INTRODUCTION

Understanding the techniques used to measure trees and stands provides landholders with the opportunity to make better management decisions. By measuring trees or plots of trees landholders can:

- Learn about the growth potential of their site and selected species and better judge their performance;
- Better plan, cost and schedule silvicultural operations such as thinning, pruning, and harvesting;
- Check to see if the work of a contractor such as pruning or thinning was done to the landholders specifications;
- Estimate growth rates and wood yields in order to estimate future wood production and log grades; and
- Determine or predict the stand’s value.

At the time of marketing the timber this information is extremely important in determining both the quantity and quality of the timber and therefore allow a fair and reasonable price to be negotiated. This paper provides a basic outline on how to establish a measurement plot, measure tree diameter, height and stand basal area and calculate tree and stand volumes.

The simple techniques described in this paper have their limitations and are not suitable where a high degree of accuracy is required, however, they are suitable for most farm forestry situations and only require cheap equipment and basic mathematical skills.

WHAT YOU’LL NEED

The basics - The MTG D-Tape, 30m Tape and a Calculator

All Master TreeGrowers receive a yellow flexible tape that can be used to estimate tree diameter, height and stand basal area. With this information growers can perform a number of calculations to estimate tree, log and forest volumes. It is advised that all growers also purchase a good quality 30m tape (available from most hardware stores) so they can also layout plots in their forest. A calculator is also very useful.
The MTG D-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 a MTG Logo along with information required to use the tape to estimate stand basal area.

![MTG D-Tape](image)

**The Extras**

Other equipment that is useful for tree measurement and data analysis include a pocket knife for measuring bark thickness and a computer (Laptop even) with spreadsheets that can process tree data (we can supply basic spreadsheet programs in Excel 4). Spray cans of paint or pegs are useful for permanently marking plots to allow for remeasuring over time.

**MEASUREMENTS OF A SINGLE TREE**

1. **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 cm at 1.3 m above the ground and is termed the “Diameter at Breast Height” (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 overbark 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).

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

2. **Diameter at Breast Height (DBH)**

   **How to measure DBH**

   The MTG D-tape has scales on both sides. The yellow side shows a normal metric scale in cm. The white side is specially marked to show the diameter (cm) of a tree or pipe when it is wrapped around the circumference.

   To measure DBH first of all determine where “breast height” or 1.3m is on you. Then, standing on the up-slope side of the tree, wrap the tape around the tree at that height 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 diameter at any point on a tree or log.

![Using the MTG tape to measure Tree Diameter at Breast Height Over Bark](image)

Fig 3. Using the MTG tape to measure Tree Diameter at Breast Height Over Bark. The DBHOB of this tree is 41.1 cm.
How it Works

The circumference of a circle is equal to $\pi \times d$ where $\pi$ (or Pi) is 3.142 and “d” is the diameter. If the diameter of a tree is 30cm the circumference will be $30 \times 3.142 = 94.3$ cm. If you look on the tape you will note that the “30” on the white side matches “94.3” cm 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

- 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 the breast height from the up-hill side since the ultimate height of the stump at harvest will be determined by the slope.
- Obvious swellings, distortions or branches at 1.3 metres need to be avoided. Move the tape 10 cm up and 10 cm down and take and average reading if there is a distortion at 1.3 metres.
- 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. The MTG tape provides a cheap method of measuring tree heights.

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, or height to an obvious defect).

Measuring Height with the MTG Tape

The technique requires two people. One person, with the tape, stands well back from the tree at a point approximately equal to the height of the tree. The second person stands at the base of the tree.

Holding a section of the MTG tape vertically out in front of themselves the first person closes one eye and looks past the yellow side of the tape so that the tree appears next to the tape. Moving the tape so that the “0” point on the yellow side corresponds to the base of the tree they can then “measure” the apparent height to the top (or any other point). They mentally calculate 10% of the apparent height.

Taking care not to move, they operator then asks the second person to move their hand up or down the stem to mark a point that corresponds to 10% of the total “apparent” height. Clearly this 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. The total tree height is simply this height multiplied by 10.

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

Fig 4. 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 14m then the tree is 14m tall.
**How it Works**

The technique simply involves the projection of two triangles of proportional dimensions as shown in the diagram. There is no need to know how far away the operator is from the tree or to worry about sloping land.

![Diagram showing the height measurement technique.](image)

**Precautions**

To be effective care must be taken that:

- The operator holds the tape vertically (let the tape hang momentarily before pulling tight and sighting).
- The operator takes care to stand very still being sure not to move their head when sighting - only move your eyes.
- The “base” of the tree is noted carefully and the vertical measure on the tree is made from the same point as noted by the operator. It may be helpful to have the second person mark the base-point with their foot and not move.

**3. Tree Basal Area**

Tree Basal Area (TBA) is the cross-sectional area (over the bark) at breast height (1.3m above the ground) measured in m². As described later, TBA can be used to estimate tree volumes.

To determine Tree Basal Area simply measure the diameter at breast height in cm (DBHOB) and calculate the basal area (m²) using the following equation which is simply adapted from the simple formula for the area of a circle (area=$\pi r^2$). This formula converts the diameter in cm to the basal area in m².

\[
\text{Tree Basal Area (TBA)} = \left(\frac{\text{DBH}}{200}\right)^2 \times 3.142 \text{ m}^2
\]

Where DBH is the Diameter at Breast height (cm) and 3.142 is $\pi$.

The same technique can be used to calculate the cross sectional area of the tree at any point. When measuring log volume for example, the cross sectional area at the centre of the log is often calculated.

![Diagram showing tree basal area.](image)
4. Tree Form

In farm forestry the shape or branching habit of a tree can affect its value markedly. The perfect "target tree" for sawmilling might, for example, have a very straight butt log with a single leading stem. When assessing trees it is therefore useful to record important aspects of their form. Most recording sheets allow for comments against each tree although 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. We recommend that when measuring trees landowners classify each tree as having either:

Form 1: Perfect form for the intended use or market
(e.g. straight 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 the form is likely to be unacceptable for milling purposes or it will severely downgrade log value.

Fig 7. Straightness is an important form characteristic in many situations. These examples show how farmers might classify their trees based on stem form.

5. Tree Volume

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

I. 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 then the following formula is appropriate:

Tree volume (m³) = \[
\frac{(DBH/200)^2 \times 3.142 \times Ht}{3}
\] or \[
TBA \times Ht \div 3
\]

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

Fig 8. Assuming the tree is conical the total tree and pruned log volumes can be estimated using the Basal Area and the formula for a cone.
Because Basal Area is measured at 1.3m above the ground and trees usually carry 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 good measure of recoverable volume of straight plantation trees considering that the bark and stump are not often used.

Fig 9. The real and assumed shape of a ten year old, pruned Eucalypt at Bambra (tree 5) showing that the assumption that the tree has the shape of a cone is quite reasonable for the butt log (0.4 - 6.4m).

More detailed formula 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.

2. VOLUME OF THE LOWER LOG

The volume of the first log (the butt log) in a standing tree can be conservatively estimated from DBH by first estimating the diameter half way up the log. This is quite simple if the tree has been felled or the butt log is very short (less than 4m long). For longer butt logs we can assume again that the tree has a cone shape and calculate the diameter at the centre of the butt log as follows:

\[
\text{Butt log centre diameter (CD) (cm)} = \frac{\text{DBH} - (\text{DBH} \times \frac{L}{Ht})}{2}
\]

Where: \(L\) is the expected log length (m) and \(Ht\) is the total tree height (m). For pruned trees the log length would be the pruned height (say 6.5m) minus stump height (say 0.4m).

The volume of the first log is then simply estimated by using CD as:

\[
\text{Log Volume (m}^3\text{)} = \left(\frac{\text{CD}}{200}\right)^2 \times 3.142 \times L
\]

For example, if the DBH of a 30m tall tree was 55 cm and the pruned log length was 6m then the centre diameter would be:

\[
\text{CD} = 55 - \left(\frac{55}{30} \times 6\right) = 49.5 \text{ cm}
\]

The pruned log volume would therefore be approximately:

\[
\text{Pruned Log Vol} = \left(\frac{49.5}{200}\right)^2 \times 3.142 \times 6 = 1.15 \text{ cubic metres of wood}
\]

This again assumes that DBH over bark is a good estimate of the diameter under bark at stump height and this can be checked using a pocket knife or by checking the bark depth on recently thinned trees of the same age and species.

After harvest the log volume can be more accurately estimated by measuring the diameter under the bark half way along the log length and using the same simple equation.
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, by using sampling techniques we are able to achieve a good estimate of stocking rate, stand basal area and log volumes by measuring as few as 2% of the trees in the forest.

1. Describing the Forest - Types & Areas

The starting point involves developing a good map of the area which 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 on the map. 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 in parts of the stand these should be treated as separate areas or sections and marked on the map. This is important so a true picture of the stand’s growth can be estimated.

ESTIMATING THE AREA

A common method to measure 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. Other maps may be suitable (e.g. 1:25,000 map or accurate large-scale farm map). Many graphical computer programs can determine areas of irregularly shaped polygons drawn over scanned photographs or maps.

Additional features such as roads, power lines, water courses, soil types and aspect should be also noted on the map.

2. Establishing a Plot

Plots as a Sample of the Total Forest

Measuring trees can be a time consuming and costly operation, therefore only a sample of trees within a stand are measured to provide an estimate of the stand’s growth (or sections of the stand’s growth if different sections have been identified).

A minimum of 3 plots should be established in any section of the forest. For very large uniform forests the total area of all the plots should account for more than 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 0.04ha in size (see below) 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 stands. 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

Between 15 and 30 trees per sample plot is required (12 being the absolute minimum) therefore plot size will depend on stand stocking rates. 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 counting the trees as you go.

Calculating Plot area

Plot area for each shape is calculated as follows:

Rectangular Plots: \[ \text{Plot area (m}^2\) = \text{Length (m)} \times \text{Width (m)} \]

Circular Plots: \[ \text{Plot area (m}^2\) = \left( \text{Radius (m)} \right)^2 \times 3.142 \]

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

Table 1. Stocking rates and plot size for sample plots that will include about 20 trees.

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 distributed throughout the area.

All plots should be either permanently marked on the ground or carefully located on a map. The reference point is the centre of circular plots and the north east corner of rectangular plots.

The Plot Sheet

A plot sheet is used to document the information collected. It is useful to add comments about the plot or individual trees that may help interpret the information collected. Note the location of the plot, any unusual features, the date and the names of those involved. The sample plot sheet provided can be copied or adapted.

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

Fig 11. Counting technique within a rectangular and circular plot.
Precautions in Locating and Laying Out Plots

- On sloping ground ensure all measurements are horizontal.
- In plantations, plots should not be located on the edge or include abnormal features (such as troughs).
- If trees are on the edge of the plot they are counted as “in” if the centre of the stem is in the plot.

3. Plot Measurements

Stocking Rate
The 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:

\[
\text{Stocking Rate (stems/ha)} = \frac{\text{Trees in plot}}{\text{Plot area (ha)}}
\]

Tree Diameters and Pruned Height
The diameter of every tree in the forest 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 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 each and every tree in the plot it is common to select a sub-sample. In most cases a number of the fattest trees of good form with be measured for height - this is called the “Mean Dominant Height”.

Mean Dominant Height
To estimate the Mean Dominant Height select the 3 fattest trees (largest DBH) of good form in each plot and measure their height. The average height of these trees is defined as the Mean Dominant Height for the plot where there are 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 basal 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 or as a useful measure of the degree of competition in the stand. SBA is often quoted when planning thinning prescriptions.
MEASURING STAND BASAL AREA

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

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

1. Sum of 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.

\[ \text{Basal Area of a tree (m}^2) = \left( \frac{\text{Diameter (cm)}}{200} \right)^2 \times \pi \]

\[ \text{Stand Basal Area (m}^2/\text{ha}) = \frac{\left( \text{Sum of the basal area of each tree in the plot} \right)}{\left( \text{area of the plot (ha)} \right)} \]

Computer spread sheets are ideal for this and data from the plot sheet can be entered into the computer for calculations.

A quicker method is to calculate Basal Area from the average tree diameter:

\[ \text{Stand Basal Area (m}^2/\text{ha}) = \left( \text{Basal Area of the tree with average diameter} \right) \times \left( \text{Stocking (tree/ha)} \right) \]

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.

2. Optical methods of assessing Basal Area

Basal Area per hectare can be estimated using a very simply optical method. A gauge of known width is held at a set distance from the eye and the observer turns on a point observing each tree (at breast height) and counts the number of trees which appear wider than the width of the gauge. If a tree appears to be exactly the same width as the gauge it is counted as 1/2 rather than 1. 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.

\[ \text{The Basal Area (m}^2/\text{ha}) = \text{Factor} \times \text{Count} \]
\[ = 2 \times (11 + 1.5) \]
\[ = 25 \text{ m}^2/\text{ha} \]
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 which 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 D-tape as an optical Basal Area Gauge.

Understanding the Optical method

Follow the steps:

1. Calculate the Basal Areas of the following hypothetical plots in figure 14 which contain trees of equal diameter using the formula present above

   Stand Basal Area (m²/ha) = \( \frac{\text{Sum of the basal area of each tree in the plot}}{\text{area of the plot, (ha)}} \)

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. Such a gauge must subtend an angle that allows us to “test” if any particular tree is “in” or “out” of a plot (centred where we stand) that has a radius equal to 50 x Tree Diameter. (Fig. 15)

   In the diagram the ratio of [Gauge Width]:[Distance from Eye] must equal [DBH]:[Radius] i.e. 1:50

   Therefore since the gauge on the MTG D-tape is 16mm across it would need to be held 80cm from the eye to act as a 1-Factor Basal Area Gauge.

4. 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. In this case the Radius of the plot would need to be 35.4 times the tree diameter. Therefore for a 2-Factor gauge the 16mm wide gauge would need to be held 56.6cm (1.6 x 35.4) from the eye.

Fig 14. Note that the Basal Area of these plots is equal to the number of trees in the plot.

Fig 15.
All that is needed to make up an optical basal area measuring tool is something of known width that can be held at a set distance from the eye. The table below gives the specifications for gauges of different Factors:

Table 3. Distance that the gauge should be held from the eye. Distances of less than 40cm are very difficult in practice due to the difficulty of simultaneously focusing the eye on both the gauge and the tree in the distance.

<table>
<thead>
<tr>
<th>Gauge Width (cm)</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
</tr>
</thead>
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<tr>
<td>Calculation</td>
<td>50xWidth</td>
<td>50xWidth</td>
<td>50xWidth</td>
<td>50xWidth</td>
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<tr>
<td>1.0</td>
<td>50</td>
<td>35.4</td>
<td>28.9</td>
<td>25.0</td>
</tr>
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<td>1.4</td>
<td>70</td>
<td>49.5</td>
<td>40.4</td>
<td>35.0</td>
</tr>
<tr>
<td>1.6</td>
<td>80</td>
<td>56.6</td>
<td>46.2</td>
<td>40.0</td>
</tr>
<tr>
<td>1.8</td>
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<tr>
<td>2.0</td>
<td>100</td>
<td>70.7</td>
<td>57.7</td>
<td>50.0</td>
</tr>
</tbody>
</table>

**THE MTG TAPE AS AN OPTICAL BASAL AREA GAUGE**

The yellow Master TreeGrower D-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 on the yellow side and the loop resting in your palm.

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 (Factor 2) or 40.0cm (Factor 4). 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 16*

*Fig 17a. This tree is counted as IN*

*Fig 17b. This tree is counted as a HALF*

*Figure 17c. This tree is counted as OUT*
Steps
1. Randomly locate a spot in the stand of trees and mark the spot on the ground.
2. Hold the tape with the appropriate point up against your check bone just below the eye.
3. Hold the gauge out straight and look along the tape closing the other eye.
4. Note your starting point (to avoid double counting) and begin counting the number of trees “in” (1 point) or “1/2 in” (1/2 a point) turning as you do 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 stand and average the results for the whole area.

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

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

Testing doubtful trees.
If a high degree of accuracy is required it is worth testing 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
- The profile of 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 1 cm away from the correct position then the error will be less than about 5%.
- The greater the number of “1/2 in” 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.
- The line of sight to the trees should be horizontal. A correction for slope may be applied, although even on a slope of 25 degrees the error is only about 10%.
- 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.
- 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

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 18 below 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 3m grid then the Spacing Factor is 300cm divided by 20cm = 15.
From the graph it can be seen that 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 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 grow quickly to this size (Basal Area less than 20m²/ha over the life of trees) then the final spacing would need to be more than 20 (from graph) x 50cm = 10m or 100 trees/ha.

Some useful number 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

![Chart showing the relationship between Spacing Factor and Basal Area](chart.png)

Fig 18. The relationship between the Spacing Factor and Basal Area
5. Volume Calculations

Stand Basal Area measurements obtained using the tape in carefully set out plots of known area or by using the optical gauge method can be used to calculate tree and butt log volumes in the same way that tree volumes were calculated.

**Forest Volume (m³/ha)**

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:

\[
\text{Standing Volume (m³/ha)} = \frac{\text{SBA} \times \text{HT}}{3}
\]

SBA = Stand Basal Area (m²/ha)
HT = Dominant Tree Height (m)

\[
\text{Standing Volume (m³/ha)} = \frac{\text{Plot Volume (m³/ha)}}{\text{Plot Area (ha)}}
\]

**Butt Log Volume (m³/ha)**

The volume of butt log per hectare in a plantation managed for sawlogs can be estimated by adding up the butt log volumes of each tree in the plot:

\[
\text{Butt Log Volume (m³/ha)} = \frac{\text{Plot Butt Log Volume (m³/ha)}}{\text{Plot Area (ha)}}
\]

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:

\[
\text{Mean Annual Increment m³/ha/yr (MAI)} = \frac{\text{Volume of stand (m³/ha)}}{\text{Age of Stand (yrs)}}
\]

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

**Example:**

Current Annual Increment at age 2 (m³/ha/yr) (CAI) = (Volume at age 3) - (Volume at age 2)

In dense plantations the CAI will increase rapidly in the early years up until competition and limiting 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.

When the CAI drops to the point that it is the same as the MAI (see Fig. 19) then MAI must too fall 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. 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 19. The effect of stand age on the Current Annual Increment and Mean Annual Increment of a E. globulus plantation on a very high quality site in Tasmania (data from Goodwin and Candy 1986)
## 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 | 266 | 227 | 200 |
| 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  |
## MASTER TREEGROWER FIELD BOOKING SHEET

<table>
<thead>
<tr>
<th>No.</th>
<th>Species</th>
<th>DBH (cm)</th>
<th>Basal Area (m²)</th>
<th>Form</th>
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### Calculations

1a. Plot Area Rectangular Plot (Ha)
\[ \text{Length (m)} \times \text{Width (m)} / 10000 \]
\[= \text{length} \times \text{width} / 10000 \]
\[= \text{ha} \]

1b. Plot Area Circular Plot (Ha)
\[= (\text{Plot Radius (m)})^2 \times \pi / 10000 \]
\[= \text{radius}^2 \times 3.142 / 10000 \]
\[= \text{ha} \]

2. Stand Density
\[= \text{No. of trees in plot} / \text{Plot Area (Ha)} \]
\[= \text{trees/ha} \]

3. Basal Area/Tree
\[= \pi \times (\text{DBH/200})^2 \]
\[= 3.142 \times (\text{DBH/200})^2 \]
\[= \text{m}^2 \]

4. Stand Basal Area
\[= \text{sum of BA for each tree} / \text{Plot Area (Ha)} \]
\[= \text{m}^2/\text{ha} \]

5. Stand Basal Area
\[= \pi \times (\text{Mean DBH/200})^2 \times \text{Stand Density} \]
\[= 3.142 \times (\text{DBH/200})^2 \times \text{trees/ha} \]
\[= \text{m}^2/\text{ha} \]

6. Tree Vol.
\[= \text{Tree BA} \times \text{Ht}/3 \text{ (Cone shape)} \]
\[= \text{BA} \times \text{Ht}/3 \]
\[= \text{m}^3 \]

\[= (\text{DBH} - (\text{DBH} \times \text{Log})/(\text{Ht} \times 2)) \times \text{Pruned Volume} \]
\[= (\text{DBH} \times \text{Ht} \times \text{Log}) / (\text{DBH} - (\text{DBH} \times \text{Log})/(\text{Ht} \times 2)) \]
\[= \text{m}^3 \]

8. Stand Volume
\[= \text{Stand BA} \times \text{Stand Ht} \]
\[= \text{BA} \times \text{Ht} \]
\[= \text{m}^3/\text{ha} \]

### Explanations:

- ** Diameter (DBHOB) (cm) ** - Tree diameter over bark at 1.3m
- ** Diameter Under Bark (DBHB) (cm) ** - DBHOB - (2 x Bark Depth) (Estimate bark depth)
- ** Basal Area/Tree (BA/Tree) (m²) ** - X-section area of tree at 1.3m
- ** Basal Area/Hectare (BA/ha) (m²/ha) ** - X-section area of 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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