REGULATING NURSERY SEEDBED DENSTITIES

DETERMINING ROW MANY SEED TO SOW AND SOWING DENSITY

John R. Scholtes[1]

Abstract.--There are numerous formulas and methods used to determine how many seeds to sow to grow the required number of shippable seedlings and how dense the seed must be sown to achieve the desired seedbed density. The following paper discusses the factors to be considered in all sowing calculations and presents one formula system. It also discusses the collection and use of Nursery Survival data.

[1] Nursery Specialist, Northeastern Area S&PF, USDA Forest Service, Broomall, PA

INTRODUCTION

It must first be acknowledged that there are many methods of developing nursery sowing plans. These range from using general rules-of-thumb based upon past experience to calculating formulas using seed test and nursery administrative study data. Even when calculations are made, formulas may appear quite different from one nursery operation to another. One reason for these differences is that terminologies are not standard. Another reason is that factors are often combined before they are used as a formula component. For instance, seedbed survival and seedling cull percentage are often combined into a single factor called the "nursery factor".

Such differences make it absolutely necessary that any discussion about sowing calculations include sufficient information to define the terms used and to describe the calculations. The following discussion will present one method of determining sowing amounts and rates. Various components for each calculation are listed and described below. Finally, collecting and using nursery surival data is discussed.

RULES OF THUMB VS QUANTIFIABLE DATA

Data is not always available for use in formulas. This can occur under several circumstances. For instance, seed collection or purchase may not leave sufficient time between receipt of the seed and the planned sowing date to allow complete testing. This is especially true of certain species which can not be stored or which may need some sort of long term treatment before being tested. In other cases, nursery factors may not be available as is the case when new nursery areas are brought into production, the soil is amended, or cultural practices are extensively changed.

In actual practice, conditions change from nursery area to nursery area, seedlot to seedlot, and year to year, so any factor used is always a projection based upon past experience. Therefore, when quantifiable data is not available, it is reasonable to draw upon past observations mellowed with your best judgement to predict one or more factors.

Even though past observations and good judgement are necessary at times, the collection of quantifiable seed and nursery performance data is still very much required. Quantifiable data taken at various points throughout the operation serves several purposes. One is to pinpoint where problems are occuring within the overall operation. Once a problem is located, changes in procedure(s) can be made to correct that problem. Additional data can then be collected to determine if the changes have been effective. Another purpose for quantifiable data is to apply statistical methods in predicting future performance of existing and new seedlots. Yet another purpose is to monitor factors for short and long term trends which can indicate whether or not management practices are performing as planned or if certain practices should be altered.

HOW MANY AND HOW DENSE

There are two very separate and independent sowing factors to consider when developing sowing plans. One is HOW MUCH SEED TO SOW to produce the required number of shippable seedlings. The other is HOW DENSE TO SOW SEED per area of seedbed to obtain the desired seedbed growing density. These factors will be presented in detail in the following discussion.

DATA REQUIRED FOR SOWING CALCULATIONS

With the exception of using crude rules-of-thumb, data must be gathered for use in all sowing formulas. In several cases, the same data is used in both HOW MUCH SEED TO SOW and HOW DENSE TO SOW SEED calculations even though they provide very different products. Data used in each calculation is listed and discussed below.

DATA	SOURCE
1. SEED/MEASURE (KG or LBS)	SEED TEST
2. PURITY %	SEED TEST
3. GERMINATION %	SEED TEST
4. OVERALL NURSERY SURVIVAL %	NURSERY FACTOR
5. SHIPPABLE %	NURSERY FACTOR
6. INITIAL NURSERY SURVIVAL %	NURSERY FACTOR

DESCRIPTION OF DATA

1. SEED/MEASURE- This is the average number of seed per pound or per kilogram. (NOTE: The use of metric measures simplifies all further calculations since, like our monetary system, it is already in a decimal format. However, the more familiar Avoirdupois system can also be used as long as portions of pounds are stated in tenths or hundredths of pounds rather than ounces. Either system can be used as long as they are not interchanged without using appropriate conversion factors.)

   Seeds per measure can be calculated several different ways. One commonly applied method is to count out 1000 seeds from a representative sample of the seedlot. The weight per 1000 seed is determined and the SEED/MEASURE is calculated using the formula below. A more accurate method is to count out 5 subsamples of 100 seeds each as described by Bob Karrfalt in a previous section of this workshop. These are weighed individually and checked to assure that the difference between the highest weight and lowest weight is not over 10% of the average weight of all the subsamples. The total weights of the 5 subsamples are then added together and multiplied by 2 to represent the weight of 1000 seeds. This data can then be used in the formula below. The method chosen may depend upon the accuracy of available scales. The weight of a 1000 seed count should be determined on scales accurate to the nearest 1/10th gram while the 100 seed subsamples should be weighed on scales accurate to the nearest 1/100th gram.

FORMULAS

1. Seed/kilogram (For 1000 seed samples)

$$\frac{1{,}000{,}000}{\text{Weight of 1000 seeds (in grams)}} = \text{Seed per Kilogram}$$

2. Seed/kilogram (For sample sizes other than 1000 seed counts)

$$\frac{\text{Number of Seeds in Sample}}{\text{Weight of Seeds in Sample (grams)}} = \frac{\text{X Seeds per Kilogram}}{\text{1000 (grams)}}$$

3. Seed/Kilogram to Seed/Pound Conversion

$$\frac{\text{Seed per Kilogram}}{2.2046} - \text{Seed per Pound}$$

2. PURITY %- This is the percent of a seedlot that is pure seed. Most seedlots contain a small quantity of cone bracts, pitch, pebbles, wood pieces, etc. which are similar in size and weight to the actual seed. These are difficult to separate out by normal seed cleaning processes. The seed drill will treat (sow) these particles of trash just as though they are seed. Therefore, any appreciable amount of trash (perhaps three percent or more) must be accounted for in the sowing formula. For instance, Picea mailana (black spruce) will have from 335,000 to 664,000 seeds per pound. If your seedlot has 400,000 seeds per pound and a purity of 97%, you would be sowing only 388,000 seeds for every pound. The 22,000 seed per pound difference could have some effect on whether or not you have enouph seedlings to fill your orders. This factor is also important when purchasing seed, especially as seed becomes more and more expensive. A 100 pound lot of seed contains one pound of trash for every one percent falldown in purity.

Purity is calculated as the percent of pure seed by weight. A representative working sample is taken from the seed test sample and weighed. All foreign matter is then separated out. The remaining pure seed is weighed and the percent of pure seed is calculated using the following formula.

[2] ______, USDA Handbook #450, "Seeds of Woody Plants in the United States". Forest Service, Washington, D.C.

FORMULA :

$$\text{Seed Purity \%} = \frac{\text{Weight of cleaned seed}}{\text{Weight of the working sample}} \times 100$$

3. GERMINATION %- The germination percent is a factor that must be fully explained when it is quoted. It may be the result of a laboratory test in which *a* sample of seed was actually germinated. Or, it may be an estimation of germination based upon some other test such as a cut test or an X-ray examination. There are several other tests commonly called quick tests which include procedures such as staining cut seed with tetrazolium (TZ test) or checking the electrical conductivity of leachate. All such tests may be useful so long as they can **be** related to actual field survival.

   Germination test results are most often reported in terms of the Maximum Germination Potential of a seedlot. This is the final or total amount of seed which germinated during the test. Such data does not inform the grower how the seedlot actually performed during the test. Standard laboratory germination procedures normally provide that counts be taken each seven days during the test period. The test normally runs for four weeks with some species requiring longer test periods such as six weeks. Individual seedlots may perform quite differently during the test period and still end up with nearly the same Maximum Germination Potential. One seedlot may germinate very quickly and reach its maximum within the first week while another may slowly progress throughout the entire period. Still others may lay fairly quiet for a week or two and then germinate rapidly near the end of the test. Such information can be of value to the grower who is attempting to predict how the seedlot will perform in the field or greenhouse situation. Of course, none of the quick tests mentioned above can supply the grower with this detailed information.

   Some nursery managers use results other than the Maximum Germination Potential of a seedlot in an attempt to better predict field performance. Obviously, a seedlot that germinates more quickly and more vigorously should perform better in the field or greenhouse. Seed that lays for two or three weeks after sowing is much more likely to suffer damage from insects, disease, drying conditions and other agents that can further weaken or kill it before it has a chance to germinate. To account for seed vigor, Intermediate Germination results are sometimes used in sowing formulas rather than the Maximum Germination Potential of the seedlot. One such scheme used in calculating conifer sowing rates is to use the 21-day results for non-stratified seed and the 14-day results for stratified seed.

   No particular method of germination test or type of data is being suggested in this discussion. The point being made here is that it is important to know what germination method was used and what criteria the Nursery Manager used in selecting data for the sowing formulas.

4. OVERALL NURSERY SURVIVAL %- This is an all inclusive factor used to account for losses which occur between the Pure Live Seed Sown and the amount of seedlings which survive through the crop rotation. The Pure Live Seed Sown must first be determined using the following formula.

FORMULA:

$$\text{Pure Live Seed Sown} = \text{Measures of Seed Sown (Lbs or KG)} \times \text{Seed Per Measure (Lbs or KG)} \times \text{Seed Purity \%} \times \text{Seed Germination \%}$$

The Overall Nursery Survival % can then be determined by taking a gross inventory before lifting the crop and working through the formula presented below. A final inventory is usually taken to estimate saleable or shippable seedlings. If all live seedlings are counted in addition to just those deemed shippable, that same inventory can be used to determine the Overall Nursery Survival %.

FORMULA:

$$\text{Overall Nursery Survival \%} \quad \frac{\text{Final Gross Inventory}}{\text{Total Pure Live Seed Sown}}$$

This one factor accounts for all losses including: Seed treatment, seed handling, sowing, pre and post germination dampening off, heat loss, frost damage, drought, seed and seedling loss to predators, mechanical damage, climatic factors, etc.

The negative feature of using such a broad factor is that individual causive agents are not identified. The positive feature is that unless management has accounted for each loss individually and is prepared to predict the effect of each one on the future crop, an overall factor is the only type that is of value. Obviously, good judgement must be used in applying this factor. If the previous ;rowing period(s) were racked with unusual losses, then one has to consider the likelihood of the same losses occuring during the next crop. On the other hand, records of several crop rotations will produce a fairly reliable figure to use.

Nursery History Plots which are permanent type plots read at various times during a crop rotation are useful to pinpoint when losses are occuring. Using data from them, a manager can formulate tests designed to discover the cause(s) of loss and possibly eliminate the losses. When predicting future crops from this data, one must be careful to assure that the potential for losses from all factors are considered and not just a few losses identified during a short term test period.

5. SHIPPABLE %- This factor accounts for any falldown between the Final Gross Inventory and the number of seedlings actually shipped. It can be calculated using the following formula.

FORMULA:

$$\text{Shippable \%}^{*} = \frac{\text{Total Seedlings Actually Packed for Shipment}}{\text{Gross Inventory From Final Inventory}}$$

* The entire seedlot or an area identifiable on the inventory records must be used to calculate this factor. Any seedlings not accounted for such as those left in the ground or destroyed would affect the percentage of shippable seedlings.

The Shippable % is the inverse of *a* Cull Factor. The Shippable % is preferred here because it allows a direct calculation of how many seedlings will be produced and can be used directly in sowing calculations. It is a general factor which accounts for all culling losses whether they are culled for size, mechanical damage, or other factors. In cases where the Final Gross Inventory was determined the previous fall, the Shippable % factor will also include overwinter loss. Again, it may be helpful to identify each loss individually so their effect can be calculated and specific steps taken to lessen one or the other. However, as in the Overall Nursery Survival Factor, **all** cull seedling losses must be accounted for whether they are lumped into a single factor or listed separately.

6. INITIAL NURSERY SURVIVAL- This is the percent of Pure Live Seed Sown that will produce a live seedling. It is used in calculations required to establish the Desired Seedbed Density. This factor can be determined *as* soon as germination is complete using a special inventory, history plots, or the 1.0 inventory. The timing of this sampling must be determined by the manager to best meet the demands of the nursery operation. However, once the timing has been established, it should be adhered to each rotation to provide data that is comparable from one crop to the next and to be useful in predicting future seedlot performance.

Since growing seasons vary significantly from year to year, it is suggested that a calendar date not be used as a reference point for determining Initial Nursery Survival. A phenological event such as when germination is deemed complete or when (conifer) seedlings drop their seedcoats, etc. could be selected as the reference point.

If the cost for a special inventory or history plots prevents early determination of Initial Seedling Survival, the 1.0 gross inventory count can be used. However, this must be considered as somewhat of a compromise since using the 1.0 inventory will not provide the manager with data until after the initial growing season is complete.

Therefore, this data will not be available for reference in making early cultural decisions such as seedbed thinning. Also, the later the factor is determined during the crop rotation, the more subfactors it will contain. This will make analysis more difficult or impossible. Since future development of the crop is highly dependent upon initial seedbed density, it is suggested that an early determination of Initial Nursery Survival be made for each seed lot sown.

FORMULA:

$$\text{INITIAL NURSERY SURVIVAL} = \frac{\text{Total Live Seedlings}}{\text{Pure Live Seed Sown}}$$

HOW MUCH SEED TO SOW

The Nursery Manager must determine what is to be produced (shipped) when developing each year's sowing plan. Production may be for customers with confirmed orders or it may be based upon speculation of what the market will demand when the seedlings are ready for shipment. Quite often, the sowing plan will include *a* mix of contract orders plus speculative production. Regardless of how the sowing plan is developed, some estimate or target amount to ship is needed before further calculations can be made.

Once the production requirements have been determined, the quantity of seed required can be calculated using the methods and formulas listed below. First, estimate the number of SHIPPABLE SEEDLINGS per measure of seed (in either KG or LBS). Then determine how many measures are needed.

FOR/4IIIAS:

$$\text{Shippable Seedlings per Measure of Seed} = \text{Seed per Measure (KG or LB)} \times \text{Purity Percent} \times \text{Germination Percent} \times \text{Overall Nursery Survival Percent} \times \text{Shippable percent}$$

$$\text{Measures of Seed to Sow (LB or KG)} = \frac{\text{Total Shippable Seedlings Required}}{\text{Shippable Seedlings Per Measure (LB or KG)}}$$

There may be cases where available seed is a limiting factor. If so, the formulas provided above can still be used to determine the amount of shippable seedlings you might expect from the quantity of seed on hand.

If seed of unknown quality must be sown or ordered from a seed dealer, rule-of-thumb figures can be entered into the formulas to estimate the volume of seed needed. Once you learn more about the seedlot or its performance through laboratory tests or from actual field performance, this information can be entered into the same basic formula to determine How Much Seed to Sow.

HOW DENSE TO SOW SEED

The establishment of proper initial seedbed density is a primary requirement for growing quality seedlings. Overcrowding can lead to several problems including tall seedlings with insufficient caliper and root systems. Several recent studies have shown that seedling caliper is highly dependent upon seedbed density. Although less critical, severe understocking may also result in seedling quality problems such as rangey-stiff lateral roots.

There are a number of references available which provide data on how seedbed density effects the development of seedlings. Studies have generally associated increased caliper growth, lateral shoot development, reduced seedling cull percent, etc. with less dense seedbeds. Although extremely sparce seedbeds may result in root development problems described above, the lower limit of seedbed density is normally established because of economic considerations or lack of seed bed space rather than concern about reduced seedling quality.

Most nursery managers already have guidelines which indicate the target seedbed densities they are to achieve. The procedure and formulas provided below will indicate how many seed to sow per unit of seedbed to achieve the target (desired) seedbed density. First, estimate the percent of seed sown that will produce a live seedling. Use the process described above to determine Initial Survival Percent. Then determine the number of seed to sow per unit of seedbed. The unit of seed bed used can be Per Square Foot, Per Square Meter, Area of a Standard Seedbed, etc. so long as the same unit of measure is used on both sides of the formula.

FORMULA.:

$$\text{Seed to Sow Per Unit of Seedbed} = \frac{\text{Desired Density Per Unit of Seedbed}}{\text{Initial Survival \%}}$$

DEVELOPING SURVIVAL FACTORS FOR USE IN SOWING FORMULAS

The procedures and calculations outlined above and those described earlier during this workshop are relatively easy to understand and perform. Yet establishing the desired initial seedbed density and producing the required quantity of shippable seedlings are among the most difficult operations for the nursery manager. The difficulty is in selecting a survival factor or range of factors which will predict the future performance of seedlots. A few considerations are provided below as well as one method of analysing data.

It is important to emphasise that the methods and formulas used in this section of the workshop consider that purity and germination factors will always be a part of the sowing formula. Therefore, all survival calculations are based only upon Pure Live Seed. Stated another way, the following survival calculations attempt to establish how many of those seeds which will germinate under laboratory conditions will survive under field conditions.

WHEN TO COLLECT DATA

The timing for taking survival information may range from initial germination counts to the final inventory plots. The intended use for the data collected will dictate when survival data should be collected. Some type of Initial Nursery Survival data is required to determine How Dense to Sow seed to establish the desired initial seedbed density. On the other hand, Overall Nursery Survival data is required for determining How Much Seed to Sow to produce the desired number of gross live seedlings at the end of the crop rotation. Intermediate Survival factors calculated at the proper times can be used to measure the amount of mortality that occurs during specific events such as overwinter loss between the first and second growing season.

SEPARATING POPULATIONS

Survival data must be assembled into useful groupings. Each species can be expected to perform differently. Therefore, it is prudent to treat each species as a separate population. If you suspect that there may be significant performance differences within a species because of seed collection area, improved vs unimproved seed, or location in the nursery, these groups of seedlots should also be treated as separate populations when analysing performance.

USE OF REGULARLY SCHEDULED INVENTORIES

One method of obtaining data to use in calculating a survival factor is to take a special seedbed or plot inventory. This is expensive and may not be warranted except in cases where problems have become apparent. One option to taking special inventories is to use data from regularly scheduled inventories. This data will have certain limitations which must be considered but it can be used to develop useful information without expending the resources to take special inventories.

When using regularly scheduled inventories, the limitations to consider are imposed by the timing of the inventory. For instance, the normal 1-0 inventory is taken late in, or at the end of, the first growing season. Therefore, it will reflect all factors affecting the seedlot during the entire season rather than just initial survival factors. Such data is of value as long as this fact is kept in mind. Another limitation is that data from inventories taken at different times during the growing cycle can not be mixed. Mixing initial survival and 1-0 survival data would be comparable to the old adage of mixing apples and oranges.

Some managers inventory only the shippable seedlings in the seedbed. This shortcut practice does not provide an estimate of the actual seedbed densities nor any information about the survival performance of seedlots. The inventory should estimate the total live seedlings in each seedlot to provide a gross inventory in addition to determining the net shippable inventory. This gross inventory can then be used in the following formula to determine the nursery survival percent for each seedlot.

FORMULA:

$$\text{NURSERY SURVIVAL \%} = \frac{\text{Total Live Seedlings (from the gross inventory)}}{\text{Pure Live Seed Sown}}$$

Note: The date or timing of the inventory must always be specified to identify the survival period. For instance, it may be survival at the end of the first growing season, 1-0 inventory, six weeks after sowing, or final inventory.

VARIATION BETWEEN INDIVIDUAL SEEDLOTS

Determining survival of individual seedlots will generally yield highly variable results from one seedlot to the next. For use in sowing formulas, these individual seedlot factors must be developed into a single factor or range of factors which will predict how future sowings may be expected to perform.

The data listed below is an example of how the viable seed of 14 individual seedlots of one species sown at the same nursery in the same season survived through to the end of the first growing season. Again, it will be emphasized that the 1-0 Nursery Survival % shown below is an expression of the number of Pure Live Seed sown which developed into a living seedling. In the case of seedlot #1, sixty-nine percent of the seed germinated in the laboratory test. However, only twenty-two percent of this sixty-nine percent actually developed into a 1-0 seedling.

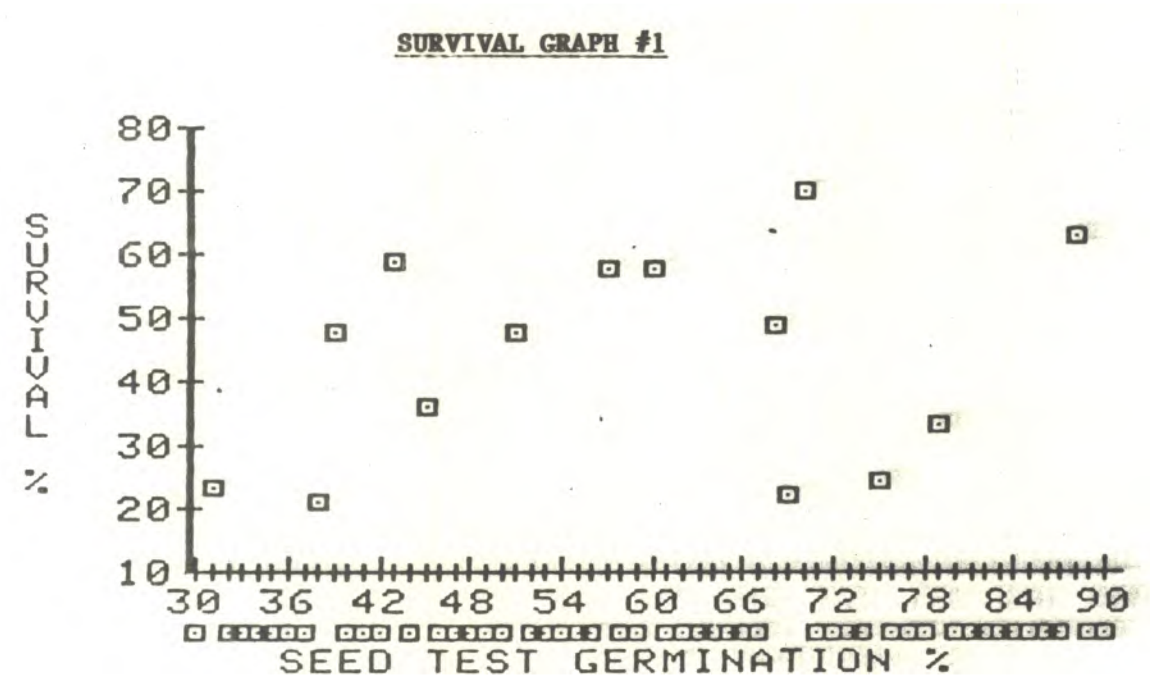
Table 1. 1-0 Nursery Survival data for 14 seedlots of a single conifer species sown in the same nursery during the same season.

SEEDLOT	LAB. GERM. %	1-0 NURS. SURV. %	SEEDLOT	LAB. GERM. %	1-0 NURS. SURV. %
1	69	22	8	38	48
2	38	21	9	51	48
3	60	58	10	70	70
4	88	63	11	45	36
5	68	49	12	79	33
6	43	59	13	57	58
7	31	23	14	75	24

COMPARING SURVIVAL TO GERMINATION PERCENT

There have been attempts to develop nursery survival curves based upon individual seedlot survival factors and the germination percent for each seedlot. It seems logical that seedlots with high germination test results would perform significantly better than seedlots with low seed test results. The assumption is that if a seedlot has a high percentage of dead seed or seed so weak that they will not germinate under laboratory conditions, then the remaining seed in that seedlot can not be expected to perform as well as viable seed from a seedlot that has shown a high percentage of viable seed under test conditions.

The graph presented below was developed from the data in table 1.



SURVIVAL BASED OH HO. OF VIABLE SEEDS

Looking at the graph, there appears to be a very poor relationship between Seed Test Germination % and how well the viable seeds sown survived the first year. Statistical analysis will prove this observation out. It is not being suggested here that one should give up on the idea that there may be a relationship between seed test viability and field performance. However, it is apparent that in this situation, other survival subfactors are masking any relationship that may exist between these two variables. Nursery managers can plot data using microcomputer programs or by hand to determine if any relationship exists at their operation.

THE ARITHMETIC MEAN

When variation within the sample population is large, the straight arithmetic mean is a poor value to use as a factor in sowing formulas. In the preceding example, the survival percent of the viable seed sown varied from 21 to 70 percent, and the arithmetic mean is 43.7142%. If 44% were used as the Initial Survival factor in the sowing formula to achieve a seedbed density of 25 seedlings per square foot, the nursery manager would have sown 57 pure live seeds per square foot. This would have resulted in actual seedbed densities ranging from 12 seedlings in the seedlot with 21% survival to 40 seedlings per square foot in the seedlot with 70% survival. Neither of these situations is desirable.

TOLERANCE LIMITS

A factor must be selected that will be both relatively safe yet reasonable. It is obvious that, if we chose the highest survival value on the graph, nearly all future seedlots sown would perform at a lower survival % and we would be reasonably assured of not having overly dense seedbeds. However, it is not logical to sow at sparse rates to cover the best possible survival. This would produce understocked seedbeds virtually every time and waste seedbed space. A more conservative value must be determined.

Let's say for instance that we can live with up to 20% of the seedlots being overly dense so long as 80% of all seedlots will be at or below the target density. The limit that we have just set is termed a Tolerance Limit. Once we have set *a* desired tolerance limit, we can use past individual survival data to develop a survival factor that should produce those results.

Caution: The following discussion and formulas are based upon a population having a normal distribution. It must be assumed that the individual survival factors will form a population having a normal bell-type distribution curve.

USING TOLERANCE LIMITS

As mentioned earlier, there are two types of survival factors that must be considered for sowing formulas. One is the Initial Nursery Survival % or the viable seed which will develop into a seedling and establish the desired initial seedbed density. The second is the Overall Nursery Survival % which is the number of the viable seed sown which will produce seedlings that will survive through to the end of the rotation.

These two factors require very different treatment when one is attempting to select a value to plug into one of the two sowing formulas. The Initial Nursery Survival % factor must be chosen high enough to provide reasonable assurance that it will not be greatly outperformed by a seedlot. If the factor were selected too low and more viable seed lived than expected, the seedbed density would be too heavy and seedlings would lack the growing space required to become strong and healthy individuals. In general, it is better to have a seedbed understocked than overstocked. Just the opposite is true about the Overall Nursery Survival %. This factor must be chosen low enough to assure that enough seedlings will survive to provide the required number of shippable seedlings to fill the orders. In general, it would be better to have more seedlings than needed to fill orders than to run out of seedlings. Therefore, it is logical to select a high value for the Initial Nursery Survival % to use in calculating How Dense To Sow seed and a low value for the Overall Nursery Survival % to use in calculating How Much Seed To Sow.

This is where the use of Upper and Lower Tolerance limits may be of value. If we selected a tolerance limit of 80% for both the upper and lower sides of a standard distribution curve, the Upper Tolerance limit can be assumed to include the population except for the uppermost 20% of that population and the Lower Tolerance Interval would include the population except for the lowest 20%.

STATISTICAL DATA USED TO CALCULATE TOLERANCE LIMITS

The 1-0 survival % for each seedlot in the previous example was fed into a microcumputer statistics program to obtain the following statistical data for the sample population.

MEAN	43.7142
STD. DEV.	16.3638

This same data can be calculated by hand or by using a preprogrammed or programmable calculator.

CALCULATION OF UPPER AND LOWER TOLERANCE LIMITS

Once the statistical data has been developed, the calculation of the upper and lower tolerance limits is relatively simple. The following formulas can be used to calculate the limits.

FORMULAS:

LOWER TOLERANCE LIMIT = Sample Mean - (z)(Standard Deviation)

UPPER TOLERANCE LIMIT = Sample Mean + (z)(Standard Deviation)

The value of "z" used in the formulas above can be located in most statistics books. The value can be located on Standard Normal Distribution Tables. A few values are given below which can be used for these formulas.

Table 2. Values to use for different Tolerance Limits.

Tolerance Limit	Value of z[3]
80%	0.85
90%	1.29
95%	1.65

[3] Bernard Ostle, "Statistics in Research", Iowa State University Press, Ames, Iowa.

EXAMPLE FOR USING THE UPPER TOLERANCE LIMIT

Given the data and formulas above, the Upper Tolerance Limit can be determined as follows:

1. The Standard Deviation (16.36) multiplied by z (0.85) equals 13.9
2. The Sample Mean (43.7) plus 13.9 equals 57.6

The Upper Confidence Level is just below the 58%. If this is used as the INITIAL SEEDLING SURVIVAL % in a sowing formula to determine How Dense To Sow the seed, the desired initial seedbed density will normally not be exceeded 80% of the time.

DETERMINING THE LOWER TOLERANCE LIMITS

The same process demonstrated above can be used with Overall Nursery Survival % data and the formula for the Lower Tolerance Limit to estimate a Overall Nursery Survival Factor for use in determining HOW MUCH SEED TO SOW.

LIMITATIONS OF TOLERANCE LIMITS

The use of tolerance limits will not reduce the variation in performance between individual seedlots. This can only be achieved by providing the seed and seedlings with more optimum survival conditions within the nursery seedbed. However, use of an Upper Tolerance Limit will provide some degree of certainty that a selected percentage of seedling lots will have a seedling density below a desired level rather than above that level. The use of a Lower Tolerance Limit will provide the same degree of certainty that a selected level of seedlots will have at least the desired number of seedlings to lift.