



The relationship between canopy volume and leaf dry matter of a shrub species on the west coast of South Africa

Swart, R¹; Saayman, N²; Rheeder, C³; Booyse, M⁴; Kirkman, K⁵

¹Western Cape Department of Agriculture, Worcester, South Africa, rudi.swart@westerncape.gov.za; ²Western Cape Department of Agriculture, Elsenburg, South Africa; mailto:nelmaries.saayman@westerncape.gov.za; ³Western Cape Department of Agriculture, Lambert's Bay, South Africa; ⁴ Agricultural Research Council, Stellenbosch, South Africa; ⁵ University of KwaZulu-Natal, Pietermaritzburg, South Africa

Key words: browse; Succulent Karoo; regression analysis

Abstract

In the winter rainfall region of South Africa, browse, such as shrubs and dwarf shrubs, is vital fodder for animals during the dry season. However, understanding how much fodder these shrubs can provide sustainably is limited. Existing methods for measuring browse production are insufficient for shrubs in this region. This study focused on *Roepera morgsana*, a common but less palatable shrub in the Succulent Karoo biome. The objectives were to find the minimum measurements needed to estimate canopy volume (CVol) and its correlation with leaf dry matter (LDM). The study was conducted at Nortier Research Farm near Lambert's Bay, selecting 25 healthy, non-browsed plants. Seven measurements, including total height and canopy diameter were taken before harvesting. After harvesting, plant material was divided into edible and non-edible parts, dried, and weighed. CVol was determined using various methods, and Pearson's correlation was used to find the best formula to describe LDM. Results showed that CVol based on three measurements (total height and canopy diameter) using Penderis' formula provided the best estimation of LDM ($p < 0.0001$). An exponential regression model best predicted LDM from CVol ($p < 0.0001$), offering a reliable non-destructive method for estimating browse availability from *R. morgsana*. This research contributes to better understanding the browse production of shrubs in winter rainfall regions, providing land managers with a valuable tool for veld management. Moreover, it lays the groundwork for developing similar models for other shrub species, enhancing the sustainability of fodder resources for browsing animals in these regions.

Introduction

The Succulent Karoo and Fynbos Biomes along the west coast of South Africa, with its mediterranean climate with warm dry summers and cool wet winters, are both recognized as biodiversity hotspots with more than 6000 recorded plant species of which many are endemic (Mittermeier et al. 2011; Mucina and Rutherford 2006). The main land use along the west coast is extensive farming, with livestock and to a

smaller degree game species. The sustainable utilisation of this natural resource is thus very important. Browse, such as shrubs and dwarf shrubs, is vital fodder for animals during the dry season, as it is the main perennial growth form utilised as fodder in this area (Nenzhelele et al. 2020). However, understanding how much fodder these shrubs can provide sustainably is limited. Non-destructive methods have previously been developed to determine the browse production of savanna trees and some shrubs (Penderis 2012; Smit 2014) and dwarf shrubs in the Nama Karoo (Malan 2015; Smit and Janse van Rensburg 2021), but no techniques exist for shrubs in the winter rainfall region. Smit (1989, 2014) and Penderis (2012) found a relation between canopy volume of the trees and shrubs and their leaf dry mass, while Smit and Janse van Rensburg (2021) found that canopy diameter and the leaf dry mass of a dwarf shrub was highly correlated.

This study focused on *Roepera morgsana*, a less palatable shrub species that is common along the West Coast and other parts of the Succulent Karoo. This species sheds most of its leaves early in the dry season but is among the first to produce new, palatable growth. It grows up to 1.5 m high, is multi-branched and has mesophyllous, slightly fleshy leaves (Le Roux 2015).

The objectives of this research were to determine the least number of measurements necessary to calculate canopy volume (CVol) with the best fit to leaf dry matter (LDM), and to determine the relationship between CVol and LDM and develop a regression model that best predicts LDM.

Methods

Study site

The study was conducted at Nortier Research Farm (32.0345° S; 18.3324° E) situated in the West Strandveld bioregion and Lambert's Bay Strandveld (FS1) vegetation type with many elements of both the Succulent Karoo and Fynbos biome (Mucina and Rutherford 2006). The long-term average annual rainfall is 200 mm with 64% received during late autumn and winter.

Data collection

Twenty-five healthy, non-browsed *R. morgsana* plants were randomly selected at the end of the peak growing season in early October. Seven measurements of each plant were taken before harvesting, namely total height (HT), height at maximum canopy diameter (HM), height of first leaves or potential leaf-bearing stems (HL), maximum canopy diameter (D; average of two perpendicular measurements) and base diameter of foliage at height of first foliage or potential leaf-bearing branches (B; average of two perpendicular measurements). After the measurements were taken the plants were cut down at ground level, and plant material was divided between edible (leaves, and twigs < 2 mm in diameter) and non-edible (stems > 2 mm diameter) parts per individual, dried to a constant mass at 70 °C and weighed. Canopy volume (CVol) was determined according to the BECVOL method (Smit 2014), Penderis' method (Penderis 2012) and basic ellipsoid and cylinder volume formulae.

Data analysis

Pearson's correlation was used to determine the volume formulae that best describe leaf dry matter (LDM). Three regression models, namely linear ($Y = a + bX$), exponential ($Y = a * e^{b(\ln X)}$) and multiplicative ($\ln Y = \ln a + b(\ln X)$), where $Y = \text{LDM (kg)}$ and $X = \text{CVol (m}^3\text{)}$, were tested to determine which volume formulae predict the LDM the best. The linear regressions were performed with XLSTAT (Addinsoft 2023), while the non-linear regression procedure (PROC NLIN) of SAS software (version 9.4; SAS Institute Inc, Cary, USA) was used to fit exponential functions to the data. The natural logarithmic values of CVol were used in the exponential and multiplicative regression models to change the line from convex to concave to get a better fit of the model (Smit 2014).

Results

Pearson's correlation matrix showed that CVol with three measurements (HT and D) using Penderis' formula was the best explanatory variable to describe leaf dry matter ($r = 0.933$; $p < 0.0001$) compared to the other measured shrub dimensions.

All the data points for each model of the three regression models fall within the 95% confidence intervals of the observed data and has very high coefficients of determination values ($r^2 > 0.87$) (Fig. 1). The exponential regression model ($Y = 0.678 \cdot \exp^{0.663(\ln X)}$) gave the best prediction of LDM ($r = 0.957$; $p < 0.0001$; RMSE = 0.163; AIC = -86.688) compared to the linear and multiplicative regression models (Table 1). The square root of variance of residuals (RMSE) is a good measure of how accurately the model predicts the response, while Akaike information criterion (AIC) is used to compare different possible models and determine which one is the best fit for the data. The lower these values are the better the fit of the model (Archontoulis and Miguez 2015).

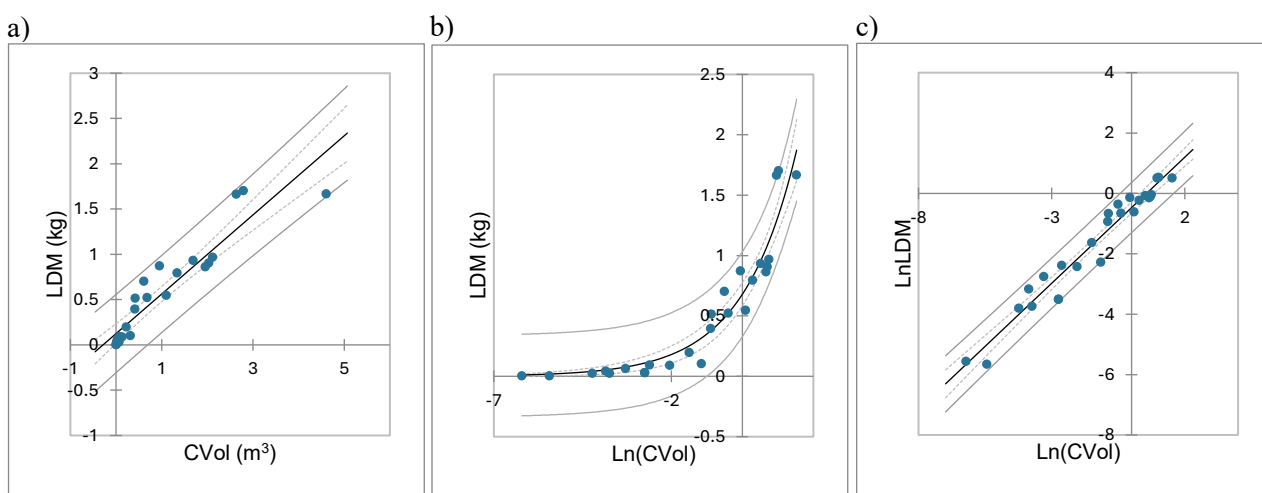


Figure 1: Three different regression analyses (a = linear; b = exponential; c = multiplicative) of the relationship between CVol (m^3) and the LDM (kg) for *Roepera margsana* following Penderis' formula. The natural logarithm conversion of CVol were used for the Exponential and Multiplicative regression analyses. (— Model; --- Confidence interval (mean 95%); Confidence interval (observed 95%))

Table 1 Results of the regression analyses of the relationship between CVol (m^3) and LDM (kg) of *Roepera margsana* following Penderis' formula.

Regression model	<i>n</i>	<i>r</i>	R^2	<i>p</i>	a	b	RMSE	AIC
Linear	25	0.933	0.870	< 0.0001	0.125	0.437	0.202	-78.051
Exponential	25	0.957	0.915	< 0.0001	0.6799	0.6633	0.163	-86.688
Multiplicative	25	0.977	0.955	< 0.0001	-0.470	0.836	0.391	-45.081

Discussion

Smit (2014) used seven measurements to determine the canopy volume of trees, Penderis (2012) found similar results with only six measurements. Smit and van Rensburg (2021) used only three measurements (HT and D) to find highly significant correlations between CVol and LDM of dwarf shrubs in the Nama

Karoo. *Roepera morgesana* has a similar shape to dwarf shrubs, although it is a much larger plant, and therefore a highly significant correlation between CVol and LDM was found with the same three measurements. Fewer measurements will result in less field work and make the model more attractive for use by land managers, and at the same time ensure that the predictive quality of the model is not sacrificed (Penderis 2012).

The exponential regression model provides a reliable non-destructive method for estimating the browse availability from *R. morgesana*. Available browse is that plant material of a shrub that is potentially edible for browsers based on the height above ground level to which the browsing animals can reach (Penderis 2012). Smit (1989) and Penderis (2012) developed different models, using their measurements for canopy volume, to determine the available browse at the different feeding levels. At 1.5 m high parts of *R. morgesana* is out of reach for sheep, the most common livestock along the west coast, that only browse up to 1.0 m high (Du Plessis et al. 2004). Using Penderis' formula for canopy volume in the regression model allows one to determine the available browse of *R. morgesana* at a specific height above ground level. Knowing the production potential of the vegetation can contribute to the success of sustainable extensive farming with livestock and wildlife (Penderis 2012; Smit 2014).

Conclusion and Implications

This research contributes to better understanding the browse production of shrubs in winter rainfall regions, providing land managers with a valuable tool for range management. Moreover, it lays the groundwork for developing similar models for other shrub species, enhancing the sustainability of fodder resources for browsing animals in these regions.

Acknowledgements

This research was financially supported by the Western Cape Department of Agriculture. We would like to thank the farm aids at Nortier Research Farm and Worcester Veld Reserve for assistance with harvesting and sorting of the plant material.

References

- Addinsoft (2023) XLSTAT statistical and data analysis solution. New York, USA. Available at <https://www.xlstat.com/en> [Accessed 09 03 2023]
- Archontoulis SV, Miguez FE (2015) Nonlinear regression models and applications in agricultural research. *Agronomy Journal* 107, 786-798.
- Du Plessis I, van der Waal C, Webb EC (2004) A comparison of plant form and browsing height selection of four small stock breeds – Preliminary results. *South African Journal of Animal Science* 34, 31-34.
- Le Roux A (2015) 'Wild flowers of Namaqualand – A Botanical Society Guide' 4th edn. (Struik Nature: Cape Town)
- Malan PJ (2015) Water use and production potential of Karoo shrubs. PhD thesis, University of the Free State, Bloemfontein, South Africa.
- Mittermeier RA, Turner WR, Larsen FW, Brooks TM, Gascon C (2011) Global biodiversity conservation: The critical role of hotspots. In 'Biodiversity hotspots' (Eds FE Zachos, JC Habel) pp. 3-22. (Springer-Verlag: Berlin)
- Mucina L, Rutherford MC (eds) (2006) 'Strelitzia 19: The vegetation of South Africa, Lesotho and Swaziland.' (South African National Biodiversity Institute: Pretoria)
- Nenzhelele E, Todd SW, Hoffman MT (2020) Long-term impacts of livestock grazing and browsing in the Succulent Karoo: a 20-year study of vegetation change under different grazing regimes in Namaqualand. *African Journal of Range & Forage Science* 35, 277-287.
- Penderis CA (2012) Browse: Quantity and nutritive value of evergreen and deciduous tree species in semi-arid Southern African savannas. PhD thesis, University of KwaZulu-Natal, Pietermaritzburg, South Africa.
- Smit GN (1989) Quantitative description of woody plant communities: Part II – computerized calculation procedures. *Journal of the Grassland Society of South Africa* 6, 192-194.

Smit GN (2014) BECVOL 3: an expansion of the aboveground biomass quantification model for trees and shrubs to include the wood component. *African Journal of Range & Forage Science* 31, 179-186.

Smit GN, Janse van Rensburg G (2021) Phytomass and ecological significance of *Chrysocoma ciliata* L. within the Lets'eng-la-Letsie catchment area of Lesotho, southern Africa. *African Journal of Range and Forage Science* 38, 102-109.