# BECVOL: Biomass Estimates from Canopy VOLume (version 2) - Users Guide

## Introduction

Savannas cover large areas of southern Africa and the need for a quantitative description of the woody component of these savannas often arises. Taking into account the ecological implications of trees in savannas, the following three aspects are the most important from an agro-ecological point of view (Smit 1989a): (i) competition with herbaceous vegetation for soil water and nutrients; (ii) food for browsers, and (iii) creation of sub-habitats suitable for desirable grass species. A qualified description will need to address these aspects quantitatively. An approach to such a quantitative description of woody plant communities, that could be generally applied and be meaningful in terms of plant and animal production, was proposed by Smit (1989a). In this manuscript an expansion on this quantitative description of woody plants is being described, which has resulted in the compilation of a computerised model, named the BECVOL-model. The model described here applies to version 2.0 (1996), which is the sixth variation of the original BECVOL-model (version1.0, 1991).

## BECVOL: Biomass Estimates from Canopy VOLume

The name of the **BECVOL-**model is derived from "**B**iomass **E**stimates from **C**anopy **VOL**ume". This model, which can be desribed as a descriptive model (Wissel 1992), provides estimates of the actual leaf volume and leaf mass of individual trees, from which Evapotranspira-tion Tree Equivalents (ETTE) and Browse Tree Equivalents (BTE) are derived (these units are described in detail in subsequent sections of this manuscript). These values are also calculated per hectare. This is done for individual species as well as for the total population.

In addition to total leaf DM ha$^{-1}$, stratified estimates of the leaf DM ha$^{-1}$ below 1.5 m, 2.0 m and 5.0 m, respectively, are also calculated by the BECVOL-model. The height of 1.5 m represents the mean browsing height of the boer goat (Aucamp 1976) and impala (*Aepyceros melampus*) (Dayton 1978), while 2.0 m and 5.0 m represent the mean browsing heights of the kudu (*Tragelaphus strepciseros*) (Wentzel 1990) and giraffe (*Giraffa camelopardalis*) (Skinner & Smithers 1990), respectively. These browsing heights are mean heights and not maximum browsing heights. It is known that large individuals are able to reach higher than these mean heights, e.g. 2.5 m and 5.5 m for kudu and giraffe respectively (Dayton 1978), while breaking of branches may enable some browsers to utilise browse at even higher stratums (Rutherford 1979b; Styles 1993).

The estimates are based on the relations between spatial canopy volume (calculated from various dimension measurements of the trees) and the tree's true leaf volume and true leaf mass. In addition, the model also calculates simple tree density data (plants ha$^{-1}$) on a species basis and CSI values (the CSI is also decribed in a subsequent section of this manuscript). This model incorporates a considerable amount of mathematical calculations, some of which are difficult and time consuming if attempted without the aid of computerised computation (e.g. calculations of partial canopy volumes). These calculations are therefore well suited for inclusion in a computer model since it will free the user from laborious calculation, and provide fast and consistently accurate calculations. For the computerisation of the model the dBASE IV programming language was used.

## The quantitative description

### *Descriptive units*

To describe a tree community in terms of the agro-ecological factors mentioned previously, suitable units are required. Density data are commonly used to describe tree communities, but are inadequate to quantify biomass accurately. Compensation for differences in tree height was implemented by Teague *et al.* (1981) who defined a Tree Equivalent (TE) as a tree, 1.5 m high. Thus a tree with a height of 4.5 m represents 3 TE's. This unit was developed in the False Thornveld of the Eastern Cape which has relatively homogeneous tree populations, regarding both species diversity and height distribution. The use of the TE is less suitable for heterogeneous tree communities since it does not compensate for structural differences between tree species. In addition, TE-values increase arithmetically with an increase in tree height, while tree volume increases exponentially (Smit 1989a).

To quantify browse material, Teague *et al.* (1981) defined a Browse Unit (BU) as a tree with a height of 1.5 m. The difference between the BU and TE is that all unacceptable species are excluded in the calculation of the BU, as well as those individuals of which the lowest browsable material is above 1.5 m. This is an example of quantifying nonmass browse data in which browse is not expressed in mass per unit area. Rutherford (1979b) cited several more such techniques: number of twigs per unit ground area (Bookhout 1965; Halls *et al.* 1970; Knierim *et al.* 1971), leaves counted in permanent plots (Crouch 1968), leaf counts per twig (MacOnochie & Lange 1970), elongation of twigs (Halls & Alcaniz 1972) and several others.

Bearing in mind the three main ecological dynamics of trees formerly mentioned, the following three quantitative descriptive units were proposed by Smit (1989a):

(i) Evapotranspiration Tree Equivalent (ETTE) - defined as the leaf volume equivalent of a 1.5 m single-stemmed tree.

(ii) Browse Tree Equivalent (BTE) - defined as the leaf mass equivalent of a 1.5 m single stemmed tree.

(iii) Canopied Subhabitat Index (CSI) - defined as the canopy spread area of those trees in a transect under which associated grasses like *Panicum maximum* is most likely to occur, expressed as a percentage of the total transect area (see also Smit & Van Romburgh 1993).

From harvested 1.5 m *Acacia karroo* trees, Smit (1989a) has defined the values of an ETTE and BTE as 500 $cm^3$ leaf volume and 250 g leaf dry mass, respectively (rounded off median values of ten harvested trees).

The estimates of leaf volume, leaf DM, ETTE and BTE obtainable with the BECVOL-model have unlimited uses. Some of the more obvious uses are the description of tree competition gradients and estimates of browse within specific browsing heights.

***Field data, terminology and calculation concepts***

The proposed technique follows a regression analyses approach using standard statistical least square regression analyses. Various equations relating tree dimensions to leaf mass have been presented, either for complete woody plants (Mason & Hutchings 1967; Barnes *et al.* 1976; Rutherford 1979a) or woody plant portions (Barnes *et al*. 1976). An objective of the develop-ment of the proposed technique was the ability to provide estimates for both complete plants and plant portions. No other existing technique allows for both from the same measurements..

The calculation of the ETTE and BTE is based on the relations between the spatial volume of a tree and its true leaf dry mass and true leaf volume respectively. The description of an ideal tree provides the basis for the calculation of spatial volume of any tree, regardless of shape or size. An ideal tree is regarded as a single stemmed tree with a canopy consisting of a dome-shaped crown and a cone-shaped base (Figure 1).

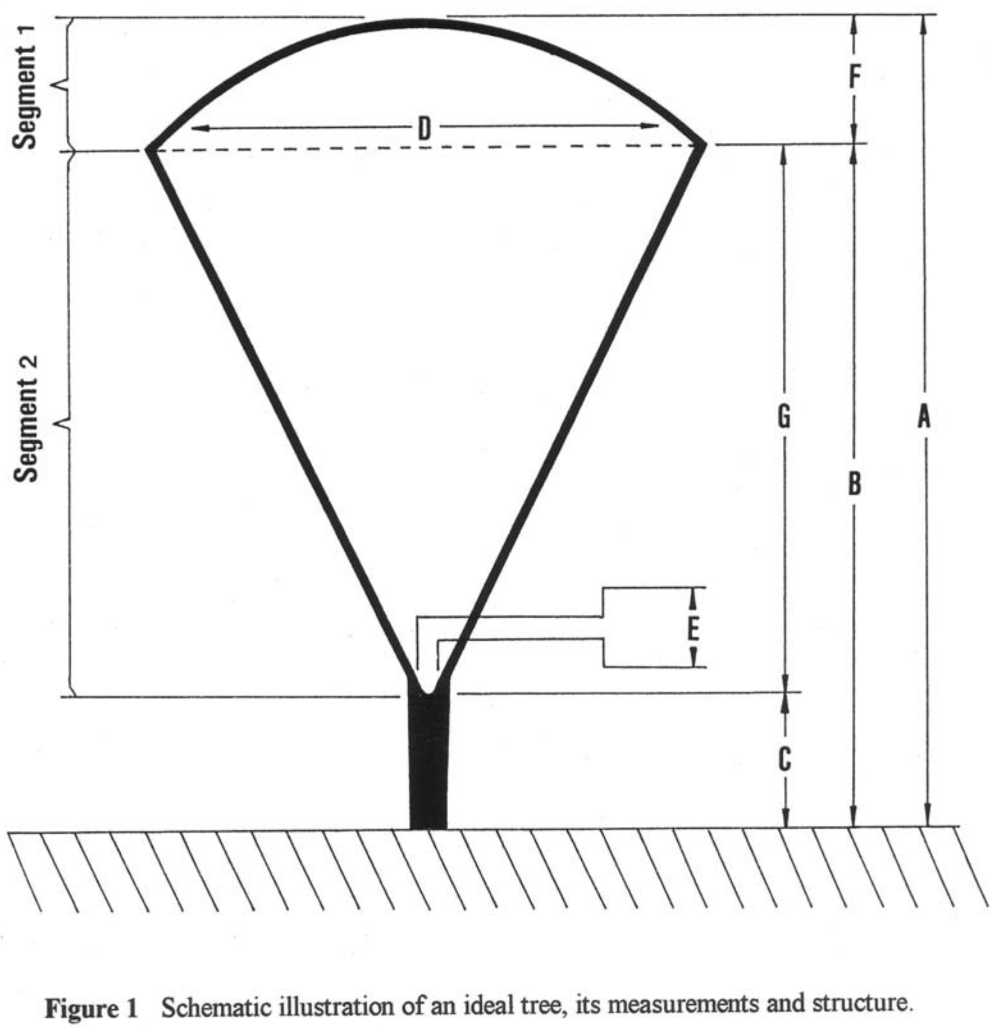


**Figure 1** Schematic illustration of an ideal tree, its measurements and structure.

The spatial canopy volumes are calculated from measurements, consisting of the following (Figure 1):

(i) tree height (A),
(ii) height of maximum canopy diameter (B),
(iii) height of first leaves or potential leaf bearing stems (C),
(iv) maximum canopy diameter (D), and
(v) base diameter of the foliage at height C (E).

The tree height is taken as the height of the main tree crown, ignoring any small stems protruding from the crown. Since the theoretical canopy is considered circular, the maximum canopy diameter is calculated as the average of two measurements rectangular to each other ($D_1$ & $D_2$) whenever the tree canopy is elliptic (horizontally). The same principle applies to the base diameter E ($E_1$ & $E_2$). All measurements are based on live tree parts only. Two segments are present, the first (segment 1) located above the level of the maximum canopy diameter and the second located below this level (segment 2).

Considerable variations in tree shape and structure do occur. A few diverse examples of possible tree shapes and their measurements are illustrated in Figure 2. In the first example the base of the tree (segment 2) is cylindrical and not cone-shaped (Figure 2a). In the second example the dome-shaped crown (segment 1) is absent and the maximum canopy diameter occurs at the top of the tree (Figure 2b). Segment 2 furthermore, represent an incomplete cone shape. In the third example only segment 1 is represented (Figure 2c).

Smit (1989a) proposed that a leaf density score (0-3) be allocated to the different tree segments (four segments versus the two described above). These scores are allocated subjectively by studying the appearance of individuals of which the leaves are dense (score 3) and those that are very sparse (score 1). Score 2 is allocated to segments with leaves between these two limits. Score 0 designates no leaves. However, this procedure proved to be responsible for unacceptable levels of variance due to inconsistent results between different operators (Hobson & De Ridder 1991). Subsequently this aspect of the technique was discarded.

According to the original technique (Smit 1989a) the estimated leaf volume and leaf mass were calculated for each tree segment individually (four segments) by substituting the segments' spatial volumes into regression equations obtained from harvested trees. These regression equations resemble the relations between spatial tree volume and actual leaf volume and actual leaf mass.

The six regression equations, one for each of the three leaf density classes for both leaf volume and leaf mass (Smit 1989a), are replaced by two regression equations: one for leaf dry mass and one for leaf volume. They account for differences in leaf density to give an estimate of potential leaf biomass. The ETTE and BTE values of a tree are calculated by dividing its calculated leaf volume and leaf mass by the unit values of an ETTE and BTE.

By calculating the canopy volume below any specified maximum browse height, an estimate of browse potentially within the reach of a browser is possible.

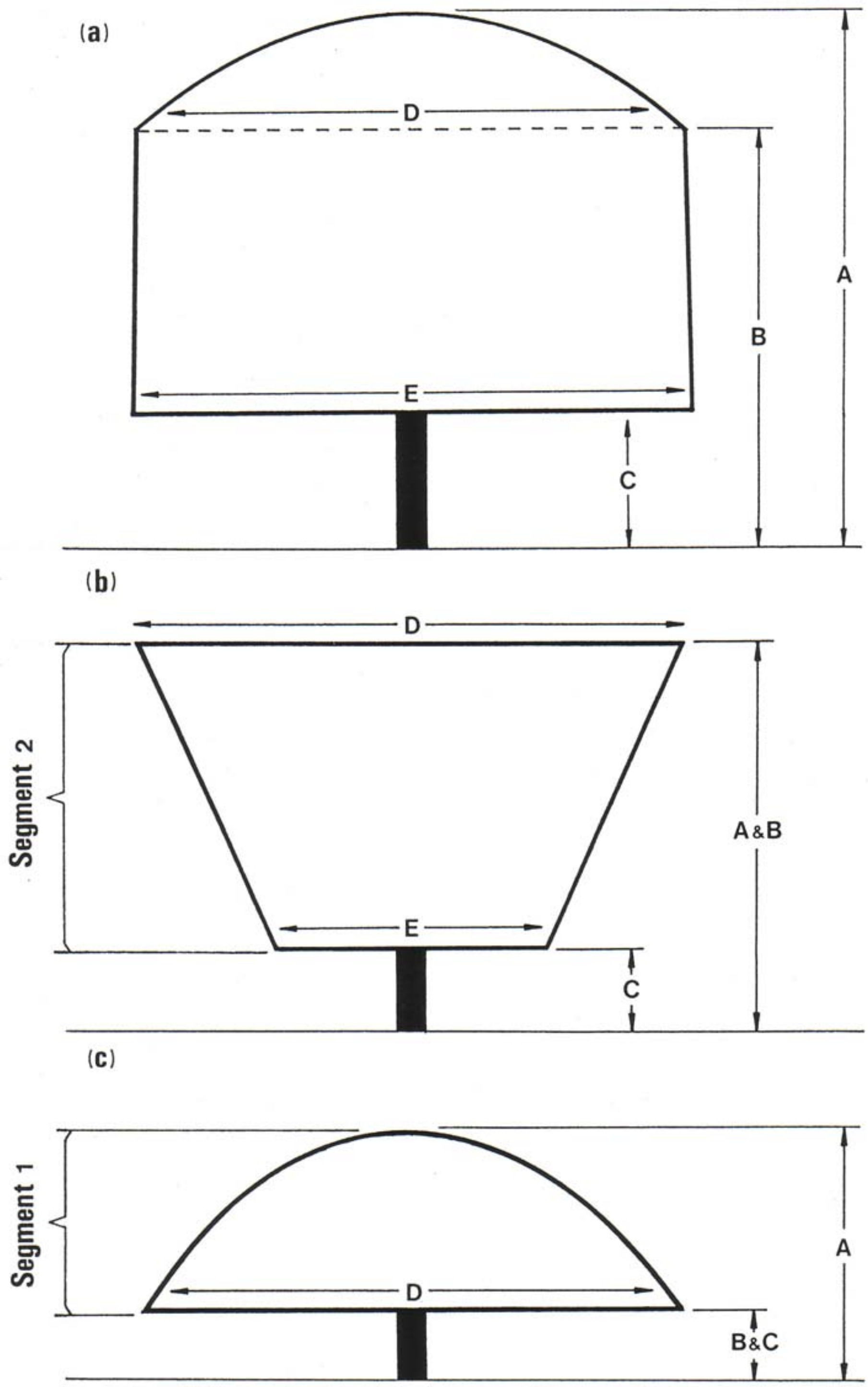


**Figure 2** Schematic illustration of a few non-ideal trees, their measurements and structures.

***Calculation of spatial canopy volume***

The spatial volume of any tree, regardless of its shape or size, is calculated from the dimension measurements by using the volume formulas of an ellipsoid, a right circular cone, a frustum of right circular cone or a right circular cylinder. These shapes correspond well with varying shapes of different trees or parts of a tree.

Depending on the shape of the tree, any one of these volume formulas may be used, or more likely two of them in combination. As the aim is the inclusion of the proposed calculations into a computer program, formulas are presented as computer compatible expressions, where applicable, using arithmetic operators and parentheses. Spatial canopy volume of a tree is calculated from the tree measurements previously described (values A, B, C, D and E). In addition, the following dimensions are needed:

F = Height of tree crown (A-B).
G = Height of tree base (B-C).

Additional symbols, and the values represented by them, will be specified. If the shape of the tree resembles parts of two different shapes the canopy volume of the tree is calculated in two parts. The first is located above the level of the maximum canopy diameter (B), and the other below this level. Theoretically, all trees are considered as symmetric.

VOLUME OF TREE SEGMENT 1

If present, tree segment 1 represents a dome shape. It is considered as being half of an ellipsoid. Using the volume formula of an ellipsoid (Spiegel 1968), the volume of this segment is calculated as follows:

Volume (segment 1) = ((4/3)∗(22/7)∗(D/2)∗(D/2)∗F)/2

or shortened:

Volume (segment 1) = ((22/7)∗D^2∗F)/6

VOLUME OF TREE SEGMENT 2

This segment represents a right circular cone or a right circular cylinder. The cone-shape may be complete or incomplete (frustum of right circular cone). If E is equal to D, segment 2 is considered as a right circular cylinder. The formula of such a cylinder (Spiegel 1968) is used for the calculation of the volume:

Volume (segment 2) = (22/7)∗(D/2)^2∗G

If E is equal to 0, segment 2 is considered as a complete right circular cone. Using the formula of such a cone (Spiegel 1968), the volume is calculated as:

Volume (segment 2) = (1/3)∗(22/7)∗(D/2)^2∗G

If E is bigger than 0, but smaller than D, it is considered as part of an incomplete right circular cone (frustum of right circular cone). The formula for such a shape (Spiegel 1968) is used to calculate the volume:

Volume (segment 2) = (1/3)∗(22/7)∗G∗((D/2)^2+(D/2)∗(E/2)+(E/2)^2)

PARTIAL VOLUMES

In order to calculate the leaf mass production (and BTE-value) of a tree below any specified Maximum Browse Height (MBH), the calculation of partial volumes of tree segments is necessary. Four main possibilities occur:
(i) MBH above A

(ii) MBH below C
(iii) MBH above B, but below A (Figure 3a)
(iv) MBH below B, but above C (Figure 3b)

In the first case the volume of the complete tree is used, and in the second case the potential available browse is 0. Partial volumes are only relevant in the third and fourth cases. In the case of the third possibility, tree segment 1 is divided by the MBH, and in the fourth case, tree segment 2 is divided by the MBH (Figure 3). Where tree segment 1 is divided by the MBH, the calculation of the partial volume consists of the calculation of the complete volume, as well as that of the part above the MBH. The latter is then deducted from the complete volume. A tree canopy divided by the MBH is illustrated in Figure 3a. For the calculation of the volume of that part above the MBH, it is theoretically considered as part of a smaller ellipsoid. The determination of H is essential for the calculation of this volume. Should the illustrated canopy be part of an ellipse, the mathematical equation is as follows:

$$\frac{x^2}{(D/2)^2} + \frac{y^2}{F^2} = 1$$

The dimensions represented by I and J are derived, through deduction, from the other known dimensions. The MBH represents a further input value. Using the given equation, H is deter-mined as follows:

set $y_1 = J$

$$\frac{4x_1^2}{D^2} = 1 - \frac{J^2}{F^2} = \frac{F^2 - J^2}{F^2}$$

$$x_1^2 = \frac{D^2(F^2 - J^2)}{4F^2}$$

$H = 2x_1$ (Figure 3a)

$$\therefore H^2 = 4x_1^2 = \frac{D^2(F^2 - J^2)}{F^2}$$

or as a computer compatible expression:

H^2 = (D^2∗(F^2-J^2))/F^2

The tree volume above the MBH is subsequently calculated as follows:
Volume above MBH = ((22/7)∗H^2∗I)/6

Where tree segment 2 is divided by the MBH, no deduction of volumes is necessary and the volume below the MBH is calculated directly. To calculate this volume, the new height L and new radius K, illustrated in Figure 3b, need to be determined. This is done as follows:

L = MBH-C

Determination of K: M = (D-E)/G
N = M∗L
K = N+E

Values K and L then replace D and G in the appropriate volume expression.

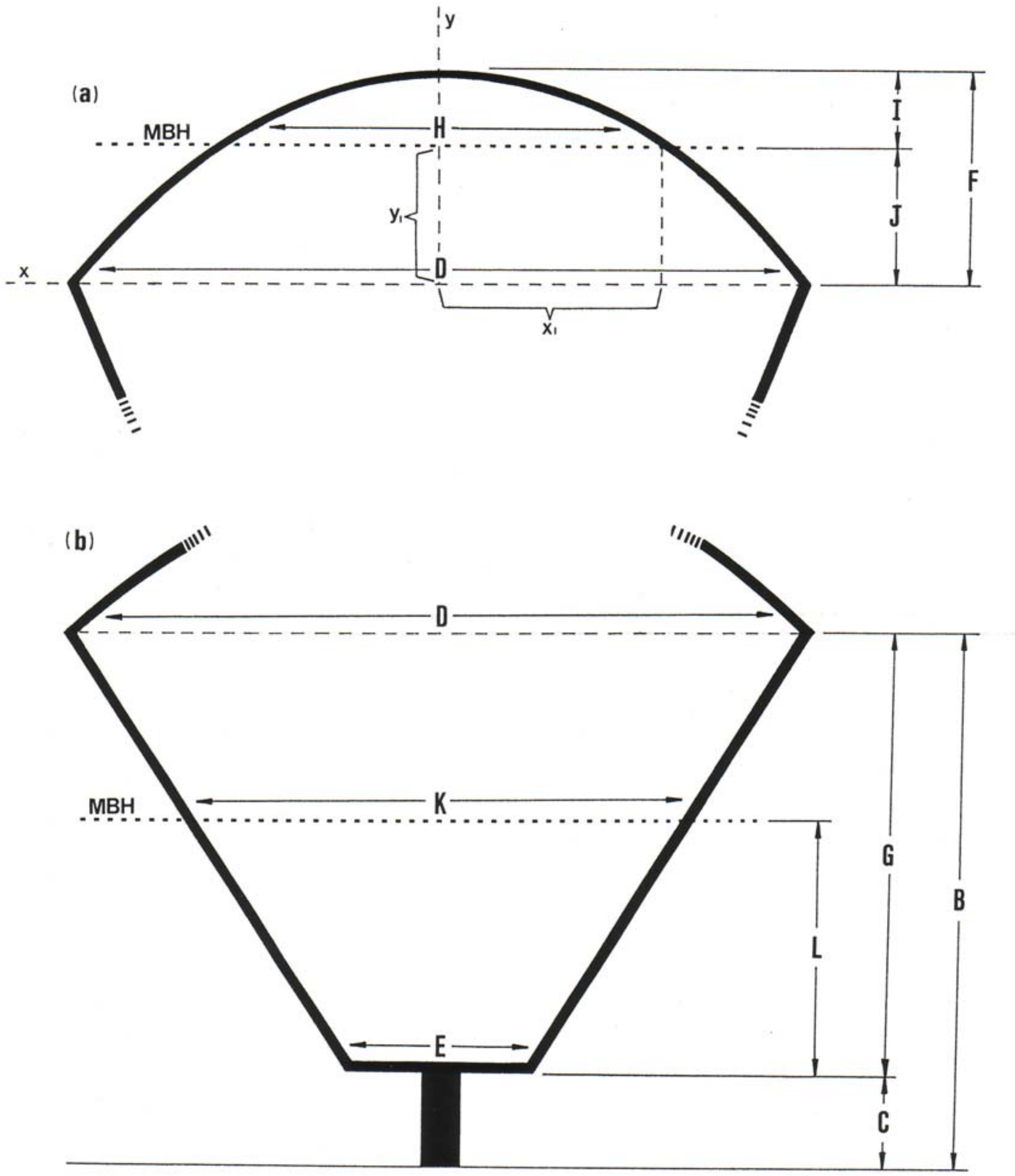


**Figure 3** Examples of tree segment 1 divided by the maximum browse height (MBH) (a), and segment 2 divided by the MBH (b), showing the symbols referred to in the text.

CALCULATION OF THE ETTE, BTE AND CSI

The leaf volume, leaf mass and ETTE/BTE-values of each tree are determined as follows:

(i) Calculate the spatial volume ($m^3$) of each of the trees' segments as described (in some cases only one segment may be present).

(ii) Multiply this volume by 1 000 000 in order to convert it to $cm^3$.

(iii) Substitute the spatial volume of the complete tree in the appropriate regression equation.

(iv) Derive a predicted leaf volume ($cm^3$) and leaf dry mass (g) from the appropriate regression equations and divide by 500 $cm^3$ (1 ETTE) and 250 g (1 BTE), respectively.

(v) Leaf mass and leaf volume values below the specified MBH are calculated as percentage fractions of the total tree mass and tree volume. The percentage fractions are calculated as the percentage the partial canopy volume comprised of the total canopy volume of a particular tree.

The canopy spread area of individual trees encountered in the transects needs to be calculated. The latter is used in the calculation of the Canopy Spread Index (CSI). The canopy spread area of each tree is calculated as:

$$\text{Canopy spread area} = (22/7) * (D/2)^2$$

The various CSI's (%) are calculated by adding the canopy spread area of those individuals higher than a specified critical height. These added canopy spread areas are subsequently expressed as percentages of the total transect area.

## Development of regression equations

### *Field data*

A minimum of 15 individual plants of some of the more important southern African savanna woody species were selected for harvesting (see Table 1). These selected individuals included all size classes, representative of the population. In some species, subject to availability, damaged plants which have coppiced from the basal stem area were also harvested, but treated separately due to considerable structural differences between them and undamaged plants. The dimensions of each tree were measured prior to being felled. The leaves were separated by hand from the twigs and stems. The volumes of the leaves were determined by measuring the volume of water displaced. Moisture losses from the leaves were limited by working under shade and keeping the leaves covered with wet sacks. After air-drying the leaves on sieves, they were dried to constant mass in a drying oven (70ºC) and then weighed.

### *Derivation of regression equations*

Regression analysis (Draper & Smith 1981; Statgraphics 1991) was applied with the true leaf volume and true leaf dry mass as dependent variables and the calculated spatial volume as the independent variable.

Positive curvilinear relations between true leaf dry mass and spatial canopy volume was established for all the harvested woody species. Similar positive curvilinear relation between true leaf volume and spatial canopy volume were found. The reason for the relations being curvilinear was mainly due to less leaves per unit canopy volume with increasing tree size. In most savanna tree species the leaves are concentrated at the outer perimeter of the foliar canopy and with increasing tree size an increasing large area in the centre of the canopy doesn't have any leaves (Van der Meulen & Werger 1984; Pauw 1988). These relations differed from the linear relations presented by Smit (1989a), mainly as a result of the predominantly small trees included in his original study.

Best line fitting to the data was obtained by transforming the spatial canopy volumes (on the x-axis) to their normal logarithmic values. In most cases logarithmic transformations are done to obtain linearity of non-linear data. This partial transformation did not alter the curvilinearity of the plotted lines, but merely changed it from being convex to concave. In this form the data was well suited for fitting the exponential regression equation. By resorting to a partial logarithmic transformation only, the problem of biased estimates by simply taking antilogarithms of values from a log-log regression line or regression function (Beauchamp & Olson 1973) was largely avoided. Highly significant regressions ($P<0.001$) with coefficients of determinations exceeding 0.88 were achieved (Table 1).

As an example the results of the regression analyses with the derived regression equations for *Colophospermum mopane* are presented in Figures 4 and 5.

## Development of a method for estimating linear tree dimensions

### *Preface*

The application of the BECVOL-model described in this manuscript requires numerous measurements of the tree canopy. Direct measurements may prove difficult to apply in the case of large trees. Reliable dimension estimates of trees can be made without the use of time consuming apparatus, such as the tape-measure, and costly and often difficultly obtained apparatus, such as the telescopic ranging rod, Blume-Leiss and Meridian meters (Nel 1965), as well as the Suunto meter. A quick one man method has been employed successfully to obtain accurate estimates of linear tree dimensions.

### *Description of the technique*

The proposed method is based on a visual overlap of two images, viz. the tree to be measured and a group of length scales (Figure 6). The length scales are incorporated on a 35 mm slide with a white background. The same principle was first used by Westfall & Panagos (1984) for canopy cover estimations. To produce such a slide, the lines in Figure 6 can be photographed on slide film. The slide with length scales is placed in a simple, inexpensive slide viewer consisting of a lens at the one end and an opal screen at the other. Slide viewers are available at most photographic dealers.

In practice one must look through the slide viewer with one eye, and at the tree of which the dimensions are to be estimated, with the other. The result is a combined image of the tree and the length scales. By moving the slide viewer, the line with the best fit is selected. It must correspond with that part of the tree to be estimated, either vertically or horizontally. The estimate in metres can then be recorded directly from the slide.

**Table 1** List of harvested tree species and the results of the regression analysis: ln y = a + bx, where y = leaf volume or leaf dry mass and x = the calculated spatial canopy volume.

| Species | L mass/ volume | n | r | $r^2$ | P | a | b |
|---|---|---|---|---|---|---|---|
| **Normal plants** | | | | | | | |
| *Acacia karroo* | L mass | 65 | 0.946 | 0.895 | <0.001 | -3.84491 | 0.712723 |
| | L volume | | 0.948 | 0.899 | <0.001 | -2.82646 | 0.693414 |
| *Combretum apiculatum* | L mass | 30 | 0.967 | 0.936 | <0.001 | -6.66795 | 0.862375 |
| | L volume | | 0.966 | 0.933 | <0.001 | -5.73831 | 0.855550 |
| *Colophospermum mopane* | L mass | 48 | 0.960 | 0.922 | <0.001 | -4.98373 | 0.759345 |
| | L volume | | 0.963 | 0.927 | <0.001 | -4.34074 | 0.760682 |
| *Dichrostachys cinerea* | L mass | 36 | 0.948 | 0.900 | <0.001 | -5.36776 | 0.790328 |
| | L volume | | 0.949 | 0.901 | <0.001 | -4.13030 | 0.765784 |
| *Grewia* species | L mass | 15 | 0.897 | 0.804 | <0.001 | -3.58694 | 0.670455 |
| | L volume | | 0.920 | 0.844 | <0.001 | -4.39578 | 0.792703 |
| *Terminalia sericea* | L mass | 27 | 0.907 | 0.822 | <0.001 | -5.27024 | 0.781664 |
| | L volume | | 0.923 | 0.853 | <0.001 | -4.39578 | 0.792703 |
| General: microphyllous | L mass | 101 | 0.941 | 0.886 | <0.001 | -3.88021 | 0.708109 |
| | L volume | | 0.948 | 0.898 | <0.001 | -2.93340 | 0.696712 |
| General: broad-leaved | L mass | 105 | 0.950 | 0.903 | <0.001 | -5.44972 | 0.789596 |
| | L volume | | 0.947 | 0.897 | <0.001 | -4.68022 | 0.791964 |
| **Coppiced plants** | | | | | | | |
| *Acacia erubescens* | L mass | 27 | 0.980 | 0.960 | <0.001 | -5.93298 | 0.854976 |
| | L volume | | 0.979 | 0.958 | <0.001 | -4.96379 | 0.836859 |
| *Combretum apiculatum* | L mass | 26 | 0.954 | 0.911 | <0.001 | -4.26560 | 0.699236 |
| | L volume | | 0.954 | 0.911 | <0.001 | -3.46766 | 0.701416 |
| *Colophospermum mopane* | L mass | 60 | 0.973 | 0.946 | <0.001 | -3.81469 | 0.728980 |
| | L volume | | 0.973 | 0.946 | <0.001 | -3.19642 | 0.727776 |
| *Dichrostachys cinerea* | L mass | 48 | 0.823 | 0.678 | <0.001 | -3.96121 | 0.638834 |
| | L volume | | 0.823 | 0.678 | <0.001 | -3.11394 | 0.640317 |
| General: microphyllous | L mass | 75 | 0.895 | 0.801 | <0.001 | -6.65355 | 0.873145 |
| | L volume | | 0.903 | 0.816 | <0.001 | -5.4836 | 0.845745 |
| General: broad-leaved | L mass | 86 | 0.935 | 0.873 | <0.001 | -3.80039 | 0.707427 |
| | L volume | | 0.949 | 0.900 | <0.001 | -3.16416 | 0.710263 |

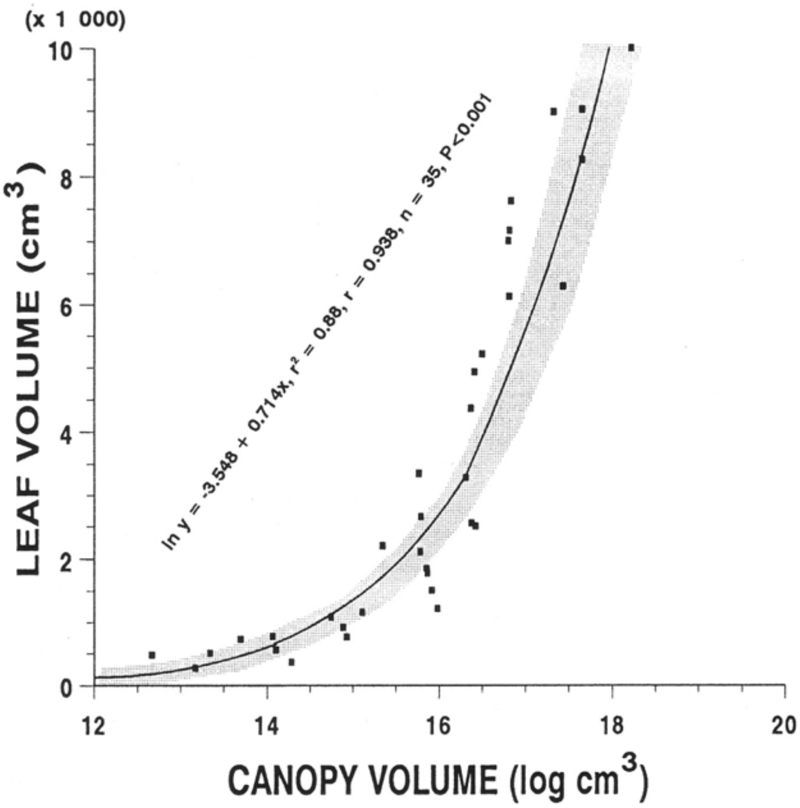


**Figure 4** Regression analysis of the relation between spatial canopy volume (normal logarithm conversion) (independent variable) and leaf volume of *Colophospermum mopane* (shaded area: 95 % confidence limits).

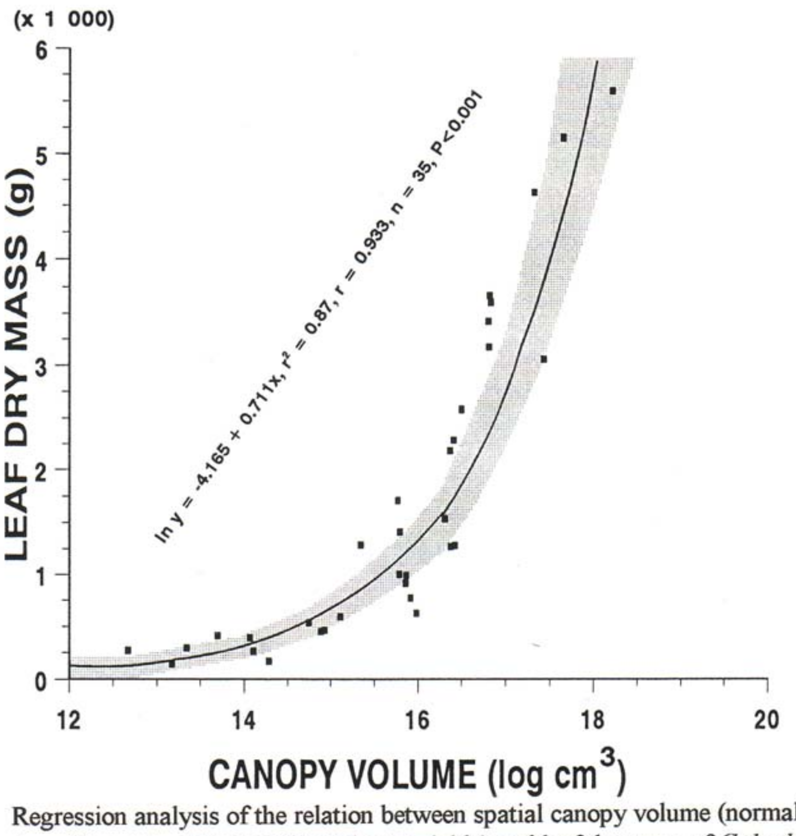


**Figure 5** Regression analysis of the relation between spatial canopy volume (normal logarithm conversion) (independent variable) and leaf dry mass of *Colophospermum mopane* (shaded area: 95 % confidence limits).

The dimension meter, as it will be called, was calibrated to estimate dimensions of 2.0 m to 12.5 m. Additional slides can be made to cover different ranges and scales according to need. The distance from the tree from where the reading should be taken, termed the observation distance, is critical and must be predetermined. For each length line in Figure 6, two values in metres are supplied. Dimensions of 2.0 m to 5.0 m are estimated from a shorter observation distance than dimensions of 5.0 m to 12.5 m (in brackets).

The observation distances must be determined for each slide, as they are dependant on the size of the reproduced image on the slide. By fitting the 2.0 m and 5.0 m representative lines exactly on 2.0 m and 5.0 m calibration poles respectively, the observation distances can be determined by measuring the distances between the slide, and thus the operator, and the calibration poles. Pro-vided the length scales occupy the main part of the slide, the two observation distances should be approximately 14.0 m and 34.0 m respectively. The measuring increments for trees up to 5.0 m and greater than 5.0 m are 0.2 m and 0.5 m respectively (Figure 6). Interpolation should be used if the part of the tree to be estimated falls between two lines.

***Test of accuracy***

The accuracy of the dimension meter was tested by comparing its estimates with actual measurements. The test was done in two parts. For the first test, 20 trees with heights between 2.0 m and 5.0 m were selected. The true tree heights were measured with poles and a measuring tape. Subsequently, the heights of the same trees were estimated with the dimension meter. For the second test, 20 positions between 5.0 m and 12.5 m were marked on a water tower. A water tower was used to facilitate accurate measurements up to 12.5 m. The height of each position was measured with a measuring tape and again estimated with the dimension meter. Subsequently, the two data sets of each test were tested for correspondence.

Highly significant correlation ($r = 0.99$, $n=20$, $P<0.001$) between the true tree heights and the meter estimates (test 1) was found. The average absolute difference between the true tree heights and meter estimated heights was 0.06 m, which is only 1.74 % of the average tree height of the 20 trees. Similarly, a highly significant correlation ($r = 0.99$, $n = 20$, $P<0.001$) between the true tower heights and meter estimates (test 2) was found. The average absolute difference between the true tower heights and meter estimated heights was 0.14 m, which is 1.56 % of the average height of the 20 tower positions.

The conclusions reached from these results are that the dimension meter produces accurate results, and with the ease and speed that large trees are measured, the dimension meter will cer-tainly be a valuable addition to surveying methods. A problem encountered with the dimension meter is obstruction by other trees in very dense situations, but this also applies to other indirect methods.

A second problem encountered, is tall grass obscuring stem bases, and seriously inter-fering with the estimates. A simple solution was to place a brightly painted rod of 1.0 m against the stem base. Estimates are then taken from the top of the rod, and 1.0 m is added to the estimates. Horizontal estimates are generally easier to make than vertical estimates.

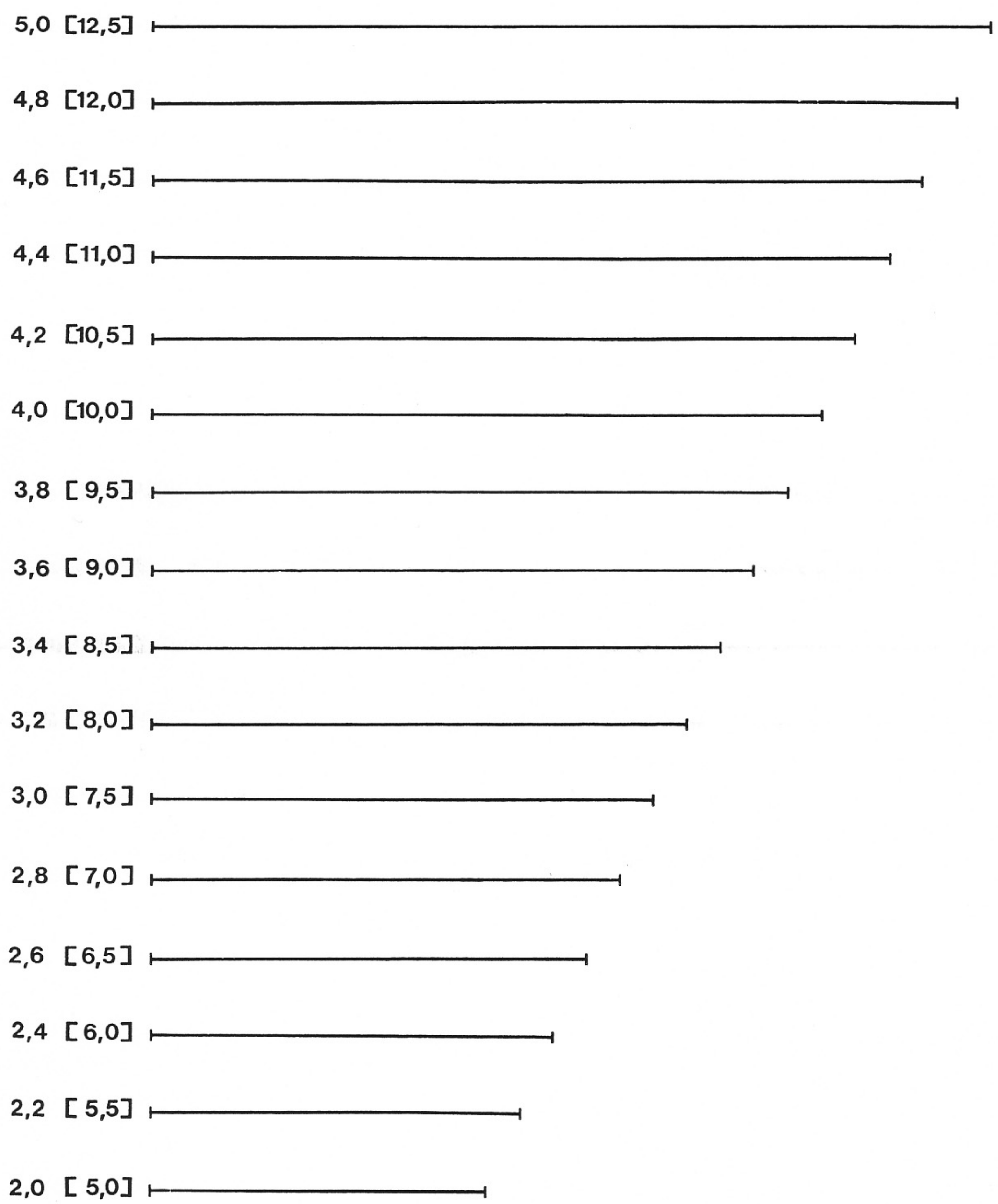


**Figure 6** Length scales for linear estimates of 2.0 - 12.5 m.

## Time factor in applying the former techniques

The time factor when conducting a plant survey is always important. A simple time test was conducted to determine the time needed to conduct a survey of woody plants according to the technique described in this manuscript. For the first part of the test, 200 undamaged *Colophospermum mopane* trees of a population varying in height from 0.3 m to 6.0 m were measured and the time recorded. For the second part 150 plants which had coppiced after being sawn, were measured and the time recorded. The tree dimensions were measured by an experienced person well acquainted with the technique and committed to accurate measurements and not crude estimates. Measurements were done with a 2 m measuring pole and the dimension meter.

It took 183 minutes to measure the 200 undamaged *C. mopane* trees and 122 minutes to measure the 150 coppiced plants. This is a mean of 54.6 seconds per undamaged tree and 48.8 seconds per coppiced plant. Depending on the area to be sampled and the tree density, an estimate of the time needed for a survey can be calculated.

## Running the BECVOL-model

### *Hardware requirements*

The BECVOL-model will run on any current model PC and is compatible with WINDOWS 95, 98, ME, 2000/XP. The BECVOL-model consists of dBASE IV program files of which the main execution file is compiled into an .EXE file, which can be run independently of dBASE.

### *Installing the software on your computer*

A CD containing the necessary files of the BECVOL-model is included. The BECVOL-model should be installed on your computer's hard disk before it can be run. Follow the following simple procedure:

(i) Create a directory C:\BECVOL2 on your hard disk

(ii) Insert the BECVOL CD in the CD-ROM.

(iii) Copy all the files on the CD into the BECVOL2 directory

(iv) Execute the file "Becvol.exe" (a shortcut to this executable file can be created and placed on your desktop)

An introduction display will appear on your monitor screen, followed by the main menu.

### *Model input and model output*

The BECVOL main menu provides the following options:

(i) Tree list / regression models
(ii) Data input [(T)est]
(iii) View/edit data files
(iv) Print data files
(iv) Primary calculations
(v) Secondary calculations
(vi) Adapt BECVOL 1.* files to BECVOL 2.0 format

TREE LIST / REGRESSION MODELS

The tree list contains a list of tree species in which it is specified which regression equation should be used by the model during execution of the primary calculations. A basic list is provided to which users can add species, or an option is provided where a new list can be started. Existing tree names in the list are discarded when a new tree list is started. The discarded names are stored in a backup list and a procedure is provided with which the discarded tree list can be restored. The BECVOL-model incorporates a number of regression equations developed for specific tree species, as well as a number of "general" regression equations (e.g. for microphyllous and broad-leaved tree species). These "general" regression quations should be used for tree species for which a specific regression equation does not currently exist. The tree list must be completed before commencing with data input and should include all tree species encountered during your field surveys. During data input you will be prompted for the species number corresponding with the particular species (you don't have to type the name of the species). It is suggested that you make a printout of the completed tree list before commencing with the data input.

DATA INPUT [(T)EST]

The file containing the field data is called the primary data file and they have a .BC2 extention. You must specify if you want the data input to be stored in a new file or an existing file. A new file is created from a standard file provided with the model (see Appendix 1). You may create an unlimited number of files. Data consists of measurements (m) taken of rooted trees in a transect of a known area. The model uses the following symbols during data input (see Figure 1):

A = tree height,
B = height of maximum canopy diameter,
C = height of first leaves or leaf bearing shoots,
D = maximum canopy diameter,
E = base diameter of foliage at height C

Note that provision was made for two measurements of D and E. Two measurements are needed when the tree crown is not circular (the model calculates the mean). The [(T)est] facility allow the user to go through the data input procedure on the screen without the data being stored in the specified data file. An example of a data sheet for use in the field is illustrated in Table 2.

VIEW/EDIT DATA FILES

With this facility data files (both primary en secondary files) can be viewed, or they can be edited. When the editing option is selected, details on the editing procedure are displayed. All primary data files have a .BC2 extension, while all secondary data files have a .BS2 extention. Refer to Appendix 1 and 2 for field names of the data files and the information they contain.

PRINT DATA FILES

Print the content of any specified data file. On selecting the "print data file" option, you will be asked whether it be a Primary data file (.BC2 extention), or a Secondary

data file (.BS2 extention). Provision is made for the listing of all data files of the requested file type by typing "L" as indicated. During printout an explanation of the field names of that particular file type is also printed.

**Table 2** An example of a data sheet for use in the field.

**Date:** ________________________

**Plot:**_________________________

| Species Nr | Species | A (m) | B (m) | C (m) | D | | E | |
|---|---|---|---|---|---|---|---|---|
| | | | | | $D_1$ (m) | $D_2$ (m) | $E_1$ (m) | $E_2$ (m) |
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PRIMARY CALCULATIONS

This is the first level of calculation during which an estimated leaf volume and leaf DM values (total DM and stratified to browsing heights of 1.5 m, 2.0 m and 5.0 m), ETTE value, BTE values and the area overspanned by the tree canopy are calculated for each individual tree in the primary data file. You will be asked the name of the source file (primary data file with a .BC2 extension). Provision is made for the listing of all data files of the requested file type by typing "L" as indicated. Secondly, you will be asked if each tree should be shown graphically [(Y)es or (N)o]. If you select "Y", a schematic illustration of each tree will appear on the screen as well as some of the estimated leaf DM data. If you select "N" the calculations will be executed without any interruption (recommended for large data files where time is of importance). The BECVOL-model will automatically execute an integrity test on the data file before commencing with any calculations. Should errors in your data be detected (e.g. A.>B, C>B, E>D) you will be warned of the fact and the records containing errors will be displayed. You will be prompted to correct them as execution will not commence before all errors are corrected.

SECONDARY CALCULATIONS

This is the second level of calculations during which values are calculated per ha (e.g. ETTE/ha, BTE/ha, DM/ha, plants/ha and the CSI. These calculations are done for each individual species and or the population as a whole. The calculations of the CSI are done for trees with a minimum height of 2.0 m, as well as for trees with a minimum height of 4.0 m. You will be asked the name of the source file (primary data file with a .BC2 extension). Provision is made for the listing of all data files of the requested file type by typing "L" as indicated. Secondly, you will be asked for which plot in the specified data file the calculations should be done. By typing "A" all plots, combined, will be included in the calculations. The transect/sampling area ($m^2$) must be provided as well as the name of the file in which the calculations will be saved. This file is created from a standard file included with the model (see Appendix 2), and will have a .BS2 extension (secondary data file). After the execution of the calculations the data file will be displayed on the screen.

## References


Aucamp A.J. 1976. The role of the browser in the bushveld of the Eastern Cape. *Proc. Grassld. Soc. sth. Afr.* 11: 135-138.

Barnes D.L., Lloyd B.V. & McNeill L. 1976. The use of shoot dimensions to estimate the leaf mass or leaf area of certain indigenous trees in Rhodesia. *Proc. Grassld. Soc. sth. Afr*. 11: 47-50.

Beauchamp J.J. & Olson J.S. 1973. Corrections for bias in regression estimates after logarithmic transformation. *Ecol.* 54: 1403-1407.

Bookhout T.A. 1965. Feeding coactions between snowshoe hares and white-tailed deer in northern Michigan. *Trans. N. Am. Wildl. Conf*. 30: 321-335.

Crouch G.L. 1968. Effects of simulated deer browsing on Douglas-fir seedlings. *J. For.* 64: 322-326.

Dayton B.R. 1978. Standing crops of dominant *Combretum* species at three browsing levels in the Kruger National Park. *Koedoe* 21: 67-76.

Draper N. & Smith H. 1981. *Applied regression analysis.* Wiley & Sons, New York.

Halls L.K., McCarty J.D. & Wiant H.V. 1970. Relative browsing of 16 species of white-tailed deer. *J. Range Manage.* 23: 146-147.

Halls L.K. & Alcaniz R. 1972. Growth patterns of deer-browse plants in southern forests. U.S. Dep. Afric. For. Serv. Pap. SO-75. 75pp.

Hobson F.O. & De Ridder C.H. 1991. Quantifying indices of potential competitiveness and browse productivity of single-stemmed *Acacia karroo* trees in south-eastern Africa. *J. Grassl. Soc. South. Afr.* 8: 1-8.

Knierim P.G., Carvell K.L. & Gill J.D. 1971. Browse in thinned oak and cove hardwood stands. *J. Wildl. Manage.* 35: 163-168.

MacOnochie J.R. & Lange R.T. 1970. Canopy dynamics of trees and shrubs with particular reference to arid-zone topfeed species. *Trans. R. Soc. S. Aust.* 94: 243-248.

Mason L.R. & Hutchings S.S. 1967. Estimating foliage yields on Utah juniper from measurements of crown diameter. *J. Range Manage.* 20: 161-166.

Nel C.F. 1965. *'n Karakterisering van die boskomponent van die Suurgemengde Bosveld van Transvaal.* M.Sc.(Agric.)-thesis, University of Pretoria.

Pauw J.C. 1988. *Riglyne vir die bestuur van die natuurlewe in die bosveldgemeenskappe van die Atherstone Natuurreservaat in die noordwes-Transvaal.* M.Sc-thesis, University of Pretoria, Pretoria.

Rutherford M.C. 1979a. Aboveground biomass subdivisions in woody species of the savanna ecosystem project study area, Nylsvley. S.A. National Scientific Programmes Report 36. 33 pp.

Rutherford M.C. 1979b. Plant-based techniques for determining available browse and browse utilization: a review. *Botanical Review* 45: 203-228.

Skinner J.D. & Smithers R.H.N. 1990. *The mammals of the southern African subregion* (second edition). University of Pretoria Press, Pretoria.

Smit G.N. 1989a. Quantitative description of woody plant communities: Part I. An approach. *J. Grassl. Soc. South. Afr.* 6: 186-191.

Smit G.N. 1989b. Quantitative description of woody plant communities: Part II. Computerized calculation procedures. *J. Grassl. Soc. South. Afr.* 6: 192-194.

Smit G.N. & Van Romburgh K.S.K. 1993. Relations between tree height and the associated occurrence of *Panicum maximum* Jacq. in Sourish Mixed Bushveld. *Afr. J. Range For. Sci.* 10: 151-153.

Spiegel M.R. 1968. *Mathematical handbook.* Schaum's outline series. McGraw-Hill book series.

Statgraphics 1991. STSC Inc., USA.

Styles C.V. 1993. *Relationships between herbivores and* Colophospermum mopane *of the northern Tuli Game Reserve.* M.Sc-thesis, University of Pretoria, Pretoria.

Teague W.R., Trollope W.S.W. & Aucamp A.J. 1981. Veld management in the semi-arid bush-grass communities of the eastern Cape. *Proc. Grassld. Soc. sth. Afr.* 16: 23-28.

Van der Meulen F. & Werger M.J.A. 1984. Crown characteristics, leaf size and light throughfall of some savanna trees in southern Africa. *S. Afr. J. Bot.* 3: 208-218.

Wentzel J.J. 1990. *Ekologiese skeiding van geselekteerde herbivoor spesies in die benede Sabie-Krokodilrivier gebied van die Nasionale Kruger Wildtuin.* M.Sc-thesis, University of Pretoria, Pretoria.

Westfall R.H. & Panagos M.D. 1984. A cover meter for canopy and basal cover estimations. *Bothalia* 15: 241-244.

**Appendix 1:** A printout of the structure of the standard data file (primary data file), showing the field names used by the program.

| Field | Field name | Type | Width | Dec |
|---|---|---|---|---|
| 1 | CAL | Character | 1 | |
| 2 | DATE | Character | 8 | |
| 3 | PLOT | Numeric | 3 | 0 |
| 4 | NO | Numeric | 3 | 0 |
| 5 | SP_NR | Numeric | 3 | 0 |
| 6 | SPECIES | Character | 25 | |
| 7 | L_A | Numeric | 5 | 2 |
| 8 | L_B | Numeric | 5 | 2 |
| 9 | L_C | Numeric | 5 | 2 |
| 10 | L_D1 | Numeric | 5 | 2 |
| 11 | L_D2 | Numeric | 5 | 2 |
| 12 | L_E1 | Numeric | 5 | 2 |
| 13 | L_E2 | Numeric | 5 | 2 |
| 14 | MOD | Numeric | 1 | 0 |
| 15 | CANVOL | Numeric | 6 | 3 |
| 16 | LVOL | Numeric | 6 | 0 |
| 17 | ETTE | Numeric | 6 | 3 |
| 18 | LMAS | Numeric | 6 | 0 |
| 19 | LM_15 | Numeric | 6 | 0 |
| 20 | LM_20 | Numeric | 6 | 0 |
| 21 | LM_50 | Numeric | 6 | 0 |
| 22 | BTE | Numeric | 6 | 3 |
| 23 | BTE_15 | Numeric | 6 | 3 |
| 24 | BTE_20 | Numeric | 6 | 3 |
| 25 | BTE_50 | Numeric | 6 | 3 |
| 26 | AREA | Numeric | | |

* CAL - Non-data field used by program
$ DATE - Date of survey
$ PLOT - Experimental/survey plot
$ NO - Numeric number of tree within any specific plot
$ SP_NR - Species number according to tree list
$ SPECIES - Tree species
$ L_A - Tree height (m)
$ L_B - Height of maximum canopy diameter (m)
$ L_C - Height of first leaves (m)
$ L_D1 - Maximum canopy diameter - first measurement (m)
$ L_D2 - Maximum canopy diameter - second measurement (m)
$ L_E1 - Base diameter of foliage at height C - first measurement (m)
$ L_E2 - Base diameter of foliage at height C - second measurement (m)
$ MOD - Model 1 (normal *C. mopane* trees) or model 2 (*C. mopane* regrowth)
# CANVOL - Canopy volume ($cm^3$)
# LVOL - Estimated total leaf volume ($cm^3$)
# ETTE - Total Evapotranspiration Tree Equivalents (leaf volume/500)
# LMAS - Estimated total leaf dry mass (g)
# LM_15 - Estimated leaf dry mass below 1.5 m (g)
# LM_20 - Estimated leaf dry mass below 2.0 m (g)
# LM_50 - Estimated leaf dry mass below 5.0 m (g)
# BTE - Total Browse Tree Equivalents (leaf dry mass/250)
# BTE_15 - Browse Tree Equivalents below 1.5 m
# BTE_20 - Browse Tree Equivalents below 2.0 m
# BTE_50 - Browse Tree Equivalents below 5.0 m
# AREA - The area overspanned by the tree canopy ($m^2$)

* - Program orientation symbols    $ - Values from data input    # - Values calculated by program

**Appendix 2:** A printout of the structure of the standard secondary data file, showing the field names used by the program.

| Field | Field name | Type | Width | Dec |
|---|---|---|---|---|
| 1 | PLOT | Numeric | 3 | 0 |
| 2 | SP_NR | Numeric | 3 | 0 |
| 3 | SPECIES | Character | 25 | |
| 4 | PL_HA | Numeric | 6 | 0 |
| 5 | LVOL | Numeric | 6 | 0 |
| 6 | ETTE | Numeric | 6 | 0 |
| 7 | LMAS | Numeric | 6 | 0 |
| 8 | LM_15 | Numeric | 6 | 0 |
| 9 | LM_20 | Numeric | 6 | 0 |
| 10 | LM_50 | Numeric | 6 | 0 |
| 11 | BTE | Numeric | 6 | 0 |
| 12 | BTE_15 | Numeric | 6 | 0 |
| 13 | BTE_20 | Numeric | 6 | 0 |
| 14 | BTE_50 | Numeric | 6 | 0 |
| 15 | CSI_2 | Numeric | 5 | 1 |
| 16 | CSI_4 | Numeric | 5 | 1 |

PLOT - Experimental plot
SP_NR - Number of species according to tree list
SPECIES - Tree species
PL_HA - Plants/ha
LVOL - Leaf volume ($m^3$)/ha
ETTE - Evapotranspiration Tree Equavalents/ha
LMAS - Leaf Dry Mass/ha
LM_15 - Leaf Dry Mass/ha below a browsing height of 1.5 m
LM_20 - Leaf Dry Mass/ha below a browsing height of 2.0 m
LM_50 - Leaf Dry Mass/ha below a browsing height of 5.0 m
BTE - Browse Tree Equivalents/ha
BTE_15 - BTE/ha below a browing height of 1.5 m
BTE_20 - BTE/ha below a browing height of 2.0 m
BTE_50 - BTE/ha below a browing height of 5.0 m
CSI_2 - Canopied Subhabitat Index based on trees with a minimum height of 2 m
CSI_4 - Canopied Subhabitat Index based on trees with a minimum height of 4 m