
Tree and forest measurement

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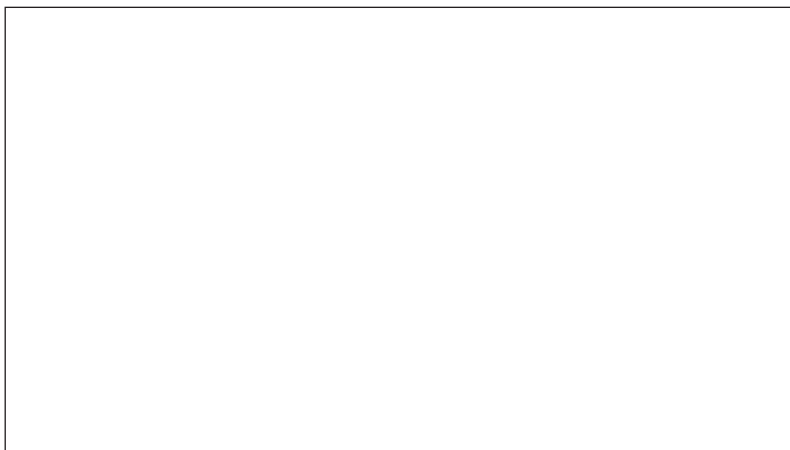
Whether it is a trailer load of firewood, a truckload of sawlogs or a trade in carbon credits, at the core of any sale will be an assessment of the quality and quantity involved. Buyer and seller must agree on the terms and the methods of measurement. Being able to measure tree growth also provides farmers with an understanding of the potential of their site and a basis for planning the management and marketing of products and services.

This chapter provides an introduction to how foresters measure trees and forests for timber production. It includes details on how to establish a measurement plot, measure tree diameter, height and stand basal area and calculate tree and stand volumes. The methods outlined are based on the use of cheap equipment and basic mathematical skills. Although the techniques have some limitations, and may not be appropriate where a high degree of accuracy is required, they are suitable for most farm forestry situations.

While the emphasis is on measuring forests, standing trees and logs for timber production the same measures often form the basis of assessments of forest services such as carbon sequestration, biodiversity and water use in recharge areas.

The MTG Diameter Tape

All Master TreeGrowers receive a yellow flexible tape that can be used to estimate tree diameter and height. With this information farmers can perform a number of calculations to estimate tree, log and forest volumes.



The MTG Tape has a normal metric rule on the yellow side and a diameter scale on the white side.



Being able to measure a forest helps farmers monitor growth, plan silvicultural operations and market products and services.

The MTG tape is specially set up for the measurement of diameter (the white side). The yellow side of the tape has a normal metric scale. We have added the MTG logo, along with information required to use the tape in estimating forest or stand basal area. A good quality 20 or 30 metre tape (available from most hardware stores) and a calculator is the only additional equipment required to complete all the measurements outlined in this chapter.

Other equipment that is useful for tree measurement and data analysis include a pocket knife for measuring bark thickness and a computer loaded with simple spreadsheets that can process tree data (we can supply basic spreadsheet programs in Excel). Spray cans of paint, pegs or marking tape are useful for permanently marking plots to allow for remeasuring over time.

Measuring a single tree

I. TREE DIAMETER

The diameter of a tree provides a measure of tree performance and is a useful starting point for estimating tree volume. By convention, the diameter of forest trees is measured in centimetres at 1.3 metres above the ground and is termed the "Diameter at Breast Height" or DBH. Because trees are measured with the bark on, this is also called the Diameter at Breast Height Over Bark (DBHOB). When measuring live trees most information is presented as over bark dimensions.

Where we are interested in the wood volume, it is possible to estimate the depth of the bark (by cutting through the bark to the wood or observing the bark of recently felled trees) and converting DBHOB to the Diameter at Breast Height Under Bark (DBHUB).

$$DBHUB = DBHOB - (\text{Bark Thickness} \times 2)$$

To measure DBH, first of all determine where "breast height" or 1.3 metres is on your own own body. Then, standing on the up hill side, wrap the tape around the tree at 1.3 metres with the white side showing, being careful not to twist the tape. Read the diameter from where the diameter scale starts. Obviously the tape can be used to measure the diameter at any point on a tree or log.

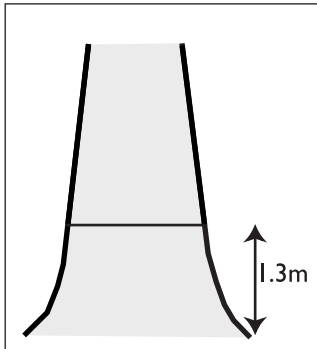


FIG 1
Tree diameter is measured at 1.3 metres above the ground on the high side of the tree.



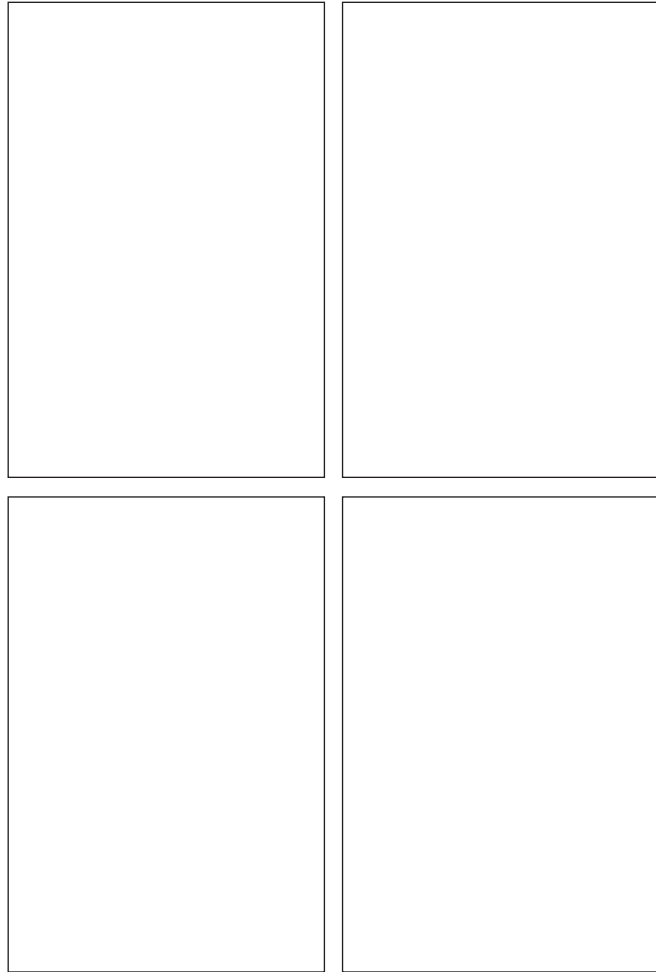
Using the MTG tape to measure Tree Diameter at Breast Height Over Bark. The DBHOB of this tree is 41.1cm.

How it works

The circumference of a circle is equal to $\pi \times d$ where " π " (or Pi) is 3.142 and "d" is the diameter. If the diameter of a tree is 30cm the circumference will be $30 \times 3.142 = 94.3\text{cm}$. If you look on the tape you will note that the "30" on the white side matches 94.3cm on the yellow side. The markings on the white side of the tape are simply 3.142 centimetres apart so that we don't have to calculate diameter, it is simply read off the tape.

Precautions when measuring diameter

- Be sure to read the scale on the white side of the tape.
- The tape must be tightly held around the tree at right angles to the main stem and any loose bark removed.
- On sloping ground, always measure breast height from the up-hill side. This is because the slope will determine the ultimate height of the stump.
- Obvious swellings, distortions or branches at 1.3 metres need to be avoided. If there is a distortion at 1.3 metres move the tape 10 cm up and 10 cm down and take the average reading.
- Measure diameter to the closest 10th of a centimetre as shown by the graduations on the tape.



2. TREE HEIGHT

The height of young trees (up to 6 metres) is easy to measure with a height-measuring pole or a simple plastic plumbing pipe marked at 0.1 metre intervals. But, as trees grow, measuring their heights becomes increasingly difficult. Although foresters use a number of expensive optical and laser tools to measure heights, the MTG tape provides a cheap method that can be accurate enough for most purposes.

Total Tree Height (Ht) refers to the vertical height from ground level to the tip of the tree. In many cases the grower is interested in the height to a particular point (such as the pruned height (PHt), or height to an obvious defect). In any event, the same techniques can be used.

Measuring height with the MTG tape

The technique requires two people. One person, with the tape, stands well back at a point approximately equal to the height of the tree. The second person stands at the base of the tree. The first person, holding a section of the MTG tape vertically out in front, closes one eye and looks past the yellow side of the tape so that the tree appears next to the tape. It is important to ensure the tape is vertical, so let the metal hinge hang down before pulling the tape tight.

Move the tape so that the "0" point on the yellow side corresponds to the base of the tree and then "measure" the apparent height to the top (or any

Master TreeGrowers measuring tree diameter with their MTG Tapes.

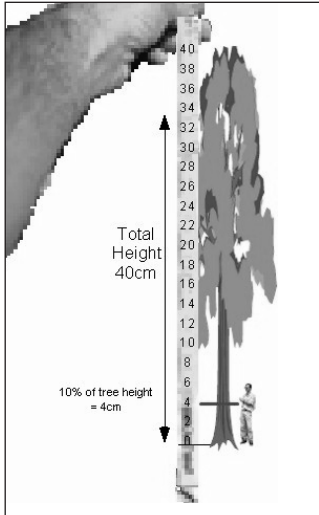


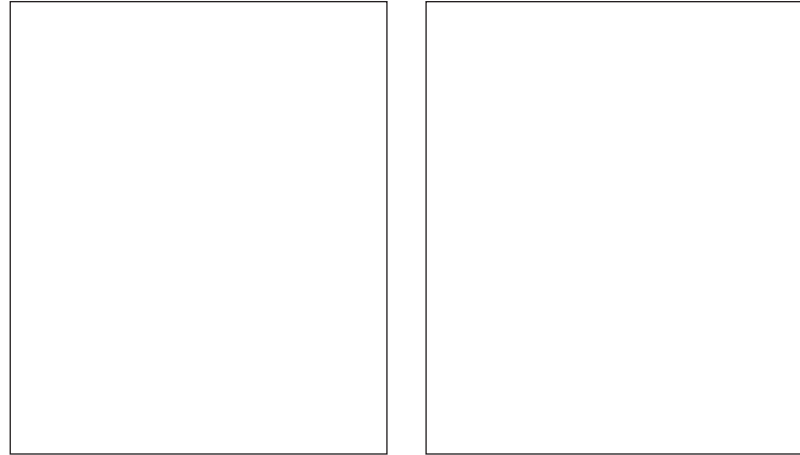
FIG 3.

Measuring tree height with the tape. The tree "appears" to be 40cm tall. 10% of 40cm is 4cm. The 2nd person is told to mark the point corresponding to 4cm on the tape. If the distance from the ground to the mark on the tree is 1.4m then the tree is 14m tall.

other point) on the tree. By mentally calculating 10% of the apparent height, the operator then asks the person standing beside the tree to move their hand up or down the stem to mark a point that corresponds to 10% of the total "apparent" height.

Clearly this point on the tree will correspond to 10% of the total tree height. The first person then returns to the tree and measures the height from the base to the second person's mark on the tree. The total tree height is simply this height multiplied by 10.

For heights of less than 10 metres, the operator should use a point that is 20% (one 5th of the apparent height) of tree height rather than 10%. For very tall trees, over 25 metres, they might find they need to use 5% (one 20th of total tree height).



Rowan (right) used the tape to guide the person standing by the tree to a point on the stem equal to 10% of the total height.

How it works

The technique simply involves the projection of two triangles of proportional dimension as shown in Fig 4. There is no need to know how far away the operator is from the tree or to worry about sloping land. Geometrically the technique is perfectly accurate.

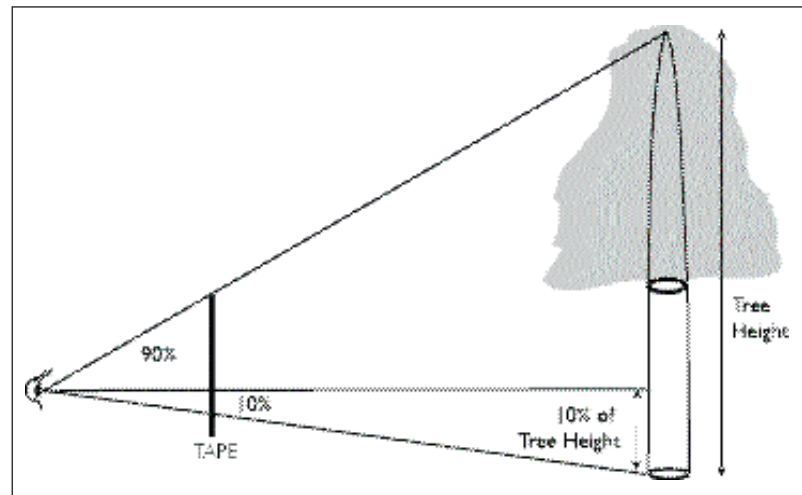


FIG. 4
How the height measurement technique works

Precautions

To be effective, care must be taken to ensure that:

- The tape is held vertically at arms length (let the tape hang momentarily before pulling tight and sighting).
- When sighting you don't move your head - if you stand well back from the tree you should be able to sight the top and bottom of the tree without moving your head.
- Careful note is taken of the bottom of the tree so the vertical measure on the tree is made from the same point. It may be helpful to have the second person mark the base-point with their foot and for the operator to sight their boot.



Measuring tree height using a Clinometer.

Other height measurement techniques

There is a range of more expensive tools that are used to estimate tree height. The most common is a Clinometer. This measures angles and allows the operator to determine the height of a tree once the horizontal distance to the base of the tree is known. Laser tools that can accurately determine distance and angle are also becoming more common in forestry. The advantage of these tools is that they reduce the likelihood of operator error and speed up the procedure, but at a cost.

3. TREE BASAL AREA

Tree Basal Area (TBA) is the cross-sectional area (over the bark) at breast height (1.3 metres above the ground) measured in metres squared (m²). TBA can be used to estimate tree volumes and stand competition. To determine Tree Basal Area simply measure the diameter at breast height in centimetres (DBHOB) and calculate the basal area (m²) using an equation based on the formula for the area of a circle (area = πr² where r = radius). The formula below also converts the diameter in centimetres to the basal area in square metres. The same technique can be used to calculate the cross sectional area of the tree at any point along the stem.

$$\text{Tree Basal Area (TBA) (m}^2\text{)} = (\text{DBH}/200)^2 \times 3.142$$

Where DBH is the Diameter at Breast Height in centimetres and 3.142 is π.

4. TREE FORM

In farm forestry the shape or branching habit of a tree can affect its commercial value markedly. The perfect "target tree" for saw milling might, for example, have a very straight butt log with a single leading stem. When assessing trees it is useful to record any important aspects of their form that may affect its marketability.

Although most recording sheets allow for comments against each tree, it is helpful to be able to quickly record a summary of the tree's form and suitability for the intended use or market. There are many different methods and systems for assessing tree form. As a minimum we recommend that when measuring trees, farmers classify each tree as having either:

- Form 1: Perfect form for the intended use or market
(e.g. straight trunk or bole, fine branches, no apparent defects etc)
- Form 2: Acceptable form for the intended use or market but not ideal
(e.g. some kinks in stem, evidence of insect attack etc)
- Form 3: Unacceptable form for the intended use or market
(e.g. severe butt sweep, double leaders, evidence of severe rot etc)

One of the most important form factors in the production of sawlogs is straightness of the butt log. If the tree deviates outside a central axis, then

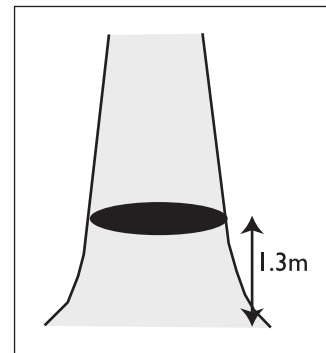
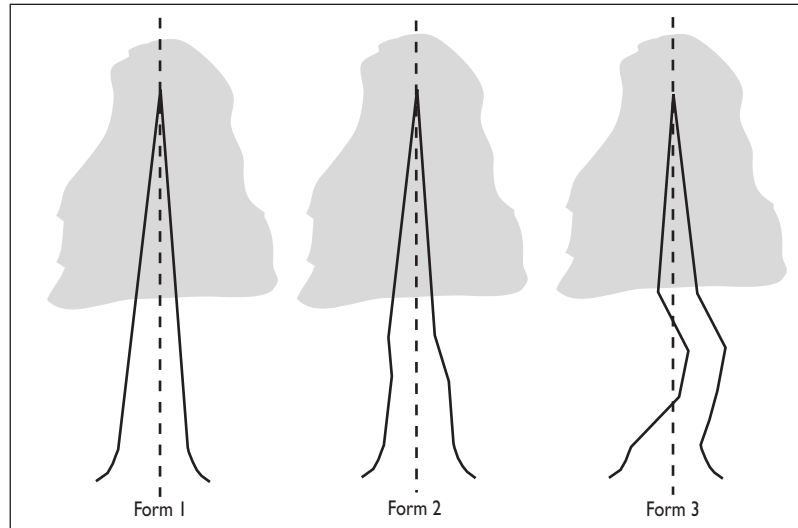


FIG 5.
Tree Basal Area is the cross-sectional area of a tree at breast height.



Straightness is an important form characteristic in many situations. These examples show how farmers might classify their trees based on stem form.

the form is likely to be unacceptable for milling purposes or will be severely downgraded.

5. TREE VOLUME

The measurements obtained using the MTG tape can now be used to calculate volumes. The accuracy involved varies and farmers should be aware of the limitations inherent in each technique.

Total Tree Volume

Using a measure of DBH and Ht, an estimation of total tree volume can be made by assuming the tree has a particular form. For example, if we assume the tree is conical in shape, with the DBH equivalent to the diameter at the base of the cone, then the following formula is appropriate:

$$\text{Tree volume (m}^3\text{)} = \frac{(\text{DBH}/200)^2 \times 3.142 \times \text{Ht}}{3} \text{ or } \frac{\text{TBA} \times \text{Ht}}{3}$$

For example, if a tree was 30m tall and 55cm in DBH, the total tree volume would be about 2.4m³.

$$\text{Tree volume (m}^3\text{)} = \frac{(55/200)^2 \times 3.142 \times 30}{3} \text{ or } \frac{0.238 \times 30}{3} = 2.38\text{m}^3$$

Because the diameter, hence Basal Area, is measured at 1.3 metres above the ground and the fact that trees usually carries a bit more volume than the cone-form would suggest, this formula is a conservative estimate of total tree volume over bark. As a result, the formula is often used as a reasonably good measure of recoverable volume of straight plantation trees considering that the bark and stump are not often used.

More detailed formulae are available for particular species grown in some areas, although rarely for farm grown trees other than pine. The important point is to be consistent in your choice of volume function especially when comparing growth on different sites or over time.

If the tree is clearly not "conical" or if the landowner can only sell the larger diameter lower logs it may be more appropriate to measure the volume of the lower log only.

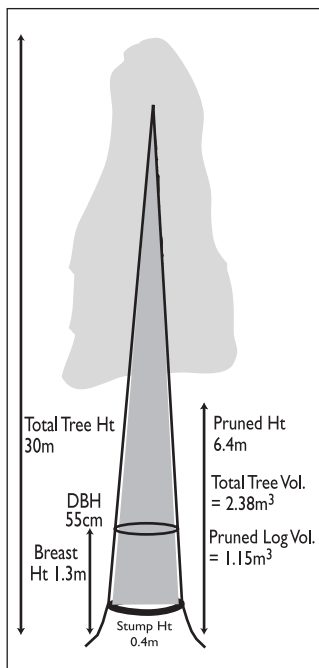


FIG. 7 Assuming the tree is conical the total tree volume can be estimated using the Basal Area and the formula for a cone.

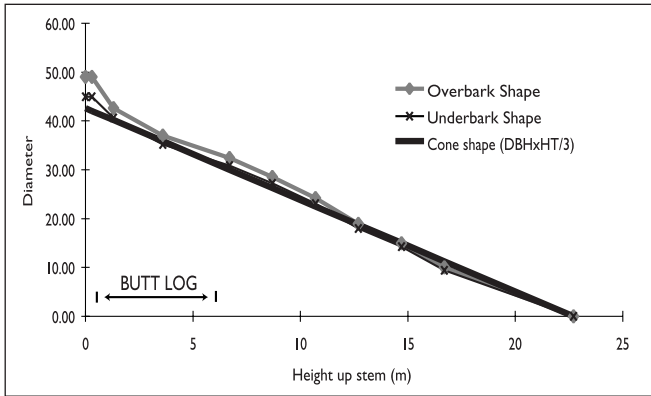


FIG 8. The real and assumed shape of a ten year old, pruned Eucalypt at Bamba showing that an assumption that the tree has the shape of a cone is quite effective for estimating underbark volume.

Estimating the volume of the parts of the standing tree

Assuming the tree is conical in shape allows the volume of different parts of the tree to be estimated. All that is required is a measure of the tree taper or rate at which the diameter decreases with height:

$$\text{Taper of a conical tree (cm/m)} = \text{DBH} / \text{HT}$$

For a tree of 55cm DBH and 30m tall, the taper is estimated to be 1.8cm/m. Once again, DBH is used despite the fact that it is measured at 1.3m above the ground.

It is interesting to note that in well-spaced pruned trees, the taper of the pruned butt log tends to decline over time, resulting in a more cylindrical log at the base and a more highly tapered upper crown. Where farmers require a more accurate measure of taper in the lower log it may be worth doing measurements of the top of the log and comparing these to the diameter at breast height.

Using a taper measurement it is possible to estimate the diameter at different points up the conical tree. Assuming that DBH is a good estimate of underbark diameter at the base of the tree (this can be easily tested) a tree pruned to 6.4 metres might have an underbark diameter as follows:

$$\text{At stump height (say 0.4m)} = 55 - (1.8 \times 0.4) = 54.3\text{cm}$$

$$\text{At the top of the pruned log (6.4m)} = 55 - (1.8 \times 6.4) = 43.5\text{cm}$$

The components of the harvested tree would be the unpruned crown, the pruned butt log and the stump. Their volumes can then be derived from the assumption that they are parts of a cone:

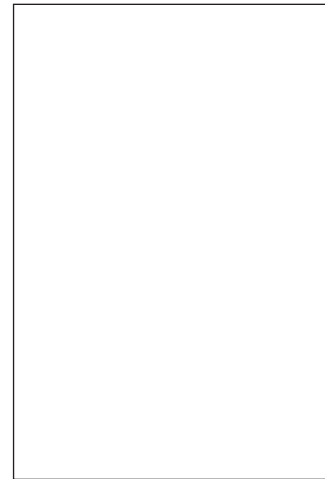
$$\text{Total cone tree volume (m}^3\text{)} = \frac{(55/200)^2 \times 3.142 \times 30}{3} = 2.38\text{m}^3$$

$$\text{Volume above stump height (m}^3\text{)} = \frac{(54.3/200)^2 \times 3.142 \times 29.6}{3} = 2.29\text{m}^3$$

$$\text{Volume above pruned height (m}^3\text{)} = \frac{(43.5/200)^2 \times 3.142 \times 23.6}{3} = 1.17\text{m}^3$$

Therefore the estimated underbark volume of the pruned log would be:

$$\text{Underbark pruned log (m}^3\text{)} = 2.29 \text{ m}^3 - 1.17 \text{ m}^3 = 1.12\text{m}^3$$



Plantation grown softwood like this Queensland Kauri (*Agathis robusta*) are commonly very conical in form.



Widely spaced pruned trees can develop a more cylindrical bole over time. 16-year-old Blue Gum (*E. globulus*) in W.A.

In some cases, farmers may need to determine the volume of the trees up to a particular stem diameter. This can again be easily done by simply estimating the volume of a cone whose base has a diameter equal to the allowable small end diameter (SED) with the same taper, then subtracting this from the volume of the upper part of the tree.

Estimating the volume of a log on the ground

If the tree has been felled or the butt log is very short (less than 4 metres long) it may be easier to measure the diameter half way along the butt log and use this as a measure of the centre diameter of the log (CD).

The volume of the log is then estimated as:

$$\text{Over bark log Volume (m}^3\text{)} = (\text{CD}/200)^2 \times 3.142 \times L$$

Where L = Log length (m)

Bark thickness at the point that CD is measured (B_{CD}) can be judged from felled trees of the same age and species on the same site or from carefully pushing a knife into the tree to the depth of the bark. Bark thickness varies up the tree so if using the centre diameter then bark depth at that point should be used in estimating underbark volume.

$$\begin{aligned} \text{Underbark log Volume (m}^3\text{)} \\ = ((\text{CD} - 2B_{CD})/200)^2 \times 3.142 \times L \end{aligned}$$

Log volume can be more accurately estimated determining the average cross sectional area from the underbark diameter at each end of the log.

$$\begin{aligned} \text{Underbark log volume (m}^3\text{)} \\ = \frac{(\text{LEDUB}/200)^2 + (\text{SEDUB}/200)^2 \times 3.142 \times L}{2} \end{aligned}$$

Where: LEDUB = Large end diameter underbark (cm)

SEDUB = Small end diameter underbark (cm)

L = Log Length

Log buyers may dictate that log volumes are determined from centre diameters, small end diameters, an average of the diameters at each end or from the average cross sectional area at each end. Whereas the latter may be more accurate, the others are much quicker and may better reflect log value.

For a perfectly conical log, using the average of the cross sectional areas will give the greatest volume. For a conical log with a LEDUB of 50cm and a SEDUB of 40cm (Figure 9), the estimated log volumes vary by almost 25% depending on the method used:

Based on small end diameter:

$$\text{Vol (m}^3\text{)} = (40/200)^2 \times 3.142 \times 6 = 0.75 \text{ m}^3$$

Based on average end diameter:

$$\text{Vol (m}^3\text{)} = (45/200)^2 \times 3.142 \times 6 = 0.95 \text{ m}^3$$

Based on centre diameter:

$$\text{Vol (m}^3\text{)} = (45/200)^2 \times 3.142 \times 6 = 0.95 \text{ m}^3$$

Based on average end area:

$$\text{Vol (m}^3\text{)} = \frac{(50/200)^2 + (40/200)^2 \times 3.142 \times 6}{2} = 0.97 \text{ m}^3$$



The underbark volume of a log can be measured in different ways. Be sure to agree on one method before selling the log to the sawmiller.

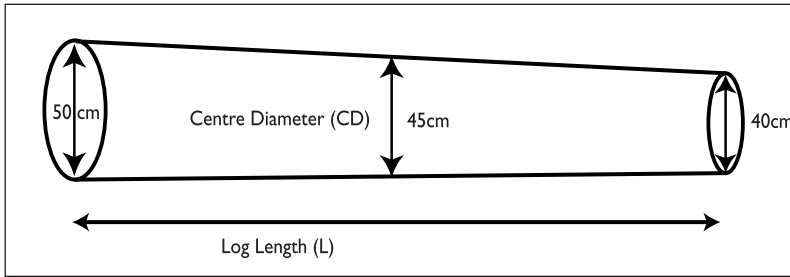


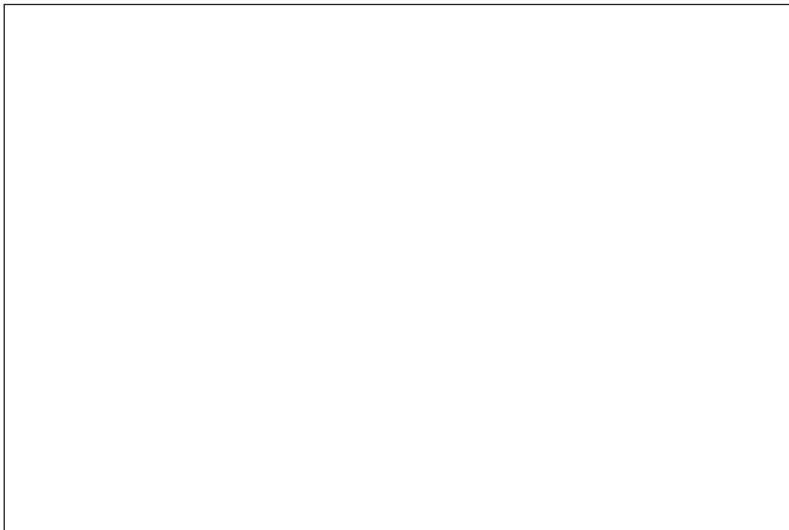
FIG 9.
After felling the log volume can be estimated in a number of ways based on the diameters at the ends and the centre. The results can vary dramatically.

Measuring a stand or forest of trees

As growers we can use the simple measurements described above to describe the characteristics of a stand of trees. Since it is unrealistic to expect growers to measure every individual tree, sampling techniques are used to achieve a good estimate of stocking rate, stand basal area and log volumes from measurements of as few as 2% of the trees in the forest.

I. DESCRIBING THE FOREST - TYPES AND AREAS

The starting point for forest measurement involves developing a good map of the area that shows the type of forest, age (if planted) and past management. If growth is affected by topography or soil types these should also be shown. Inspect the forest and make a judgment as to the different forest 'blocks'. If tree management, performance, provenance, age, soil types or environment are quite clearly different and have effected growth in parts of the forest, these should be treated as separate areas and marked on the map. This "stratification" of the forest into uniform bits is critical if a true picture of the forest is to be estimated.



Estimating the volume of a forest is done by measuring a representative sample of trees in a plot of known area. Silver Quandong (*Elaeocarpus grandis*) in Far North Qld.

Estimating the area and mapping the site

A common method of measuring the area of a stand is to use a large-scale, aerial photograph (1:10,000) and calculate the area using a dot grid (used in whole farm planning courses) or planimeter. Where it is possible to correct



More than 3 randomly located plots that are large enough to include between 15 and 30 trees could be used to measure this Black Walnut (*Juglans nigra*) plantation in Victoria.

the photograph for the distortions inherent in aerial photographs this should be done to improve accuracy. Topographic maps may be suitable where the farmer can clearly delineate the boundaries of different forest areas (e.g. 1:25,000 map or accurate large-scale farm map). Many computer programs can determine areas of irregularly shaped polygons drawn over scanned photographs or maps, thereby providing an easy estimate of ground areas.

Additional features such as roads, power lines, water courses, soil types and aspect should be also noted on the map. These may be critical in designing harvesting plans or designing management for environmental services.

Good documentation - a "Tree Diary"

Having a documented history of the management of the forest that includes the genetic make up of planted trees, past management and early performance is invaluable. Photographs taken before planting and after pruning or thinning can complement notes. Include anything that may be of future interest in a log book, along with measurements of forest growth.

2. ESTABLISHING A SAMPLE PLOT

Plots as a sample of the total forest

Because measuring trees can be a time consuming and costly operation, most forest owners only measure a sample of trees as an estimate of the growth of different parts or 'blocks' of the forest. An absolute minimum of 3 plots should be established in any uniform section, unless one or two plots cover most of the site, in which case all trees should be measured. For very large uniform forests, the total area of all the plots should be an absolute minimum of 2% of the total forest area. For example, in a forest of 10 hectares, a total area of 0.2 hectares should be measured. If the plots were to be 0.04 hectares in size (this is dependent on tree stocking and is discussed later) then at least 5 plots would be required for a sufficient sample.

Plot dimensions- circle or rectangle plots?

Plots are generally circular or rectangular: Rectangle plots are useful and preferred in stands where planting rows are well defined, as in young stands or in heavily stocked forests. Circular plots, on the other hand, are easier to lay out in mature or irregularly spaced stands with low stocking rates or where the rows are poorly defined or not present, such as in native forests.

Plot size

In order to obtain a representative sample, between 15 and 30 trees per plot is required (12 being the absolute minimum). Plot size will therefore depend on the stocking rate. The more sparse the trees, the larger the plot will need to be to include sufficient trees. Tree stocking can be quickly estimated from average spacing or, alternatively, the size of the plot can be gradually increased until it includes sufficient trees.

Calculating plot area

Plot area for each shape is calculated as follows:

$$\text{Rectangular Plots: Plot area (Ha) = Length (m) x Width (m)/10000}$$

$$\text{Circular Plots: Plot area (Ha) = [Radius (m)]}^2 \times 3.142/10000$$

Establishing a Plot

'Establishing a plot' means marking out a known area within a stand of trees. (Trees within the plot then become the sample). Within a particular section of the forest the plots are randomly located or, more commonly, evenly



Rectangular plots are easy to layout when the tree rows are clearly defined. Native Pine (*Callitris spp*) plantation near Darwin.

distributed throughout the area. To avoid bias in the location of plots it is common to systematically mark the plots on a forest map prior to entering the forest. For large forest areas it is also common practice to locate plots away from the edge of the forest due to the "edge effect".

Stocking Rate (stems/hectare)	Sample Plot Size (hectares)	Dimensions of Rectangular plot	Radius for Circular plot
100	0.2	50m x 40m	25.2m
200	0.1	40m x 25m	17.8m
400	0.05	25m x 20m	12.6m
600	0.033	20m x 16m	10.2m
800	0.025	20m x 12.5m	8.9m
1000	0.02	16m x 12.5m	8.0m

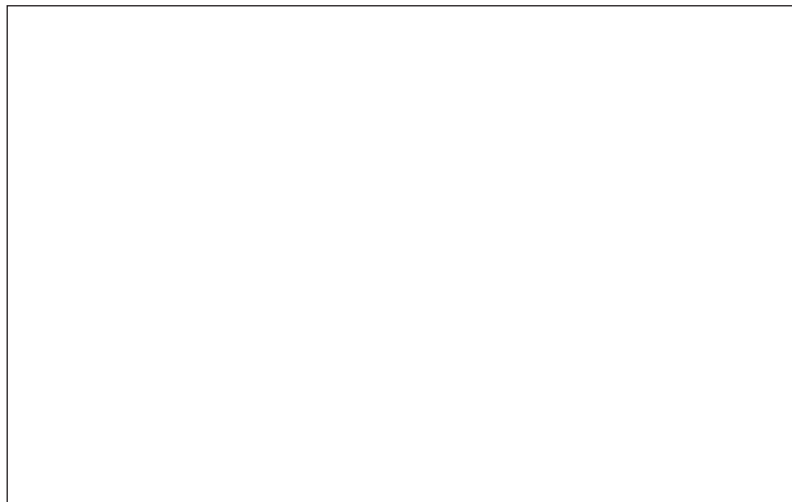
In many farm forestry situations the trees are planted in small blocks, belts or strips with many, perhaps most, of the trees growing on the edge. Where this is the case, using a plot of known area to determine the stocking rate or volume per hectare is not legitimate, as trees growing on the edge utilise resources from outside the forest area. For belts it may be better to measure the trees in a length of belt to assess yield per 100 metres of belt (rather than yield per hectare).



Measurements of belts or rows of trees could be based on the stocking or yield per 100 metres of row rather than per hectare.

Highly irregular forests

Where the forest is very irregular (such as along water courses), rather than establishing fixed area plots it may be preferable to identify a number of individual "plot trees" scattered through the forest that are measured individually. To assess what affect any adjacent trees may have on the growth of the "plot trees", individual trees located within a distance of 30 times the diameter of the "plot trees" should be measured.



These trees growing adjacent to the paddock were monitored by measuring a number of selected "plot" trees and all others within 12 metres. (See Chapter 4).

For example, if the trees in the plantation are nearing 40cm in diameter then any tree within 12 metres of the "plot tree" should be measured. It would be

inappropriate to try and convert the results from irregular plantations or belts into yields per hectare for comparison with conventional large block plantations.

Recording or permanently marking the plot location

All plots should be either permanently marked (e.g. with a steel peg) or carefully located on a map. The reference points are the centre of circular plots and the north east corner for rectangular plots. Being able to return to the same trees for later measurement is very useful for assessing tree growth and planning silvicultural operations. Species, like pine, that do not shed their bark can be numbered or marked with a spray can.

The Plot Sheet

A plot sheet is used to document the information collected. It is useful to add comments about the plot (e.g. undergrowth, slope etc) or individual trees (e.g. presence of disease or other abnormalities) that may help interpret the information collected. Note the location of the plot, any unusual features and the date and names of those involved in measuring. A sample plot sheet is provided in this book, which can be copied or adapted to suit your requirements.

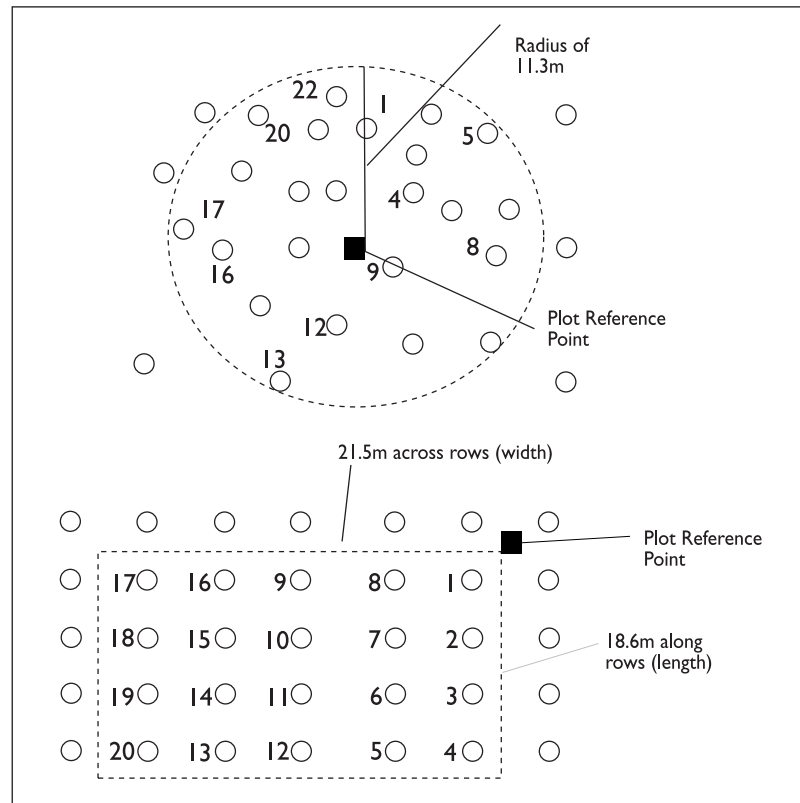


FIG 10.
Counting technique within a rectangular and circular plot.

Once sample plots have been established, trees need to be measured in a systematic way across all plots in the stand. The system illustrated in Figure 10 for rectangular and circular plots allows trees to be easily referenced during the measurement exercise.

Precautions in locating and laying out plots:

- On sloping ground, ensure all distance measurements are horizontal.
- In large plantations, plots should not be located on the edge or include abnormal features (such as dams).
- If trees are on the edge of the sample plot, they are counted as "in" if the centre of the stem is in the plot.
- Check all information has been collected before leaving the plot.

3. PLOT MEASUREMENTS

Stocking Rate

The tree density or stocking rate of a forest is described as the number of trees per hectare. This can be easily calculated for each plot as follows:

$$\text{Stocking rate (stems/ha)} = \text{Trees in plot} / \text{Plot area (ha)}$$

In belts, stocking rates might be better described as the number of trees per 100 metres of belt.

Tree Diameters and Pruned Height

The diameter of every tree in the sample plot is measured (as described earlier). While measuring diameter, inspect the form of the tree and record a form factor (as described earlier) and note any points of interest. While moving through the plot it is also worth recording the pruned height for each tree. One simple technique involves using a graduated extension pole such as those used for pole pruning.

Stand Height

Measuring the heights of trees can be difficult and time consuming. Fortunately, the heights of the tallest trees in a plantation or native forest are usually quite uniform and therefore, rather than measure the height of all trees in the sample plot, it is common to select a sub-sample. In most cases a number of the fattest trees (largest DBH) of good form are measured for height, this is called the "Mean Dominant Height".

To estimate the Mean Dominant Height, select the 4 fattest trees of good form in each plot and measure their heights, averaging the height of the 3 tallest trees to calculate the Mean Dominant Height. Where there is more than one species or age class, it will be necessary to determine a Mean Dominant Height for each.

4. STAND BASAL AREA

Stand Basal Area (SBA) is simply the cross-sectional area of all the trees at breast height per hectare of forest or plantation (m²/ha). Stand Basal Area can be used to estimate stand volume and is a useful measure of the degree of competition in the stand. SBA is often quoted when planning thinning prescriptions.

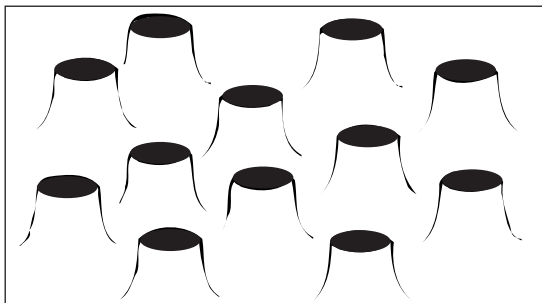


FIG 11.

Stand Basal Area is simply the total of Tree Basal Areas per hectare of forest or plantation measured at 1.3m above the ground.

Measuring Stand Basal Area

The basal area of a stand or plot can be measured in different ways:

1. The sum of individual tree basal areas.
2. The optical method of assessing basal area.
3. The spacing factor method.

1. Sum of individual tree basal areas

The most accurate method of assessing the basal area of a stand of trees is to measure all tree diameters in a plot, calculate individual tree basal areas and add these up. Computer spreadsheets are ideal for this.

$$\text{Basal Area of a tree (m}^2\text{)} = (\text{DBH}/200)^2 \times 3.142$$

$$\begin{aligned} \text{Stand Basal Area (m}^2\text{/ha)} \\ &= \frac{\text{(Sum of the basal area of each tree in the plot)}}{\text{(Area of the plot (ha))}} \end{aligned}$$

A quicker method is to calculate the basal area using the average tree diameter. Because larger trees contribute more to the basal area than small trees, this technique will underestimate the true basal area by about 10%, depending on how varied the tree size is on the plot:

$$\begin{aligned} \text{Stand Basal Area (m}^2\text{/ha)} \\ &= (\text{Basal area of the average tree diameter}) \times (\text{Stocking (tree/ha)}) \end{aligned}$$

2. Optical methods of assessing Basal Area

Basal Area per hectare can be estimated using an optical method. A gauge of known width is held at a set distance from the eye and the observer turns around on a set point observing each tree (at breast height) and counts the number of trees that appear wider than the width of the gauge. If a tree appears wider than the gauge, it is considered as 'in' and counted as 1. If a tree appears to be exactly the same width as the gauge it is then counted as 1/2. Trees that appear smaller than the gauge width are ignored. The total count is multiplied by the "Factor" of the gauge to give the Basal area per hectare.

EXAMPLE:

Using a 2 Factor gauge, the operator counts 11 trees that appear wider than the gauge and 3 that appear to be the same width.

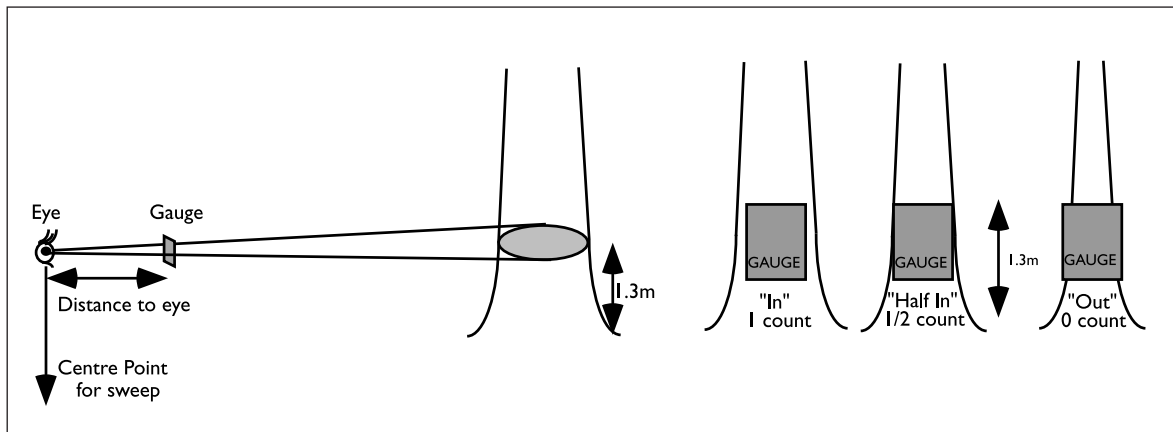


FIG 12.

Measuring Stand BA using an optical gauge. If the tree appears wider than the tree stem at breast height, the tree is counted as "in" or "1". If the tree is the same width as the gauge, it is counted as "1/2". Any tree smaller than the width of the gauge is ignored. Count x Gauge Factor = Stand Basal Area (m²/ha).

$$\begin{aligned} \text{The Basal Area (m}^2/\text{ha)} &= \text{Factor} \times \text{Count} \\ &= 2 \times (11 + (3 \times 0.5)) \\ &= 25 \text{ m}^2/\text{ha} \end{aligned}$$

How does it work?

This method was developed by foresters in Europe in the 1930's and was introduced to Australia as recently as 1952. The mathematics behind the technique is not that complicated, but then again neither is it important to understand it in order to use the technique. In some cases foresters use a glass prism that subtends the angle, although the gauge method is just as legitimate and much cheaper.

For those interested in understanding how the process works, the following may be of interest. Those with faith in the technique might simply refer to the method of using the MTG tape as an optical basal area gauge.

Understanding the Optical method

Follow the steps:

1. Calculate the basal areas of the following hypothetical plots (Figure 13) that contain trees of equal diameter using the formula presented above
Stand Basal Area (m²/ha)
= $\frac{\text{Sum of the basal area of each tree in the plot}}{\text{Area of the plot (ha)}}$

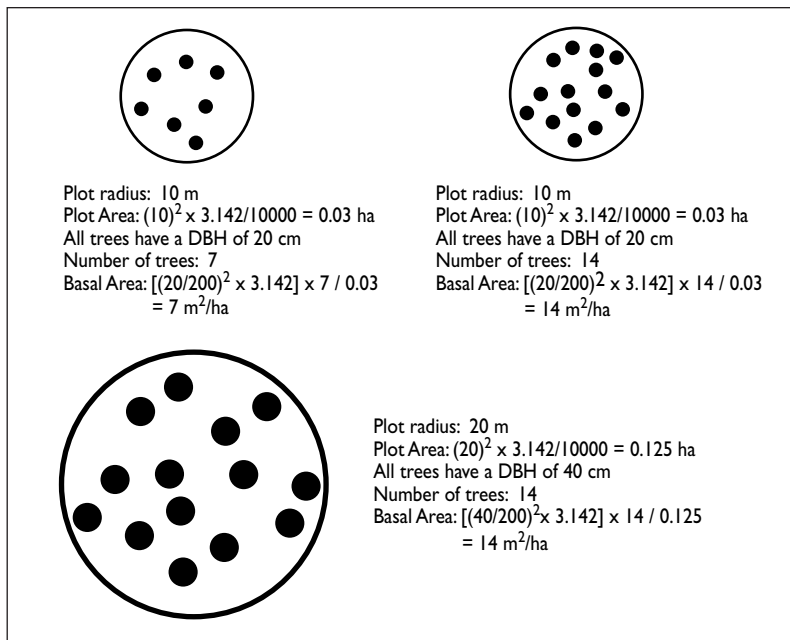


FIG 13.

Note that the basal area of these plots is equal to the number of trees in the plot.

2. Note that if the radius of the plot is equal to the Tree Diameter x 50 then the basal area of the plot is equal to the number of trees in the plot. Therefore each tree is contributing 1m²/ha to the stand basal area.
3. Using this principle we can devise the appropriate dimensions of a 1-Factor optical gauge, which will mean that the number of "in" trees (when we spin in a full circle) will be equal to the stand basal area.



A forester using a glass prism to measure the basal area of a farmer's native forest.

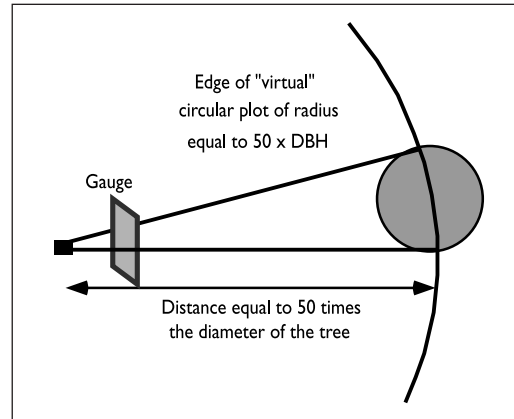


FIG 14.
For a "1-Factor" Basal Area Wedge, the distance of the gauge from the eye would be equal to 50 x Gauge Width.

Such a gauge must subtend an angle that allows us to "test" if any particular tree is "in" or "out" of our probability plot (centred where we stand) that has a radius equal to 50 x Tree Diameter (Fig. 14). In the diagram, the ratio of [Gauge Width]:[Distance from Eye] must equal to [DBH]:[Radius] i.e. 1:50. Therefore, since the gauge on the MTG tape is 16mm across, it would need to be held 80cm from the eye to act as a 1-Factor basal area gauge.

- Since holding the gauge out 80cm is quite clumsy it is possible to calculate the distance from the eye for a 2-Factor gauge. In this case each tree counted as "in" would contribute 2m²/ha. Hence the radius of the plot would need to be 35.4 x tree diameter. Therefore for a 2-Factor gauge, the 16mm wide gauge would need to be held 56.6cm (1.6cm x 35.4) from the eye.

All that is needed to make up an optical basal area gauge is something of known width that can be held at a set distance from the eye. Table 2 gives the specifications for gauges of different factors.

Gauge Width (cm)	Factor 1	Factor 2	Factor 3	Factor 4
Calculation	50xWidth	$\frac{50 \times \text{Width}}{\text{SQRT}(2)}$	$\frac{50 \times \text{Width}}{\text{SQRT}(3)}$	$\frac{50 \times \text{Width}}{\text{SQRT}(4)}$
1.0	50	35.4	28.9	25.0
1.4	70	49.5	40.4	35.0
1.6	80	56.6	46.2	40.0
1.8	90	63.6	52.0	45.0
2.0	100	70.7	57.7	50.0

The distance a gauge should be held from the eye. Distances of less than 40cm are impractical due to the difficulty of simultaneously focusing the eye on both the gauge and the tree in the distance.

MTG Tape

The MTG Tape as an optical basal area gauge

The yellow Master TreeGrower tape can be easily used as a basal area Gauge. Note that the metal plate is 16mm wide and is longer on the white side where it meets the tape, allowing the tape to be held so that the plate forms an ideal gauge. Hold the metal plate between the thumb and forefinger of the left hand with the thumb of your right hand on the yellow side of the tape and the loop resting in your palm.



David Jenkins estimates basal area using his MTG tape.

Hold the tape at the appropriate point between the forefinger and thumb of the right hand. For a 2-Factor gauge put your right forefinger on the 49cm mark (yellow side) or for a 4-Factor gauge, at the 32.5cm mark. This means the total distance from your right forefinger to the metal plate is 56.6cm (2-Factor) or 40.0cm (4-Factor) as suggested in Table 3. Pull the tape tight and look along the white side towards the metal plate. Note that the end of the plate on the white side is now raised above the tape - this is what is used as the "gauge".



FIG 15a.
This tree is counted as
"IN" or "1"



FIG 15b.
This tree is counted as
a "1/2"



FIG 15c.
This tree is counted as
"OUT" or "0"

How to estimate the forest basal area with the MTG Tape

1. Randomly locate a spot in the forest and mark the spot on the ground.
2. Hold the tape as shown in Figure 15 with the white side up and at the right distance from your eye. The distance beside the MTG logo on the tape corresponds to the marks on the yellow side of the tape. For 2-factor gauge hold the 49cm mark against your cheekbone.
3. Hold the gauge out straight and look along the tape closing the other eye.

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4. Note your starting point (to avoid double counting) and begin counting the number of trees "in" (1 point) or "equal" (1/2 point) turning to complete a full circle.
5. Multiple the total count by the Gauge Factor (2 or 4) to obtain the basal area (m^2/ha)
6. Repeat this process at a number of well distributed points (about 10 samples may be required) in the forests and average the results for the whole area.

It is important to count between 5 and 15 trees. Therefore in dense stands with a high basal area, hold the tape at the 32.5cm point to create a 4-Factor gauge. This will measure basal area quite accurately between 20 and 60 m^2/ha . The 2-Factor gauge is used in more open stands for basal areas of between 10 and 30 m^2/ha .

Stands of any species that are less than 10 m^2/ha are very open, whereas very dense stands are likely to have basal areas over 60 m^2/ha .

Testing doubtful trees.

If a high degree of accuracy is required it is necessary to test doubtful trees:

A tree is "in" if its DBH is greater than:

- ~ the distance from the operator/50.0 for a 1-factor gauge,
- ~ the distance from the operator/35.4 for a 2-factor gauge,
- ~ the distance from the operator/25.0 for a 4-factor gauge.

Precautions

- Each tree must be viewed at breast height (1.3m)
- Be sure to turn on a single point keeping your eye over the same point on the ground.
- Leaning trees should be viewed at right angles to the stem.
- The distance from the eye to the gauge is important, although if the user holds the tape 1cm away from the correct position then the error will be less than about 5%.
- The greater the number of "1/2" trees the less reliable will be the result. For accurate measurements you must measure the diameter and distance to these trees to confirm their status.
- Care must be taken to view trees hidden behind other stems or undergrowth. If necessary the user can move sideways provided the distance to the tree is not altered. They should then return to the original point before turning to view the next tree.
- A total count of about 10 trees is recommended. If the count is lower than 5 or greater than 15 use a different factor gauge.

Basal Areas in plantations and native forests normally vary from about 10 to more than 60 m^2/ha and therefore gauges with factors of 2 and 4 should be sufficient in most cases. The more sample points used and the care of the operator to ensure that the correct method is used will increase the accuracy of the results.

3. SPACING FACTOR METHOD OF ESTIMATING BASAL AREA

In planning silvicultural regimes, it is useful to have a feel for how basal area varies with the average spacing between trees. The Spacing Factor is simply the average distance between the trees (in cm not metres) divided by the average stem diameter (cm) and is a useful way of estimating Basal Area in uniform plantations. For example, if the trees are spaced at an average of 5m (500cm) and the mean diameter is 20cm the spacing factor is $500/20 = 25$

Figure 16 shows the relationship between the Spacing Factor and basal area. The technique assumes all trees are of equal size and is helpful to predict the basal area at maturity for a given final stocking and tree size. To thin a plantation to a certain basal area, simply thin to an average spacing equal to the diameter of the retained trees, multiplied by the appropriate Spacing Factor. The higher the Spacing Factor the lower the competition or basal area.

For example, if your eucalypt trees are 20cm in diameter and spaced on a regular 3 metre grid (or 1111 trees/ha), then the Spacing Factor is 15 (300cm divided by 20cm = 15). From the graph it can be seen that if the Spacing Factor is 15 then the basal area is therefore about 35m²/ha. To thin the stand to a BA of 20 m²/ha, the stocking rate would need to be reduced to 625 stems per hectare or an average spacing of 4m (20 times the diameter). If the final target tree size is 50cm diameter and we know we want the plantation to grow quickly to this size (basal area less than 20m²/ha at maturity), then the final spacing would need to be more than 20 (from graph) x 50cm = 10m or 100 trees/ha.

The spacing table provided at the end of this chapter makes it easy to determine the average spacing required, given the stocking rates.

Some useful numbers to remember are:

- If the Spacing Factor = 12.5 Basal area is approximately 50m²/ha
- If the Spacing Factor = 15 Basal area is approximately 35m²/ha
- If the Spacing Factor = 20 Basal area is approximately 20m²/ha
- If the Spacing Factor = 30 Basal area is approximately 10m²/ha

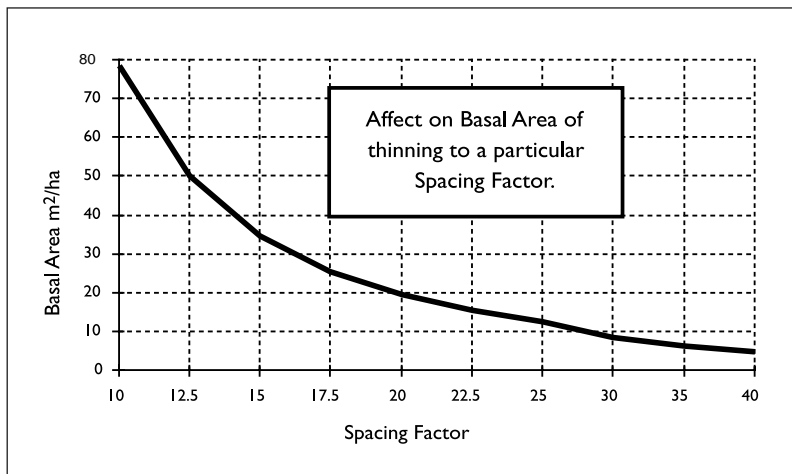


FIG 16. The relationship between the Spacing Factor and Basal Area

5. FOREST VOLUME

Total forest volume can be calculated from the plot measurements:

$$\text{Standing Forest Volume (m}^3\text{/ha)} = \frac{\text{Plot Volume (m}^3\text{)}}{\text{Plot Area (ha)}}$$

Forest basal area measurements can be used to calculate tree and butt log volumes in the same way that tree volumes were calculated. In plantations where we might assume all the trees are "cone" shaped and quite uniform, a quick estimate of total volume can be made from the Stand Basal Area and Dominant Tree Height:

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$$\text{Standing Volume (m}^3\text{/ha)} = \frac{\text{SBA} \times \text{HT}}{3}$$

Where SBA = Stand Basal Area (m²/ha) and Ht = Dominant Tree Height (m)

6. MEAN ANNUAL INCREMENT (MAI) & CURRENT ANNUAL INCREMENT (CAI)

The Mean Annual Increment is simply the average volume production per year, for a forest of known age:

$$\text{Mean Annual Increment m}^3\text{/ha/yr (MAI)} = \frac{\text{Volume of stand (m}^3\text{/ha)}}{\text{Age of stand (yrs)}}$$

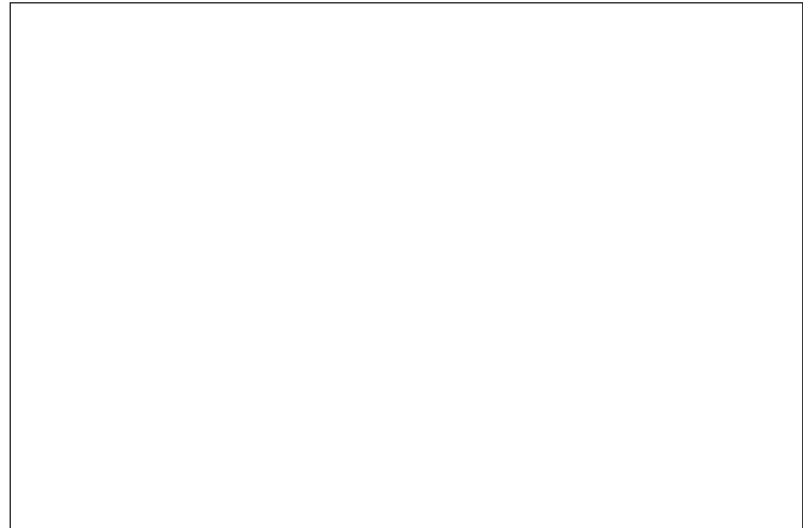
Current Annual Increment (CAI) is the increase in volume at a particular age and is determined by annual measurements of standing volume.

Example:

$$\begin{aligned} \text{Current Annual Increment (CAI) at age 2 (m}^3\text{/ha/yr)} \\ = (\text{Volume at age 3}) - (\text{Volume at age 2}) \end{aligned}$$

In dense plantations, the CAI will increase rapidly in the early years, up until competition for light, moisture or nutrients mean that CAI reaches its peak. The decline in CAI can be more rapid than the early rise.

In a mature native forest, the CAI is often close to zero, meaning there is no change in the total wood volume on the site from year to year - for some trees to grow others must die.



Dense plantations of eucalypts on dry sites may reach their maximum productivity by age 3 or 4 with growth rates declining quickly thereafter as competition limits growth.

When the CAI drops to the point that it is lower than the MAI (see Figure 17), then MAI must fall also, since the increase in the next year will be less than the average. MAI is a much used (and often abused) forestry measurement for tree growth, but whenever a MAI or CAI figure is quoted, the age of the forest must also be known. Because MAI changes with time, a plantation that has grown at 20 m³/ha/yr over 10 years might have 200m³/ha, but if grown for another 10 years it will not necessarily have 400m³/ha.

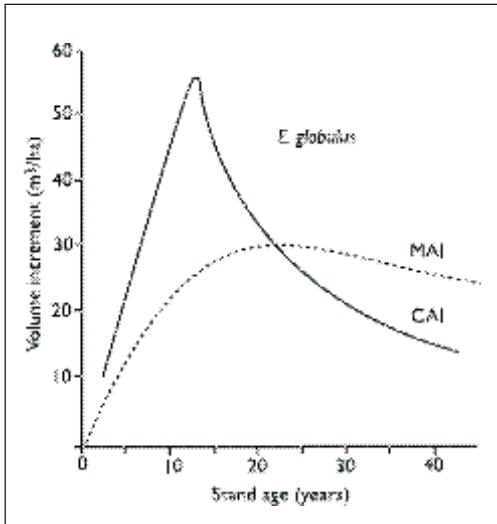
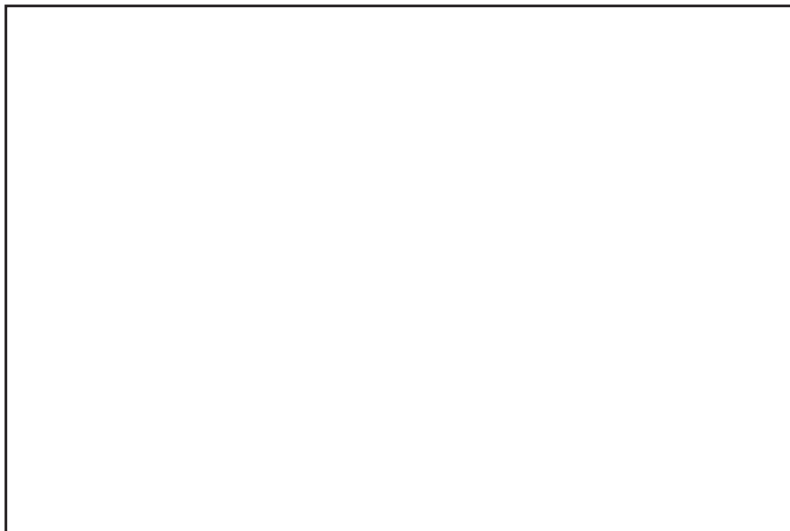


FIG 17.
The effect of stand age on the Current Annual Increment (CAI) and the Mean Annual Increment (MAI) of a *Eucalyptus globulus* plantation on a very high quality site in Tasmania (Data from Goodwin and Candy 1986).

Measuring Other Products and Services

This chapter has provided a basic introduction to the measurement of trees and forests for wood production. If the farmer is producing non-timber products such as eucalyptus oil or seed then they will require other measurement techniques that are appropriate for the product. As markets for environmental services, such as biodiversity or carbon, develop there will be a need for special forest measurements. In most cases an assessment of the number of trees, the range of different species, their size and distribution will still be required, in which case the techniques outlined in this chapter are still relevant.



A biodiversity assessment of a native forest will include measurements of stocking rate, basal area and height for each tree species.

TREE SPACING & STOCKING GUIDE

Distance between rows (m)	Distance Between Trees Along Rows (metres)										
	1	2	2.5	3	3.5	4	4.5	5	6	7	8
2	5000	2500	2000	1667	1429	1250	1111	1000	833	714	625
2.5	4000	2000	1600	1333	1143	1000	889	800	667	571	500
3	3333	1667	1333	1111	952	833	741	667	556	476	417
3.5	2857	1429	1143	952	816	714	635	571	476	408	357
4	2500	1250	1000	833	714	625	556	500	417	357	313
4.5	2222	1111	889	741	635	556	494	444	370	317	278
5	2000	1000	800	667	571	500	444	400	333	286	250
5.5	1818	909	727	606	519	455	404	364	303	260	227
6	1667	833	667	556	476	417	370	333	278	238	208
6.5	1538	769	615	513	440	385	342	308	256	220	192
7	1429	714	571	476	408	357	317	286	238	204	179
7.5	1333	667	533	444	381	333	296	267	222	190	167
8	1250	625	500	417	357	313	278	250	208	179	156
9	1111	556	444	370	317	278	247	222	185	159	139
10	1000	500	400	333	286	250	222	200	167	143	125
11	909	455	364	303	260	227	202	182	152	130	114
12	833	417	333	278	238	208	185	167	139	119	104
13	769	385	308	256	220	192	171	154	128	110	96
14	714	357	286	238	204	179	159	143	119	102	89
15	667	333	267	222	190	167	148	133	111	95	83

Calculations

1a. Plot Area Rectangular Plot (Ha)

$$= \text{Length (m)} \times \text{Width (m)} / 10000$$

$$= \dots \times \dots / 10000$$

$$= \dots \text{ Ha}$$

1b. Plot Area Circular Plot (Ha)

$$= (\text{Plot Radius (m)})^2 \times \pi / 10000$$

$$= \dots \times 3.142 / 10000$$

$$= \dots \text{ Ha}$$

2. Stand Density

$$= \frac{\text{No. of trees in plot}}{\text{Plot Area (Ha)}}$$

$$= \frac{\dots}{\dots}$$

$$= \dots \text{ Trees/Ha}$$

3. Basal Area/Tree

$$= \pi \times (\text{DBH}/200)^2$$

$$= 3.142 \times (\dots/200)^2$$

$$= \dots \text{ m}^2$$

4. Stand Basal Area

$$= \frac{\text{sum of BA for each tree}}{\text{Plot Area (Ha)}}$$

$$= \frac{\dots}{\dots} = \dots \text{ m}^2/\text{Ha}$$

Or as an estimate (slight underestimation)

5. Stand Basal Area

$$= \pi \times (\text{Mean DBH}/200)^2 \times \text{Stand Density}$$

$$= 3.142 \times (\dots/200)^2 \times \dots$$

$$= \dots \text{ m}^2/\text{ha}$$

6. Tree Vol.

$$= \text{Tree BA} \times \text{Ht}/3 \text{ (Cone shape)}$$

$$= \dots \times \dots / 3 = \dots \text{ m}^3$$

7. Pruned Log Vol.

(Log = butt log length in m)

$$\text{CD} = \text{DBH} - (\text{DBH} \times \text{Log}) / (\text{Ht} \times 2) = \dots \text{ cm}$$

$$\text{Pruned Vol} = (\text{CD}/200)^2 \times \pi \times \text{Log length}$$

$$= (\dots/200)^2 \times 3.142 \times \dots = \dots \text{ m}^3$$

8. Stand Volume

$$= \text{Stand BA} \times \text{Stand Ht}$$

$$\text{Shape Factor}$$

$$= \dots \times \dots$$

$$= \dots \times 3 \text{ (Cone Shape)}$$

$$= \dots \text{ m}^3/\text{ha}$$

MASTER TREEGROWER FIELD BOOKING SHEET

Property: _____ **Paddock:** _____ **Plot No.:** _____ **Year Planted:** _____

Measured By: _____ **Date Measured:** _____

Plot Notes: _____ **Plot Marker:** _____

Species 1: _____ **Species 2:** _____ **Species 3:** _____

Tree No.	Species	DBH (cm)	Basal Area (m ²)	Form 1,2,or3	Height (m)	Volume (m ³)	Pruned (m)	Pruned (m ²)
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
				No.				
	Totals			1:				
	Means			2:				
				3:				

Explanations

- Diameter (DBHOB) (cm) ~ Tree diameter over bark at 1.3m
- Diameter Under Bark(DBHUB) (cm) ~ DBHOB - (2xBark Depth)(Estimate bark depth)
- Basal Area/Tree (BA/tree) (m²) ~ X'section area of the tree at 1.3m
- Basal Area/Hectare (BA) (m²/ha) ~ X'section area of the stand at 1.3m
- Tree Height (Ht) (m) ~ Height to top of tree
- Stand Height (Ht) (m) ~ Mean height of the 3 fattest trees in the plot
- Form: 1 = Perfect form for target tree, 2 = Acceptable form for target tree but not perfect, 3 = Unacceptable or Cull
- Volume (Vol/tree, Vol/Ha) (m³/tree or m³/ha) ~ Use volume tables or taper function
- Cone shaped tree ~ Shape factor of 3

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