Inventory Methods

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T. Starkey
Tom Starkey is retired from Southern Forest Nursery Management Cooperative, Auburn University, Auburn, AL

Outline

Facing Page: *Inventory methods photo collage. (Photos by Chris Rosier.)*

Introduction

The Value of an Inventory

An inventory is a complete listing of the goods and stock produced by a company, including a value of these goods. It does not matter whether the company sells toothpaste, cars, aspirin, or tree seedlings. The ultimate goal is the same and involves several factors: (1) making a reliable estimate of the number of goods produced, (2) making an estimate of the marketability or quality of the goods produced, and (3) making these estimates within certain economic constraints.

Those working in the forest seedling nursery industry realize there are stumbling blocks to accurate inventories. The first stumbling block is that it is impossible to count (inventory) every seedling in the nursery. Nursery managers must settle for an estimate. How close this estimate is to the true number of seedlings varies by species grown and how much time (money) managers are willing to invest in the inventory. The second stumbling block is that seedlings are not of uniform quality. There is a range of acceptable seedling quality within every nursery bed. During the inventory process, the number of marketable seedlings must be estimated.

Why is an accurate inventory necessary? First and foremost, an accurate inventory is needed so those selling the seedlings know how many can be sold. A nursery manager growing 1,000,000 hardwoods should not be satisfied with a sampling error of 10 percent. This means there could be a surplus or a shortage of 100,000 seedlings at the end of the season. If hardwoods were selling for $250 per thousand seedlings, the nursery would either lose $25,000 by underestimating the true number of sellable seedlings or the nursery may need to return $25,000 to customers because it oversold the true number of seedlings.

An inventory is deemed accurate when, at the end of the season, the number of seedlings reported in the fall inventory closely approximates the number of seedlings sold by the sales team, plus any unsold seedlings. The ability to achieve accurate inventories have always been an issue of discussion between nursery managers growing hardwood seedlings and administrative accounting personnel. Pine inventories are generally much more accurate than hardwood inventories. The difference is due to the large amount of variation associated with hardwood seedlings compared to pine seedlings. It is probably safe to say that because of this variability, the accuracy of hardwood inventories will seldom be as good as pine inventories.

Types of Inventories

There are various types of inventories performed in forest seedling nurseries (Rosier 2015). The first is an inventory of seed in storage and is generally only done in nurseries with long-term seed storage. The second type of inventory is conducted the first few weeks after sowing to determine sowing efficiency and detect any early problems in seed germination. The spring and fall seedling inventories are the third type. The fourth type of inventory is a history plot to track seed germination and/or the growth of seedlings during the season. The fifth and last type of inventory is the packing inventory, which is done at the time of shipping, to determine quantity and quality of seedlings shipped to customers.

This chapter focuses on seedling inventories conducted in the spring and fall as well as history plots. In the Southeastern United States, the spring inventory is usually conducted in June or July, after germination is complete. The primary purpose of the spring inventory is to provide nursery administration with an estimate of the number of potentially sellable seedlings by species and seedlot. Since at this point it is not possible to determine the actual number of cull seedlings (those that will not reach sellable quality standards), nurseries will use past experience to estimate a certain percent loss during the growing season. The spring inventory also provides valuable information as to seedling density and total linear bed feet of each seedlot or species. In addition, problems due to washout or poor germination should be noted at this time, as they will provide valuable information that can increase the efficiency of the fall seedling inventory.

The most important inventory is the fall seedling inventory, usually conducted in September. It provides an estimate of the number of shippable seedlings per linear bed foot. Very seldom do the spring and fall inventories match. The fall inventory also will estimate the number of seedling considered as culls, which usually result from variances in height, root collar diameter (RCD), stem form, or other abnormalities or diseases. Providing a reliable estimate of the number of shippable seedlings is a little more difficult due to the fact that the seedlings may continue to grow until they lose their leaves. Nurseries will routinely estimate that the final RCD of a pine seedlot will increase by 0.5 to 1.0 millimeters (mm) between the time of inventory and lifting. However, for hardwoods, nurseries do not commonly allow for a similar increase in RCD between the fall inventory and lifting, since most hardwood species stop growth in the fall before conifers.

Variation Within Inventories

The objective of all inventories is not to measure every seedling in the nursery—this would be impossible and/or cost prohibitive. Rather, samples taken at multiple locations within the nursery are averaged to provide an estimate of the true number of seedlings in the nursery.

Variation in seedling numbers and quality is inherent to every nursery bed. For example, if you were to pull and measure every seedling in a 1-foot (ft) (30-centimeter [cm]) swath across a nursery bed in 3 locations, you would quickly observe the following variation:

1. The total number of seedlings will vary in the 3 locations sampled.
2. The number of seedlings in each of the drills across a counting frame will vary.
3. The seedling size (both RCD and height) across a nursery bed within a counting frame will vary.
4. The number of seedlings per square foot will vary.

Sources of variation frequently common to both hardwood and conifer nursery beds may include washed out areas due to irrigation or heavy rains and areas of loss due to insect or disease problems.

Sources of Hardwood Seedling Variation

The variation in hardwood seedlings is substantially greater than is found with conifer seedlings. Some of the common sources of within hardwood production variation are listed below:

- Since nearly all hardwood seed originates from open-pollinated, wild-collected trees, the genetic and resulting phenotypic variation can be substantial.
- Very seldom do nursery managers have seed germination data as they do with conifers. Therefore, planting densities are based generally upon previous years' germination, which can vary from year to year.
- It is not uncommon for one seedlot at a nursery to be composed of seed collected over a wide geographic area resulting in germination variation.
- Even when the seed is sized for sowing the calculation of seeds per pound needed to calibrate the sower is much more variable than with conifers.
- The stratification methodology used by the nursery can interact with the maturity of the seed at the time of collection and result in germination variation.
- Nursery managers have reported that the type of planter used can affect seedbed densities, resulting in additional sources of variation. It is very important that the person responsible for the sowing can actually see the seed being sown to assure the sowing machine is functioning properly.
- Hardwood species that require endomycorrhizae must have uniform distribution of the endomycorrhizae within the seedbed.
- Animal and bird predation can result in seedbed variation.

These sources of variation can result in the following seedbed variation:

- Erratic germination of seed.
- Rapidly germinating seed shading out slower germinating seed, resulting in RCD and height variation.
- Varying number of seed per bed drill.
- Areas of seed bed with either no seed germination or erratic growth of germinates.

When seedbed densities are not consistent within a seedlot, resulting in erratic growth, a bareroot hardwood nursery inventory requires many more sample plots to achieve the same degree of sampling accuracy as a bareroot conifer nursery. All of the above-mentioned sources of variation must be taken into consideration when formulating an inventory plan.

Inventory Tools

Although methods of recording or calculating actual inventories may vary, all nurseries use what is called a "counting frame." This tool, made from either metal or polyvinyl (PVC), is used to standardize the area of the nursery bed being inventoried. Since all nursery beds are 4 ft (1.2 meters [m]) across, all counting frames are 4 ft (1.2 m) long (or slightly larger) to sample across the bed. The width of the frame varies among nurseries. Frames may be 12, 9, or 6 inches (in) (30.5, 23, or 15 centimeters [cm]) wide, with the 12-in (30.5-cm) being most common in both hardwood and pine inventories. It is important that only one size be used by a nursery.

Counting frames are used to calculate the number of seedlings per square foot. When a 12-in (30.5-cm) frame is used, the total number of seedlings counted within the 4-ft (1.2-m) frame is divided by 4 to provide seedlings per square foot. When a 9-in (23-cm) frame is used, the total number of seedlings within the 4-ft (1.2-m) frame is divided by 3. When a 6-in (15-cm) frame is used, the

***Table 10.1**—Calculations using different size counting frames.*

Width of a 4-foot counting frame (in)	Total number of seedlings counted within frame	Appropriate counting frame divisor	Seedlings per square foot
12	80	4	20
9	60	3	20
6	40	2	20
12	75	4	18.75
9	43	3	14.33
6	27	2	13.50

ft = feet. in = inches.

total number of seedlings within the 4-ft (1.2-m) frame is divided by 2 (table 10.1). With the large amount of variation associated with hardwood inventories, a 12-in (30.5-cm) counting frame is recommended.

Some hardwood species have large canopies, which may make it difficult to place the counting frame over the nursery bed. One modification that can be made with PVC counting frames is to have an end that can be removed. With the end removed, the frame is slid across the bed at the ground line and the removable end replaced. Care must be taken that long sides of the frame remain parallel as it is placed on the ground and slid across the nursery bed before the removable end is attached.

When a counting frame is placed over seedlings and pushed down to the soil, the sides of frame frequently bend seedlings over. These are called border seedlings. It is important that all employees involved in the inventory be made aware of how to count these border seedlings. If the ground line of the seedling originates within the counting frame, it should be included in the frame count. However, if the top of seedling is bent over into the interior section of the frame, but the seedling originates outside the frame, it should not be included in the frame count.

Typically, nursery inventories involve several crews assigned to specific areas. Each crew, generally two or three people, has a counting frame and a method of recording the counts (either manually or on a data recorder). With a two-person crew, each person is responsible for counting seedling drills within half the 4 ft (1.2 m) bed. With a three-person crew, the third person generally is responsible for locating the plots and recording the counts.

Sampling Designs

Four sampling designs are commonly discussed when determining how to inventory a nursery (May 1984, Barton and Clements 1961, Duffield 1963, Mullin 1964, Mullin et al. 1955, Ware et al. 1967): random sample, stratified random sample, systematic sample, and stratified systematic sample.

Each of these designs has limitations in its use in a nursery situation.

Random Sample

It is generally assumed that random sampling is better than nonrandom sampling, which may introduce bias into the inventory. This method might work if a nursery only grew one seedlot of one species and seedlings were very uniform. However, all nurseries grow multiple species and frequently multiple seedlots within each species. (For the purposes of this chapter, a "seedlot" is understood to be the smallest uniquely identified population from the same genetic source.) The total number of seedlings in each seedlot may vary. In this case, a truly random sample presents some problems. For example, one seedlot (A) may account for 30 percent of the total hardwoods; the second seedlot (B), 5 percent; the third seedlot (C), 42 percent; the fourth seedlot (D), 17 percent; and the fifth seedlot (E), 6 percent of the total hardwoods.

If a manager decides that 50 samples (plots) are to be taken across the nursery, the location of any of these plots is decided randomly. For example, if the total length of all the bed rows is 6,000 feet, 50 numbers between 1 and 6,000 would be generated. These would be the location of the 50 plots. One problem with this method may be that the seedlots with fewer seedlings (B and E) may not have any plots fall within those seedlots. Another problem by using a strictly random approach is that seedlots with the larger number of seedlings may have a disproportional number of plots. For example, seedlot A and C may have 40 of the total number of plots, leaving just 10 plots for the other seedlots.

Stratified Random Sampling

In this sampling design, all areas of the nursery are divided into units called "strata." Each stratum must be more uniform within than compared to the neighboring stratum. Each seedlot within a nursery would make up individual strata, since each seedlot is more similar then neighboring seedlots. Once the strata are identified, sample plots within each stratum are taken. This sampling design achieves better sampling accuracy than a random sampling design.

The efficiency of this sampling design can further be increased by identifying additional stratum within a strata. For example, a strata consisting of one seedlot may not be uniform because of areas where stand density is low due to poor germination. Another example may be a nursery unit of a single seedlot but further divided into stratum representing large and small seed. The efficiency of the sampling design can be increased by creating substrata that include these areas of low stand density or seed size.

Systematic Sampling

As the name implies, when using systematic sampling within a nursery, sampling units are not chosen at random but are located at fixed intervals. Sometimes the location of the starting point may be chosen at random and then every sampling point after that fixed at a designated interval. A very simple example of a systematic sampling design is to locate sample plots in the third and seventh riser in every fourth bed.

This sampling design is simple to administer and can be done by unskilled workers and results in fewer mistakes. However, a nursery inventory requires all seedlots be sampled, which could be a problem with this method. Also, this sampling design is not favored by statisticians due to its lack of randomness (Mullin 1964, Freese 1962).

Stratified Systematic Sampling

The random, stratified, and systematic sampling designs discussed above all have advantages and disadvantages. Most nurseries in the Southern United States have chosen to combine some of the advantages of the above methods into a fourth design called the stratified systematic sampling, in an effort to increase sampling efficiency (May 1984).

The key to this method is the stratification of the various seedlots within the nursery. First, seedlots are located on a nursery map and designated as strata to be sampled. Areas of nonuniform seedling density within seedlots may also be identified as strata to be sampled. Sampling can begin once all areas of the nursery with seedlings have been assigned to one and only one strata. At this point, there are two approaches commonly used to determine where to locate individual sample plots.

The first approach is to start in the first bed of the first stratum and place a sample plot every "X number" of feet or every "X number" of irrigation risers. The second approach is to start in the first bed of the first stratum and randomly determine "X number" of sampling points within each bed. The number of sampling points per nursery bed is predetermined and based primarily upon previous experience with adjustments made due to seedlot size.

Number and Location of Plots Needed

The number of plots recommended for sampling hardwood seedlings varies between nurseries and even between nurseries within the same ownership. There are various statistical procedures available (May 1984) to determine the number of plots needed, such as using a sample size formula, a specified error limit, or a graphic approach based on historic plot numbers used at the nursery. Current inventory data recorders handle this process automatically. Based on a survey of growers, the most common method currently used is to start with a fixed number of plots based on the nursery manager's experience with that seedlot. This minimum number may or may not be adjusted, depending upon whether a sampling efficiency is calculated. One nursery surveyed that grows fewer than 500,000 hardwoods will start with 4 to 5 samples per seedlot and increase this number as needed. Another nursery growing more than 500,000 hardwoods specifies 8 to 10 plots per seedlot, with a minimum of 3 plots per nursery bed per seedlot, and adjusted as needed. The actual sample plot location may be random or fixed. One nursery using fixed distances between plots in its conifer inventory follows the same practice when sampling the hardwoods. This nursery recommends that all plot locations be evenly spaced across the nursery seedlot. The precise spacing between sampling plots per seedlot is calculated by dividing the total linear bed length in feet by the total number of samples needed. Limits are specified that no plot should be within 40 ft (12.2 m) of another plot or more than 200 ft (61 m) from another. The starting point of first sample is randomly chosen so that it falls within the first 15 ft (4.6 m) of the seedlot.

Data To Be Recorded

In the spring inventory, the total number of living seedlings is reported. This number, minus a nursery cull factor, is used to determine the number of seedling available for sale. Since the ultimate goal of the fall seedling inventory is to determine the number of shippable seedlings, nursery workers conducting the inventory must have a clear understanding of the target specifications for each species. This is a monumental task since it is not uncommon for each State or counties within a State to have specific minimum quality standards. All specifications would include a minimum RCD and minimum height. Any stem abnormalities such as low stem forking or galls would also be important. At the fall inventory, these morphological variables would determine whether a hardwood seedling would be shippable or a cull. Although numerous other variables from previously collected history plots or independent seedling quality evaluations (Wilson and Jacobs 2006) may be considered, they are not normally part of the fall inventory.

Only two items are normally recorded for each sample plot during the fall inventory: the number of seedlings that meet or exceed specifications and the number of culls. One nursery reported that nursery workers will carry calipers to measure seedlings if they are not sure whether a seedling is a cull or shippable. Another nursery may measure the height and RCD on three seedlings within each plot. The nursery manager will then be able to estimate the number shippable seedlings per linear bed foot when all subplots are totaled.

Data Analysis and Determination of the Need for More Sample Plots

The data collected from the field is entered—either by hand or from an electronic data logger—into a computer spreadsheet, such as MS Excel, for analysis. Two approaches can be used to determine if additional plots are required to be within the desired level of accuracy, which is most commonly 5 percent.

The following analysis should be done on each stratum separately to determine if additional plots are needed before combining stratum for a single seedlot.

Method 1

1. Seedling counts are calculated from the inventory to provide an estimate of the number of plantable seedlings per linear bed foot.
2. For each plot, the coefficient of variation (CV) is calculated either by formula or by dividing sample standard deviation by the sample mean and multiplying by 100. The coefficient of variation is expressed as a percent and is a good tool for comparing samples that have different size means. The larger the CV the greater amount of variation. Large amounts of variation from plot to plot are undesirable and will give a large coefficient of variation.
3. The observed level of precision of the mean estimate is calculated by taking the square root of the following equation: $((4*CV^2)/n)$ where n is the number of samples taken.
4. If observed precision is less than 5, no additional plots are required. If it is more than 5, additional plots are required. If observed precision is very large, consideration should be given to further stratifying the plot so that areas within the strata are more similar to one another than to areas outside the strata. The number of additional plots needed can either be determined by trial and error or by solving the following equation for n: $n = ((4*CV^2)/25)$ where $25 = (\pm 5\%^2)$ (Rosier 2015).

Method 2

1. Seedling counts are calculated to provide an estimate of the number of plantable seedlings per linear bed foot.
2. A determination is made as to how wide of a confidence interval (usually 95-percent) about the sample mean you desire. In other words, for the seedling density per sample plot, you may desire that the average sample mean be ± 2 seedlings per linear bed foot.
3. For each plot, a 95-percent confidence interval is calculated. If the confidence interval is within the ± 2 seedlings per linear bed foot, no additional plots are needed. If it is greater than the desired limit, additional plots should be taken.
4. This calculation of the confidence interval can be done in Excel either with the formula function or using the Data Analysis function choosing Data Summary.

Once the degree of desired accuracy has been achieved, the number of seedlings per linear bed foot for the stratum within seedlots can be calculated and combined for the total seedlot.

Another similar method to determine the required sample size can be found in van Belle (2002), chapter 2; this provides an example for calculating sample size using the coefficient of variation.

It is important at this point to distinguish how lifting of conifers differ from lifting of hardwoods. When a conifer nursery lifts 10 linear bed feet (3 m), all seedlings are generally placed into the box or bag. When a hardwood nursery lifts 10 linear bed feet (3 m), only the shippable seedlings are lifted and placed into a bag, leaving the culls in the field. Due to the large amount of variation associated with hardwood inventories, it is not uncommon for a nursery to revise its estimate of the number of shippable seedlings per linear foot during the lifting season. Following the fall inventory, the nursery manager has an estimate of the number of hardwood seedlings per linear foot prior to lifting. After the first few larger orders are lifted, the nursery manager should compare how many bed feet were actually lifted versus how many were estimated to be lifted based on the fall inventory. If these numbers differ substantially, additional sample plots should be added and the new seedling estimate per linear bed foot recalculated. Before adjusting the inventory numbers, however, the nursery managers should determine if the nursery beds lifted are representative of the remaining beds for that seedlot. Although this evaluation procedure is valid for conifers, it is more frequently done for hardwoods because of the increased variation within the seedbed.

Life History Plots

Many nurseries use history plots to provide valuable information for management decisions and tracking seedling development (Belcher 1964). As the name implies, life history plots track various aspects of seedling development and growth over the life of the seedlings. History plots were initially developed as a means of both tracking seedling growth during the season and providing seedling counts for inventories (Belcher 1972). Today, history plots are used primarily as a decision-making tool for information on the current seedling crop, although information from previous years should also be utilized to make decisions most effectively.

Types of History Plots

Nursery history plots can either be permanently established plots that are remeasured or random plots that are relocated at each measurement interval. In either case, history plots have two objectives. First, nearly all nurseries use history plots to monitor germination following sowing. The rate of seed germination is generally tracked over several weeks in permanently established plots within each seedlot. Once germination is complete, the plots are either abandoned or utilized in the next type of history plot.

The second type of history plot is one that monitors seedling growth throughout the growing season. The type of data collected can be as minimal as recording just RCD or more extensive, including multiple parameters such as RCD, height, root development, and seedling nutrition using foliar nutrient analysis (Wilson et al. 2006). Information may be recorded by tracking all seedlings within the designated area, a set number of random seedlings within the area, or specific seedlings within the area. One cautionary regarding the use of permanent plots is that repeated measurements of the same seedlings over the course of a growing season may result in seedlings with a smaller RCD than comparable seedlings outside the plot.

Plot Establishment

Whether history plots are used to monitor germination, follow seedling development, or both, plots should be established immediately after sowing the seed using either a random or systematic procedure. The most common method to establish plot location is to place a counting frame across the seedling bed and the four corners marked with either pin flags or long nails. Twine is used to connect the four corners and establish the plot perimeter. Seed or seedlings that may lie directly on the perimeter are frequently removed so as to better define which seeds or seedlings are within the plot and will be measured.

Measuring History Plots

When only seed germination is of concern, weekly measurements that begin at germination and continue to full germ are the standard. If, during the period of counting, any seed germinates and then dies or fails to properly send down a root radical, that seed should be removed from the area, noted in the data sheet, and then added to all subsequent counts in order to calculate total germination (May 1984, Belcher 1964).

If the history plots are being used to monitor seedling growth, nursery staff who will be recording the data must be properly trained on how to use calipers to measure RCD. Training should include the proper positioning of the calipers on the stem of the seedling and the proper operation of the calipers. Many calipers have two sets of jaws (arms) for measuring items internally or externally. The external jaws are used to measure RCD. The external jaws of many brands are very narrow at the tip of the reference arms and much flatter behind the narrow tip. In order to avoid squeezing the stem too hard using the narrow tip and damaging the seedling, the flatter portion of the arms should be used. The arms should just touch the stem to obtain a proper reading.

History Plot Data Use

There are two primary issues to be addressed when history plots are used to monitor seedling development. First, the nursery manager needs to know if the growth of the current seedling crop is ahead or behind that of previous years. Second, the nursery manager seeks to compare the quality of the current seedling crop to that of previous years. Similar seedling quality data must be available from previous years to address these basic issues and grouped together to generate a generalized growth curve. The relationship of RCD to seedling age is a good example. History plots that monitor seedling quality can be specific to a seedlot that is sown year after year, or more generalized to represent a grouping of similar seedlots. For example, a generalized growth curve for oaks would not be helpful because of the growth differences among hardwoods. Growth curves specific to a species or closely related species would provide better information.

Although growth curves related to RCD and height are the most frequently used, any seedling parameter that is measured routinely can be included. At any point during the growing season when seedling measurements are made, they should be compared to the growth curves generated from previous years' data to determine if the current seedling growth is on target, ahead of, or behind previous years. Based on the results, fertilization or irrigation can be altered to bring the growth in line with previous years.

Important Statistical Terms

Listed below are the definition of some statistical terms that are used in nursery inventories and data summaries.

Measures of Central Tendencies:

Mean. The sum of all the values in the data set divided by the number of values. Used interchangeably with the average of the values.

Median. When all the values of a data set are listed in numerical order, the median is the value at the middle of the list.

Measures of Dispersion (Variability):

Coefficient of variation. A measure of the spread of data points in a data series around the mean. It is calculated by dividing the standard deviation by the mean. Large values indicate that variation is high, which is undesirable.

Confidence interval. Expresses the probability the sample mean will fall between two set values. The confidence interval can take any number of probabilities, with the most common being 95 or 99 percent.

Standard deviation. A measure of the spread of a set of data from its mean. It is calculated as the square root of variance (defined below) divided by the number of samples (usually using the degrees of freedom, so the number of samples -1, denoted as n-1).

Standard error of the mean. A measure of the variation among sample means, and calculated as the standard deviation divided by the square root of the number of individuals in the sample, or "n."

Variance. The spread between numbers in a data set. Variance measures how far each number in the dataset is from the mean. Variance is calculated by taking the differences between each number in the dataset and the mean, squaring the differences (to make them positive).

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