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SHORT COMMUNICATION

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Correlations between growth parameters and establishment of *Vachellia tortilis* (Forssk.) Hayne populations in the Limpopo Province, South Africa

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1 | INTRODUCTION

Growth rings are the concentric circles visible in tree-trunk cross sections. They provide records of ecosystem events like fire, insect outbreaks and logging. Meteorological conditions have a substantial effect on the formation of growth rings. Under optimum growth conditions (warm temperature and regular rainfall), the rings that is formed will be wider than those in a colder year, or one with extensive water shortages (Fritts, 1966). Growth rings have proven to be an invaluable resource for age determination in woody plants (Bowman, Brienen, Gloor, Phillips, & Prior, 2013).

Tree growth form may have a positive or negative effect on the growth of grass, which in turn, will affect tree establishment and growth. Due to the higher organic carbon content the soil, bulk density is often lower in soil under tree canopies (Smith & Goodman, 1986). Furthermore, Smit (2004) found that there is a significant increase in both stem diameter and shoot extension of *Vachellia nilotica* trees whose neighbours had been removed within a radius of 5 m.

Vachellia tortilis (Forssk.) Hayne subsp. *heteracantha* (Burch.) Brenan (previously *Acacia tortilis* subsp. *heteracantha*) is a distinctive African tree. The species belongs to the family Fabaceae (Mimosoideae). Its distribution and habitat are widespread throughout the savannah biome and dry zones of Africa, from Senegal to Somalia and southwards to South Africa (Hegazy & Elhag, 2006). It is morphologically variable, and can be multistemmed shrubs (ssp. *tortilis*), or single-stemmed trees, up to 20 m tall, with rounded (ssp. *raddiana*) or flat-topped (ssp. *heteracantha* and *spirocarpa*) crowns. It is a slow-growing dryland species, with deep rooting habits and a spreading umbrella-shaped crown (National Research Council, 2002).

Vachellia tortilis and various other *Vachellia* species are categorized as species that indicate bush encroachment in South Africa (Nel et al., 2004). Using *V. tortillis* as an example, it is critical to study the growth and the development of these species, to have a clearer understanding of their growth determinants and ultimately the causes of them encroaching. The study thus investigated the relationship between two growth determinants of *V. tortilis*, namely; rainfall and soil type, on a select number of growth parameters, at two sites in the Limpopo Bushveld, South Africa.

2 | MATERIALS AND METHODS

The research was conducted in the Capricorn and Waterberg districts of the Limpopo Province, at two locations (150 km apart), namely; the University of Limpopo's Syferkuil Experimental Farm (Capricorn district) and the Sondela Nature Reserve (Waterberg district). Three experimental sites were involved; two at Syferkuil and one at Sondela. Two experimental sites at Syferkuil (Site 1 and Site 2) were used to study growth ring formation of *V. tortilis* on different soil types at the same mean annual rainfall. Two sites, one at Syferkuil and one at Sondela (Site 1 and Site 3), were used to study growth ring formation of *V. tortilis* on a similar soil type at different mean annual rainfalls.

The Syferkuil experimental farm (Syferkuil) is situated near Mankweng (23°49′S; 29°41′E) in the Pietersburg plateau false grassveld (Acocks, 1988). The long-term daily average maximum and minimum temperatures at Syferkuil range between 30 and 13°C for December and 18 and 0.6°C for July, respectively. The average long-term annual rainfall is 450 mm per annum. Dominant grasses are *Aristida* species, *Heteropogon contortus* and *Themeda triandra*, while *Vachellia* species dominate the woody component. The soil types are of the Hutton (Site 1) and Glenrosa (Site 2) forms (Soil Classification Working Group, 1991).

The Sondela Nature Reserve (Sondela; Site 3) is situated on the southern part of the Springbok flats, near Bela Bela (28°21′E, 24°25′S). Long-term daily average maximum and minimum temperatures vary between 29.7 and 16.5°C for December and 20.8 and 3.0°C for July, respectively. Average long-term annual rainfall of this site is 630 mm per annum. The vegetation type is classified as Sourish Mixed Bushveld (Acocks, 1988) or, according to Low and Rebelo (1998), Mixed Bushveld. *Eragrostis* species, *H. contortus*, *Panicum maximum* and *T. triandra* dominate the herbaceous layer. *Vachellia* species and *Dichrostachys cinerea* dominate the woody layer. The soil is of the Hutton form (Stella family) (Soil Classification Working Group, 1991).

Fifty *V. tortilis* trees were randomly selected at each site. Their heights were measured with a survey staff, and represented by five height classes, namely; >0.0–0.5 m (representing seedlings/young trees), >0.5–1.5 m, >1.5–2.0 m, >2.0–3.0 m and >3.0 m. Each class included 10 trees. The canopy diameter of each tree in the different height classes was also determined, using the line intercept method (Canfield, 1941). The selected plants were then felled, using a chainsaw.

Tree stems were cut at a height of 0.75 m, for the determination of growth rings (Guiot, 1986). Trunk circumference was obtained with a tape measure. To determine the number of year rings, stem samples of 500 mm long were cut. Discs of 200 mm width (to prevent cracking) were sectioned from the samples and sanded, using a belt sander and a series of belts between 60 and 120-grain size. Growth rings were counted by means of an Olympus SZ30 dissecting microscope with an eyepiece graticule. Rings were counted in a Y pattern emanating from the centre of the stem (Stokes & Smiley, 1996). Scalloped areas at branch entry points were not used for ring counting or stem diameter measurements. The three lineage counts per stem were averaged and where necessary, adaptations were made to compensate for fungal infected areas. Where growth rings were not clearly visible or where holes occurred in the trunks, the number of rings that occurred in unaffected heartwood was divided by the length of the affected area and equalled the years approximated to that area (Mushove, Prior, Gumbie, & Cutler, 1995).

Data were analyzed using GenStat® (Payne, Murray, Harding, Baird, & Soutar, 2012). To determine the differences in tree characteristics (tree heights, number of growth rings, canopy diameter and stem circumference), data were subjected to a two-tailed *T* test for independent samples. To determine the relationships between tree heights, stem circumference, canopy diameter and number of growth rings, tree characteristic data were totalled and subjected to multiple regression analyses (Draper & Smith, 1981). Regressions that were obtained relating to meteorological factors (rainfall and soil) and growth rings (tree age) were compared, using Pearson's correlation coefficient.

3 | RESULTS AND DISCUSSION

Where stem circumference of *V. tortilis* on the Hutton and Glenrosa soil types is concerned (Site 1 and Site 2), insignificant differences ($p > .05$) occurred in two of the height classes, namely; the >0.0–0.5 m (1 cm difference) and the >2.0–3.0 m height class (4.6 cm difference) (Table 1). Stem circumferences in the other three height classes differed significantly ($p < .05$,). No significant differences in tree height, for any of the height classes, occurred between the two sites (Table 1). In four of the five height classes, differences in crown diameter between sites were significant ($p < .05$), namely in the >0.0–0.5 m (36.5 cm difference), >0.5–1.5 m (132.1 cm difference) >1.5–2.0 m (206.9 cm difference) and >3 m height classes (73.2 cm difference). The only insignificant difference occurred in the >2.0–3.0 m height class (37.2 cm difference) (Table 1). Where the number of growth rings is concerned, significant differences ($p < .001$) occurred in two of the height classes (Table 1), namely; the >0.0–0.5 m (14 rings difference) and the >3.0 m height class (32 rings difference).

Where stem circumference at the two sites that differed in rainfall is concerned (Site 1 and Site 3), significant differences ($p < .001$) occurred in only two of the height classes, namely in the >0.5–1.5 m (11.1 cm difference) and the >1.5–2.0 m height class (12.8 cm difference) (Table 1). In two instances, insignificant differences ($p > .05$) occurred in tree height, namely; in the >0.5–1.5 m (9 cm difference) and the >2.0–3.0 m height class (2 cm difference). Tree height in the other three height classes differed significantly ($p < .05$, Table 1). Only two crown diameter groups differed significantly ($p < .05$), namely; the >2.0–3.0 m (159.2 cm difference) and the >3.0 m (267.9 cm difference). Similarly, in only two of the height classes, differences in growth rings between sites were significant ($p < .05$), namely; in the >0.5–1.5 m (11 rings), >1.5–2.0 m (21 rings) and >3 m height class (20 rings).

In general, soil type affected tree rings, crown diameter and stem circumference. Although, the effect of soil type was significant on crown diameter and stem circumference, it was, however, insignificant on tree rings. While tree height and tree rings were affected by rainfall, only tree height was significantly influenced. Upon speculation, keeping the physical properties, especially the water holding capacity, of the specific soil type in mind, the difference in annual rainfall was apparently not large enough to allow soil water to be a limiting factor between the two sites where both crown diameter and stem circumference were concerned.

As indicated in Table 2, various plant growth parameters were highly correlated with each other ($p < .01$). There was a significant relationship ($p < .01$) between the number of growth rings and stem circumference ($r^2 = .9803$), tree height ($r^2 = .8485$) and a lower, but significant relationship with crown diameter ($r^2 = .6920$). Stem circumference gave the highest correlation with the number of growth rings ($r^2 = .9803$), compared to other growth parameters that were included in the study. There was also a significant ($p < .01$) relationship between stem circumference and tree height ($r^2 = .6565$). Similarly,

TABLE 1 Statistical analysis for the effects of rainfall and soil type on *Vachellia tortilis* growth parameters

	Tree characteristic	Height class (m)	Mean	p-Value
Site 1 versus Site 2 (Similar rainfall)	Stem circumference	>0.10–0.50	1.000 ± 0.750	.201
		0.50–1.50	10.800 ± 1.190	<.001**
		1.50–2.00	4.700 ± 1.980	.029*
		2.10–3.00	4.600 ± 3.780	.239
		>3.00	15.000 ± 3.670	<.001**
	Tree height	>0.10–0.50	0.010 ± 0.030	.611
		0.50–1.50	0.040 ± 0.120	.707
		1.50–2.00	0.030 ± 0.060	.606
		2.10–3.00	0.160 ± 0.130	.221
		>3.00	0.220 ± 0.220	.333
	Crown diameter	>0.10–0.50	0.370 ± 0.110	.006**
		0.50–1.50	1.320 ± 0.350	.002**
		1.50–2.00	2.070 ± 0.230	<.001**
		2.10–3.00	0.170 ± 0.350	.630
		>3.00	0.730 ± 0.260	.556
	Number of growth rings	>0.10–0.50	1.70 ± 0.980	.099*
		0.50–1.50	12.900 ± 0.980	<.001**
		1.50–2.00	10.700 ± 5.870	.093
		2.10–3.00	7.300 ± 9.040	.430
		>3.00	31.200 ± 7.940	<.001**
Site 1 versus Site 3 (Similar soil types)	Stem circumference	>0.10–0.50	0.400 ± 0.670	.556
		0.50–1.50	11.100 ± 1.400	<.001**
		1.50–2.00	12.800 ± 2.600	<.001**
		2.10–3.00	2.800 ± 3.920	.484
		>3.00	1.200 ± 5.980	.843
	Tree height	>0.10–0.50	0.009 ± 0.025	.0727
		0.50–1.50	0.274 ± 0.078	.006**
		1.50–2.00	0.120 ± 0.049	.024*
		2.10–3.00	0.002 ± 0.118	.987
		>3.00	0.992 ± 0.372	.019*
	Crown diameter	>0.10–0.50	0.180 ± 0.120	.132
		0.50–1.50	0.040 ± 0.230	.870
		1.50–2.00	0.260 ± 0.350	.467
		2.10–3.00	1.590 ± 0.500	.008**
		>3.00	2.680 ± 0.740	.005**
	Number of growth rings	>0.10–0.50	1.500 ± 1.040	.167
		0.50–1.50	11.100 ± 2.120	<.001**
		1.50–2.00	21.000 ± 6.390	.004**
		2.10–3.00	10.300 ± 6.770	.146
		>3.00	20.100 ± 9.600	.059

*Significant at $p = .05$.
**Highly significant at $p = .01$.

there was also a significant relationship between stem circumference and crown diameter ($r^2 = .8712$). Tree height and crown diameter were also significantly ($p < .01$) correlated ($r^2 = .6240$).

When data was initially analyzed, using linear regression modelling, a highly significant relationship between the stem circumference and number of growth rings occurred ($p < .001$; $r^2 = .941$). However, there was evidence of nonlinearity, which then was added to the regression model to improve the predictions of number of rings per site, using quadratic modelling. The end product was a highly significant ($p < .001$) quadratic relationship ($r^2 = .9803$; Figure 1).

The Pearson's correlation coefficient indicated significant differences between models from the three different sites (both linear and quadratic; Table 3). Site 1 appeared to have a linear relationship during young growth (up to 7 cm stem circumference), after which it changes to nonlinear. Relationships at Site 3 appeared to be linear throughout (Pearson's coefficient of correlation = 0), whereas relationships at Site 2 appeared to be nonlinear (Figure 1). Subsequently, the equations to estimate the number of growth rings were as follows:

Site 1: $Y = 1.019 + 1.5757xSC - 0.00042SC^2 - 0.3337SC + 0.01102SC^2$

Site 2: $Y = 1.019 + 1.5757xSC - 0.00042SC^2 - 0.548SC + 0.02074SC^2$

Site 3: $Y = 1.019 + 1.5757xSC - 0.00042SC^2$

where: Y, the number of growth rings; SC, stem circumference.

Many studies have explored the relationship between growth rate and wood properties, such as density. Commonly, these studies use diameter at a given tree age to indicate growth rate (Downes, Beadle, & Worledge, 1999). This study indicated that there is a direct, positive relationship between stem circumference and the number of growth rings, and that tree age can be determined, based solely on stem circumference. As a second alternative, the relationship between tree height and number of growth rings can also be used (Table 4).

As living organisms growing in an uncontrolled environment, trees respond to numerous natural growth modifying influences that are both beneficial and detrimental to annual ring formation (Cook, 1987). These factors represent the depth and level of influence that can be exerted by a variety of external factors. The presence of this variability

TABLE 2 Correlation matrix for correlations between the number of growth rings and different growth parameters of *Vachellia tortilis*

	Growth rings	Stem circumference	Tree height	Crown diameter
Growth rings	–	.9803**	.8485**	.6920**
Stem circumference	.9803**	–	.6565**	.8712**
Tree height	.8485**	.6565**	–	.6240**
Canopy diameter	.6920**	.8712**	.6240**	–

**Highly significant at $p < .01$.

TABLE 3 Pearson's coefficients of correlation for differences between relationships (number of growth rings and stem circumference of *Vachellia tortillis*) at the different sites

Parameter	Estimate	*SE*	*T* (*n* = 142)	*t* pr.
Constant	1.019	.916	1.11	NS
SC Linear	1.5757	.0847	18.60	**
SC Quadratic	−0.0004	.0013	−0.32	NS
SC Linear Site 1	−0.3337	.0831	−4.01	**
SC Linear Site 2	−0.548	.102	−5.38	**
SC Linear Site 3	0	*	*	*
SC Quadratic Site 1	0.0110	.0016	6.59	**
SC Quadratic Site 2	0.0207	.0025	8.02	**
SC Quadratic Site 3	0	*	*	*

NS, not significant.
**Highly significant at $p < .001$.
*Significant at $p < .005$.

TABLE 4 Correlation between tree age and tree height within height classes

Height class	Tree height versus Tree age
>0.0–0.5	.0267
>0.5–1.5	−.1009
>1.5–2.0	.3752
>2.0–3.0	.3575
>3.0	.2537

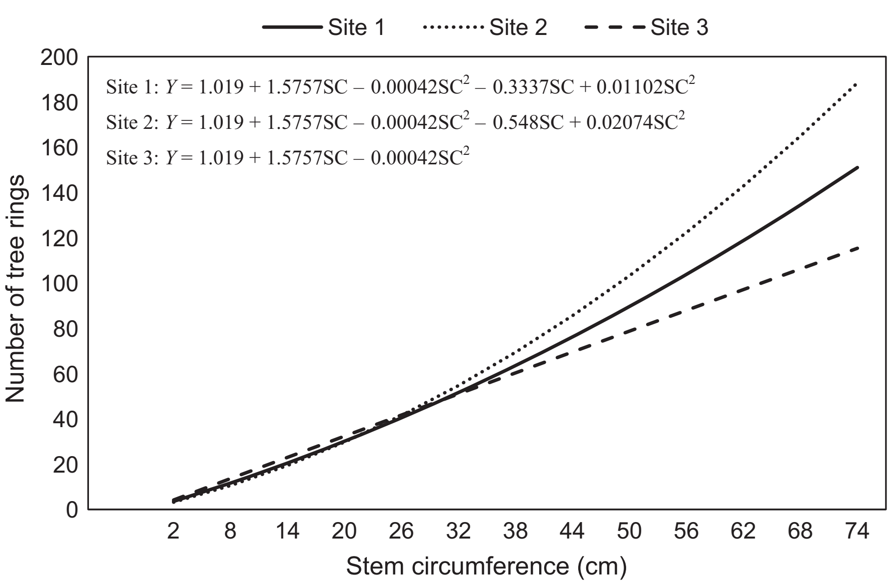

FIGURE 1 Relationships between the number of growth rings and stem circumference of *Vachellia tortilis* at the three sites

makes the identification of a particular disturbance, such as anthropization, very difficult and uncertain. Furthermore, because this study did not measure the size of the tree rings, determining the influence of external factors on formation of tree rings grows difficult.

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REFERENCES

Acocks, J. P. H. (1988). *Veld types of South Africa* (3rd ed.) Mem. Bot. Surv. Sth. Afr., 57. Pretoria: Botanical Research Institute.

Bowman, D. M. J. S., Brienen, R. J. W., Gloor, E., Phillips, O. L., & Prior, L. D. (2013). Detecting trends in tree growth. *Trends in Plant Science*, *18*, 11–16.

Canfield, R. H. (1941). Application of line interception method in sampling range vegetation. *Journal of Forestry*, *39*, 388–394.

Cook, E. R. (1987). The use and limitations of dendrochronology in studying effects of air pollution on forests. In T. C. Hutchinson & K. M. Meema (Eds.), *Effects of atmospheric pollutants on forests, wetlands and agricultural ecosystems* (pp. 277–290). Berlin, Heidelberg: Springer.

Downes, G., Beadle, C., & Worledge, D. (1999). Daily stem growth patterns in irrigated *Eucalyptus globulus* in relation to climate. *Trees*, *14*, 102–111.

Draper, N., & Smith, H. (1981). *Applied regression analysis* (2nd ed.). New York, NY: John Wiley and Sons.

Fritts, H. C. (1966). Growth-rings of trees: Their correlation with climate. *Science*, *154*, 973–979.

Guiot, J. (1986). ARMA techniques for modelling tree-ring response to climate and for reconstructing variations of paleoclimates. *Ecological Modelling*, *33*, 149–171.

Hegazy, A. K., & Elhag, M. (2006). Considerations of demography and life table analysis for conservation of *Acacia tortilis* in South Sinai. *World Applied Sciences Journal*, *1*, 97–106.

Low, A. B., & Rebelo, A. G. (1998). *Vegetation of South Africa, Lesotho and Swaziland: A companion to the vegetation map of South Africa, Lesotho and Swaziland*. Pretoria: Department of Environmental Affairs and Tourism.

Mushove, P. T., Prior, J. A. B., Gumbie, C., & Cutler, D. F. (1995). The effects of different environments on diameter growth increments of *Colophospermum mopane* and *Combretum apiculatum*. *Forest Ecology and Management*, *72*, 287–292.

National Research Council (2002). *Tropical legumes: Resources for the future*. New York, NY: Books for Business.

Nel, J. L., Richardson, D. M., Rouget, M., Mgidi, N., Mdzeke, N., le Maitre, D. C., . . . Neser, S. (2004). A proposed classification of invasive alien plant species in South Africa: Towards prioritizing species and areas for management action: working for water. *South African Journal of Science*, *100*, 53–64.

Payne, R. W., Murray, D. A., Harding, S. A., Baird, D. B., & Soutar, D. M. (2012). *GenStat® for windows™ introduction* (15th ed.). Hemel Hempstead: VSN International.

Smit, G. N. (2004). An approach to tree thinning to structure southern African savannas for long term restoration from bush encroachment. *Journal of Environmental Management*, *71*, 179–191.

Smith, T. M., & Goodman, S. (1986). The effect of competition on the structure and dynamics of *Acacia* savannas in Southern Africa. *Journal of Ecology*, *74*, 1031–1044.

Soil Classification Working Group (1991). *Soil classification: A taxonomic system for South Africa*. Pretoria: Department of Agricultural Development, Soil and Irrigation Research Institute.

Stokes, A., & Smiley, T. L. (1996). *An introduction to tree-ring dating*. Tucson, AZ: University of Arizona Press.

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