The Importance of Crop Growth Monitoring

by Thomas D. Landis

Coaxing plants to grow the way we want them to grow is the essence of nursery culture, and growth records from past seasons are one of a grower's best tools to accomplish this goal. Unfortunately, many nurseries only measure their crops during the annual inventory and before harvest. While absolutely necessary to good nursery management, inventory measurements don't give any hints about how the plants reached that size. The only way to really know how your crops perform is to monitor their growth during the season. However, in a survey of bareroot nurseries from the 1980s, less than one-third kept crop growth records (Royce 1984).

I don't know how many times I've been asked for my opinion about why a crop isn't growing up to expectations, but when I ask the nursery manager for some growth records, they don't have any. Growth records are like a road map — if you don't have a reliable map, you probably won't get where you want to go. So, I thought it might be a good idea to review how plants grow and what type of measurements a prudent nursery manager should be taking.

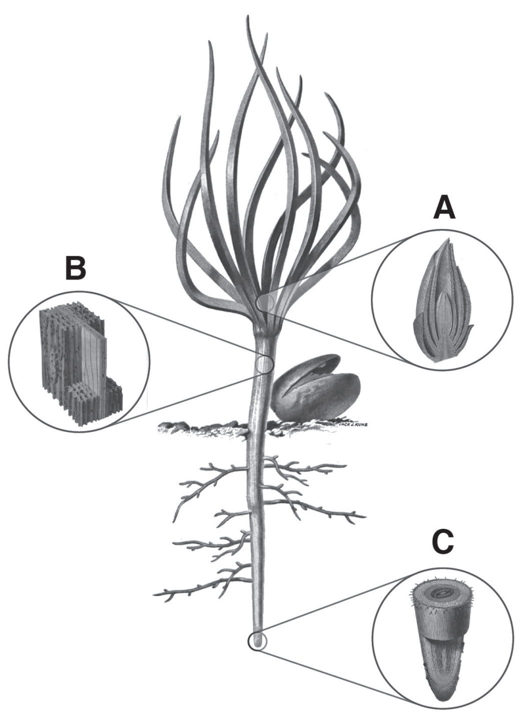

Figure 1 - Woody plants grow in size from 3 different meristems: shoot grow in height from the terminal meristem (A), woody stems and roots grow in diameter from the lateral meristem (B), and roots grow outward from the root tips (C).

How Plants Grow

Woody plants grow from 3 different meristems: the terminal bud, the lateral meristem, and the tips of the roots (Figure 1). By comparison, grasses grow from basal or intercalary meristems, which are found at the base of the plant. For the rest of this discussion, however, we'll be discussing shoot growth of woody plants. We'll cover root growth in the next issue.

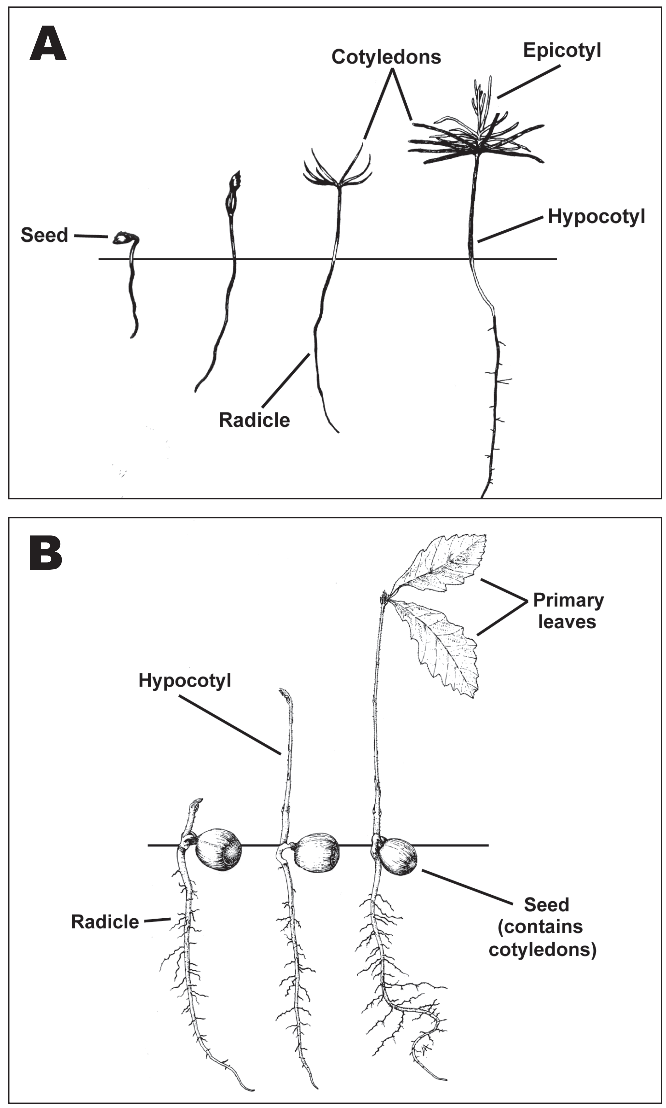

Figure 2 - In epigeous germination (A), the cotyledons carry the seedcoat above the surface of the soil or growing medium whereas, in hypogeous germination (B), both the cotyledon and seedcoat remain below the surface (modified from Schopmeyer 1974).

Seed germination and emergence. During seed germination, the root system begins growth first, when the radicle penetrates the seed coat and begins to extend downward under the influence of gravity (geotropism). After the radicle becomes established in the growing medium, the seedling follows either of two patterns of seed germination (Kozlowski 1971). Most conifers and some broadleafed species exhibit epigeous germination, in which the cotyledons ("seed leaves") are pushed above the surface of the growing medium by the expanding hypocotyl (Figure 2A). Conifer cotyledons carry the seedcoat on their tips to form a "birdcage." Other broadleaved species, such as oaks (*Quercus* spp.), exhibit hypogeous germination in which the cotyledons remain underground while the epicotyl ("shoot") elongates upward and produces primary leaves above the surface of the growing medium (Figure 2B). Some genera, such as *Prunus* spp., contain some species that have epigeous germination and others with hypogeous germination (Grisez and others 2008).

Shoot Growth Patterns

The shoots of nursery plants grow in two different ways (Powell 1982). Preformed ("predetermined") growth is a result of the expansion of preexisting structures, either those preformed in the embryo for first year shoots or those in terminal and lateral buds in subsequent years. Neoformed ("free") growth, on the other hand, does not depend on any preformed structures and shoots grow directly from the meristems (Figure 3). Some species exhibit both preformed and neoformed shoot growth in a given year, whereas other plant shoots grow either one way or the other. This growth form is genetically determined and cannot be changed by cultural means (MacDonald 1998).

The presence or absence of buds also affects shoot terminology (Kozlowski 1971). The shoots of many temperate zone species, including spruces (*Picea* spp.), form buds at the end of the growing season (determinate shoots) whereas other species, such as junipers (*Juniperus* spp.), do not (indeterminate shoots).

First Season Shoot Development. Seedling growth and development is different during the first growing season than in subsequent years because all species exhibit both preformed and neoformed growth (Figure 4). In the first season, the amount of preformed growth is determined by the size of the embryo (which is preformed in the seed), the stored energy in the seed, and the germination environment.

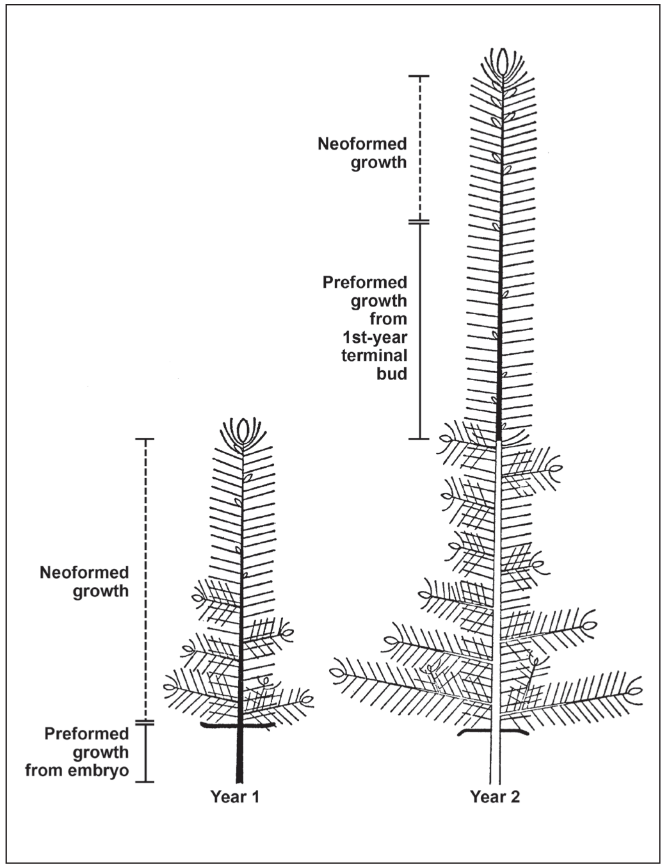

Figure 3 - Shoot growth can be divided into two categories: one that expands from preexisting structures ("preformed") and one that develops freely during the growing season (neoformed") (modified from Powell 1982).

Seedlings may or may not develop typical buds at the end of the first growing season. The shoots of determinate species, such as pines (*Pinus* spp.), cease growth and form ("set") terminal buds (Figure 4A&D). Other indeterminate species, such as junipers, never do form true dormant buds (Figure 4B&C). The shoots of pine seedlings, in particular, can look remarkably different during the first growing season, depending on species and growth environment. At least 4 variations in shoot development have been documented with pines (Powell 1982; Thompson 1989). Some pines produce only awl-shaped primary foliage and instead of a true bud form a rosette of needles at the end of the first growing season (Figure 4C). Other pines produce fascicled secondary needles in the axils of the primary needles and form a typical resting bud (Figure 4D). In some temperate zone pines, the time of budset is under strong genetic control and the shoot will not continue to extend even under the ideal growing conditions in a fully controlled greenhouse (Thompson 1989). For example, ponderosa pine (*Pinus ponderosa*) seedlings typically set a firm

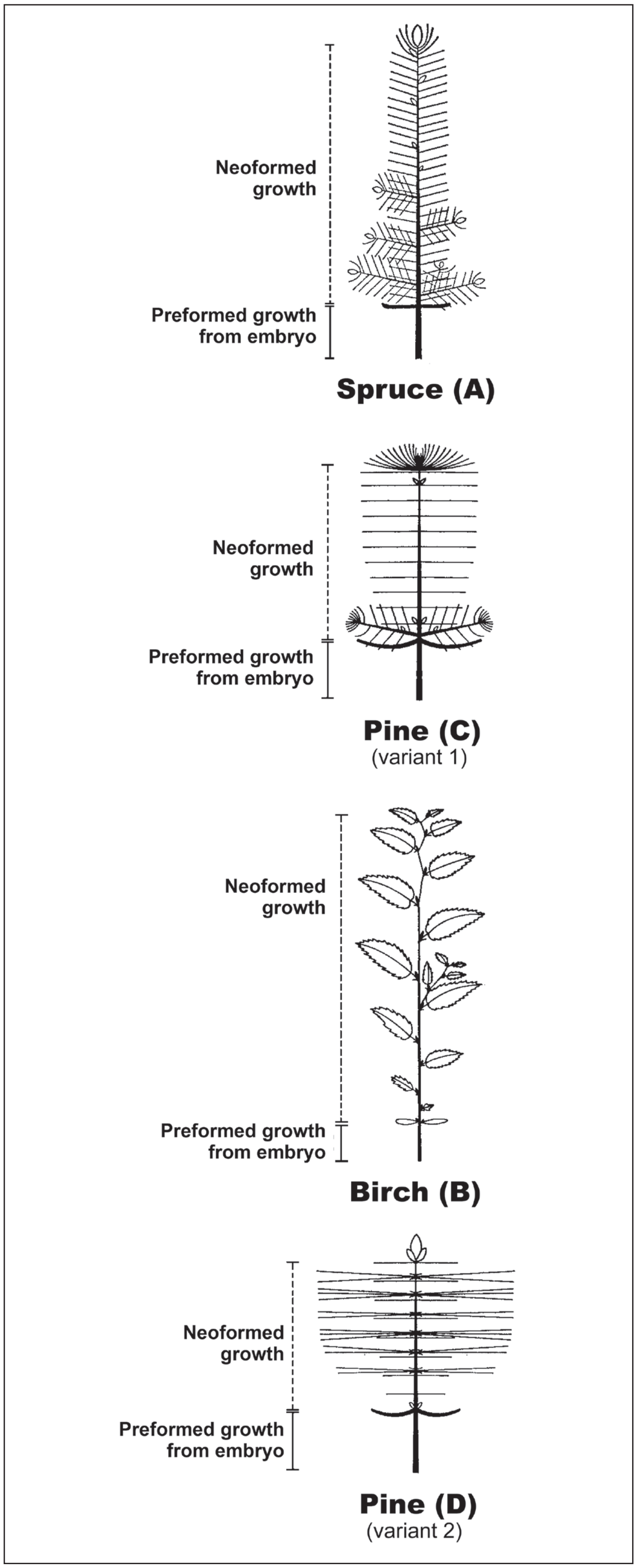

Figure 4 - First-year seedlings exhibit several different shoot growth patterns in nurseries, depending on the species, propagation environment, and daylength (modified from Powell 1982).

terminal bud in early July even though they are growing in a greenhouse under long-day photoperiod and high fertilization. In other species, such as blue spruce *(Picea pungens*), shoot growth will continue for over a year under ideal growing conditions before forming a bud (Young and Hanover 1978). Growers must induce budset in these species by radically changing the propagation environment. Ecotypes from northern latitudes are particularly prone to free growth during the long days of summer, and growers need to use extraordinary cultural measures, such as blackout curtains, to promote budset and dormancy. Bud development is particularly important because the presence and size of buds are considered by many customers to be a sign of seedling quality.

The shoot growth of broadleaved species is also variable under nursery conditions. In oaks, a temporary resting bud with scales may form between several growth spurts and a firm dormant bud is only formed at the end of the season. Leaf size and shape will also change between these growth spurts, with those formed later being larger and more deeply lobed (Powell 1982). In other indeterminate species such as birch (*Betula* spp.) and elm (*Ulmus* spp.), however, a true terminal bud never forms (Figure 4C). Instead, the shoot tip aborts at the end of the season and a lateral bud functions as the new terminal bud (Kozlowski 1991).

Second Season Shoot Development. If woody plants are held for a second growing season, some species will produce only preformed or neoformed shoot growth, whereas others will produce both types in sequence (Figure 3). Determinate species, such as pines, exhibit preformed growth as their entire second-season shoot extension comes from either preformed stem units in the dormant bud, resting rosettes, or long-shoot buds (Powell 1982). Shoot growth in other indeterminate species including junipers and birches does not depend on preformed structures from the first growing season but consists of only neoformed growth. Spruces and basswood (*Tilia* spp.) seedlings exhibit both preformed and neoformed growth, with the amount of neoformed growth strongly controlled by ecotype (Von Wuehlisch and Muhs 1991).

Measuring Woody Plant Growth

For nursery purposes, the following morphological attributes are measured (Armson and Sadreika 1979):

Shoot height is the vertical distance from the surface of the soil or growing media to the tip of the terminal leader, and is easily measured with a ruler. Although shoot height is easy to measure in the nursery bed or container, it is more challenging to measure on harvested stock because you are no longer sure of the original ground line. One way to determine this is to scrape the outer back and notice where the color of the inner bark changes from white to green, but this is slow and destructive (Mexal and Landis 1990). Other useful techniques are to measure height either 1 cm above the uppermost lateral root (Hodgson and Donald 1980), or approximately halfway between the uppermost lateral root and the cotyledon scar. The top of the seedling shoot can also be difficult to determine, particularly when the seedling is actively growing or with indeterminant species such as cedar (*Thuja* spp.) or juniper. If no obvious terminal bud is present, the measurement should be taken from the slightly swollen part of the shoot tip indicating the position of the terminal meristem.

Stem diameter, also called root collar diameter or caliper, is the diameter of the main stem of the seedling just above the ground line and is measured with calipers. Because the stem diameter can change significantly in this area, measurements should be made at a standardized location. Some nurseries specify that stem diameter be measured at the cotyledon scar or 1 cm above the first lateral root (Mexal and Landis 1990). Experience has shown that repeated measurements of stem diameter on the same plant causes stem thickening just due to the additional flexing during the measurement process. Therefore, it's better to measure a sample of plants and calculate an average stem diameter.

Dry weight represents the net gain between photosynthesis and respiration and, when monitored over time, gives an excellent index of how fast a plant is growing (Armson and Sadreika 1979). Although dry weight is commonly used for research purposes, the fact that it is time consuming and destructive makes it unpopular in nurseries. In addition, dry weight gain does not distinguish between the type of tissue. Two seedlings could have the same dry weight of roots but one could have a few large woody roots and the other more desirable mix of medium and fine roots.

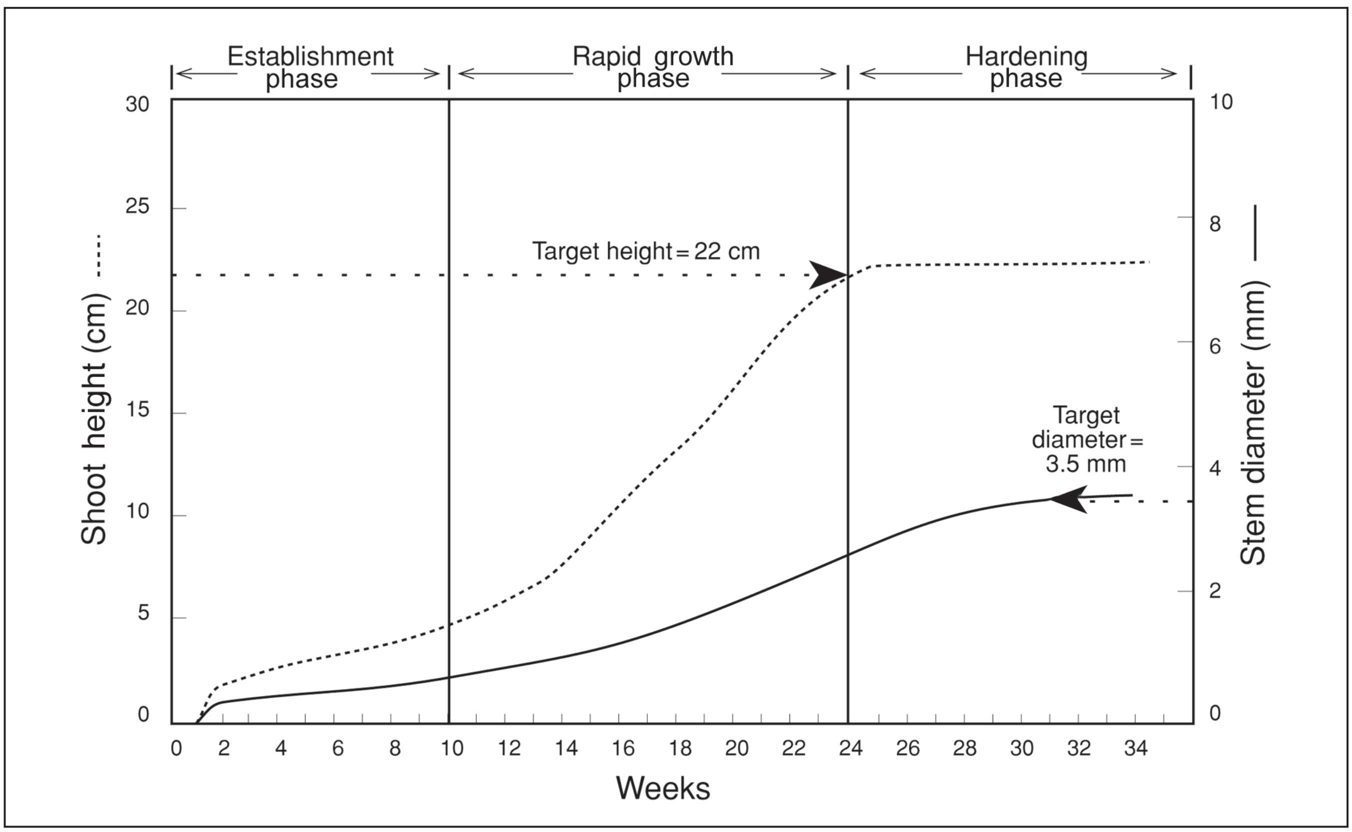

Figure 5 - The cumulative growth curve for height and stem diameter shows how a crop is progressing compared to target specifications.

Analyzing Plant Growth Patterns

The best way to utilize plant growth data is to record it in graphic form as you collect it. This can be as simple as a pencil and graph paper or a complicated as a spreadsheet, which will generate graphs.

Plant growth cycles can be plotted in 2 different ways: cumulative growth and incremental growth. The cumulative growth curve is the most commonly used graphing method and shows seedling dimensions plotted against time throughout the growing season (Figure 5). Total growth curves are useful for showing seedling growth progression relative to the target specifications of shoot height and stem diameter. The relative growth rate is illustrated by the slope of the line—the steeper the slope of the curve, the faster the seedling is growing.

The other, less-common type of growth curve is the incremental growth curve, which plots growth rate, rather than total growth. Incremental growth curves are useful because they reveal growth periodicity patterns during the growing season (Figure 6). Shoot growth of first year crops begins with emergence or with spring bud break for older stock. Stem diameter growth in newly germinated seedlings begins after the vascular cambium develops and starts producing wood cells at about 4 to 6 weeks of age (MacDonald 1998). In older seedlings, stem diameter growth begins early in the spring, slowly increases until it peaks after terminal bud set, and then gradually tapers off until cold weather induces dormancy. Note that competition occurs between the shoot and root for photosynthate, and so an increase in shoot growth causes a relative decrease in root and cambial growth. All woody plants follow this same general pattern, although the growth rate varies between different species.

Growth curves are also useful for detecting problems or for scheduling changes in cultural practices. After several seasons of growth records have been accumulated, nursery managers can compare the current shoot and stem diameter growth to a computed average or target growth curves (Figure 7).

One added benefit of monitoring crop growth is that it forces you to get out in the nursery on a regular basis, and you can use this time to scout for insects and diseases or notice other growth problems.

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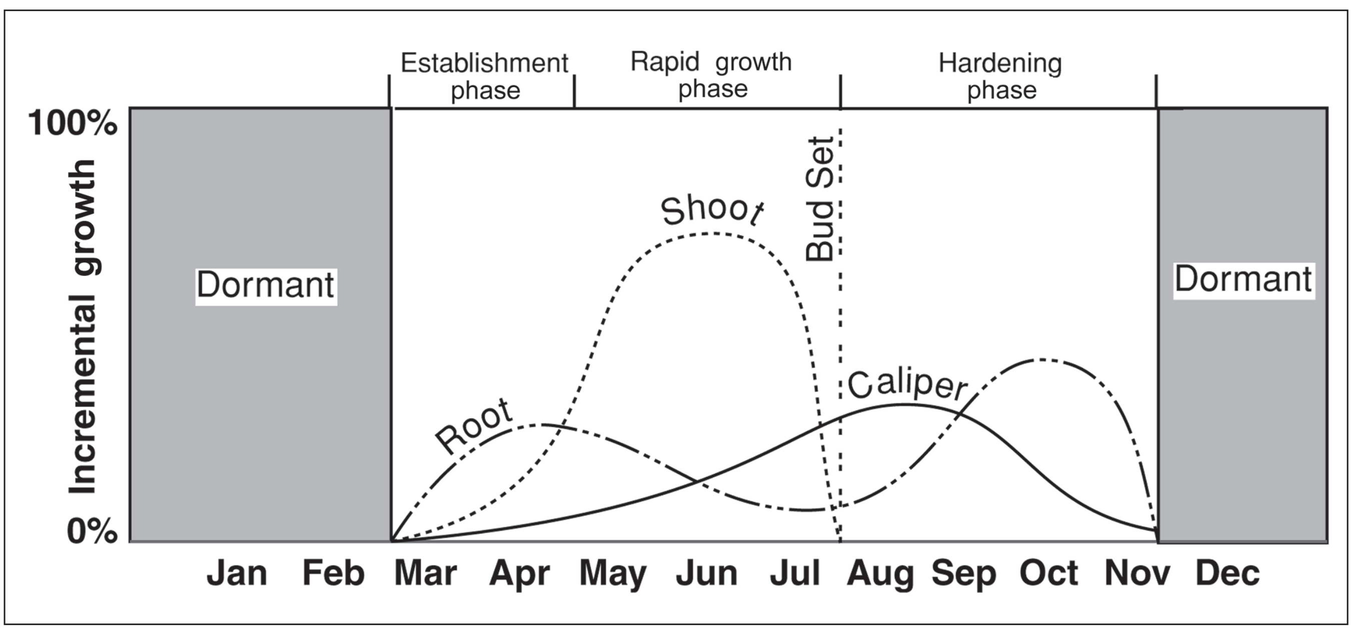

Figure 6 - Although less common, incremental growth curves show growth rate changes over time and give a good view of when growth of shoots, roots, and stem stem diameter occur during the season.

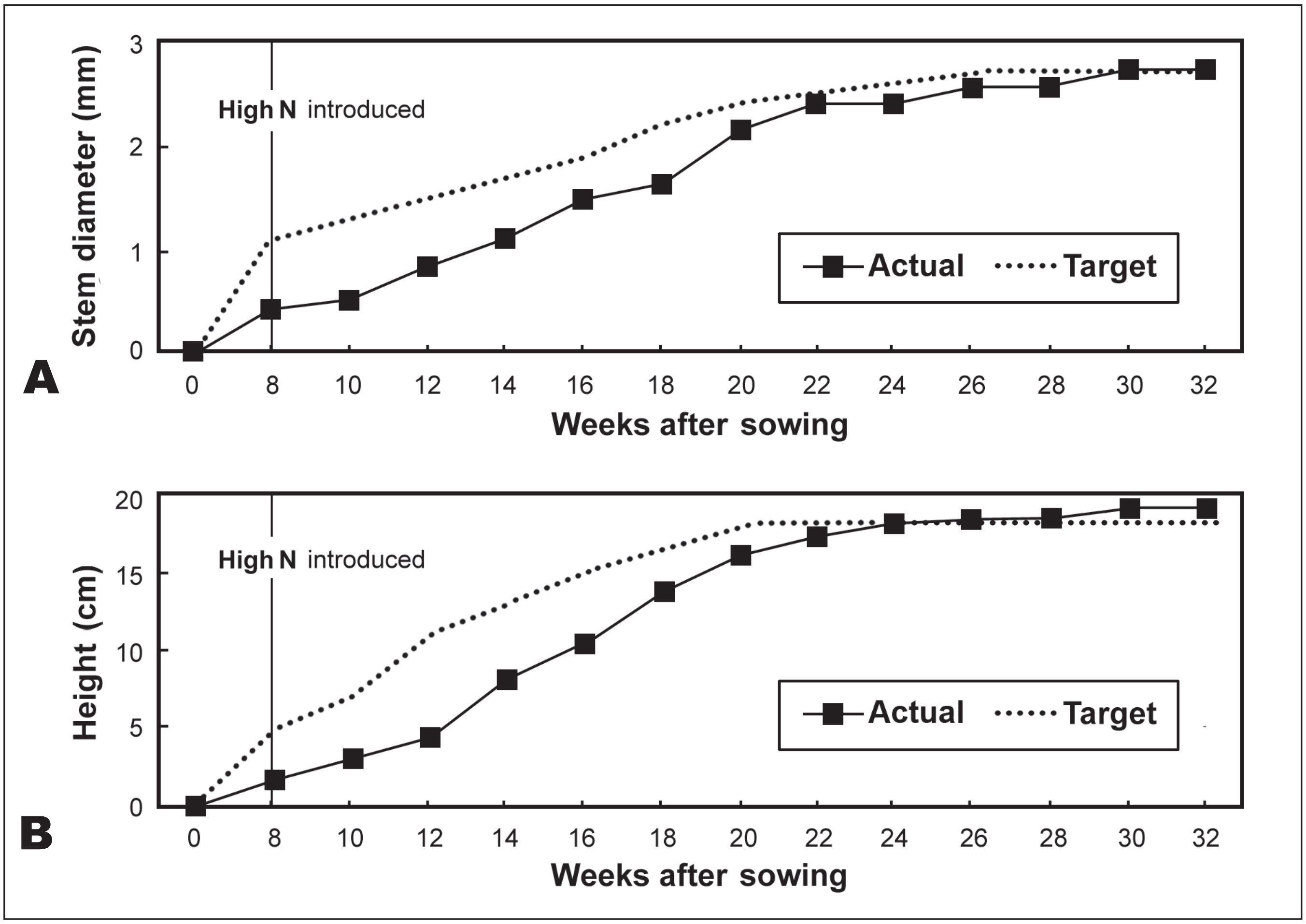

Figure 7 - One of the most useful applications for growth data is for diagnosing problems and scheduling cultural adjustments. In this example, these Colorado blue spruce (Picea pungens) container seedlings were growing much slower than expected so a high nitrogen (N) fertigation was started at week 8 and both stem diameter and height met the targets by the end of the season.

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