
soil 2
soil 1

4

Crop Planning: Propagation Protocols, Schedules, and Records

Kim M. Wilkinson and Douglass F. Jacobs

A successful nursery provides healthy, high-quality plant materials ready to plant when clients need them. For areas with a pronounced dry season, clients usually need plants at the beginning of the rainy season. For areas with adequate rainfall all year or that can be irrigated, the outplanting date may be anytime. In addition to being ready on time, plants must also be of the correct species, quantity, genetic source, size, age, and container type, as defined by target plant requirements described in Chapter 3, Defining the Target Plant (figure 4.1). To ensure that plants germinate, grow, remain healthy, and become hardy to survive outside the nursery, all the plant's environmental and nutritional requirements must be met while they are in the nursery. These requirements change as the plants develop. The planning and scheduling to meet these requirements is called nursery crop planning. Crop planning coordinates time, resources, labor, and space to produce a healthy crop of plants on time. Throughout this chapter, the following example of how target plant requirements work with nursery crop planning is used.

> *In March, a retired cattle rancher calls your native plant nursery. To leave a legacy for her grandchildren, she wants to plant 500 koa trees (*Acacia koa*, an endemic species important in many Hawaiian forests) on a former cattle pasture now fenced and free of cows. Her property is at 2,000-ft [610-m] elevation on the leeward side of the Big Island of Hawai'i. The area has been in pasture for more than a century. She had the soils analyzed, and they are typical from a nutrient standpoint. She wants easy-to-plant trees. Although the rainy season starts in mid-November, she plans to plant with help from her son, daughter-in-law, and two grandchildren during the holiday, so her ideal delivery date is December 15. She plans to remove the grass from the planting areas and then plant the seedlings using a mattock and shovel.*

With these details, you can now begin to work with the client to establish target plant requirements for her koa seedlings (figure 4.1).

Facing Page: *Crop planning organizes schedules, resources, labor, and space to produce a healthy crop of plants on schedule. Victoria Henry records some information on a crop in the Agroforestry Research Greenhouse at the University of the Virgin Islands, Agriculture Experiment Station in St. Croix. Photo by Brian F. Daley.*

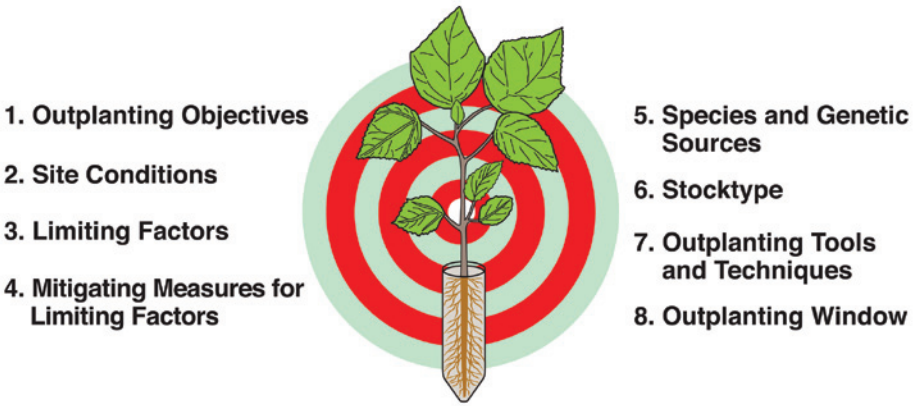

***Figure 4.1**—Crop planning begins with defining specifications of the "target plants" the nursery will produce, as described in Chapter 3, Defining the Target Plant. Adapted from Landis (2011) by Jim Marin.*

1. **Objective**—Native reforestation/legacy planting with locally adapted *Acacia koa*.
2. **Site Evaluation**—Client's soil analysis is unremarkable; she has looked at existing vegetation (pasture grasses, weeds) and realizes control is needed; she examined climate data for the area, especially historical trends of when the rainy season starts and ends, and the average rainfall.
3. **Limiting Factors on Outplanting Site**—Likely shortage of viable population of appropriate beneficial local microorganisms (*Rhizobium* bacteria and mycorrhizal fungi); competing grass and weeds; minor risk of a cow or horse eating the young trees.
4. **Mitigating Measures for Limiting Factors**—Seedlings will be inoculated with *Rhizobium* bacteria and mycorrhizal fungi in the nursery. Client will remove competing grass and weeds before planting; advise her to mulch around trees and diligently continue to control weeds. Client has fenced site to minimize risk of a cow or horse getting in and eating the seedlings and will keep secure.
5. **Genetic Considerations**—Seeds sourced according to transfer guidelines from forestry department for locally adapted, genetically appropriate koa for this site. In this case, seeds will be collected (by permission) from a nearby koa forest at a similar elevation: minimum 50 parent trees of good form.
6. **Type of Plant Materials**—500 *Acacia koa* seedlings from genetic sources listed previously. Containers: Ray Leach "Stubby" cells; Size: 15 cm height, 3.5 mm stem diameter; Roots: firm and nodulating with *Rhizobium*, inoculated with mycorrhizal fungi (AMF). Seedlings will be watered thoroughly while still in their containers immediately before they are outplanted.
7. **Outplanting Tool or Technique**—Seedlings will be outplanted with a mattock and shovel. After outplanting, seedlings will be mulched with a biodegradable weed barrier topped with macadamia nut husk mulch, being careful not to let the mulch touch the stems. Trees will be flagged with a bamboo stake and bright flagging for ease of monitoring and maintenance.
8. **Timing of Installation/Outplanting Window**—This area's rainy season usually begins in November, but labor will not be available until December. Target date for seedling delivery is December 15.

For complex, large, or specialized projects, the assistance of a professional planner is usually needed to assess the site and create a plan, including appropriate species selection and determination of the other target plant needs for each species to be planted. Examples of more specialized plans include projects that warrant a Forest Stewardship Plan, a Conservation Plan, a Habitat Restoration Plan, Farm Plans (such as the U.S. Department of Agriculture, Natural Resources Conservation Service might do for soil conservation or riparian areas) and others. If your client requires this level of assistance, steer him or her to the appropriate agency or professional and invite the client to place an order when the plan is ready. See Chapter 18, Working With People, for more information on client education and project planning.

Based on the client's target plant requirements, including the agreed-upon delivery date, the nursery manager can now schedule crop production (figure 4.2). Crop production generally includes these activities:

- Developing and refining propagation protocols for the species so that requirements are met during germination, establishment, rapid growth, and hardening.
- Developing growing schedules for the crop based on the crop's three growth phases (establishment, rapid growth, and hardening) and the distinct requirements for each phase.
- Developing facilities schedules to ensure that space, labor, equipment, and supplies to support the crop (and the other crops being grown simultaneously) during all growth stages are available.
- Keeping written records, including a daily log and plant development record, so that any shortcomings can be corrected and successes can be replicated in future crops.

Developing Propagation Protocols

A propagation protocol describes all the steps necessary to grow a species under local conditions, from the collection of seeds or cuttings all the way through shipping the plants to the client. It is meant to be a reliable, repeatable guide to producing and scheduling a crop of that species. It will also help you coordinate the production of all crops being grown simultaneously in the nursery.

A protocol is ideally comprehensive, systematic, and detailed, much like a cookbook recipe. Protocols with the most detailed information make it easier to plan and schedule the next crop. The example protocol in table 4.1 shows the type of information usually included. The exact schedule and performance of any species will vary greatly depending on the unique conditions of the nursery and on other variables, such as seed sources and weather patterns so protocols may need to be adjusted accordingly to produce the best plants.

After protocols are developed, they are refined with each crop, leading to dramatic improvements in nursery efficiency and effectiveness from season to season. Propagation protocols serve as an essential guide for planning and scheduling each crop.

A protocol typically describes the following aspects and characteristics:

- Species name and ecotype.
- Time necessary to grow to target plant specifications.
- Target plant specifications (for example, height, root system, and stem diameter).
- Propagule sources, characteristics, collection, and processing.
- Preplanting propagule treatments.
- Growing area preparation.
- Management for, and length of, establishment, rapid growth, and hardening phases.
- Harvesting and shipping practices.
- Outplanting window and planting technique(s).

Draft a Protocol

The protocol is developed using firsthand experiences and outside sources of information. If little to nothing is known about the species, the process of drafting a protocol can help you organize what is known and take an educated guess at how to proceed with growing a particular species. Start by systematically searching relevant literature published by trade journals, native plant societies, and botanical gardens. An excellent source of propagation protocols, continually updated by growers and free of charge, is online at the Native Plant Network (http://www.nativeplantnetwork.org) (Landis and Dumroese 2000; 2002). If specific information on the desired species is unavailable, try to find another species within the same genera or even a related species grown in similar climatic zones, to see if any information may be applicable. Next, gather information from observations of how the plant grows in nature. This information may be observed first hand in the field and by asking local people who are familiar with the plant. Although collectors of plant materials for cultural uses may have never propagated the species,

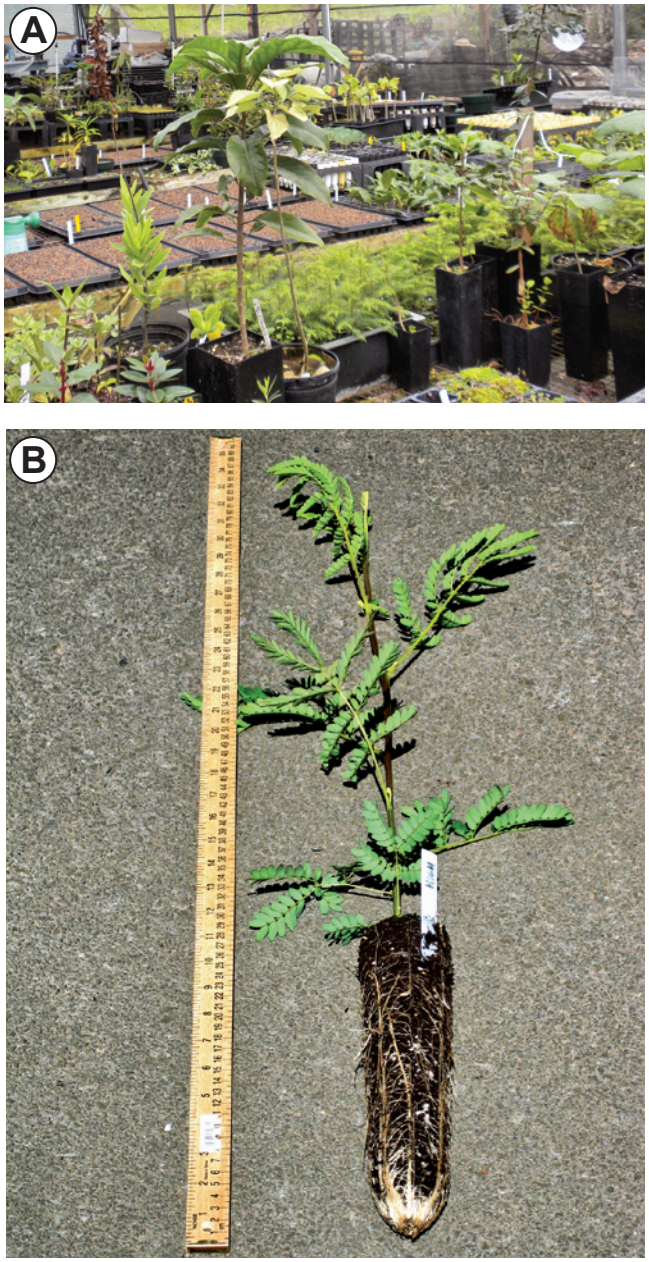

Figure 4.2—*The diversity of species grown in native plant nurseries (A) calls for detailed crop planning and scheduling to ensure that high-quality plants (B) are delivered to clients when they need them. Photo A by Diane L. Haase, and photo B by Douglass F. Jacobs.*

they are likely to know the plant's life cycle such as when and how seeds are dispersed. Finally, seek advice from other nursery managers. Although some managers of private nurseries may be disinclined to share their propagation methods, government nurseries and botanical gardens are often excellent sources of information.

Based on the information gathered, the first draft is the best-informed guess of what will be required to grow a species in your nursery the first time. The plants themselves will prove the protocol right or wrong as they grow. Nursery records, including the daily log and plant development record described later in this chapter, will enable a comparison between projected development and actual growth.

Test and Adjust Protocols

Refine the protocol with site-specific information from your nursery after the production of each crop. Do not be discouraged if a protocol drafted from background research or another nursery's experience does not produce the same results; the goal is to adjust the protocol to reflect your nursery conditions. Year-to-year variations in weather or unforeseen operational changes often keep crops from growing exactly as projected. Allow room for flexibility and make adjustments based on observed factors. You may want to tinker with growing media ingredients, seed germination methods, irrigation practices, and so on. Keeping records is key. Sometimes new information and discoveries will significantly improve

***Table 4.1**—An example protocol for* Acacia koa, *adapted from Wilkinson and Elevitch (2003; 2004).*

Family scientific name	Fabaceae
Family common name	Legume
Scientific name	*Acacia koa* Gray
Common name	Koa
General distribution	Native to six major Hawaiian Islands: Hawai'i, Moloka'i, Maui, Lana'i, O'ahu, and Kaua'i. Original range: 300–7,000 ft (90–2,134 m). Today, most thriving koa trees are found between 3,000 and 6,000 ft (915 and 1,830 m) elevation. Introduced pests and diseases limit their presence below 2,000 ft.
Propagation goal	Plants (tree seedlings)
Propagation method	Seed
Product type	Container: 115 ml Ray Leach "Stubby" Cell
Time to grow	16 to 18 weeks
Target specifications	Seeds from locally adapted, genetically appropriate source matched to outplanting site; seedlings approx. 15 cm tall; diameter 3.5 mm; and roots firm and nodulating with *Rhizobium*.
Propagule collection	Genetic quality is crucial; source must be carefully matched with the outplanting site before seeds are collected. Diversity is also important to withstand diseases; collect at least 50 mother trees, throughout the canopy. Pods are about 6 in (15 cm) long and 1 to 1.5 in (2 to 4 cm) wide, with 6 to 12 seeds per pod. Pods are ready to pick when brown, and when opened the seeds inside are deep brown and full (not green, flat, or small). Seeds can also be collected from the ground. In some populations, koa seeds can be collected any time of year, in other populations August to October (end of dry season) is best time to collect.
Propagule processing	Pods are dried in the sun until they can be opened easily. Seeds are extracted by hand or by threshing. Once out of the pods, seeds are dried more as necessary (ideal moisture content 6 to 8%). Dried seeds can be stored in an airtight container away from direct sunlight. Properly dried seeds can store for 12 to 24 months at room temperature, many years longer in cooler conditions.
Seeds/kg	Seed size is highly variable, a kilo of processed seed can contain between 5,000 and 15,000 seeds (2,500 to 7,500 seeds/lb).
Purity	100%.
Germination	70 to 90% (can be lower depending on weather conditions during ripening).
Pre-sowing treatments	Scarification is required. Mechanical scarification (nicking with a nail clippers on the side opposite the point of attachment to the pod) is used for small lots. Hot water treatment (195 °F, 90 °C) in a volume ratio of at least 5 parts water to 1 part seeds for 1 to 3 minutes. In either case, scarified seeds are soaked overnight to allow water to penetrate into the seed. Seeds germinate in 2 to 7 days.
Growing area	If possible, some cover (greenhouse or temporary cover) is ideal for the first 2 weeks after germination to protect sprouts from seed-eating birds and rodents and from hard rains. Thereafter, uncovered growing areas work well.

Table 4.1 (continued)

Growing medium	Most well-drained media work fine. One example media is 50% peat moss, 25% perlite, 25% vermiculite, amended with compost, dolomite lime, gypsum, and triple super phosphate. Media should also be inoculated mycorrhizal fungi, local strains if available. Seedlings will be inoculated with *Rhizobium* at 2 weeks.
Establishment phase	Scarified seeds will germinate in 2 to 7 days. They may be direct seeded after scarification (1 seed/cell) or, for less viable seedlots, seeds (sown on paper towels or in beds) are transplanted into tube containers that have been pre-filled with medium (1 seed/cell) as soon as the root begins growing from the seed. Cover with growing medium shallowly (about 1/4 inch or 0.6 cm deep), followed by a thin mulch layer such as #2 poultry grit. Water with a fine-headed sprayer to keep moist, but not wet. Full sun is best. Daily water is usually necessary, by hand or with an automated system. Protect from bird and rodent predators who are attracted to the sprouts. At 2 weeks of age, inoculate with *Rhizobium* using a slurry made from native nodules collected from seed source areas.
Length of establishment phase	2 to 3 weeks
Rapid growth phase	Seedlings are watered daily, usually in the morning. Especially hot, dry days may necessitate a second watering in the early afternoon. (Late afternoon and evening watering is not recommended, as it facilitates pest problems, such as sooty molds.) The media should not be allowed to dry out. After about 4 weeks, check to ensure *Rhizobium* inoculation was effective. After about 6 weeks, seedlings may be double-spaced in the Ray Leach trays (from 98 trees per tray to 49 trees per tray) to ensure each seedling receives full sunlight and good air movement to facilitate strong stem development. At the period, depending on seed lot, about 5 to 10% of the seedlings will be apparent poor performers, and these should be culled. Remaining seedlings are monitored for pests, but pests are generally not problematic in the nursery. If any weeds enter the media, they should be removed. No fertilizer application as necessary if seedlings were inoculated with *Rhizobium* and mycorrhizal fungi. No pruning.
Rapid growth phase	7 to 10 weeks
Hardening phase	Seedlings should never be allowed to dry out, but watering frequency is reduced to introduce seedlings to temporary, moderate water stress. If the outplanting site is an especially windy area, "brush" seedlings gently using a length of PVC pipe to improve stem strength. Seedlings remain outside, exposed to full sunlight, not fertilized.
Length of hardening phase	6 weeks
Harvesting, storage, and shipping	When seedlings have reached target size, they may be delivered to the planting site. Water thoroughly before shipping and just before outplanting. They are not extracted from their container until the moment they are planted, as keeping them in the container is necessary to protect the roots and the viability of the *Rhizobium* nodules. Seedlings may be stood up in buckets, cardboard boxes, or delivered in their trays. Seedlings must be protected from wind and excessive heat during transport, but refrigeration is not recommended. Empty containers and trays may be returned after the planting is complete.
Outplanting and cultivation comments	Planting areas must be fenced to exclude any grazing animals, and competitive vegetation must be removed. At planting, seedlings should be carefully removed from their container and planted at the correct depth, so the ground is even with the root collar. Soil should be firmed around the tree, muddied in with water if possible. A weed barrier/mulch around the tree (but not touching the trunk) can aid establishment.
Citations	Wilkinson, K.M.; Elevitch, C.R. 2004. Propagation protocol for production of container *Acacia koa* Gray plants; permanent agriculture resources, Holualoa, Hawai'i. In: Native Plant Network. URL: http://www.nativeplantnetwork.org (September 2013). Moscow, ID: University of Idaho, College of Natural Resources, Forest Research Nursery.

production methods (see Chapter 20, Discovering Ways to Improve Nursery Practices and Plant Quality) and will be added to the protocol. As the protocol is updated, the nursery develops an increasingly accurate and helpful guide for how to grow each species.

Developing Growing Schedules

With the propagation protocol in hand, it is time to develop a growing schedule that covers all phases of crop production and the time necessary to complete each step. When the timing for nursery crops is understood, appropriate dates for sowing seeds or striking cuttings can be calculated by counting backwards from the desired outplanting date. Knowing when propagules can be collected and how long the species will take to produce enables the nursery to work with clients' schedules. For example, koa requires 18 weeks to grow, including time for preparing seeds for sowing. So, if plants are needed for outplanting on December 15, seeds must be ready for sowing by August 11. The total time required for the production of each crop will vary by species, container size, season, and nursery environment. Genetics and the variability of seedlots may also cause variations in crop scheduling even for the same species. Less well-known or more temperamental species require the nursery manager to build a safety margin of 2 to 4 weeks into the schedule in case of problems with germination or growth. The growing schedule focuses on these steps as plants move through the nursery: propagule collection, cleaning, and treating; the three phases of plant growth (establishment, rapid growth, and hardening); and storage and shipping. Although other chapters cover these topics in detail, in this chapter, they will be discussed in general terms as they relate to scheduling.

Propagule Collection, Processing, and Treatment

Collection

Most often, nurseries growing native and culturally important plants cannot obtain their seeds or cuttings from a central supplier or mail-order catalog. Therefore, key questions are where, when, and how to collect seeds or cuttings. The where is usually answered by the location of the outplanting sites: locally adapted, genetically appropriate materials should be collected from the same or similar areas as the outplanting site (figure 4.3A). For some native species, usually commercially important trees, recommendations for appropriate sources or seed zones may be available, as mentioned in Chapter 3, Defining the Target Plant. For most other native species, the nursery will have to do its best to research, define, and obtain locally adapted and genetically appropriate propagules for its client's site. The when question is answered by the plants living in the collection sites: when does this species, in the appropriate collection site(s), produce seeds? (Or for vegetative propagation, when is the best time to collect cuttings?) For some species, it may be possible to collect throughout the year. For other species, a narrow window may be all that is available, and if this window is missed, orders will have to wait until the following year. Seeds of some species may store well for many years, enabling the nursery to develop collections to keep on hand. Finally, how to collect may be determined based on published literature, local knowledge, and experience. To provide plants when the client needs them, the nursery manager has to account for the time needed to obtain the propagules and grow the plants.

Processing

Propagules need to be processed immediately after collection. For most seeds, processing helps ensure that the

***Figure 4.3**—Nursery crop planning includes scheduling propagule collection (A), processing, and seed treatments (B) to produce target plants by the delivery date. Photo A by J.B. Friday, and photo B by Craig R. Elevitch.*

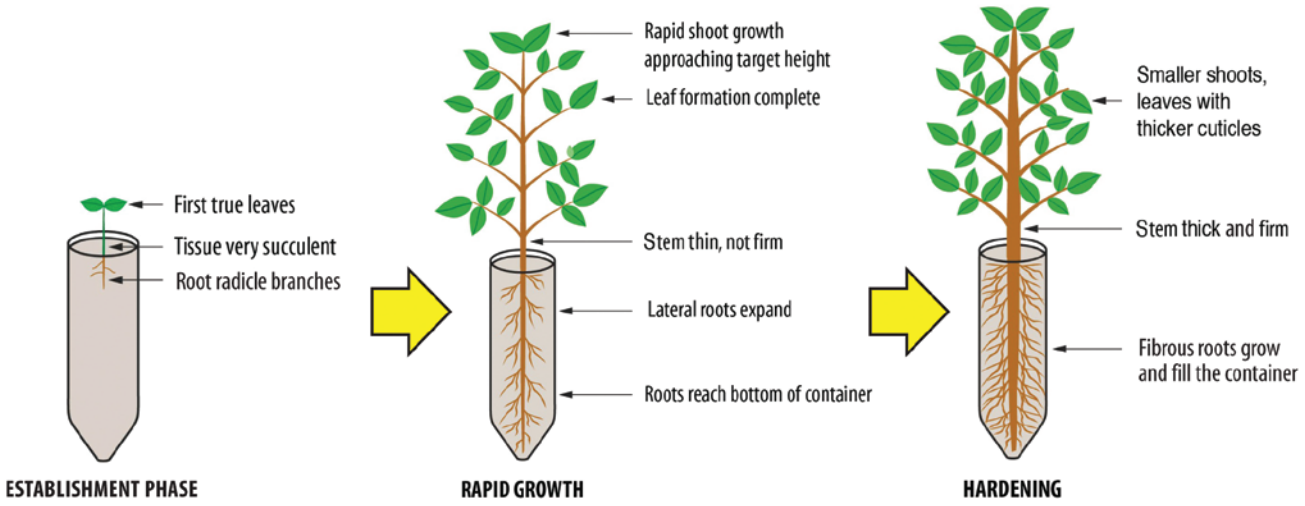

Figure 4.4—*Understanding the growth phases that crops go through is essential to crop planning. The development of most nursery crops can be divided into three phases: establishment, rapid growth, and hardening. Adapted from Dumroese and others (2008) by Jim Marin.*

seeds stay dormant until they are needed. Depending on the species, seeds may need to be processed in one or more of the following ways: extraction from pods or fruits, washing, winnowing, sorting, grading, and drying. Some seeds do not store and must be sown when they are fresh. Cuttings may need to be dried, soaked, placed in rooting beds, or other treatments. Processing requirements and the time and space needed to complete them need to be considered as part of the schedule.

Treatment

Seeds of native species, and sometimes seedlots of the same species, vary widely in dormancy, so seed treatments need to be scheduled properly. Similarly, the optimum time to harvest cuttings varies among native species. Scheduling when to treat propagules is important for planning a target sowing or cutting establishment date for the crop (figure 4.3B).

Crop Growth Phases

Because a tiny germinant has different needs than a large plant that is nearly ready for outplanting, understanding the growth phases of crops is essential to nursery planning. The development of most nursery crops can be divided into three phases: establishment, rapid growth, and hardening (figures 4.4, 4.5). Plants in each phase have distinct requirements for light, water, nursery space, and the types of attention and labor necessary to keep them healthy. The nursery manager's objectives for the crop are also different at each phase. Table 4.2 summarizes some typical aspects of each of the three phases.

Establishment

For plants grown from seeds, the establishment phase is defined as the time from the sowing of the seeds through the germination, emergence, and development of the first true leaves or primary needles (figure 4.6A). For plants grown from cuttings, the establishment phase extends from placing cuttings into containers through the initial development of roots and shoots. This phase is of critical importance because mistakes can prevent or delay emergence or rooting. For seeds, some species require light to germinate and need to be surface sown while seeds

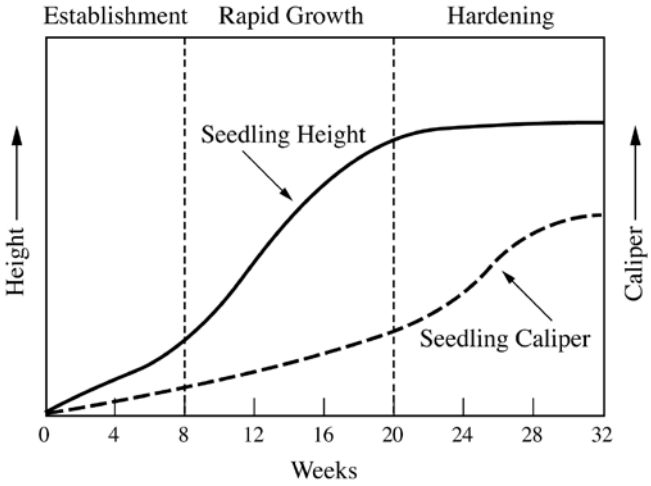

Figure 4.5—*Changes in seedling morphology during the three growth phases. Growth is relatively slow during the establishment phase. Most shoot growth occurs during the rapid growth phase, which ends when target height specifications are met. During hardening, roots continue to grow, resulting in an increase in seedling stem diameter (caliper).*

Table 4.2—The three general phases of crop development for seedlings. After the three phases of crop development are understood for a species, the growing and facilities schedules can be developed to meet crop needs during each phase. Adapted from Landis and others (1998).

Phase	Establishment	Rapid growth	Hardening
Definition	From germination through emergence and formation of true leaves.	From emergence of true leaves to when seedling approaches target size. Rapid increase in size, particularly in terminal shoot.	Energy diverted from shoot to root growth; seedling reaches target height and stem diameter; seedling is conditioned to endure stress.
Duration	Typically 14 to 21 days for germination; 4 to 8 weeks for early growth.	Varies widely, typically about 10 to 20 weeks.	Varies widely, normally from 4 to 12 weeks.
Objectives	• Fill containers efficiently • Maximize uniform germination • Maximize survival • Minimize damping-off	• Minimize stress • Encourage shoot growth • Maintain environmental factors near optimum levels • Monitor as seedling approaches target height and roots fully occupy container	• Slow shoot growth • Encourage root and stem diameter growth • Acclimate to outplanting environment • Condition to endure stress • Fortify for survival after outplanting
Special needs	• Protect from weather and pests • Keep temperature warm • Irrigate to keep soil "moist, but not wet" • No or low fertilizer	• Protect from stress • Monitor sun exposure • Irrigate appropriately • Fertilize properly	• Induce moderate moisture stress • Progressively expose to sun equivalent to outplanting conditions (full sun or partial shade) • Expose to ambient temperatures and humidity • Provide good air flow/wind • Reduce fertilization rates and change mineral nutrient ratios
Labor	• Monitor germination • Introduce beneficial microorganisms • Thin • Resow and transplant if necessary • Scout for pests and diseases	• Monitor environment • Modify crop density to encourage good development • Adjust culture to avoid excessive shoot height • Scout for pests and diseases	• Monitor crops and environment carefully; see Chapter 14, Problem Prevention and Holistic Pest Management, and Chapter 19, Nursery Management, for details • Deliver crops to clients in a timely fashion to avoid problems with holdover stock • Scout for pests and diseases

of other species may be covered with mulch. For cuttings, some species need rooting hormones applied at the proper rates and timing. The establishment phase typically lasts 4 to 8 weeks, although species slow to germinate from seeds or root from cuttings may take 1 year or more. The main goal of this phase is to maximize survival with uniform germination and establishment of the plants.

Rapid Growth

During the rapid growth phase, plant shoots increase dramatically in size, often approaching target size (figures 4.6 B and C). Plants need to be somewhat protected during this phase to encourage rapid (but not excessive) shoot growth and minimize stress.

Hardening

Although it is relatively easy to grow a seedling to target size, the tricky part is the hardening phase. During hardening, energy is diverted from shoot growth to root growth (figures 4.6 D, 4.6 E). Hardened plants are conditioned to endure the stresses of shipping, handling, and outplanting and fortified so that they have the energy and nutritional reserves to survive and grow after outplanting. If the hardening phase is too short and plants do not

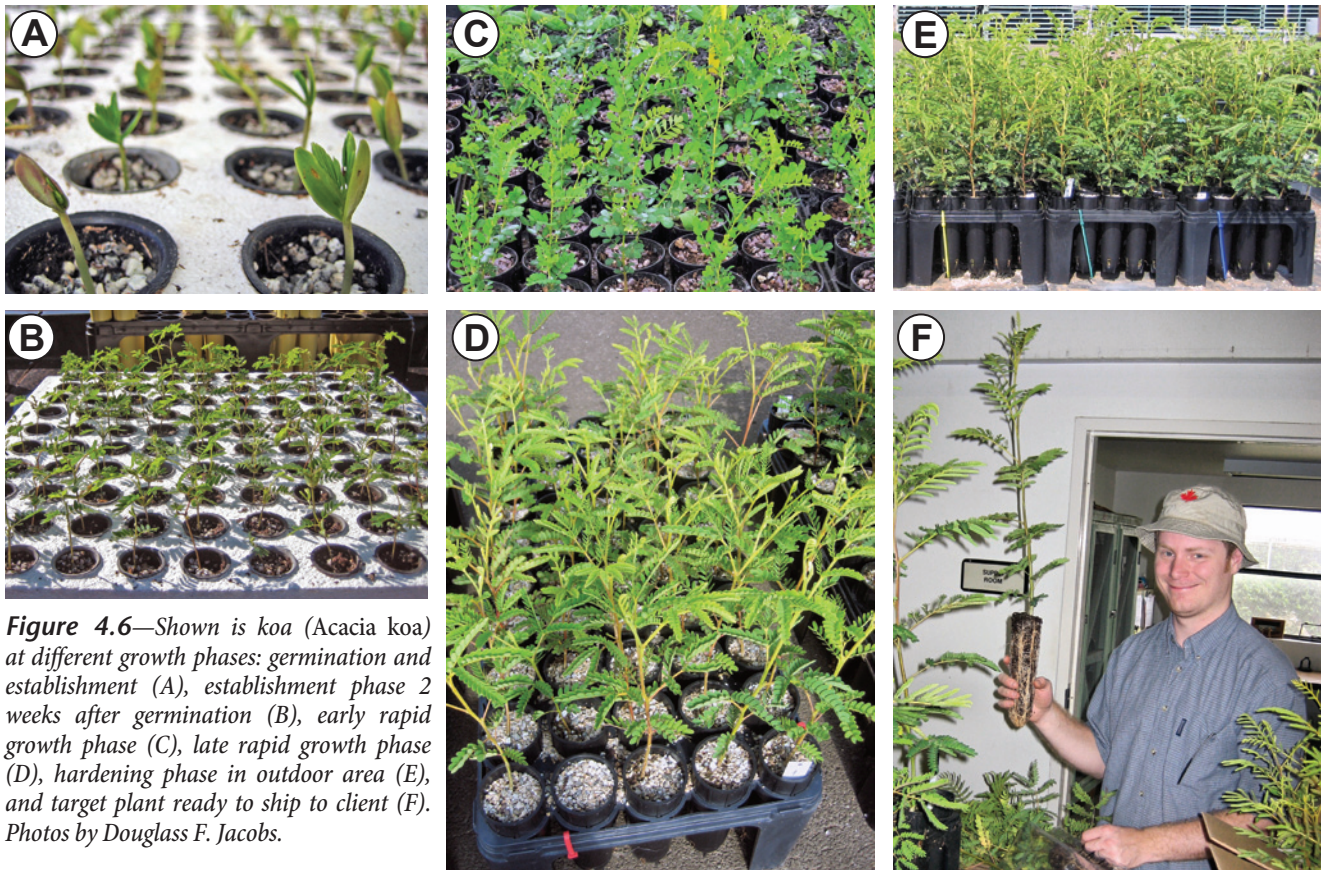

***Figure 4.6**—Shown is koa (*Acacia koa*) at different growth phases: germination and establishment (A), establishment phase 2 weeks after germination (B), early rapid growth phase (C), late rapid growth phase (D), hardening phase in outdoor area (E), and target plant ready to ship to client (F). Photos by Douglass F. Jacobs.*

have time to reach the appropriate physiological condition, plants may still have the correct physical size, but survival and growth after outplanting are compromised. Therefore, good crop planning ensures adequate hardening before on-time delivery to the client. See Chapter 15, Hardening, for more discussion on this topic.

Harvesting and Shipping

After plants are hardened, prompt outplanting is essential to ensure that they can take full advantage of their hardened condition. Proper crop scheduling ensures that a crop goes through the three phases of growth and that healthy plants are ready for shipping (figure 4.6 F) and outplanting on the agreed-upon delivery date. See Chapter 16, Harvesting and Shipping, for more discussion on this topic.

Problems With Holdover Stock

A common problem is the failure of clients to pick up plants on schedule. This problem can be avoided by good scheduling practices and frequent communication with clients, especially by providing periodic updates to advise them when seedlings will be ready. In some cases, having penalties, such as storage fees, in the contract for late pick-ups may also encourage clients to pick up their plants in a timely fashion. When communicating with clients, emphasize upfront that prompt outplanting is in everyone's best interest, not only for the nursery and the health of the plants, but also for the success of the client's project. See Chapter 19, Nursery Management, for more information about contracts and communicating with clients.

If the schedule to outplant after hardening is not met, problems can develop. When plants are held too long in the nursery, the root system becomes woody and loses its ability to take up water and nutrients (figure 4.7A). Structural problems may also occur; roots may spiral (figure 4.7B) and, instead of expanding outward and downward into the soil after outplanting, girdle the plant or cause it to be unstable in high winds. Shoot growth may resume and negatively affect the root-to-shoot ratio (figure 4.7C), and the plant loses its resistance to stress. Making a growing schedule as shown in table 4.3 is very helpful to provide plants on time; neither ready too early or too late.

Developing Facilities Schedules

Ensuring that the nursery facilities and resources required to meet plant needs through the growing cycle are available at the appropriate times is the goal of facilities scheduling. The

space, labor, equipment, and supplies required for each crop during the different stages of propagation must be planned.

Except for nurseries with elaborate climate control systems, crops are often moved from one structure to another as they progress through the three development phases. See Chapter 5, Propagation Environments, for additional information. Using the koa example, crops are protected in a special germination area during the establishment phase and then moved to an outdoor growth area for rapid growth and hardening (table 4.4). Needs differ for various crops and nurseries; for example, another species might have seeds in trays on benches, then be moved to containers in a shade house, and finally transplanted to large pots in full sun for hardening. The amount of space the crop will require varies by growth phase: emerging seedlings may take up little room, but plants take up much more space after they have been transplanted into larger containers or spaced more widely as they grow larger. Although the example in table 4.4 does not go into such detail, the facilities schedule should include calculations for how much space each crop will use, how many hours of labor will be needed, and the quantities of materials (such as growing media) required during crop production.

A good facilities plan considers crop layout, that is, what crops and stocktypes go where in the nursery. This layout is planned to effectively provide appropriate growing requirements (temperatures, sunlight) and other cultural requirements (frequency of fertilization, watering, or other treatments) for all the crops grown each season. Fast-growing species with similar growing and cultural requirements usually can be grouped together in one area, and moderate and slower growing species can be grouped together in another area of the nursery. This grouping method allows for species with similar requirements and growth rates to be treated effectively and efficiently. Likewise, the flow of plants out of a protected area to an outdoor nursery needs to be taken into consideration so that plants that finish in the same timeframe can be moved out and a new crop, if scheduled, can be planned for the available empty space.

Facilities scheduling is indispensable in determining how resources within a nursery can be best distributed to maximize production and minimize conflicts associated with overlapping needs (figure 4.8). The facilities schedule (table 4.4) may be combined with or posted side by side with the growing schedule (table 4.3) and the staff needs to have easy reference to it.

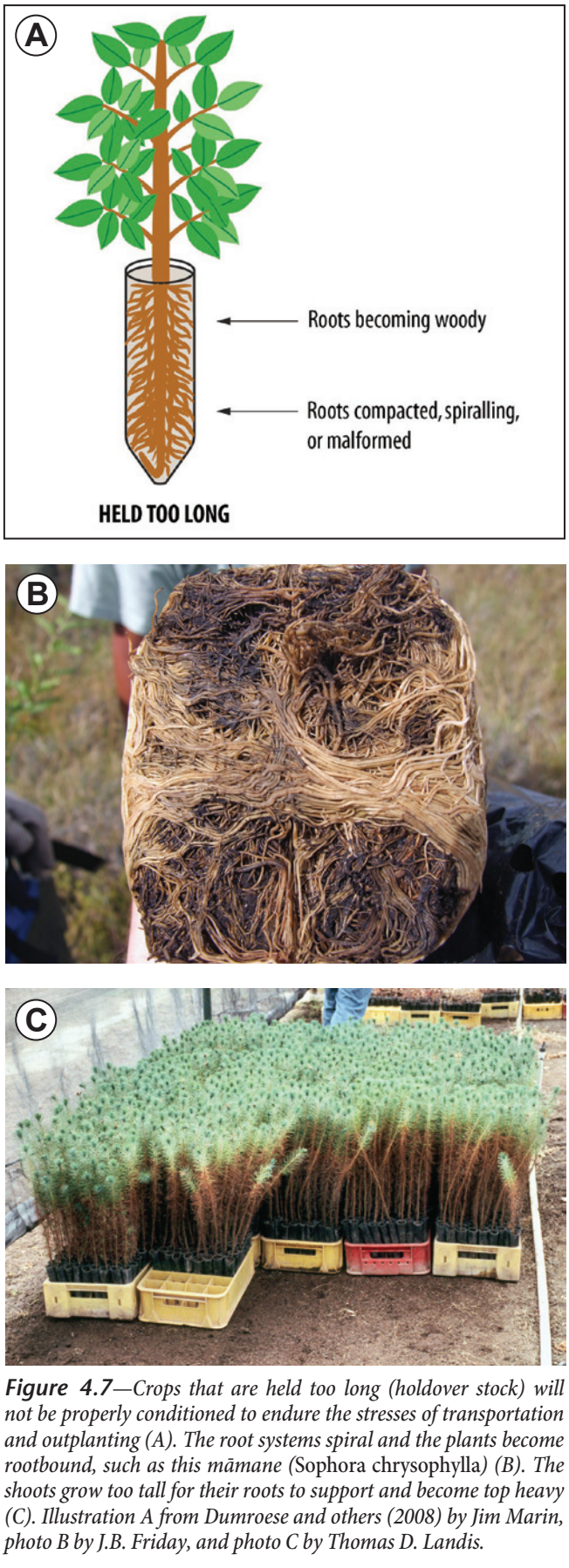

Figure 4.7—*Crops that are held too long (holdover stock) will not be properly conditioned to endure the stresses of transportation and outplanting (A). The root systems spiral and the plants become rootbound, such as this māmane (*Sophora chrysophylla*) (B). The shoots grow too tall for their roots to support and become top heavy (C). Illustration A from Dumroese and others (2008) by Jim Marin, photo B by J.B. Friday, and photo C by Thomas D. Landis.*

Table 4.3—*This example crop schedule shows the necessary steps in each crop development phase and the time required to complete each. This schedule should be posted in the nursery so that staff can track the crop's development and understand what cultural practices are required. If appropriate, the schedule can also be shown to clients to help them fully understand the time required to produce their crop.*

Activity	Seed collection and processing	Seed treatments	Establishment phase	Rapid growth phase	Hardening phase
Duration	2 days	2 days	3 weeks	10 weeks	6 weeks
Dates	Scope July 15; collect Aug. 1; process Aug. 2	Aug. 3 to scarify; Aug. 4 to sow	Aug. 4 to Aug. 25	Aug. 26 to Nov. 3	Nov. 3 to Dec. 14
Propagation environment	Field-collection sites	Indoors	Germinant area protected from slugs, birds, rodents, rain, etc.	Main outdoor growth area and full sun	Main outdoor growth area and full sun
Fertilization	None	None	In growing media: triple super phosphate, dolomite lime, gypsum, and mycorrhizal fungi; inoculate at 2 weeks with *Rhizobium*	None	None
Irrigation	None	None	Daily gentle hand watering to keep moist	Once daily by hand to saturation	Gradual reduction
Target size at end of phase	600 viable seeds plus extras to store for future orders	600 germinants	Not applicable (they will usually be about 1 to 2 in (2 to 5 cm) tall, but no target is set)	Approx. 10- to 12-cm height, 2.5- to 3-mm root-collar diameter	15 cm tall, stem diameter 3.5 mm; Roots: firm with *Rhizobium* nodules
Actions	Field collection of pods. Extract, dry and clean seeds at nursery	Mechanical scarification; soak overnight in clean water	Make potting media; sow seeds; inoculate seedlings with *Rhizobium* at 2 weeks of age	Pest management; check nodulation with *Rhizobium*; space double in trays; cull poor performers	If to be outplanted in windy areas, "brush" daily to simulate wind and improve stem strength

Scheduling Multiple Crops

Most native plant nurseries must deliver a suite of diverse species on a single shipping date to meet client needs. Therefore, the growing and facilities schedules are essential to coordinate production of multiple crops of different species. The schedules must reflect the growth rates (time required to grow the crop) of each species. For example, without proper scheduling, the faster growing species may become overgrown before the delivery date or the slower growing species may not be ready in time. Therefore, slow-growing species need to be sown earlier than fast-growing species so they will all be ready to plant at the correct time.

In the example in figure 4.8, the nursery is growing six species that need to be ready for the same outplanting date in December. To meet the target outplanting, koa needs to be sown in August, as they take about 18 weeks to grow, but if a client also wanted native sandalwood trees in 1-gallon pots at the same time as the koa, nursery work would need to begin 1 year in advance to bring this slower growing species through

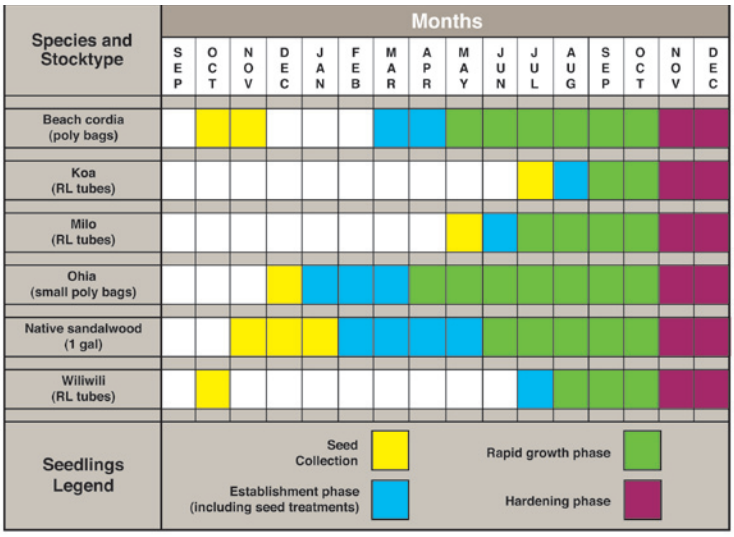

Figure 4.8—*In this hypothetical schedule from Wilkinson and Elevitch (2004), six Hawaiian species must be ready at the same time in December. Different stock types and species require more or less time to grow in the nursery, depending on many factors. Please note this schedule is hypothetical only—timing will vary by location, species, and seed sources. Illustration by Jim Marin.*

all the phases of development. Some species may be fast growing, such as the native wili-wili, but seed collection sites may be seasonal and require more advanced notice to collect. (Please note: these examples are hypothetical—timing, especially of the seed collection, will vary by location and species.)

Keeping Written Records Makes Planning Easier

Propagation protocols, growing schedules, and facilities schedules can all be improved each season by keeping good records. It is important to keep records of how to replicate each crop. How long did it take to produce the crop? What materials were purchased? How was the crop fertilized, watered, and managed during each growth phase? What did we learn that will help us next time we grow this species?

Propagation protocols should be revised on a seasonal or annual basis, becoming more accurate each year, which then improves the usefulness of the crop and facilities schedules.

The best way to improve the accuracy of your protocols is to keep two kinds of written records:

1. The daily log is a journal that notes nursery conditions, activities, and management practices on a daily basis. In other words, what was done?
2. Regular plant growth records describe the development of each crop. In other words, how did the crop respond to particular management practices?

The daily log and plant development records interrelate with the propagation protocols (figure 4.9).

Daily Log

A daily log is a key record that provides a history of nursery management, problem-solving, and crop development (figure 4.10). A daily log example is in table 4.5, and appendix 4.B includes a blank daily log form that a small nursery might use. Make it a habit to at least jot down something each day. Large nurseries may keep more complicated daily

Table 4.4. *An example of a facilities schedule for* Acacia koa.

Activity	Seed collection and processing	Seed treatments	Establishment phase	Rapid growth phase	Hardening phase
Length	2 days	2 days	3 weeks	10 weeks	6 weeks
Dates	Scope July 15; collect Aug. 1; process Aug. 2	Aug. 3 to scarify; Aug. 4 to sow	Aug. 4 to Aug. 25	Aug. 26 to Nov. 3	Nov. 3 to Dec. 14
Labor	Two staff members to scout out collection site in July (1/2 day). Two staff members to go to collection site on Aug. 1 and collect (1 full day per person). Two staff members to dry, process, and clean seeds on Aug. 2 (a few hours intermittently throughout day as pods dry).	One staff member to hand-scarify seeds late in day on Aug. 3, and put them in water to soak overnight.	Make growing media; fill containers; sow seeds; hand water daily; monitor germination; protect from slugs, birds, and rodents. Collect *Rhizobium* nodules and inoculate seedlings on Aug. 18. Update client on progress.	Move to outdoor growth area, irrigate, monitor growth, double-space in trays as seedlings grow larger, and manage weeds/pests. Update client as end of phase nears. If overstock seedlings will be available, offer them to the client or look for another home for them.	Monitor growth; monitor and gradually reduce irrigation; brush to encourage stem diameter. Keep in regular touch with client. Schedule pick-up day and time.
Facility/space needed	Permissions and/or permits to collect at collection site(s). Sunny, level area at nursery to lay out pods for drying.	Indoors (home or nursery office).	Benches in germinant area (protected).	Benches in main outdoor growth area.	Benches in main outdoor growth area.
Materials needed	For collection: vehicle, pole pruner, pruning ladder, collection bags, maps, and written collection permissions. For processing: tarp and seed storage containers.	Seeds, nail clippers, a clean container, and clean water for soaking the seeds.	Scarified seeds, containers and trays, growing media and amendments, mycorrhizal inoculant, fine-headed sprayer and hose for irrigation, blender and nodules to make *Rhizobium* inoculant (on Aug. 18).	Extra trays for double-spacing seedlings, irrigation supplies.	PVC pipe or bamboo pole for brushing, irrigation supplies, boxes or buckets for transport unless plants will be transported in trays.

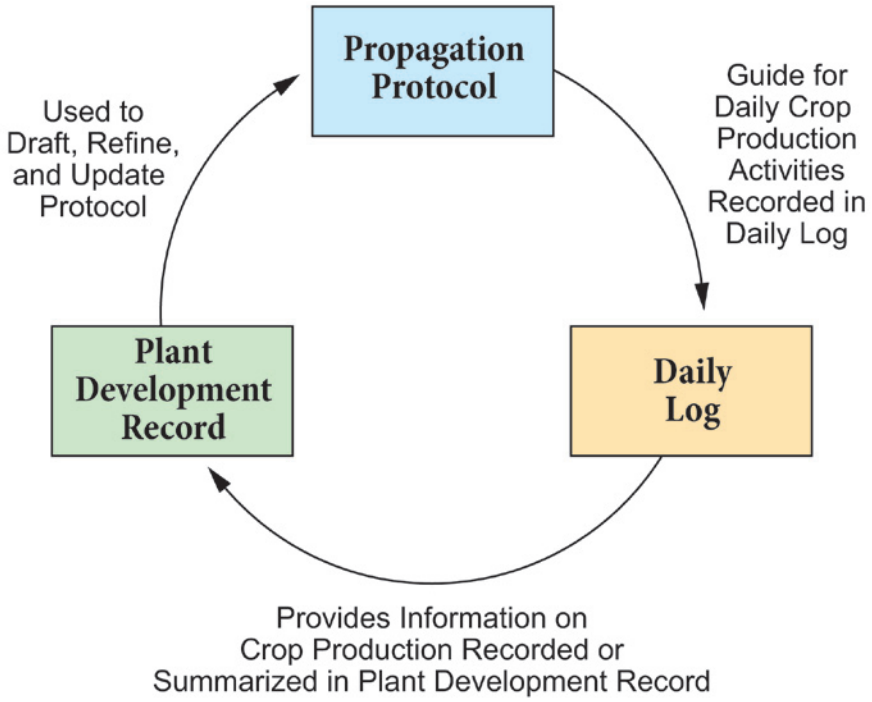

***Figure 4.9**—The three basic crop records and how they relate. Use a protocol to plan and schedule daily activities. Record activities in the daily log. The log helps with the collection of information about the development of each crop. This information is recorded in the plant development record. The protocol is then refined and expanded based on this new information, which will improve production practices the next time the crop is grown. Illustrationfrom Dumroese and others (2008) by Jim Marin.*

records and may have separate logs for irrigation, fertilization, and the like. Tailor the daily log to suit your nursery. What is recorded in the daily log about management practices, environmental conditions, and general crop performance will become an invaluable resource for many years to come.

Plant Development Record

Keeping a simple plant development record (or register) for each crop is a great way to build a foundation for accurate, site- and species-specific protocols. Some growers choose to record a large amount of detail in their daily log and then later summarize information about each crop into a plant development record. Others jot notes into a plant development record for each crop on a regular basis; weekly, monthly, or when the crop is entering a new stage in its development.

A plant development record notes what is happening with a crop of plants from crop initiation through delivery. At a minimum, you can simply put a couple of fresh sheets of paper in a three-ring binder, make a tab with the species name and date for that crop, and jot down notes on a regular basis as the crop progresses. One way to make it easier to keep track of this valuable information is to use a form such as the one provided in appendix 4.C or by entering information into a computer. An example Plant Development Record is in table 4.6.

***Figure 4.10**—Jot down a few notes every day about what was done and what happened with the crop. These records become invaluable resources when adjusting protocols and fine-tuning crop and facilities schedules. Photo by Tara Luna.*

***Table 4.5**—An example of a daily log.*

Daily log	
Date	April 4, 2015
Environmental conditions in growing areas (light, temperature, and humidity)	Outdoor growing area: 65 °F min; 78 °F max
Sunrise/Sunset times	Sunrise: 5:40 a.m. Sunset: 6:55 p.m.
Moon phase	Full moon.
Other weather notes (cloud cover, and so on)	Partly cloudy, no rain today.
What water did plants receive? (irrigation type and frequency or precipitation)	First thing in the morning, automatic overhead watering for 1 hour on most plants in main rapid-growth outdoor area. Hand-watered benches 1- to 6-in outdoor growing area. Handwatered germination area with fine-headed sprayer in morning.
Today's activities (note how many person-hours per activity) (fertilization, pest management, transplanting, packing and shipping, making potting media, moving crops from one structure to another, treating or sowing seeds, and so on)	Growing media and filled trays for the new order for 300 seedlings, 2 hours total. Handwatered the germinant area and hardening areas, 1 hour. Fixed the small leak (noticed yesterday) in the main water line, 1 hour. Answered e-mail correspondence, 1 hour. Fertilized the beach cordia, sandalwood, and ʻōhiʻa with 200 parts per million (ppm) Peter's 20-20-20 (40 ppm nitrogen), 1 hour. Checked on status of milo germinants, 30 minutes. Weed control around perimeter of outdoor growing area, 1 hour.
Growth phase status (make notes when a crop moves from one phase to another)	The milo seedlings sown earlier this month are germinating well. I better make space in the rapid growth area because I will be able to move them in a couple weeks. The sandalwood seedlings that are to be outplanted this December are all transplanted and starting the rapid growth phase.
Purchases (what supplies or equipment were purchased and their cost)	Bought a new coupling for fixing the irrigation line plus an extra one to have on hand in case of another leak: $10.87. Bought potting media materials for upcoming order: $28.45.
Orders (what plant materials were delivered and payments made)	Next week is the pickup of 250 sandalwood seedlings for the high school's graduating class to plant as a class gift to the community forest. The seedlings are ready; I just have to keep the slugs at bay.
General crop/nursery observations	Things look good in general.
Questions or concerns	There seem to be lots of slugs out… I would like to explore some other organic slug control options… maybe I will call around and see if anyone I know has had success with that copper barrier stuff and what the cost might be. I need to follow up with the Smiths to see if they are ready to confirm koa seedling order for November planting—if so I need to give them their contract, collect a deposit, and get planting so we can be ready when the rainy season starts.

***Table 4.6**—An example of a plant development record for an* Acacia koa *crop.*

Plant development record (Koa crop for Waimea Ranch due Dec. 15)	
Species name	*Acacia koa*
Propagule source	Collection site ABDA, at 2,000 ft (610 m) elevation on the leeward side of the Big Island of Hawai'i from 55 parent trees of good form.
Date(s) of propagule collection	July 15 and Aug. 1
Establishment	
Type and length of propagule treatment (for example, scarified, stratified)	Hand scarified then soaked in water overnight.
Date of propagule establishment	Aug. 2 to 3
Growing media and tray or container type used	Direct sown in Ray Leach Stubby cells; growing media consisting of 50% peat, 25% perlite, and 25% vermiculite with amendments and mycorrhizal fungi.
Germination notes (including date begins and ends, percent germination)	Fairly uniform germination of about 92% from Aug. 5 to 12.
Cutting notes (for example, special conditions, hormone treatments)	N/A*
Date transplanted (if not direct sown)	N/A*
Container type and growing media for transplanting	N/A*
Microorganisms used?	Mycorrhizal fungi inoculant in media; inoculated with *Rhizobium* on Aug. 20, 2014
Misting/Irrigation (type and frequency)	Daily hand-watering
Fertilization type, rate, and frequency, if any	N/A
Environmental conditions for crop (light, temperature, humidity)	Under plastic cover of screened-in greenhouse during establishment so birds and rodents do not eat the seeds.
Horticultural treatments (for example, cultivation practices)	N/A*
Date establishment phase completed	Aug. 26
Notes (resowing or thinning activities, problems, or challenges)	N/A*
Rapid growth	
Time after sowing and sticking to enter rapid growth phase	3 weeks (seeds scarified Aug. 1 and moved to rapid growth area Aug. 25)
Plant size at start of phase (height)	About 5 cm tall
Irrigation (type and frequency; for example daily, every other day, etc.)	Daily hand-watering
Fertilization type, rate, and frequency	N/A*
Environmental conditions for crop (light, temperature, and humidity)	Moved to full sun Aug. 27
Horticultural treatments (for example, spacing, cultivation practices)	Spaced out 50% on Sep. 9
Date rapid growth phase completed	Nov. 3, 2014
Notes (development, vigor, and health, challenges or problems)	Culled about 5% that were not growing quickly before beginning hardening phase on Nov. 3.

Table 4.6—Continued

Hardening	
Plant size at start of phase (height and stem diameter)	Average about 10- to 12-cm height, 2.5- to 3.0-mm stem diameter on Nov. 3
Irrigation (type and frequency; for example, daily, every other day, etc.)	Approximately every other day hand-watering or as needed (very hot days will water daily)
Fertilization type, rate, and frequency, if any	N/A*
Environmental conditions for crop (light, temperature, and humidity)	Full sun, ambient temperature
Horticultural treatments (for example, spacing, cultivation practices)	Some weeding. Weather has been windy; no need to brush.
Plant size at end of phase (height and stem diameter)	15-cm tall; 3.5-mm stem diameter
Date hardening phase completed	Dec. 10—ready to go
Date plants delivered	Dec. 15
Notes (vigor and health, challenges or problems)	
Other notes	
Notes on performance of crop after outplanting	Follow up by phone call scheduled for Jan. 5. Client is using a mattock and shovel to plant.

*N/A: Not applicable

***Figure 4.11**—Proper planning ensures that the needs of the nursery, the plants, and the clients are met in a timely fashion. Photo by Douglass F. Jacobs.*

Keep a separate plant development record for each crop grown, even if it is just a small trial of a few plants or even if the species has been grown before. Any intended improvements, trials, or experiments done with a species (such as increasing ventilation in the nursery area or switching to a new kind of fertilizer) can also be recorded in a plant development record. When these records are reviewed, the information enables nursery managers to determine if intended improvements actually had a positive effect on plant health and growth compared with what was normally done (figure 4.11). More information on trials, or experiments is provided in Chapter 20, Discovering Ways to Improve Nursery Practices and Plant Quality.

References

Dumroese, R.K.; Luna, T.; Landis, T.D. 2008. Nursery manual for native plants: volume 1, a guide for tribal nurseries. Agriculture Handbook 730. Washington, DC: U.S. Department of Agriculture, Forest Service. 302 p.

Landis, T.D.; Tinus, R.W.; Barnett, J.P. 1998. The container tree nursery manual: volume 6, seedling propagation. Agriculture Handbook 674. Washington, DC: U.S. Department of Agriculture, Forest Service. 166 p.

Landis, T.D.; Dumroese, R.K. 2000. Propagation protocols on the Native Plant Network. Native Plants Journal. 1: 112–114.

Landis, T.D.; Dumroese, R.K. 2002. The Native Plant Network: an on-line source of propagation information. International Plant Propagators' Society, Combined Proceedings. 51: 261–264.

Landis, T. D. 2011. The Target Plant concept - a history and brief overview. In: Riley, L.E., Haase, D.L. and Pinto, J.R.tech coords. National Proceedings: Forest and Conservation Nursery Associations – 2010. Proceedings RMRS-P-65. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Proceedings. 61-66.

Wilkinson, K.M.; Elevitch, C.R. 2003. Growing koa: a Hawaiian legacy tree. Holualoa, HI: Permanent Agriculture Resources.

Wilkinson, K.M.; Elevitch, C.R. 2004. Propagation protocol for production of container *Acacia koa* Gray plants: permanent agriculture resources, Holualoa, Hawai'i. In: Native Plant Network. Moscow, ID: University of Idaho, College of Natural Resources, Forest Research Nursery. http://www.nativeplantnetwork.org. (September 2009).

Wilkinson, K.M.; Elevitch, C.R. 2004. Propagation protocols for production of container *Cordia subcordata*, *Thespesia populnea*, *Santalum freycinetianum*, *Metrosideros polymorpha*, and *Erythrina sandwicensis* species. In: Native Plant N etwork. Moscow, ID: University of Idaho, College of Natural Resources, Forest Research Nursery. http://www.nativeplantnetwork.org. (September 2009).

Additional Reading

Evans, J. 1992. Forest nurseries. In: Plantation forestry in the tropics: tree planting for industrial, social, environmental, and agroforestry purposes. Second edition. New York: Oxford University Press. Chapter 10.

Jacobs, D.F.; Wilkinson, K.M. 2008. Planning crops and developing propagation protocols. In: Dumroese, R.K.; Luna, T.; Landis, T.D., eds. 2008. Nursery manual for native plants: a guide for tribal nurseries. Agriculture Handbook 730. Washington, DC: U.S. Department of Agriculture, Forest Service. 302 p

Wescom, R.W. 1999. Nursery production scheduling. In: Wescom, R.W. 1999. Nursery Manual for Atoll Environments. RAS/97/330 Working Paper No. 9. U.S. Department of Agriculture, Natural Resources Conservation Service: 12–14. Chapter 5.

***Appendix 4A**—A sample propagation protocol form*

Propagation protocol	
Family scientific name	
Family common name	
Scientific name	
Common name	
General distribution	
Propagation goal	
Propagation method	
Product type	
Time to grow	
Target specifications	
Propagule collection	
Propagule processing	
Seeds/kg	
Purity	
Germination	
Pre-sowing treatments	
Growing area	
Growing medium	
Establishment phase	
Duration of establishment phase	
Rapid growth phase	
Duration of rapid growth phase	
Hardening phase	
Duration of hardening phase	
Harvesting, storage, and shipping	
Outplanting and cultivation comments	
Citations	

***Appendix 4B**—A sample daily log form*

Daily log	
Date	
Environmental conditions in growing areas (light, temperature, humidity, etc.)	
Sunrise/Sunset times	
Moon phase	
Other weather notes (cloud cover, etc.)	
What water did plants receive? (irrigation type and frequency or precipitation)	
Today's activities (note how many person-hours per activity) (fertilization, pest management, transplanting, packing and shipping, making growing media, moving crops from one structure to another, treating or sowing seeds, and so on)	
Growth phase status (make notes when a crop moves from one phase to another)	
Purchases (what supplies or equipment were purchased and their cost)	
Orders (what plant materials were delivered and payments made)	
General crop/nursery observations	
Questions or concerns	

***Appendix 4C**—A sample plant development record form*

Plant development record	
Species name	
Propagule source	
Date(s) of propagule collection	
Establishment	
Type and length of propagule treatment (for example, scarified, stratified)	
Date of propagule establishment	
Growing media and tray or container type used	
Germination notes (including date begins and ends, percent germination)	
Cutting notes (for example, special conditions, hormone treatments)	
Date transplanted (if not direct sown)	
Container type and growing media for transplanting	
Microorganisms used?	
Misting/irrigation (type and frequency)	
Fertilization type, rate, and frequency, if any	
Environmental conditions for crop (light, temperature, humidity)	
Horticultural treatments (for example, cultivation practices)	
Date establishment phase completed	
Notes (resowing or thinning activities, problems or challenges)	

Appendix 4C—Continued

Rapid growth	
Time after sowing and sticking to enter rapid growth phase	
Plant size at start of phase (height)	
Container type and growing medium	
Irrigation (type and frequency; for example, daily, every other day, etc.)	
Fertilization type, rate, and frequency	
Environmental conditions for crop (light, temperature, and humidity)	
Horticultural treatments (for example, spacing, cultivation practices)	
Date rapid growth phase completed	
Notes (development, vigor and health, challenges or problems)	
Hardening	
Plant size at start of phase (height and stem diameter)	
Irrigation (type and frequency; for example, daily, every other day, etc.)	
Fertilization type, rate, and frequency, if any	
Environmental conditions for crop (light, temperature, and humidity)	
Horticultural treatments (for example, spacing, cultivation practices)	
Plant size at end of phase (height and stem diameter)	
Date hardening phase completed	
Date plants delivered	
Notes (vigor and health, challenges or problems)	
Other notes	
Notes on performance of crop after outplanting	