is possible, and it can be cultivated by

EXAMPLE: STEP 6— RESULTS

The final count of germinants from the control treatment is tallied: 114 germinants out of 450 seeds, slightly over the usual 25-percent germination. A graph could be made to show their cumulative germination on each day—in the example cumulative germination was increasing at a constant rate throughout the 4 weeks of the trial and it appeared germination would continue to occur even though the experiment had concluded. For the seeds that were mechanically scarified, 79 out of the 100 seeds germinated: 79 percent. If a graph were made of the number of germinants emerging per day, it would show that most of the germinants emerged 3 to 8 days after sowing, with germination rates tapering off dramatically after the eighth day. For the third treatment, in which seeds were treated with hot water for 20 seconds as a scarification technique, no germinants had emerged by the end of 4 weeks. Therefore, mechanical scarification yielded high germination percentages that occurred rapidly—germination characteristics desired in a nursery. The protocol will be revised to call for mechanical scarification as the method of seed treatment.



asking questions. Research is a way of exploring and learning from plants through direct experiences. Experimenting is a key part of nursery development because it leads to an increased understanding of the plant's needs and, potentially, to increased productivity.

Keeping some baseline records is invaluable for nursery productivity and development. Daily logs, plant development records, and propagation protocols form the foundation of future research and trials to improve plant quality. Nurseries that are interested in

EXAMPLE: STEP 7— NOTING FAILURES AND SUCCESSES FROM EXPERIMENTS

Mechanical scarification worked very well, resulting in improved germination percentages and more uniform timing for germination. Mechanical scarification will become part of the standard protocol for seed treatments. As far as the hot water treatments, even though a closely related species is known to respond well to hot water, the 20-second treatment in 200 °F (93 °C) hot water on these seeds resulted in 0 percent germination. It is likely that the 20-second exposure was too long for this species and "cooked" the seeds. A note should be made of this result and of the questions that arise: Perhaps a shorter time in the same temperature water or a lower water temperature could scarify the seeds effectively without harming them? Next time, maybe just 10 seconds in 200 °F (93 °C) hot water should be tried or 20 seconds in 170 °F (77 °C) hot 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.

engaging in larger scale or more intensive research may be able to get assistance from a local college or university.

Remember the following essential aspects of experimentation:

- Always have a control treatment (that is, the way the nursery usually does things).
- Keep it simple; define the problem and hypothesis to alter just one variable.
- Eliminate other variables (amount of water or light, for example, must be equal).
- Carry out several repetitions on groups or blocks of plants.
- Take data accurately and precisely.
- Keep records updated.
- Share important findings with staff and others.
- Stay curious and open to learning more: working with plants is an endless process of discovery.

Figure 17.6—*A few basic measuring tools and a good way to keep records is all you need for many kinds of experiments*. Photo by Tara Luna.

Figure 17.7—*Keeping good records is a key part of successful experimenting.* Photo by Tara Luna.

LITERATURE CITED

Dumroese, R.K.; Wenny, D.L. 2003. Installing a practical research project and interpreting research results. Tree Planters' Notes 50(1):18–22.

ADDITIONAL READINGS

Landis, T.D.; Tinus R.W.; McDonald, S.E.; Barnett, J.P. 1994. The container tree nursery manual: volume 1, nursery planning, development, and management. Agriculture Handbook 674. Washington, DC: U.S. Department of Agriculture, Forest Service. 188 p.

Wightman, K.E. 1999. Good tree nursery practices: practical guidelines for community nurseries. Nairobi, Kenya: International Centre for Research in Agroforestry. 95 p.

APPENDIX 17.A.
PLANT MENTIONED IN THIS CHAPTER

Candle yucca, *Yucca schidigera*