Combined phosphorus and water management options in P-deficient lowlands of sub-Saharan Africa

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Outline

- Importance & challenges for rice production
- First step of the research (more fundamental)
- Second step of the research (more applied)
- Conclusions
Rice in sub-Saharan Africa (SSA)

A critical situation?
- Strong population growth (UN, 2015)
- High yield gaps, high undernourishment rates (FAO, 2015 & 2016)

Rice in SSA
- Most rapidly growing food source (Saito et al., 2014)
- High dependence on import (45%) (Seck et al., 2013)
- Urgent need for further intensification of rice production!
Major limitations for rice production in SSA

- Phosphorus (P) deficiency
- Drought events

{ Importance of roots!

- Little known about interactions between P & water availability & effects on rice performance
Objectives and hypotheses

Objectives

- Document responses of rice roots to water- x P availability
- Explore the existence of beneficial root traits
- “Roots ~ W x P x Genotypes”?

Hypotheses

- Root traits can explain different performance of varieties in stressed conditions
- Root responses to water stress overrule the responses to low P availability
- Water availability can thus alter P uptake efficiency (or vice versa)
First step of the research

Root characteristics under combinations of P & water availability?

Set-up:
- 2 pot trials
- 2 field trials

Root Harvesting:
- Digging out the root system
- Washing out the root system
- Analysis of Root System Architecture (Shovelomics and root imaging)

- Both upland and lowland conditions
- From P deficient to non-limiting
- From soil submergence to water stress
- Three contrasting varieties
Major findings:

1) Genotypic variation in basal lateral root density explains tolerance to low P

![Diagram showing genotypic variation in basal lateral root density and its effect on tolerance to low P](image)
Major findings:

2) Importance of root plasticity  
   *(plastic versus non-plastic traits!)*
   
   - Water availability has a dominant effect on architectural root traits.
     
     With reduced water availability:
     
     - Secondary branching degree increases
     - Nodal root thickness decreases
     - P uptake efficiency increases
Conclusions:

- Importance of root characteristics for tolerance to low P (and water stress).
- Reduced water availability can enhance tolerance to low P (and water stress).

Hypothesis:

“Reduced irrigation can modify root characteristics of lowland rice and hence enhance low P tolerance.”
Second step of the research:

What can farmers do?
=> Focus on management in P deficient lowlands

- P management options
  - No P fertilization
  - Conventional broadcasting (25-30 kg P/ha)
  - Sub-optimal broadcasting (<20 kg P/ha)
  - Micro-dose placements (3-8 kg P/ha)

- Water management options (if possible!)
  - No irrigation/drying periods (DP)
  - Field Capacity (FC)
  - Alternate Wetting and Drying (AWD)
  - Soil Submergence (SS)

⇒ Interactions between water and P management!?
Experimental set-up

- One extensive pot trial mimicking all PxW management options
- Two field trials subjected to PxW management combinations

Water: FC, (safe-)AWD, SS
P: No P fertilization
Micro-dose placements (3.45 <--> 6.9 kg/ha)
Conventional broadcasting (25 kg/ha)
First results from the management trials

- Follow-up season of the field trial still going on...
Rice Development

Initial observations from pots:

- Sufficient P/conventional broadcast:
  FC~AWD~SS

- Sub-optimal broadcast (82 mg P per pot)
  Micro-dose placement (24 mg P per pot)
  (FC>AWD~SS)

- P deficiency/No fertilization:
  FC>AWD~SS
Root distribution & plasticity

- Field Capacity & Drying Periods:
  - Enhances deep rooting
    - Tolerance to future drought events
  - More efficient root system for P uptake
    - Reduced nodal root thickness
    - More secondary root branches

Water Treatments
- DP: Drying Periods
- FC: Field Capacity
- AWD: Alternate Wetting & Drying
- SS: Soil Submergence
Grain Yields from the field:

Grain yield (kg/ha)

- No P
- Micro P (3.45 kg/ha)
- Micro P (6.9 kg/ha)
- Optimal broadcasted (25 kg/ha)

Water
- Field Capacity
- Alternate Wetting & Drying
- Soil Submergence
Besides effects of root modifications:

**Additional factors** contributing to reduced growth under soil submergence in P deficient lowlands

Under strong P deficiency:
- Stronger anoxic stress under soil submergence
- Larger potential of iron toxicity under soil submergence

With P placements:
- Stronger diffusion under saturation
- Finally larger fractions of P sorbed
  - Modeling P diffusion from P placements
  - Based on Degryse and McLaughlin (2014)

\[
\frac{\partial c}{\partial t} + \frac{\rho}{\theta} \frac{\partial (k c^n)}{\partial t} = f \frac{D}{r^2} \frac{\partial}{\partial r} (r^2 \frac{\partial c}{\partial r})
\]

At Field Capacity:
Efficiency and Sustainability?

=> High Agronomic and Use Efficiency of P fertilizer under placements!

Phosphorus Balance:

Fertilization Rate:
3.45 kg/ha $\Leftrightarrow$ 6.90 kg/ha
Conclusions

- Importance of **root traits** for tolerance to abiotic stresses
  - Large unexploited pool of opportunities!

- Strong interactions between P x Water availability:
  - Need for strategic combinations of **genotype selection, P -, and water management**, depending on specific site characteristics
  - Need for agricultural extension! (at all levels: i.e. pest management, soil fertility, irrigation...)

- When P is limiting:
  - Reduced water application (i.e. field capacity) enhances low P tolerance!
  - Which additionally contribute to drought tolerance through root plasticity
  - And saves water...

- Large potential of P placements in lowlands
  - Option to reverse the P declines on deficient soils (for small-scale farmers)
  - But for small doses: interactions with water management!
Thanks for your attention!
Additional Slides
References


Solubility of P fertilizer placement under field capacity and soil saturation
Three approaches of root research
To cope with abiotic stresses

- **Biological approach**
  - Interactions with the ‘soil microbiome’

- **Chemical approach**
  - Root exudates
  - Organic Acids, Phosphatases...

- **Physical approach**
  - Architecture
  - Morphology
  - Growth responses
Root trait Analysis

Manually:
- Scores of ‘basal lateral root density’ (shovelomics)
- Measuring nodal root thickness
- Scoring second order banching degree

Image-based:
- Take picture of root system on diffuse black background + scale marker
- Convert to black and white
- Analysis of root characteristics using software (DIRT)
P uptake efficiency of rice at 100 days after sowing:

- Modifications of the root system architecture!
Agronomic Efficiency (kg/kg) and P balance (kg/ha)

Agronomic Efficiency

- AWD?

P balance

Fertilization Rate:
3.45 kg/ha ⇔ 6.90 kg/ha

Efficiency and Sustainability?