At the dark side of the tree? - Root architecture of indigenous fruit tree species from Botswana

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Introduction

Investigations of root structure of tropical tree species are few. However, information on the rooting structure of locally and economically important species can be of great benefits. This is especially the case for fruit trees, where knowledge of root structure can provide a solid basis for sustainable use and integration into agriculture.

Figure 1: Digital compass (Tectronic 4000) in action.

Results

Root Architecture

Coarse root systems from four individuals were chosen for presentation and comparison [see Fig. 2].

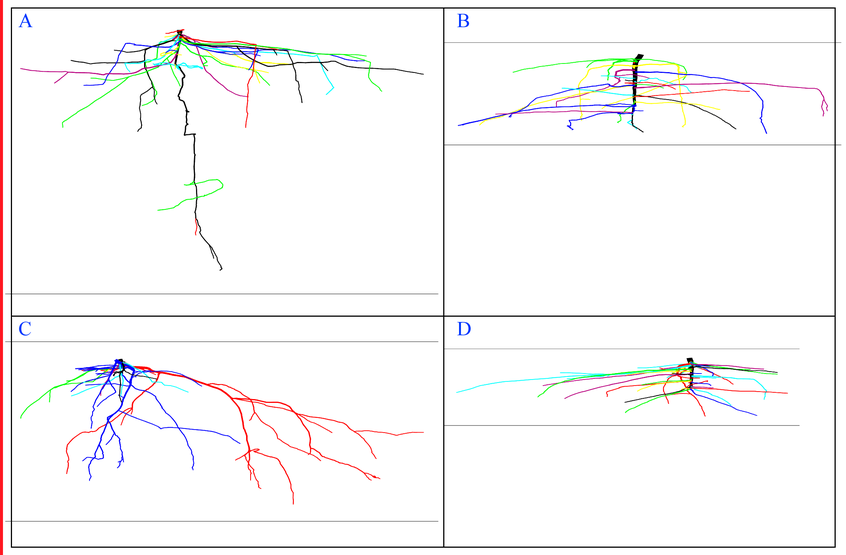

Figure 2: Side view of coarse root systems from *Grewia flava* (A), *Strychnos cocculoides* (B), *Vangueria infausta* (C), *Strychnos spinosa* (D), scale 1:300.

Morphology

Data from GROGRA 3.2 were transformed for analysis of spatial distribution to quantify morphological differences between the species.

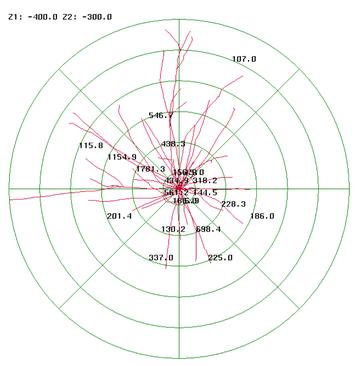

Figure 3: Plotted root system for morphological analysis (values: sum of root length in a defined 3D spatial segment).

Analysis of the total length shows that there is no preference into a certain growth direction neither in the horizontal nor in the vertical distribution. In all species, about half of the coarse roots were concentrated in a depth between 0 and 800 mm.

Grewia flava and *Strychnos spinosa* are the most shallow rooted species with an extremly high concentration in the first horizon in *Strychnos spinosa* (40.6%), whereas in *Grewia flava* half of the total root length is concentrated in the first two horizons (h1: 27.8%, h2: 24.5%). Both species must be regarded as relatively shallow-rooted. *Strychnos cocculoides* and *Vangueria infausta* show a more homogenous vertical root distribution. But *Strychnos cocculoides* has a relatively homogenous horizontal accumulation of rootlength within the single horizons. Different from that characteristic, due to the higher branching orders and intensity, in *Vangueria infausta* the concentrations of roots are higher with increasing depth and increasing distance from the stem.

Methods

The architecture of *in situ* grown coarse root systems from *Grewia flava* [Tiliaceae] (Moretlwa), *Strychnos cocculoides* [Loganiaceae] (Morogorowane), *Strychnos spinosa* (Morojwa), and *Vangueria infausta* [Rubiaceaea] (Mmilo) was studied in natural habitats.
The investigation site is located on sandveld near Mogorosi (Serowe Region, Central District, Botswana) between longitude 26° 36.26' and 26° 36.47' E and latitude from 22° 25.09' to 22° 25.30' S.
Each species was represented by five replicates, which were excavated by manual digging. According to their vertical and horizontal changes in the growth direction, roots (> 3 mm) were divided into segments of different lengths, and their positions were recorded with a digital compass (see **Figure 1**). The diameters of the segments were measured with a digital calliper (Sylvac).
The root systems were semi-automatically encoded, using the dtd coding system (digital tree data format, Kurth 1994). Subsequently, for 3-D reconstruction, topological and geometrical analysis of the root architecture and further morphological studies, the software GROGRA 3.2 (Kurth 1994) was used.

Fractal Geometry

Data from fractal analysis of the coarse root systems were calculated with GROGRA 3.2. The fractal dimension (D), which is a measure how an object fills the space, can be approximated by the box counting dimension (D'). Calculation of D' as an indicator of space-filling geometrical structure can therefore be used as a measure of the spatial intensity of coarse root distribution. The following plots show one example of a box counting discretization of the root system (top view) and the corresponding regression line "number of boxes vs. scale" (**Figure 4a, b**).

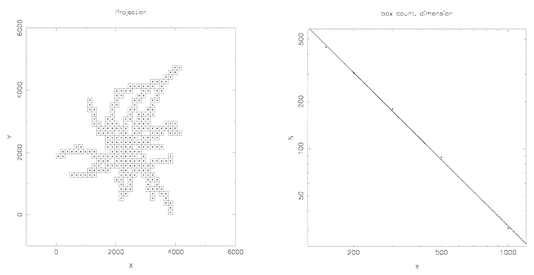

Figure 4: Projection of analysed root system in the 150 mm resolution grid (left) and doubly logarithmic plot of number of boxes (n) vs. resolution (s) (right)

Species	nr	D'	av.(D')	ste. dev.
Grewia flava	203	1.40	1.37	0.07
	206	1.46		
	213	1.40		
	214	1.28		
	215	1.30		
St. cocculoides	405	1.50	1.29	0.14
	409	1.17		
	412	1.20		
	425	1.27		
	426	1.32		
St. spinosa	501	1.41	1.41	0.11
	508	1.24		
	509	1.41		
	510	1.55		
	511	1.45		
Vang. infausta	706	1.60	1.52	0.17
	708	1.33		
	711	1.34		
	712	1.62		
	713	1.70		

Table:
Box count dimensions of the sample root systems

Calculation of fractal dimension was done on the following scales: 1000, 500, 300, 200, 150 mm. The scales are representing the length of the side of a box and the values of D' depend on the chosen range of scales.
Results from the analysis of the fractal dimension (cf. Table) confirm observations from the field: *Strychnos cocculoides* with the apparently weakest root system turned out to have the lowest box counting dimension D'. The maximum value of D' for *Vangueria infausta* confirms the expectation that, due to high branching orders and intensity, these root systems are exploring the three-dimensional space in the most intensive way. However, the values of the box counting dimension for *Stychnos spinosa* and *Grewia flava* are surprising. From observations in the field it was expected that the latter has the more intensive coarse root system. The average values for the box counting dimensions of *Grewia flava* (D' = 1.37) and *Strychnos spinosa* (D' = 1.41) indicate that the root systems of *Strychnos spinosa* are more intensively exploiting the space. But both values for the fractal dimension are relatively near (ΔD' = 0.04), whereas the difference between D'_{min} from *Strychnos cocculoides* to *Grewia flava* (ΔD' = 0.08) and from D'_{max} for *Vangueria infausta* (ΔD' = 0.12) to *Strychnos spinosa* are more obvious. Surprising is that a higher branching order (*Grewia flava:* 3, *Strychnos spinosa*: 2) seems to be not - necessarily - a good indicator for the intensity of exploration of the soil.

Discussion

The analysis has shown that, although they grow under the same environmental conditions, the investigated species have developed different strategies which become apparent in the architectures of the coarse root systems.
The observation proved that both *Strychnos* species tend to expose a primarily deep rooting behaviour. The ecophysiological advantage is probably a save long-term supply of deep water ressources.
The development of coarse root systems in *Grewia flava* shows an initially shallow rooting behaviour: The plant is able to use quickly and efficently periodic rain falls - especially low quantities - before the water is evaporating from the soil. Additionally, this feature ensures a better nutrition supply from the upper horizons which contain more organic substrates.
Vangueria infausta shows an intermediate strategy with increasingly diagonal root growth, so that long- and short-term water supply is guaranteed.

On the base of a quantitative analysis by GROGRA 3.2, it was possible to test some mathematical theories on *in situ* measurements with a positive correlation to field observations. Besides fractal analysis, a pathlength analysis was conducted (results not shown). Especially the fractal analysis seems to be a useful tool to quantify the exploration of a three dimensional continuum (here: the soil). If the fractal dimension is used as an indicator of exploration, practical applications on agroforestry stystems can emerge, with the perspective to develop indicators for competition between adjacent roots as well as for a weak exploration of soil resources.

Acknowledgements

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Literature

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