Impacts of bush encroachment on groundwater recharge – Evidence from 9 years of soil hydrological monitoring in a Namibian thornbush Savanna

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Research question

What are the interactions between soil water dynamics and vegetation in Namibian Savanna ecosystems?

How are plants adapted to the dry environment?

What are the consequences of bush encroachment?
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Water balance equation for plot with soil profile:

\[ \text{In} = P + \text{R}_{\text{on}} - \text{R}_{\text{off}} - \text{I}_{\text{c}} \]  \hspace{1cm} (1)

\[ D = \text{In} - E - T - \Delta S \]  \hspace{1cm} (2)

\[ D = P + \text{R}_{\text{on}} - \text{R}_{\text{off}} - \text{I}_{\text{c}} - E - T - \Delta S \]  \hspace{1cm} (1+2)

- \text{In} = \text{Infiltration}
- P = \text{Precipitation}
- \text{R}_{\text{on}} = \text{Runon}
- \text{R}_{\text{off}} = \text{Runoff}
- \text{I}_{\text{c}} = \text{Interception}
- D = \text{Deep drainage}
- E = \text{Evaporation}
- T = \text{Transpiration}
- \Delta S = \text{Change in Storage}
Site characteristics

Farm Otjamongombe (Erichsfelde)
40 km N of Okahandja, east of B1 and Ombutozu Plateau about 1500 m a.s.l.
Part of the Omatako catchment

Soils of 0 to >2 m thickness above hardrock
Luvisol – Cambisols (+ Calcisols, Vertisols)

Thornbush savanna
Bush encroachment with Acacia mellifera

Cattle farming, about 500 cattle plus wildlife
Different measures taken to reduce dense bush around farm house
Site characteristics

Chromic Luvisol

pH(CaCl2) 5 – 5.5

Organic carbon ≈ 0.35 %

Bulk density ≈ 1.5 g/cm³

Total porosity 42 – 49 % volume

Clay increasing with depth ≈10 → 20 %

Sand decreasing with depth ≈80 → 65 %

intensive biological activity (termites, ants, beetles...)

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Methods
Methods

Soil moisture monitoring stations:

1 Raingauge (Mike Cotton Systems, 0.2 mm accuracy, 30 min resolution, logging)

8 Soil moisture probes (TDR, Institute of Agrophysics, Poland; 100 mm rod length, installed horizontally in the depth 20, 40, 60 and 80 cm below soil surface, connected to data logger; readings at 8 – 16 – 24 o’clock)

8 Soil water potential sensors (type WATERMARK® 200SS, Irrometer Company Inc., USA; installed in the depth 20, 40, 60 and 80 cm below soil surface, connected to data logger; readings every 2 hours)

additional: Climate station (SASSCAL) in farm, logging climate data in hourly resolution

sensors installed at a profile below canopy and a profile in the intercanopy space. About 5 m distance
Site ES

tree coverage 4.4%

below canopy (BC)

intercanopy (IC)

10.3.2014

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Site EL

18.03.2008

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Site EL

tree coverage 12.0 %

12.3.2011

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Site EG

11.4.2017

grass 1

grass 2)

tree coverage 0.5%

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Data availability

Soil water potential

Soil water content

Rain gauge

year


EC
EP
ES
EL
EG

SASSCAL

Data availability
Weather conditions

Annual rainfall (1.10. – 30.9.)

Mean = 437 mm
What happens to the raindrops

Rain - soil water potential – soil water content 2013/14
(site EL, Intercanopy)
What happens to the raindrops

Rain induced increase in soil water storage – site ES

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1. Rain events in the range of 0 to 18 (-32) mm are adsorbed by plant surfaces and the upper 20 cm topsoil → no reaction of sensors

2. At some stronger rain events, the increase in total soil water is substantial larger than the precipitation, at other events smaller
   → short-term surface ponding with short-distance water flows
   → local soil water budgets strongly modified
3. Comparison between adjacent below-canopy and intercanopy sites → less water infiltration below canopies
How much water is consumed?

Rain – soil water content – soil water potential: 2013/14

EL - intercanopy

Rain (mm)

SWC (mm)

SWP (pF)

Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

4,0 3,5 3,0 2,5 2,0 1,5 1,0

2013 / 2014

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How much water is consumed?

Soil water potential – daily change in stored soil water

ES – below canopy

δ SWC [mm d⁻¹]

mean SWP [pF]

dry        semi-dry   moist    wet
How much water is consumed?

Soil water potential – daily change in stored soil water

ES – intercanopy

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δ SWC [mm d⁻¹]

- dry
- semi-dry
- moist
- wet

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Conclusions

1. Water consumption is strongly **controlled by water availability**. If the soil is moist ($pF < 2.4$) 6 to 8 mm are lost per day. If the soil become dry ($pF > 3$) daily transpiration reduces to $< 1$mm.

2. **Peak soil water losses** do not differ between intercanopy and below-canopy profiles.

3. The **efficiency of water uptake** below-canopy is higher than in the intercanopy area. There we can often observe a state of the vegetation cover that is unable to use the available water directly.
Conclusions

Summary of evapotranspiration

Median ET at moist soils (1.9 < pF < 2.3)
Median ET at intermediate soils (2.9 < pF < 2.3)

5. In the summary for all years, plant water uptake below canopies is 1.7 to 2.7 fold of the uptake in the intercanopy area.
Is groundwater recharge possible?

Deep drainage is possible

- if the subsoil is sufficient moist and
- if the deeper underground is able to transfer the water (sufficient water conductivity)
Is groundwater recharge possible?

Frequency of moist subsoils (2007 – 2016)

Site ES

Site EL

Frequency (% days)

intercanopy  below canopy  intercanopy  below canopy

moist  slightly wet  wet

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Is groundwater recharge possible?

Calculation of deep drainage for days with (slightly) wet subsoil

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</table>
Is groundwater recharge possible?

Rainfall vs. deep percolation

![Rainfall vs. deep percolation graph](image)

- **Deep percolation [mm]**
- **Rain [mm/a]**

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Conclusions

1. There are only few events, when deep drainage is physical possible.

2. These events depend on rainfall distribution and are enhanced by run-on processes.

3. In years with < 500 mm rainfall the likelihood of deep drainage below canopies is zero, in the intercanopy areas small but existing.

4. Even in wet years (> 500 mm rainfall) the deep drainage below canopies is smaller than in the intercanopy area.
The likelihood of deep drainage is about 3.0 to 3.8fold larger in the intercanopy area compared to the below canopy area.

Summary of potential deep percolation:

<table>
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<tr>
<th>EG 2</th>
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</table>
Conclusions & Outlook

1. Our long-term soil water monitoring shows, that encroaching trees (*A. mellifera*) modify the local soil water balance substantially
   - reduce infiltration,
   - faster soil water uptake, higher (evapo)transpiration
   - less deep drainage (≈ 1/3)

2. The increase in tree density with the respective reduction of intercanopy areas is thus likely to **negatively impact on groundwater ressources**.

3. To solve open questions about the **sustainable use of groundwater ressources** for the dry country Namibia we propose
   - a **large-scale analysis of groundwater dynamics** combined with
   - **soil water monitoring,**
   - analysis of **tree species water consumption** patterns using sap-flow devices and
   - the **monitoring of the vegetation dynamics** at least for some of the dominant landscape types.
Conclusions & Outlook

Thank you for your attention

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further readings in: Acacia trees modify soil water dynamics and the potential groundwater recharge in savanna ecosystems

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