Species-level diversity of belowground structure in savanna woody plants: Evidence from a new excavation method

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Determinants of Woody Cover in Savannas

Percent Woody Cover:
- 65%
- 40%
- 20%
- 14%

Percent Grass Cover:
- 0-10%
- 5-15%
- 10-40%
- 2-20%

Savanna
Woodland
Open
Savanna

Photos by L. Wang
Determinants of Woody Cover in Savannas

Fire

Resource Competition

Megafauna Activity
Determinants of Woody Cover in Savannas

Disturbance Exclusions
Belowground Competition

*Determinants of Woody Cover in Savannas*

...
Determinants of Woody Cover in Savannas

The Modeled Root Zone

Density-based

Trees + Grasses

Trees Only

Individual-based

Grass

Tree
Representing Diversity

(a) Terminalia sericea

(b) Baikiaea plurijuga

Holdo and Timberlake, 2008
Representing Diversity

Terminalia sericea  

Baikiaea plurijuga

Holdo and Timberlake, 2008
Research Goals

Measure roots in a way that supports the development of realistic, individual-based models.

Quantify observed diversity in root system structure.
The AirSpade

Concept Engineering, Verona, PA
2-3 times faster than manual excavation
Leaves roots > 2 mm diameter in place and intact
Root Mapping

Grid System

A “Voxel”
Root Mapping

Tagged Roots

Following Roots
Challenges

Overburden

Maximum Depth ~1.5 m
Quantifying Diversity - The Kalahari Transect

Shakawe
539 mm MAP

Bokspits
177 mm MAP

Tshane
358 mm MAP
Quantifying Diversity - Species

Shakawe (Rainy)

- *Terminalia sericea*
  - Drought deciduous small tree or shrub
- *Ochna pulchra*
  - Semi-evergreen tree

Bokspits (Dry)

- *Acacia mellifera*
  - Drought deciduous shrub
- *Boscia albitrunca*
  - Evergreen tree
Lateral Root Distributions

**Shakawe**

*Terminalia sericea*
- $r_{90} = 5.3\ m$
- Lateral Root Mass: 14 kg

*Ochna pulchra*
- $r_{90} = 1.3\ m$
- Lateral Root Mass: 1.9 kg

**Bokspits**

*Acacia mellifera*
- $r_{90} = 3.5\ m$
- Lateral Root Mass: 2.5 kg

*Boscia albitrunca*
- $r_{90} = 4.7\ m$
- Lateral Root Mass: 30 kg
Lateral and Vertical Root Distributions

Acacia mellifera
Vertical Root Distributions

$r_{90} = 3.5\, \text{m}$

Cumulative Biomass (kg)

$B = 2.45\, e^{-0.67r}$

$r^2 = 0.98$

rmse = 0.10 kg

Acacia mellifera
Lateral and Vertical Root Distributions

Acacia mellifera
Exponentially distributed
Shallow-rooted

B = 2.55 \( e^{-4.2z} \)
\( r^2 = 0.99 \)
rmse = 0.12 kg

B = 2.45 \( e^{-0.67r} \)
\( r^2 = 0.98 \)
rmse = 0.10 kg
Lateral and Vertical Root Distributions

B = \frac{c}{\Gamma(7.62)} \gamma(7.62, \frac{z}{0.199})

r^2 = 0.99
rmse = 1.4 kg

Boscia albitrunca
Gamma distributed
Deep-rooted
Small-scale Structural Diversity

Sinuosity Index = \frac{L}{D}

- **Sinuous Root**
- **Straight Root**

**Graph:**
- **X-axis:** Site (Wet, Intermediate, Dry)
- **Y-axis:** Sinuosity index
- **Legend:**
  - Ochna pulchra
  - Terminalia sericea
  - Acacia mellifera
  - Boscia albitrunca

- **More sinuous**
- **Straighter**
**Probabilistic Rooting Distributions**

**Cumulative Distribution Function**

*Acacia mellifera*
Exponentially distributed

\[
B = 2.55 e^{-4.2z} \\
r^2 = 0.99 \\
\text{rmse} = 0.12 \text{ kg}
\]

**Boscia albitrunca**
Gamma distributed

\[
B = c \left[ \frac{1}{1(7.62)} \right]^{\frac{z}{7.62}} \left( \frac{z}{0.199} \right) \\
r^2 = 0.99 \\
\text{rmse} = 1.4 \text{ kg}
\]

**Probability Density Function**
Probabilistic Rooting Distributions

Vertical Marginal Density Function

Depth (m)

Lateral Marginal Density Function

Radial Distance from Stem (m)

0

Joint Density Function: Farlie-Gumbel-Morgenstern Model

\[ f_B(r, z) = f_B(r)f_B(z)\{1 + 3\rho[2F_B(r) - 1][2F_B(z) - 1]\} \]

\[ F_B(r, z) = F_B(r)F_B(z)\{1 + \rho[1 - F_B(r)][1 - F_B(z)]\} \]
Probabilistic Rooting Distributions

**Acacia mellifera**

**Boscia albitrunca**
Probabilistic Rooting Distributions

Lateral Distributions
- Shallow-Rooted
- Deep-Rooted

Vertical Distributions
- Shallow-Rooted
- Deep-Rooted

Canopy Radius
- 0.5 m
- 1 m
- 2 m
- 3 m
Root System Interactions

Lateral distribution: \( B(r) = a_r e^{-b_r r} \)

Vertical distribution: \( B(z) = a_z e^{-b_z z} \)

More lateral spread

\( \frac{b_r}{b_z} \)

More vertical spread
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