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Part II: Nitrate removal from drainage water and greenhouse effluent

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Moving Bed Bioreactor: Case study Belgium

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Process & Environmental Technology Lab

KU LEUVEN

Introduction: Moving Bed Bioreactor

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- Biological denitrification in anoxic conditions

$$5C_3H_8O_3 + 14NO_3^- + 14H^+ \rightarrow 15CO_2 + 7N_2 + 17H_2O + biomass$$

$$NO_2^- \rightarrow NO \rightarrow N_2O$$

Carbon source (glycerol-based)

pH increase

No recovery possible

- Moving-bed Bioreactor technology
  - Biofilm growth on AnoxKaldnes® plastic carriers (K5)
  - <u>Benefits</u>: Limited growth of biomass & high active biomass concentration
  - Treating high nitrate concentrations is possible

Considerations design MBBR concept

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Tile-drained agricultural fields

- 50 – 200 mg NO_3/L
- High flow rates (7.5 – 15 m^3/d)
- November – April

Greenhouse effluent

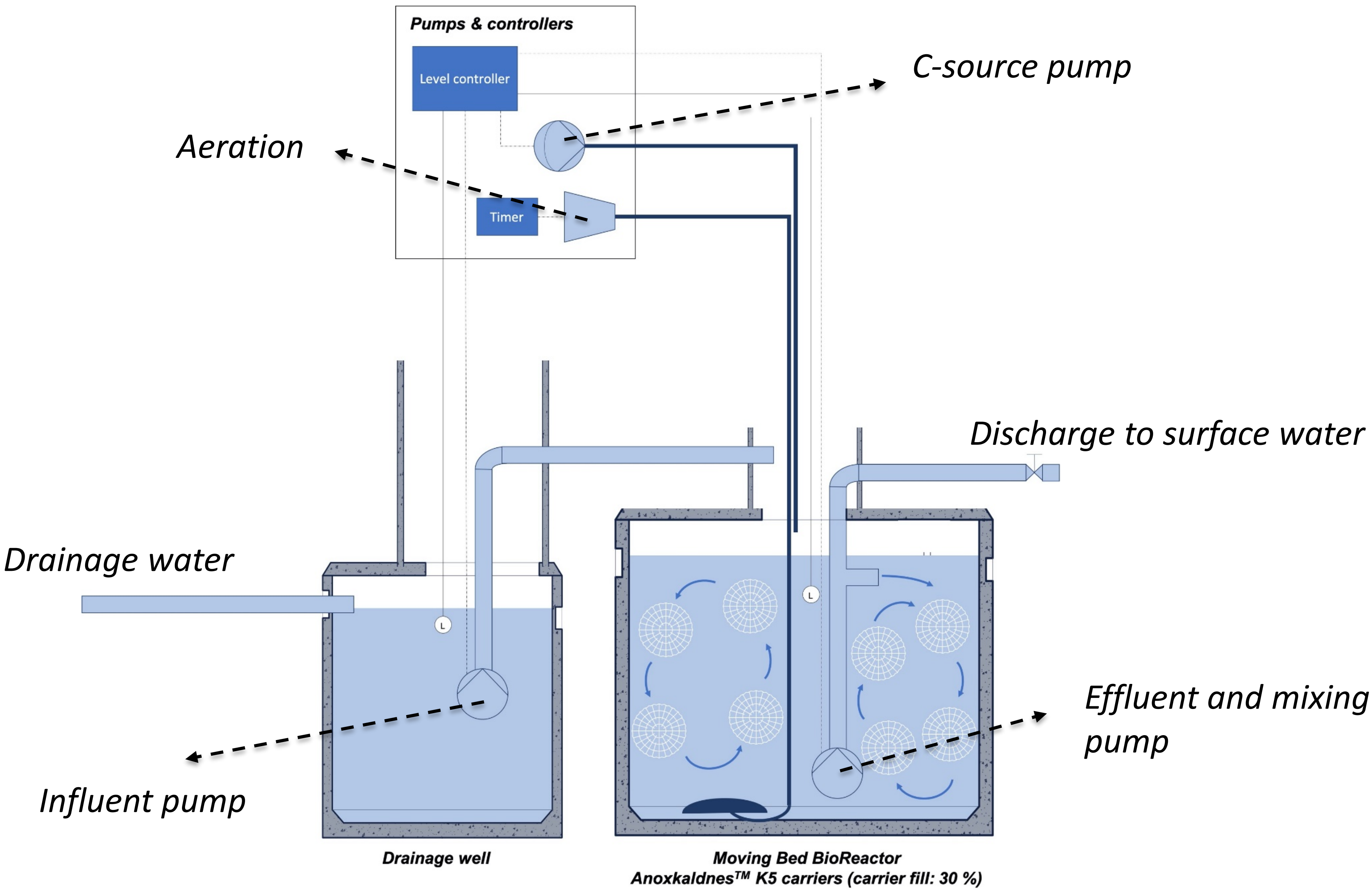
- 100 – 400 mg NO_3/L
- Low flow rates (3 m^3/d)
- During the whole year

Design considerations

→ Simple and robust system
→ Low water temperatures (between 5 – 15 °C)
→ Variable flow rates and nitrate concentrations
→ Remote locations
→ Low budget solution

Discharge limit: 11.29 mg NO_3-N/L

MBBR concept to treat agricultural waters



Field Case – Tile drained fields

Proefstation voor de Groenteteelt

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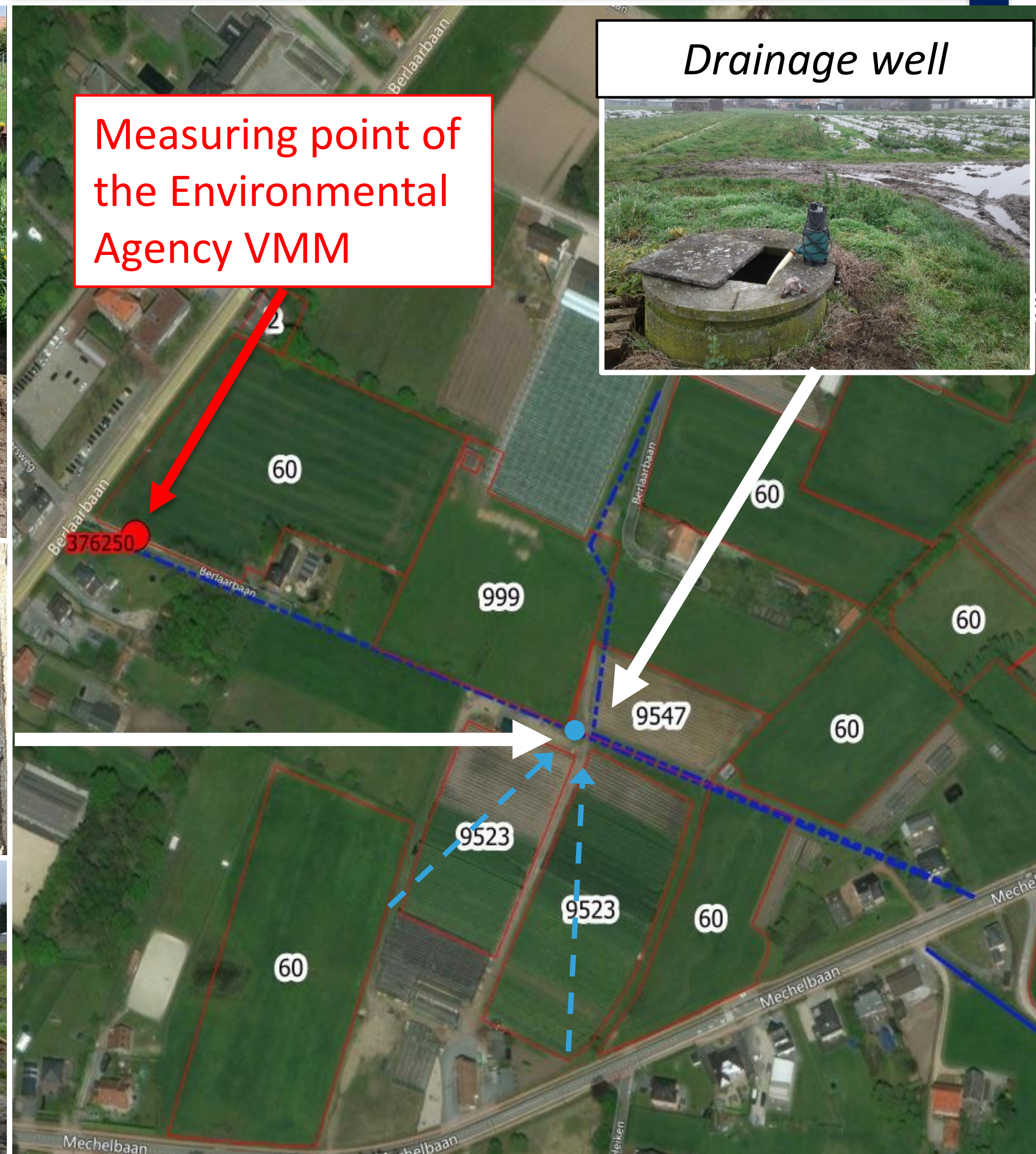

Field Case – Tile drained fields

Proefstation voor de Groenteteelt

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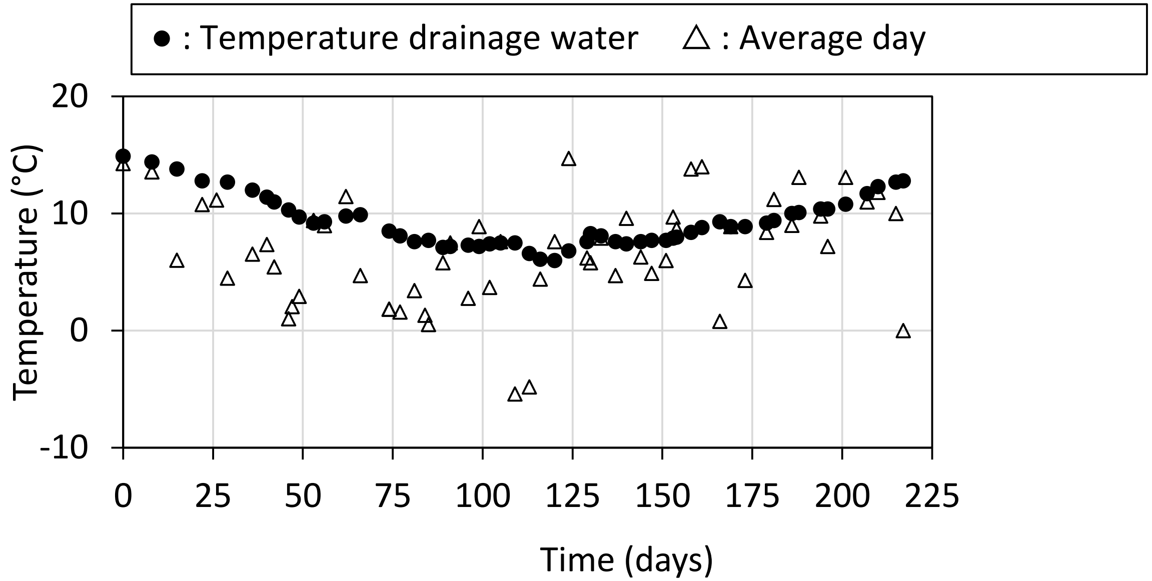
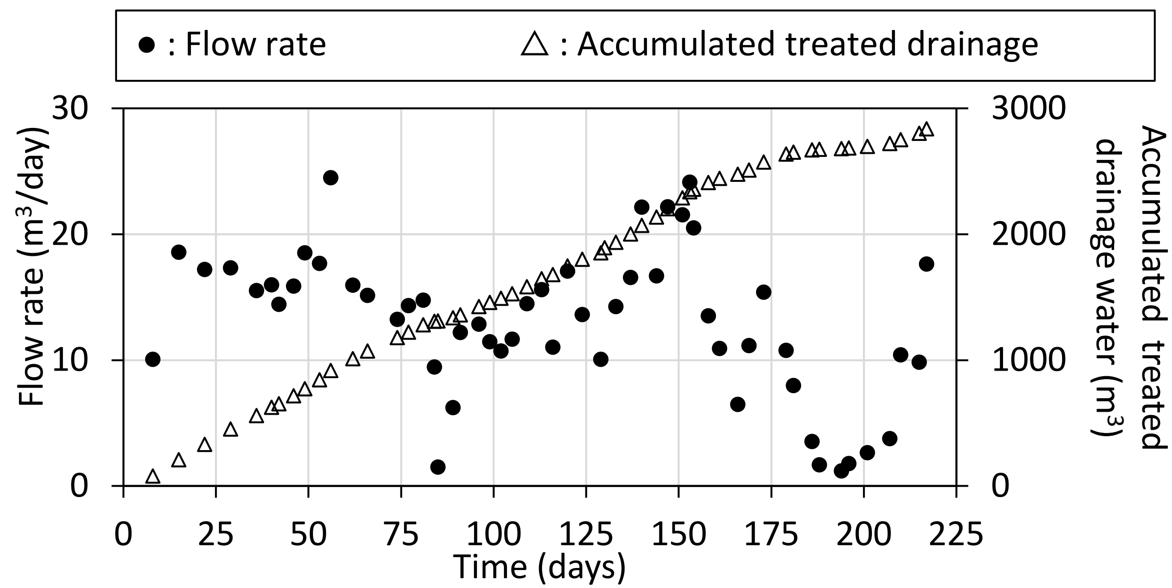
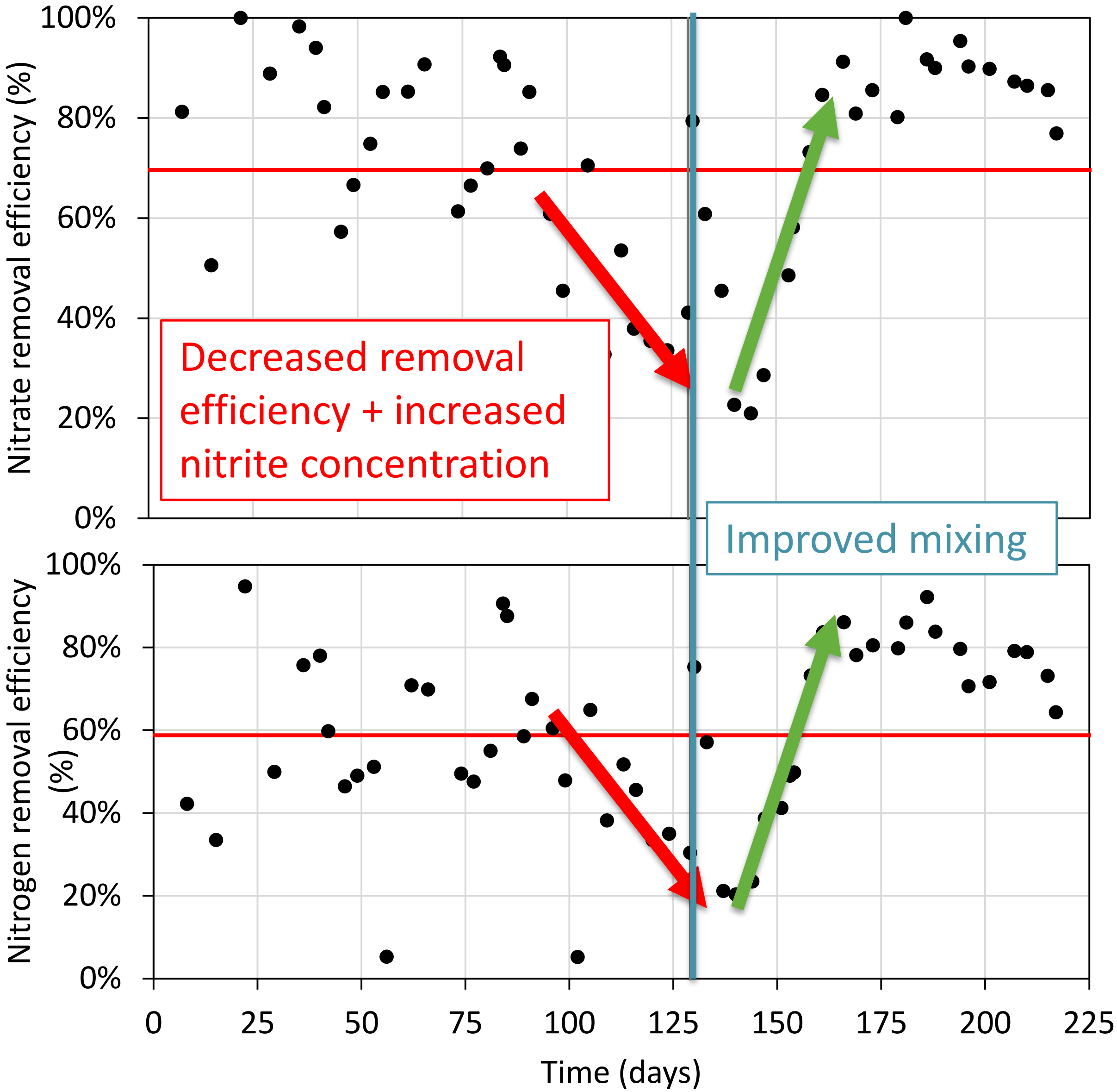
Key numbers of 2020-2021

- Drainage season: 217 days (from October to May)
- T_{max} = 14.3 °C
- T_{min} = 6 °C
- Total treated drainage water = 2837 m^3
- Flow rate: from 1.2 m^3/day to 24.5 m^3/day
- Average nitrate conc. = 30.7 mg NO_3-N/L
- pH drainage water: 6.54 ± 0.17
- pH MBBR effluent: 6.73 ± 0.16





Field Case – Tile drained fields



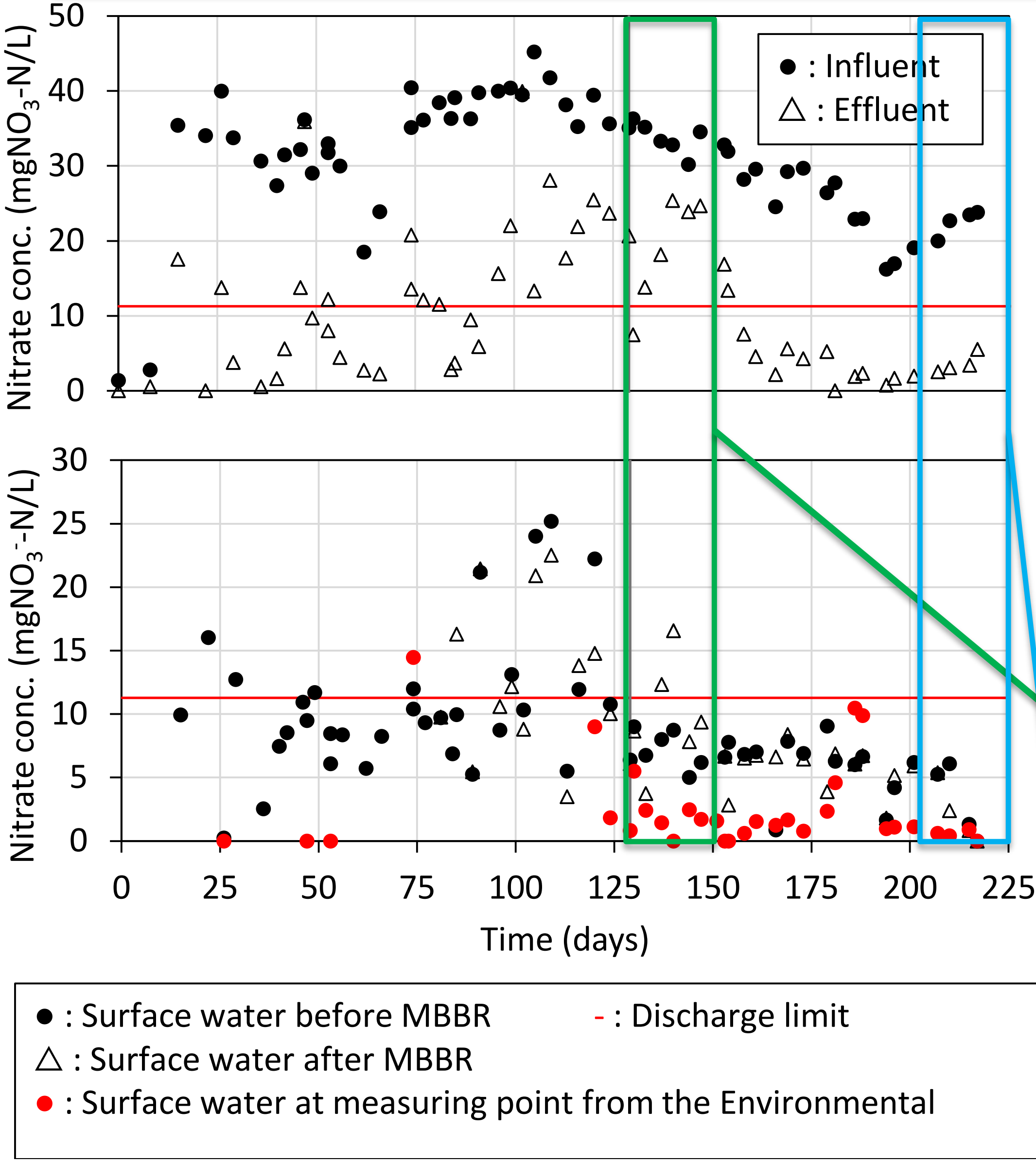
Removal efficiency

- Total period:
  - NO_3-N: 70%
  - TN: 60%
- Improved mxing:
  - NO_3-N: 87%
  - TN: 79%

Total nitrate removal

- 57.6 kg NO_3-N

Field Case – Tile drained fields



Moving Bed Bioreactor

- Influent
  - Average: 30.7 mgNO$_3$-N/L
  - Min: 16.2 mgNO$_3$-N/L
  - Max: 45.2 mgNO$_3$-N/L
- Effluent
  - Average: 10.8 mgNO$_3$-N/L
  - Min: 0 mgNO$_3$-N/L
  - Max: 39.9 mgNO$_3$-N/L

Effect on surface water

- If the removal efficiency is low, the nitrate concentration of the surface water increases
- At high removal efficiency, the nitrate concentration after the MBBR is similar or lower than before the MBBR.

Field Case – Greenhouse (DIY-concept)

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HOW DO I BUILD A MOVING BED BIOFILM REACTOR (MBBR)?

1. What is a MBBR?

A Moving Bed Biofilm Reactor (or MBBR for short) removes nitrogen from water by converting nitrate into nitrogen gas by means of biological processes. A MBBR consists of a tank filled with water, in which plastic carriers are located that are set in motion (Photo 1Photo 1). The irregular and large specific surface area of the carriers forms an ideal habitat for various micro-organisms (Photo 2Photo 2). On these carriers grows active sludge (biofilm) and this carries out the denitrification.

A MBBR requires little maintenance and is simple to construct yourself with the help of this information sheet.

Photo 1: Set-up of Moving Bed Biofilm Reactor (MBBR) at PCS Ornamental Plant Research

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Field Case – Greenhouse (DIY-concept)

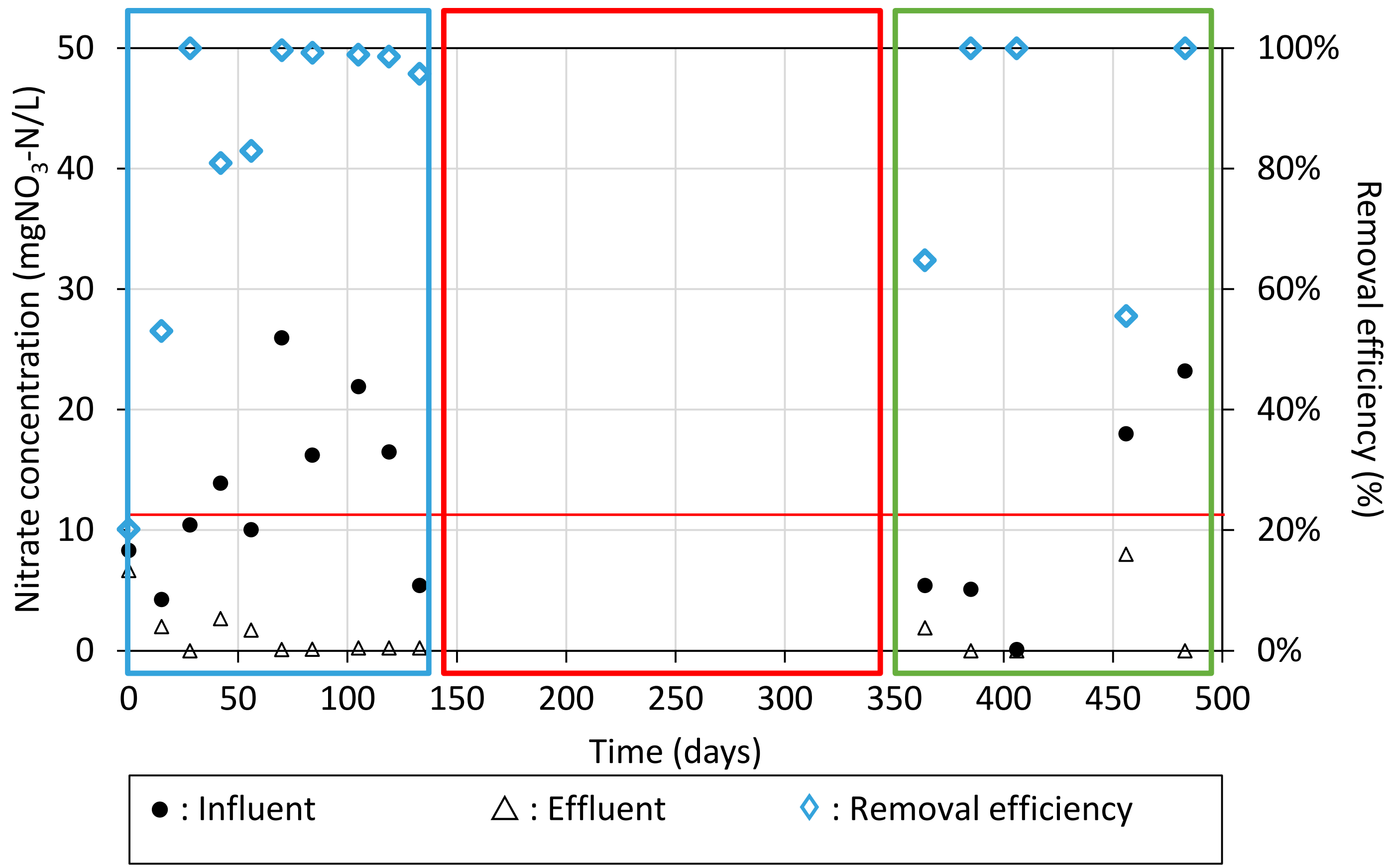
Storage pond: Day 0 - 133

- Influent: 13.3 $mgNO_3$-N/L
- Effluent: 1.4 $mgNO_3$-N/L
- Removal efficiency: 83%

Shut down during the winter

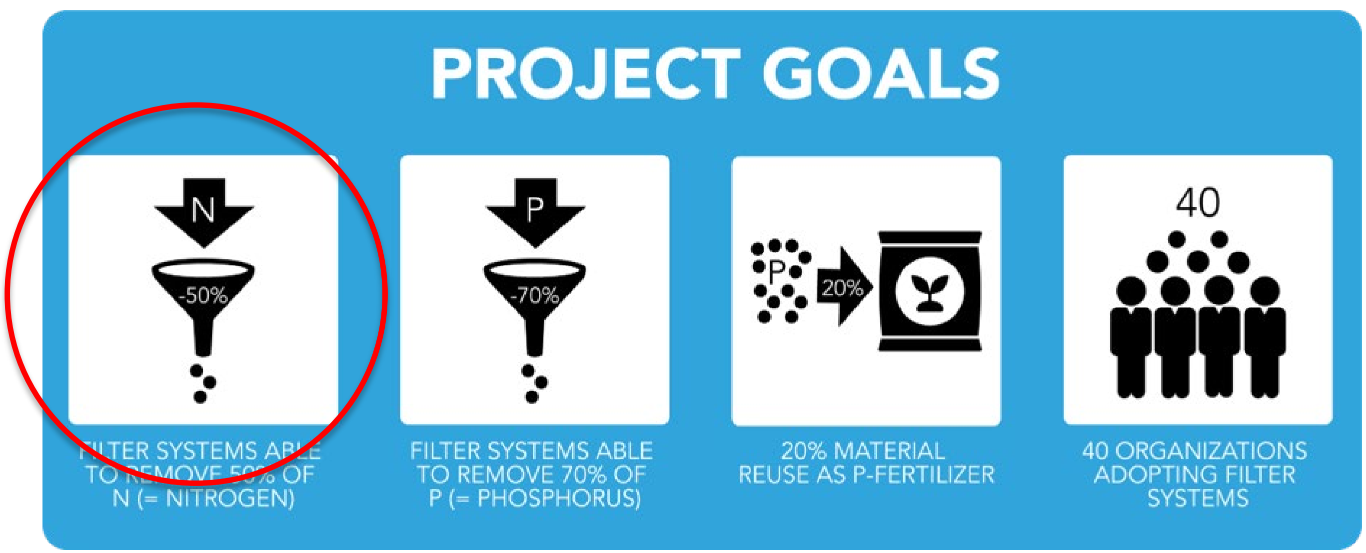
Drain water: Day 364 - 483

- Influent: 10.4 $mgNO_3$-N/L
- Effluent: 2.0 $mgNO_3$-N/L
- Removal efficiency: 84%



Conclusions

- Underground MBBR: temperatures higher than 5°C
- Mixing is very important: Improved removal efficiency from 70% to 87%.
- The nitrate concentration of the surface water is similar or even lower when the MBBR achieves high removal rates.
- Total cost efficiency: 103.4 €/kg NO_3-N



Zero Valent Iron for N and P removal

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The Nitrogen wheel

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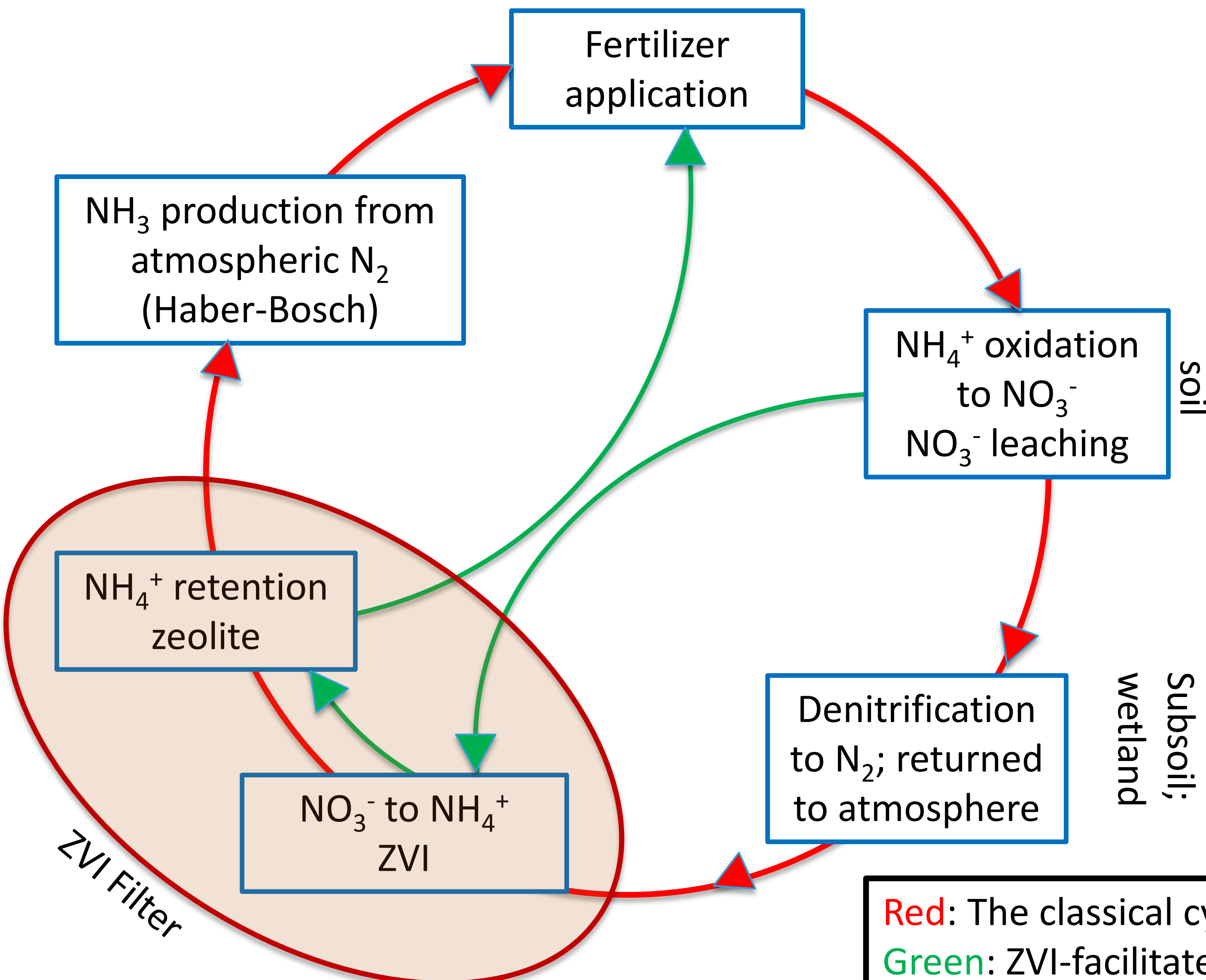
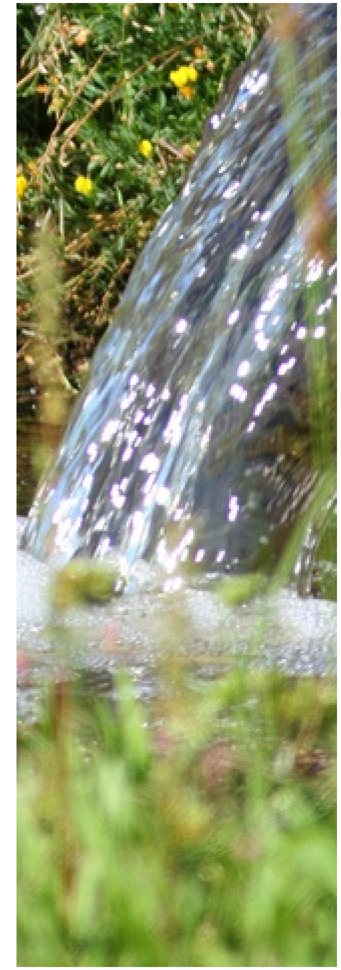




Red: The classical cycle
Green: ZVI-facilitated cycle

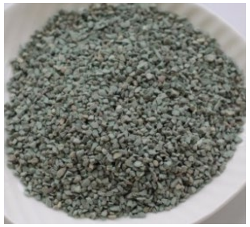
Zero valent iron filter

- Objectives: to develop a filtration system that can remove nitrate (NO_3^-) and recover nitrogen as ammonium (NH_4^+) from agricultural drainage water.
- Field scale setup and principle

$$4\,Fe^0 + NO_3^- + 10\,H^+ \rightleftarrows 4\,Fe^{2+} + NH_4^+ + 3\,H_2O$$

- Filter constructed of three units:
  - **Section 1**: ZVI unit + sand; 45 kg ZVI
  - **Section 2**: Oxidation (air bubbling)
  - **Section 3**: Ammonium capture (zeolite); pre-treated with NaCl; 70 kg zeolite
- Agricultural drainage water flow: 1 L/min
- Retention time: 35-45 min for each unit

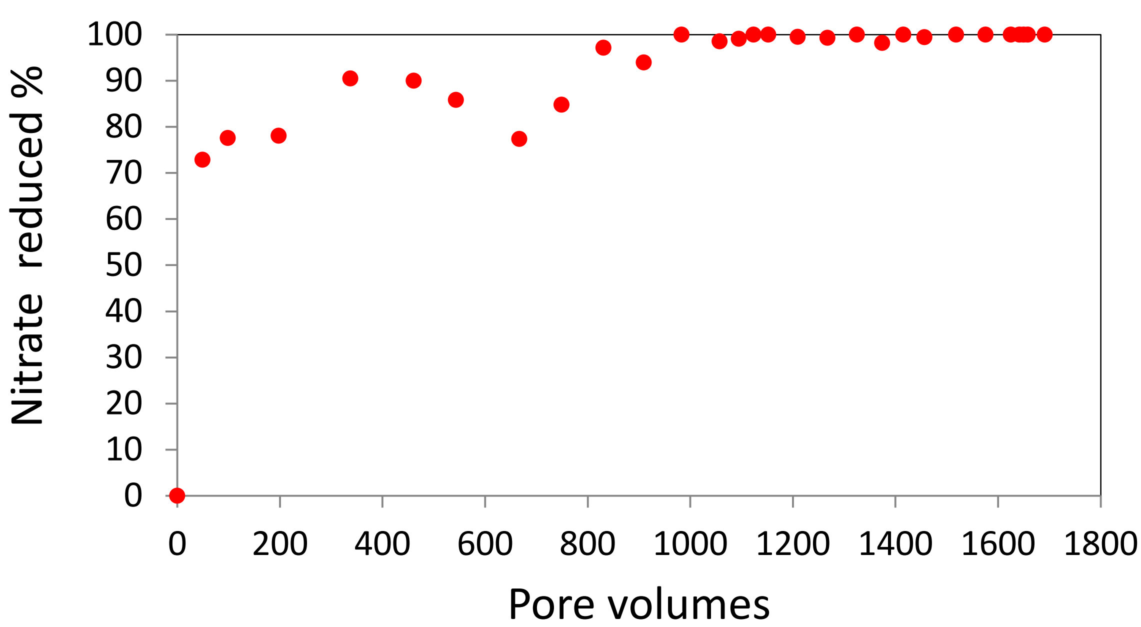
ZVI



Zeolite

Results - 1

Nitrate removal



NO_3^- measured at end of column 1

- High NO_3^- removal efficiency regardless the initial nitrate concentration (3 to 8 mg/L nitrate
- Average NO_3^- reduction for the entire running period: 94%

Results - 2

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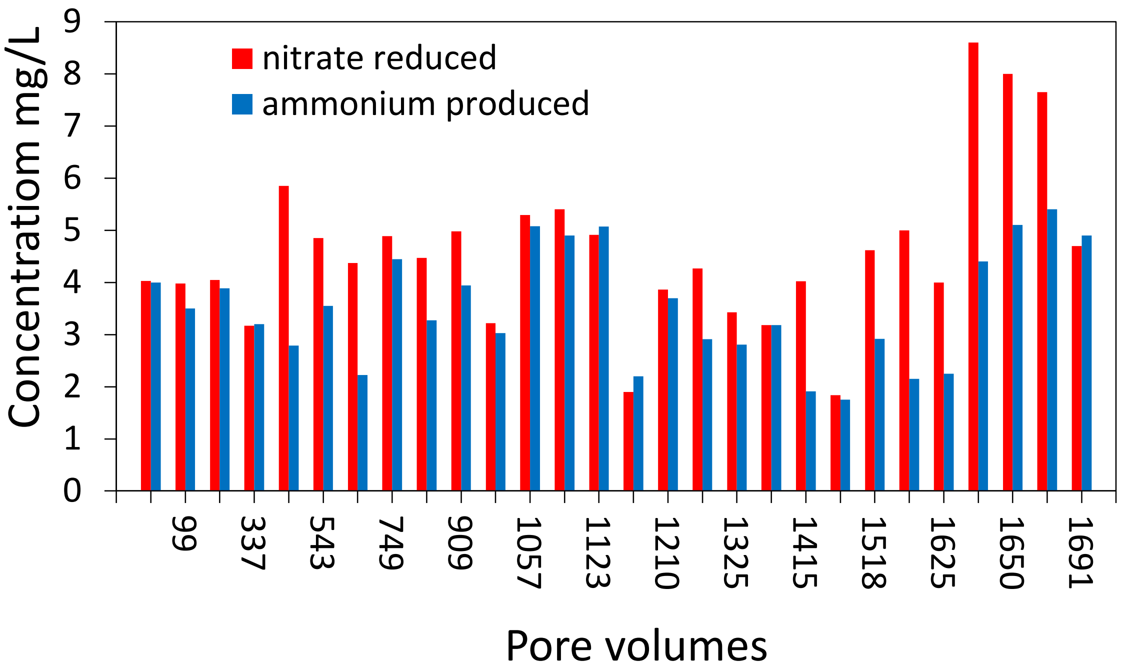
Nitrate is converted to ammonium



NO_3^- and NH_4^+ measured at end of column 1

- NO_3^- is converted to NH_4^+. 100 % at start and then at about 70 % at end of the period
- Similar results as in laboratory experiments
- Incomplete conversion could be due to production of unmonitored nitrogen gas species (NO_2, N_2O, N_2H_4)

Results - 3

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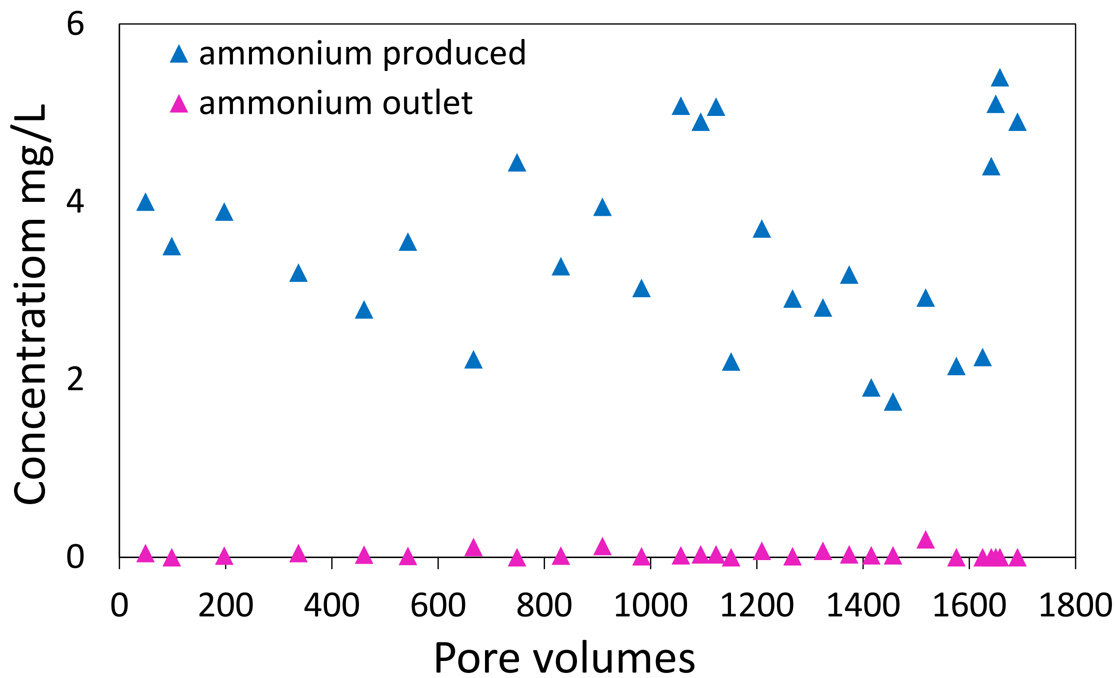
Ammonium capture

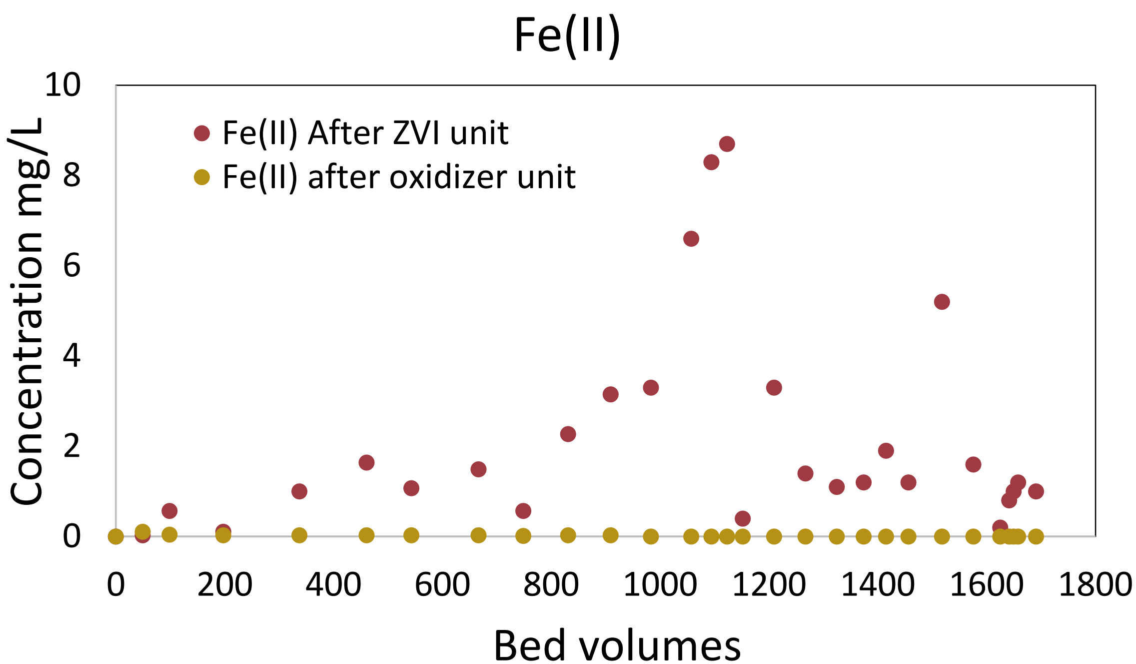


NH_4^+ measured at inlet and outlet of column 3

- Almost 100 % NH_4^+ retained in zeolite over the entire running period
- No decrease of NH_4^+ retention as in laboratory experiments
- Higher efficiency of zeolite layer, as in laboratory experiments

Results - 4

Removal of iron(II)



Fe(II) measured at inlet and outlet of column 2

- 100 % of iron(II) removed through oxidation in the aeration section
- Iron(II) oxidized and iron(III)oxide (”rust”) precipitated (yellow-brownish)

Results - 5

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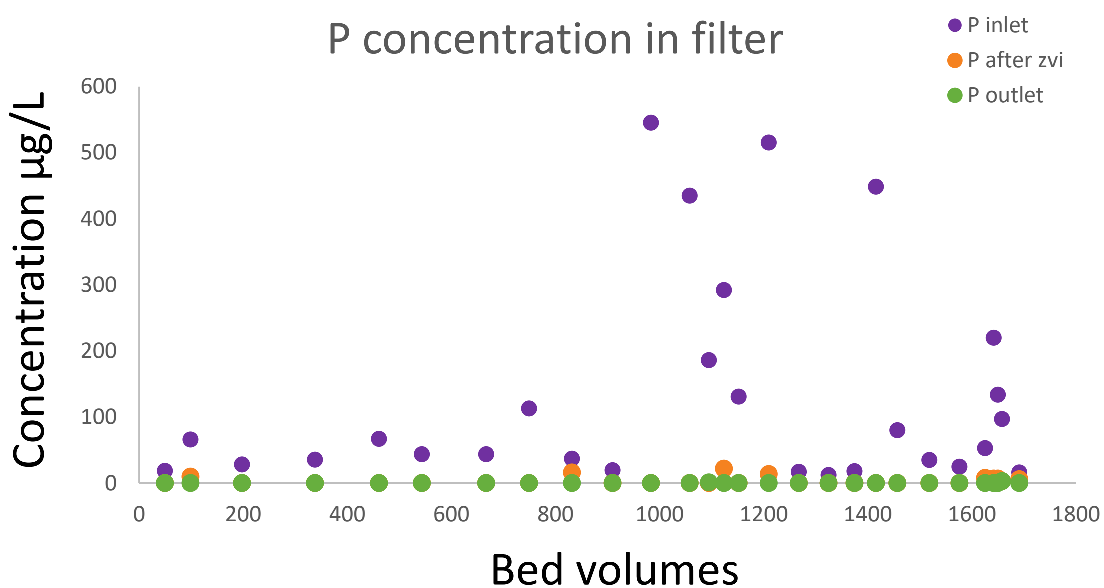
Phosphate is 100 % retained



HPO_4^{2-}

- No phosphate was detected in the outlet from column 1 and 2
- Inlet phosphate concentration: 0.5 mg/L
- Phosphate sorbed to the ”rust” formed and thus is fully retained

Results - 6

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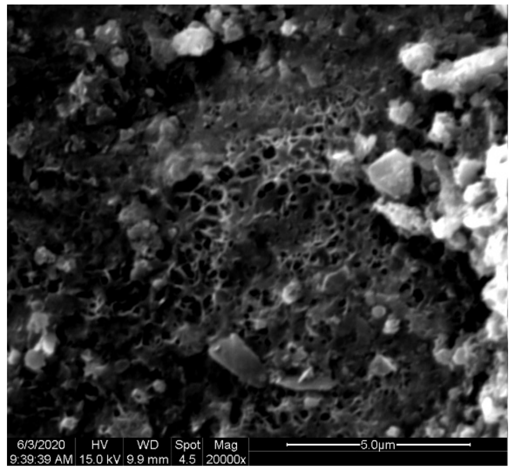
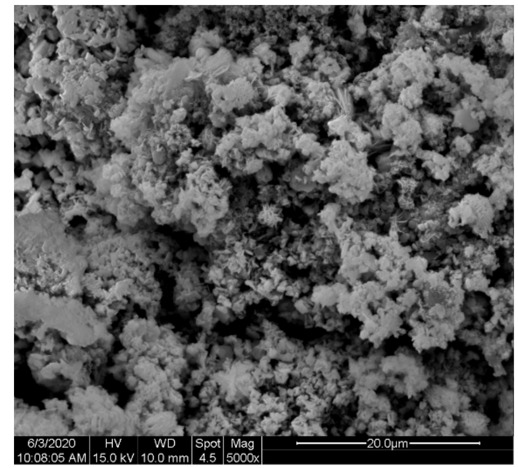
Green rust formation in ZVI unit





- Green rust (GR) is an unstable corrosion product that forms in the ZVI unit.
- GR facilitates reduction of nitrate to ammonium and reduces the mass of ZVI needed
- GR may also contribute to phosphate sorption

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Investment and operationnal costs

Investment cost

	Price	Amount needed/ha/year (2000 m^3 drainage water)	Price/ha/year	Removal and recovery/ha/year
ZVI	0,85 – 1 €/Kg	72 Kg	60 – 72 €	100% Nitrate removal
Zeolite	2,5 – 3 €/Kg	500 Kg	1250 – 1500 €	70% Ammonium formation + retention
Filter system + tubing + pumps	2000 €		2000 €	14 Kg N retained
Total:			3500 €	

Operational cost: electricity

Filter evaluation

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Pros

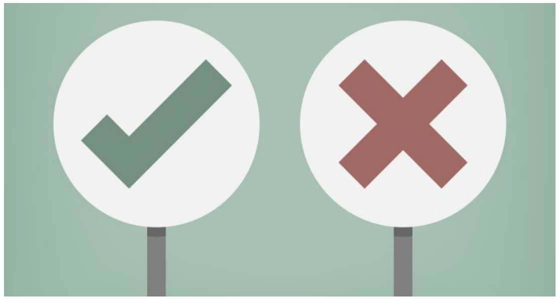
- Nitrate can be completely removed, even at low concentrations and low temp. ✓
- Ammonium can be recovered enabling nitrogen to be recycled ✓
- Phosphate is fully removed and can be recycled ✓
- Iron(II) formed during ZVI corrosion can be oxidized and removed ✓
- The unit advantageous for production facilities such as greenhouses ✓

Cons

- Nitrate removal can decrease due to passivating ZVI corrosion layers ✗
- Oxygen in drainage water will also consume ZVI ✗
- Reduction of water generates H_2 (gas formation in column) ✗
- Maintenance: requires aeration (pump) ✗
- High iron consumption ✗

Improvements

- Smaller ZVI particles to increase reaction efficiency
- Remove ZVI corrosion layers
- Recycling of phosphate



Moving Bed BioReactor and constructed wetland for drainage water
Case study Belgium

Dominique Huits
Inagro

West Flemish agriculture in figures

- ✓ 8300 farms good for 200.000 ha or 65% of the total surface area
- ✓ 63% of Flanders’ production of vegetables
- ✓ 49% of Flanders’ production of arable crops

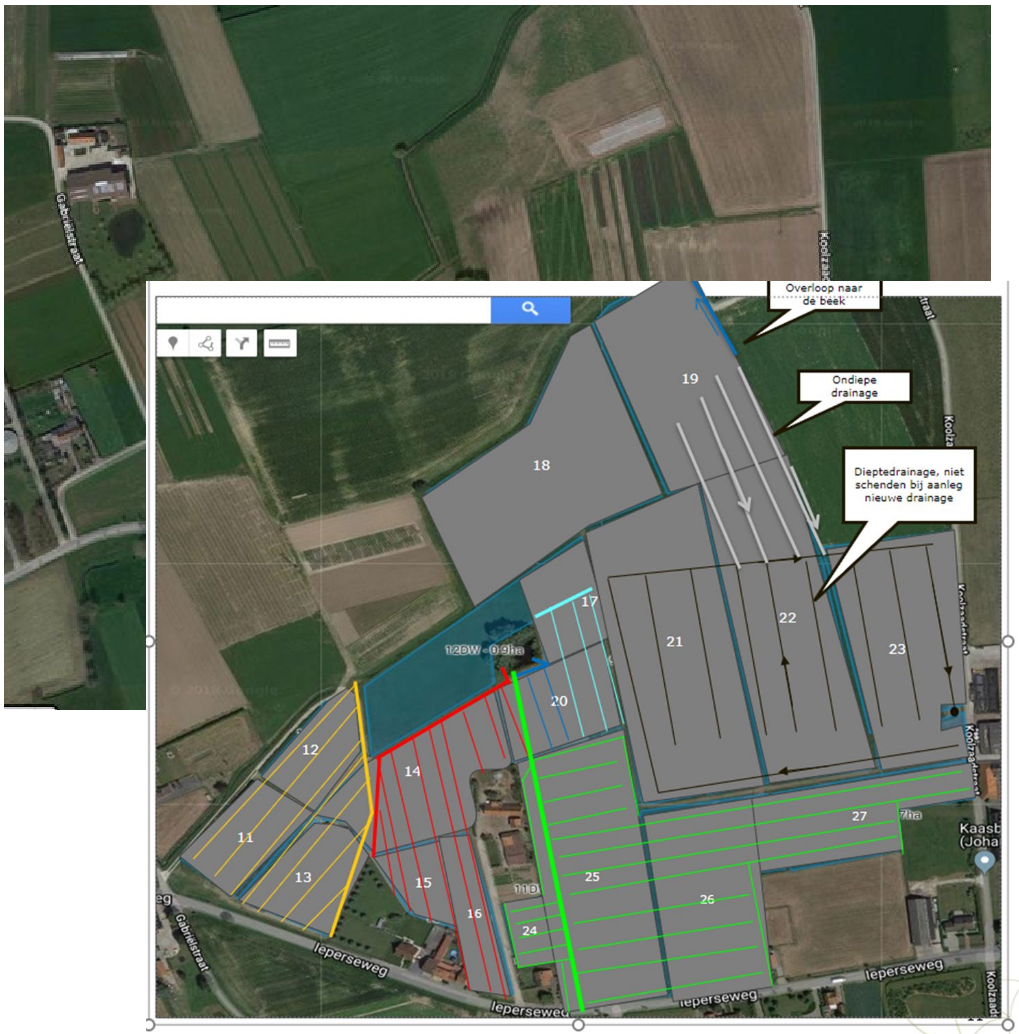
Inspired by Denmark

- New field for field trials
- Drainage to be installed
- Nitrate losses from field drainage are an important issue to get under control

↓

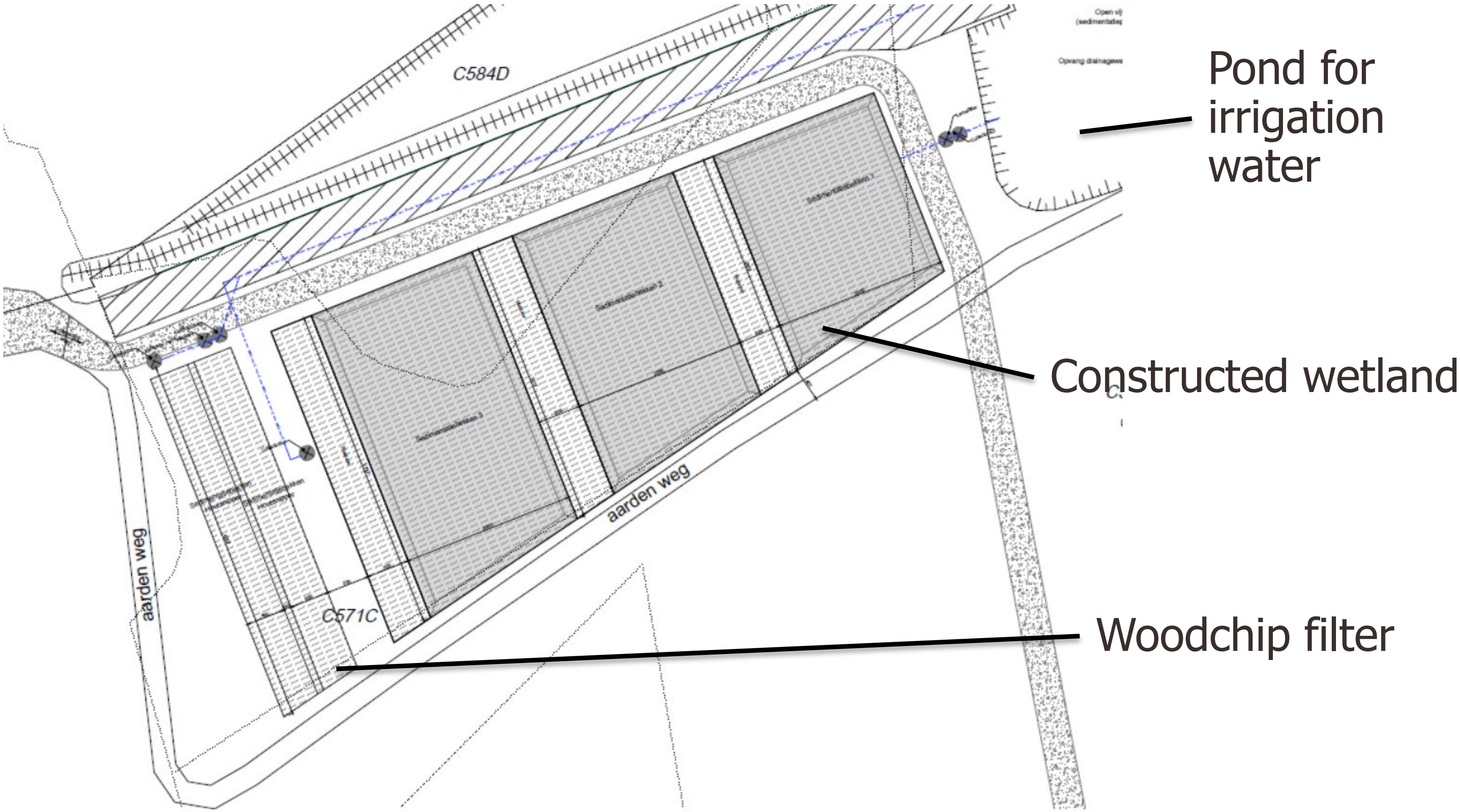
Can a constructed wetland be (part of) the solution?

From idea to design



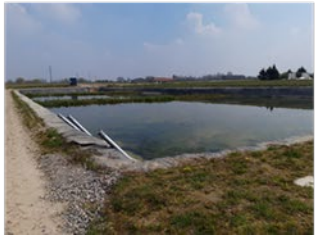
1. Reservoir to collect irrigation water
2. Determination of the location for the constructed wetland
3. Design of the drainage system
4. Design of constructed wetland

Design of constructed wetland and woodchip basin



Denitrification units installed

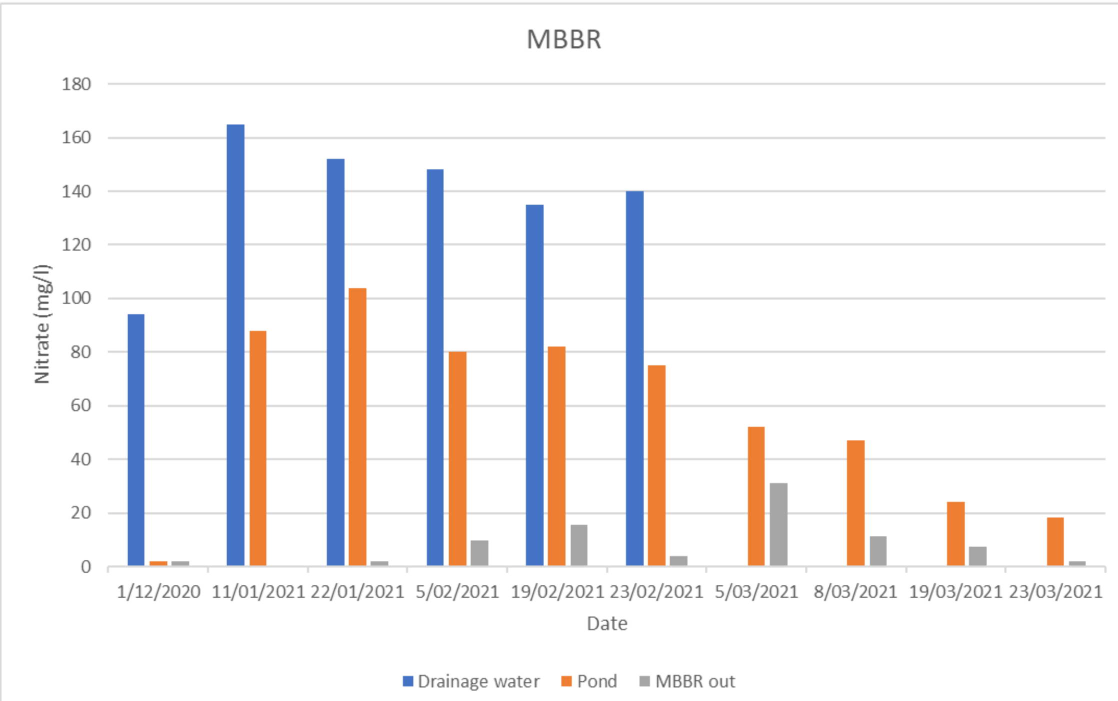
MBBR



Wetland

Woodchip filter

Results MBBR winter period 2020-2021



CarboST dosis : 0,13 L/h during the whole period

01/12/2020
Start drainage season
MBBR flow 1,5 m³/h

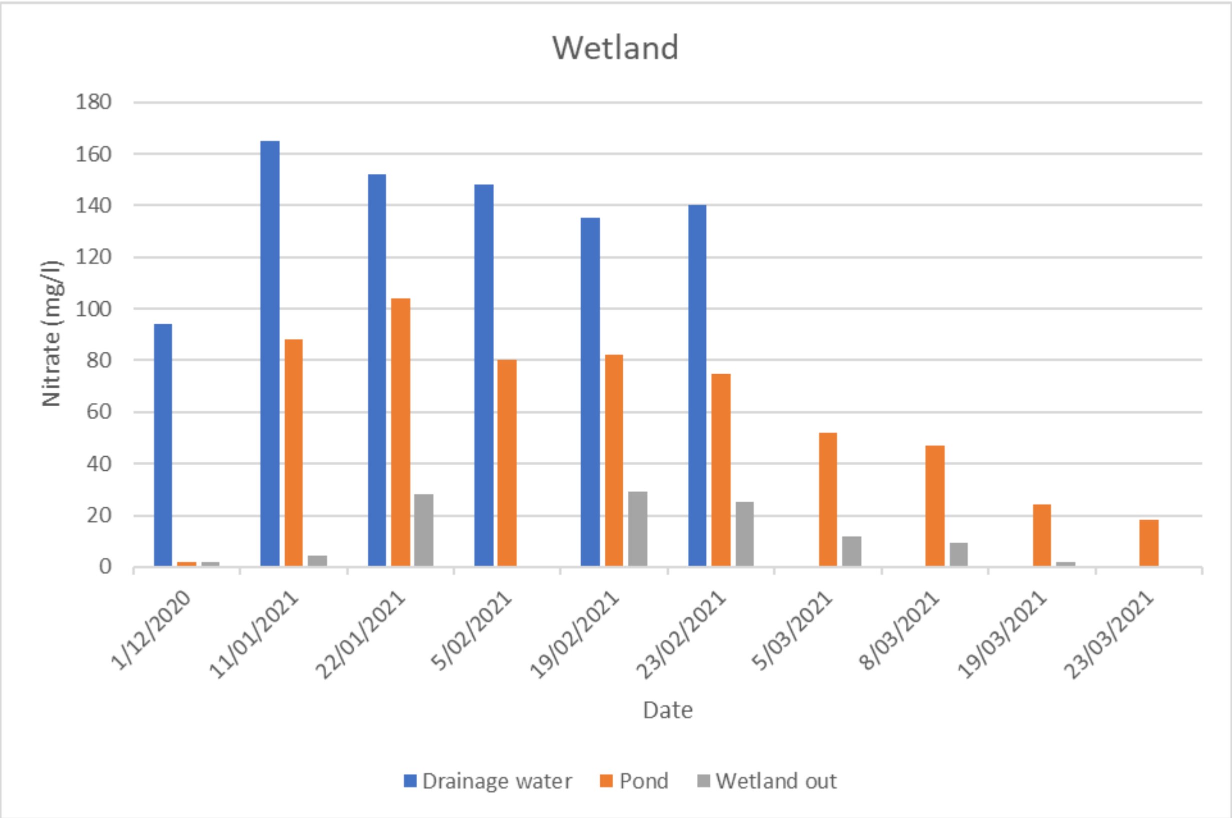
08/02/2021-18/02/2021
Due to frost internal recirculation of MBBR

18/02/2021
MBBR flow 1,5 m³/h

03/03/2021
MBBR flow 2 m³/h

17/03/2021
MBBR flow 2,5 m³/h

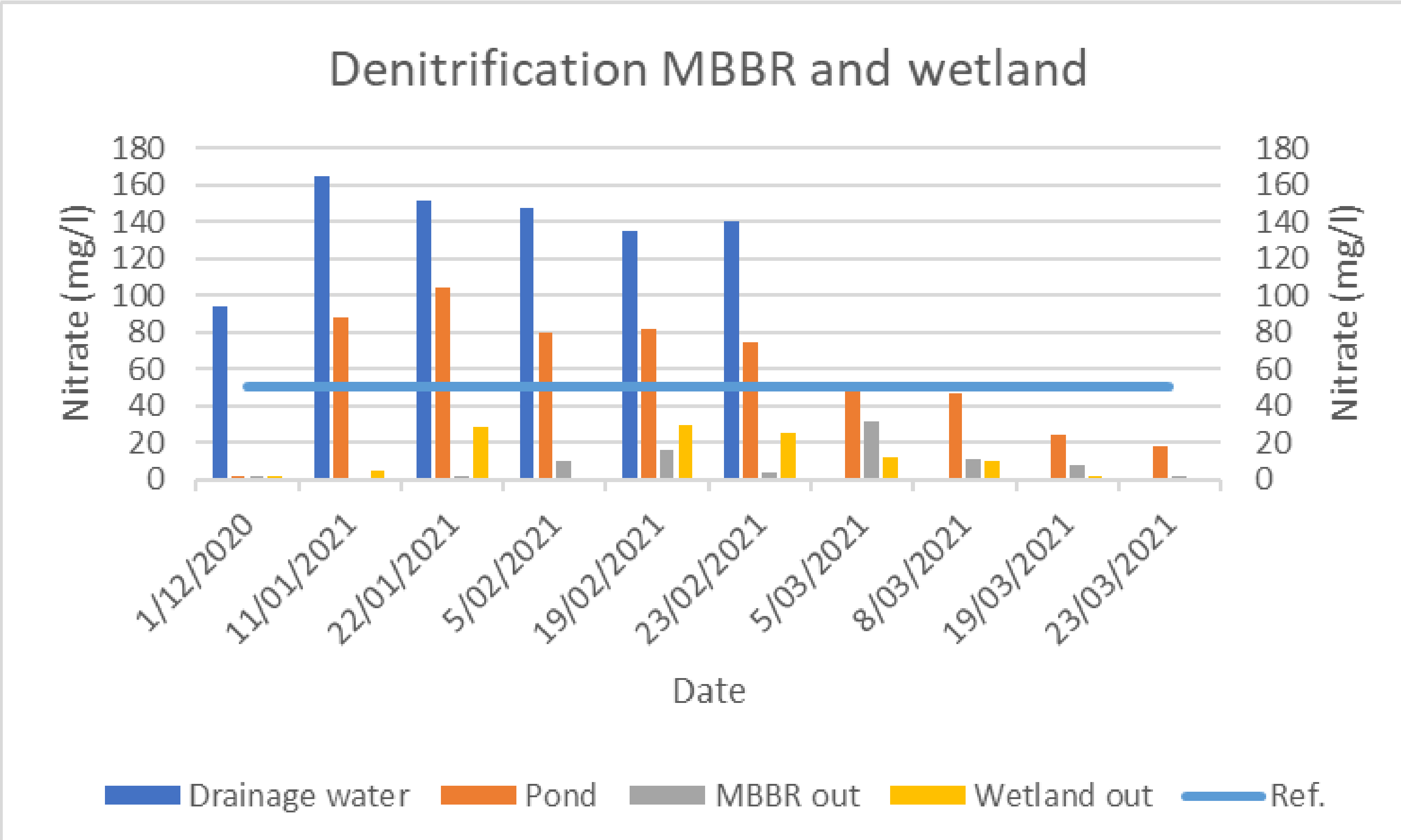
Results MBBR winter period 2020-2021



01/12/2020
Start drainage season

19/03/2021
End of drainage season

Results MBBR winter period 2020-2021



Conclusions

- First results of MBBR and wetland are quite good

But

- Only one year of experience
- Will this work at catchment level

Q & A

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Part III: The bumpy road of phosphate recovery and reuse

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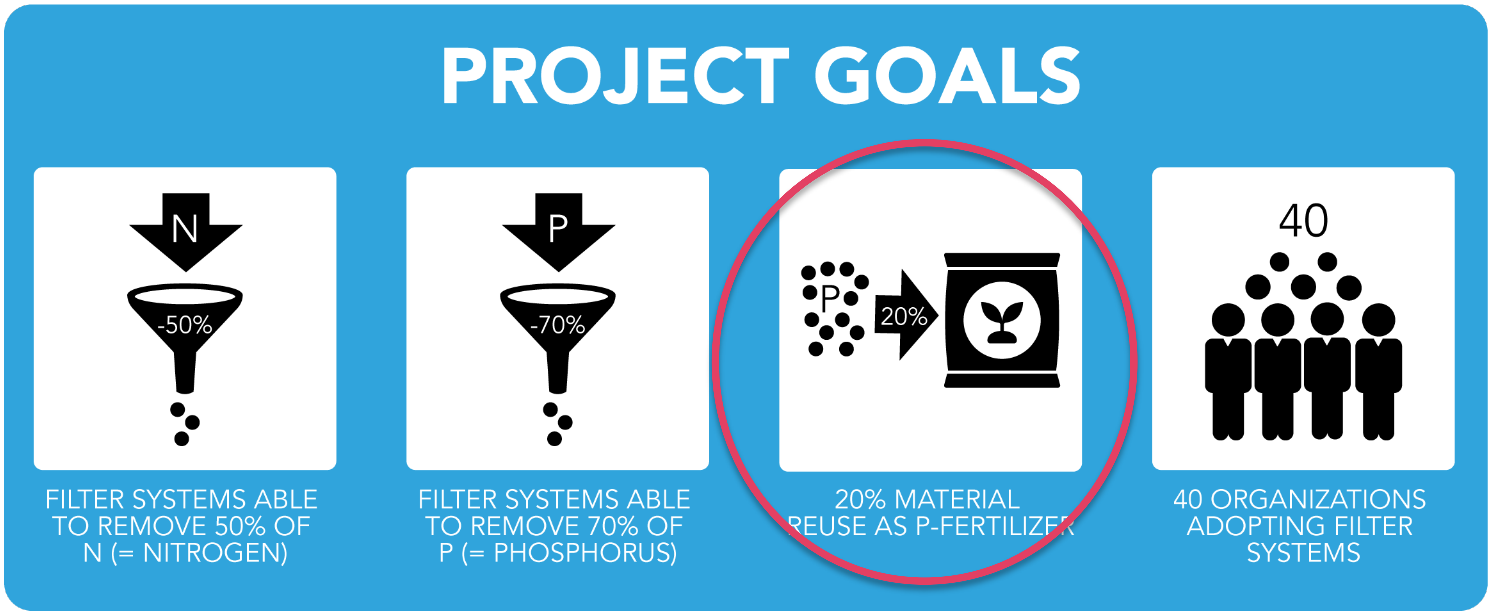
Reuse of saturated filter materials as fertilizer for ornamentals and vegetables

Els Pauwels

Ornamental Plant Research (PCS), Belgium

Project goals



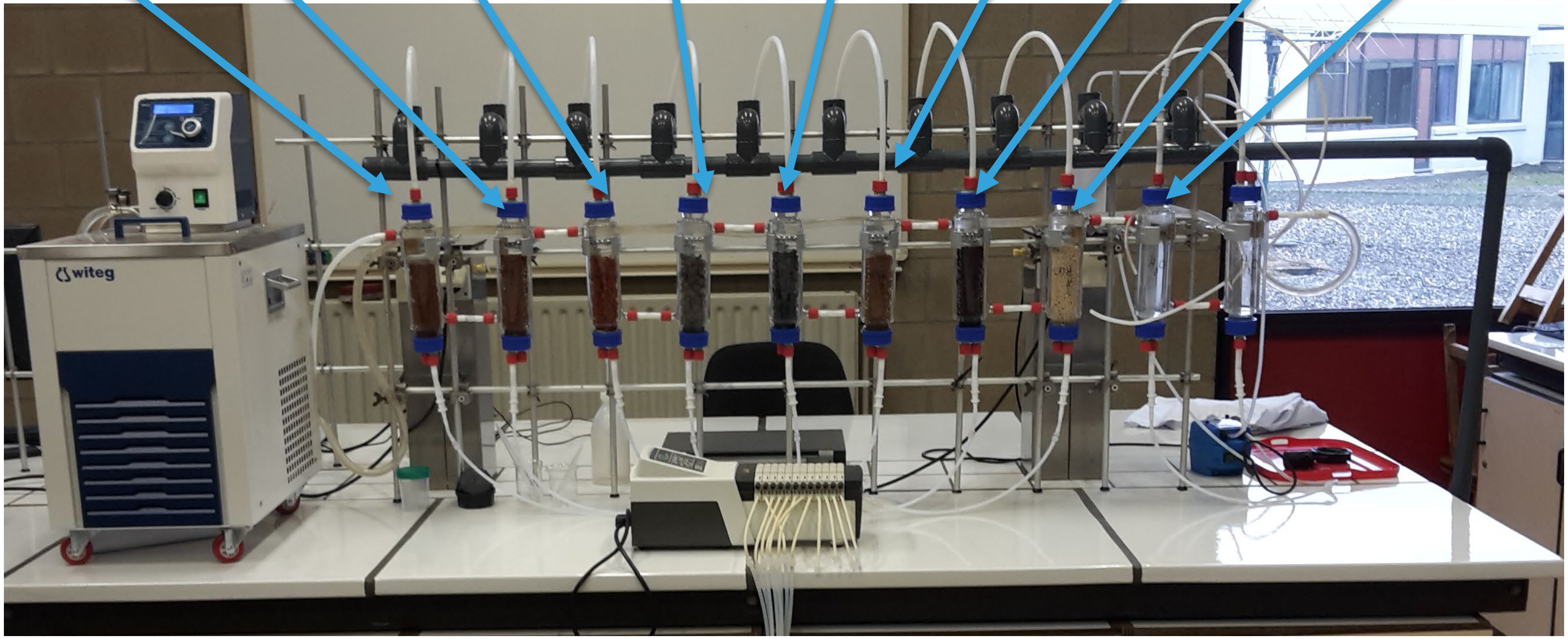
Problem statement

- Phosphorus recovery potential

P-removal – Column tests

- PO_4-P solution: 0.5 ppm P
- Bed height: 14 cm ⇒ corresponds with a bed volume of 150 mL
- Temperature: 20 °C
- Flow rate: 0.66 L/24 h

ICS, Diapure, Redmedite, BaseLith, LiDonit, Vito A, Vito B, LDH, FerroSorp



Problem statement

Available: ICS (Iron coated sand) :

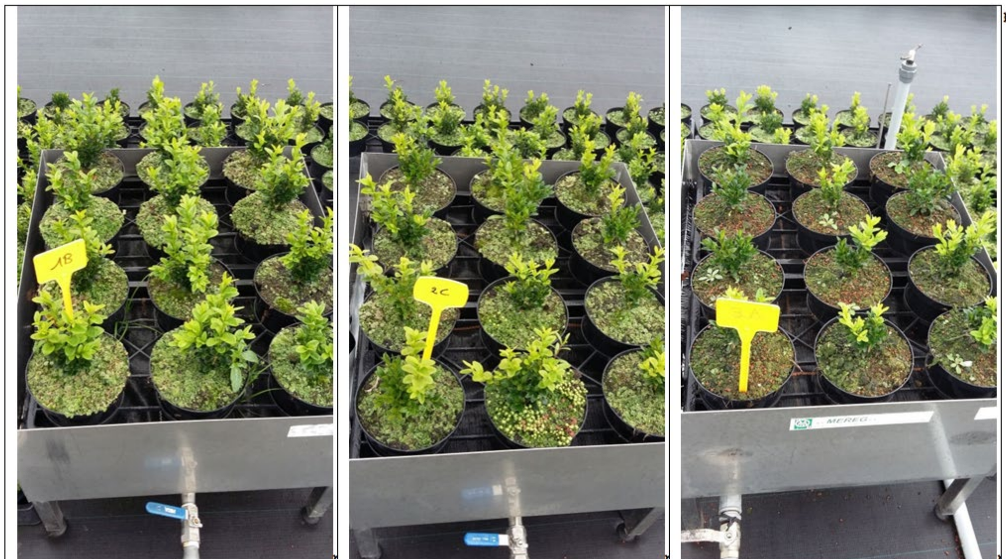
- Waste product from drinking water production
- Good removal of P - rich drainage waters
- High conductivity of filters (depending on size of particles)
- (Sufficiently) available and (relatively) cheap

- Reuse as a fertilizer without treatment?

P recovery

Direct reuse as P fertilizer

- Pot trials done on Azalea, Lavender, Boxwood, Hedera, …

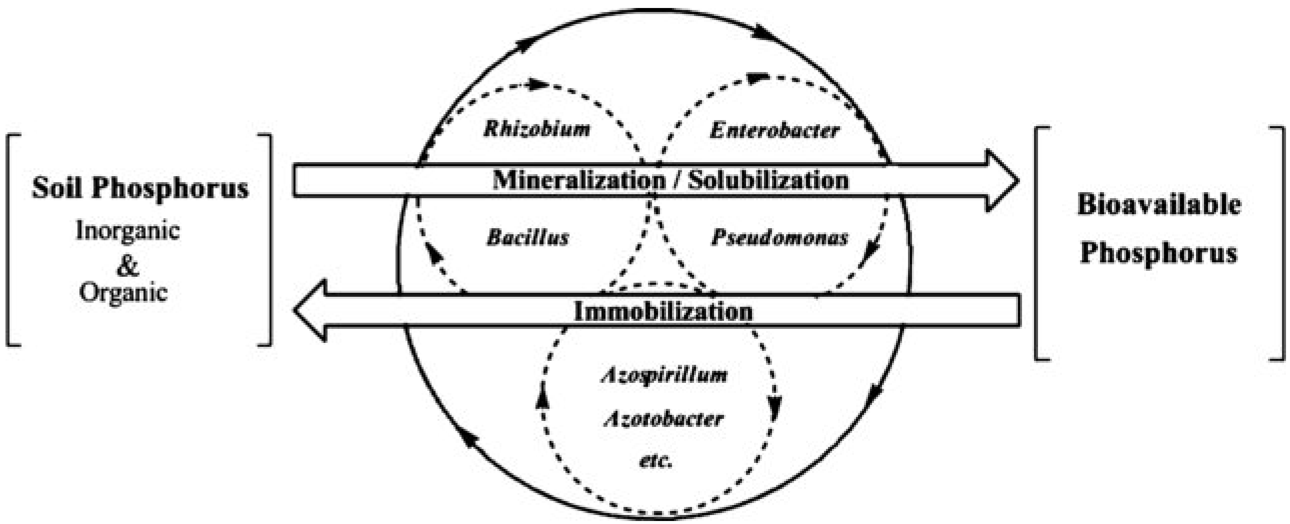


Standard N + standard P	Standard N without P	Standard N without P + 30% ICS

→ P strongly bound to FeO, not available for the plant

PSB

Schematic diagram of soil phosphorus mineralization, solubilization and immobilization by rhizobacteria



- Predominant bacterial PSB's (sharma et al, 2013):
  - Pseudomonas spp.
  - Bacillus spp.
- P – SOLUBILIZING POTENTIAL depends on :(Sharma et al, 2013)
  - Iron concentration in the soil
  - Soil temperature
  - C and N sources available

Addition of PSB

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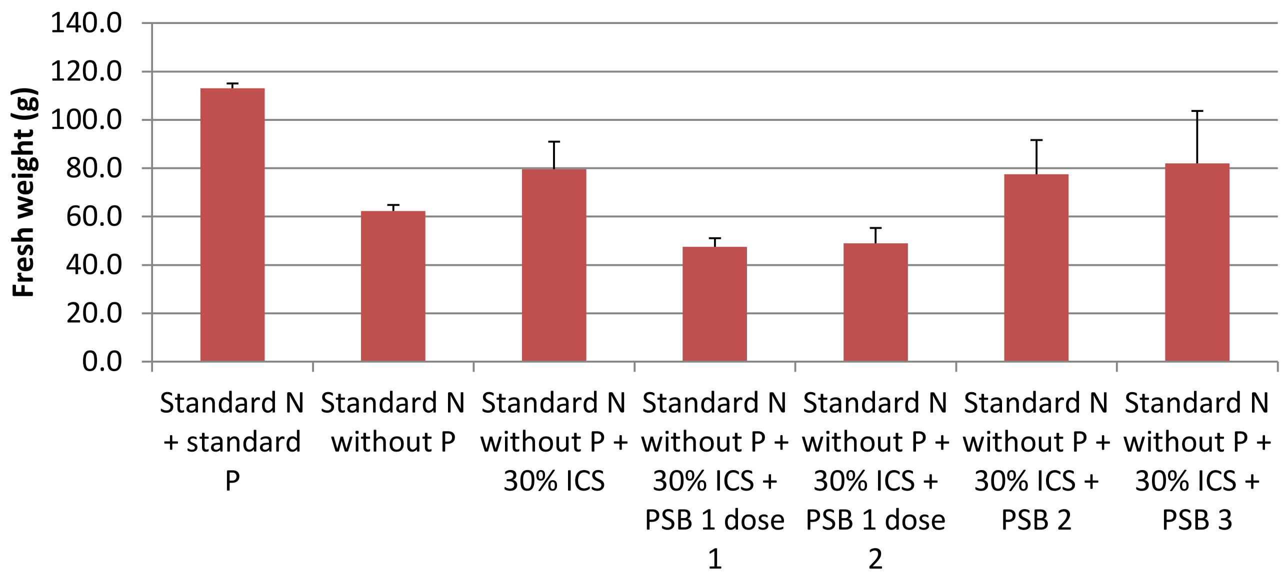
- PSB = Phosphate Solubilizing Bacteria



→ No effect of PSB

Trials Inagro in agriculture

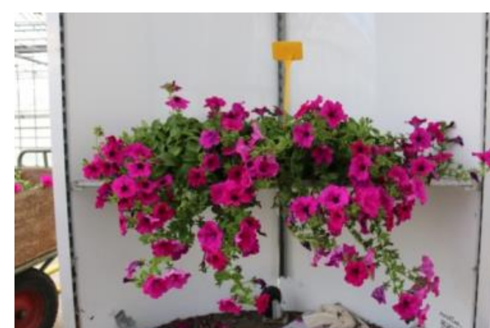
Endive:

- growth chamber experiment + pot experiment
- Use of ICS as a P – fertilizer
- Use of PSB’s
- Evaluation of commercial products

Maize:

- Pot experiment
- Evaluation of commercial products

Trial PCS: 14 different plant species



Trial PCS: As addition to the substrate? Chlorophytum

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- Evaluation at end of trial (16/07/2018)

rooting 5 (left) – rooting 7 (right)

	# rootings trough pot	rootscore 1-7	Fresh weight (13 plants)	Visual plant quality
With ICS	8,3	6,2	333,13	9
Without ICS	8,5	6,2	310,37	9

Exceptions

- **Chrysanthemum**

- **Chlorophytum**

left without ICS – right with ICS

- **Petunia**

Trial PCS 2020

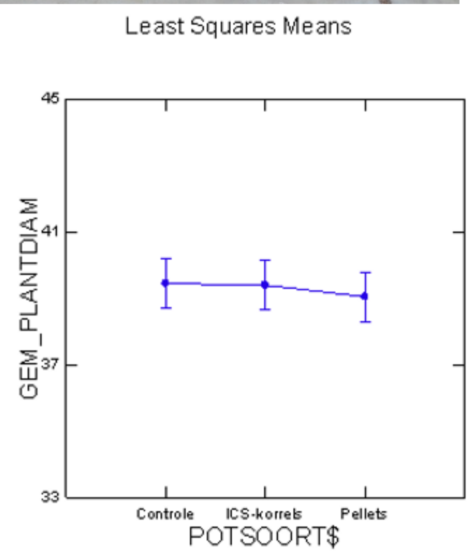
20 plants/treatment

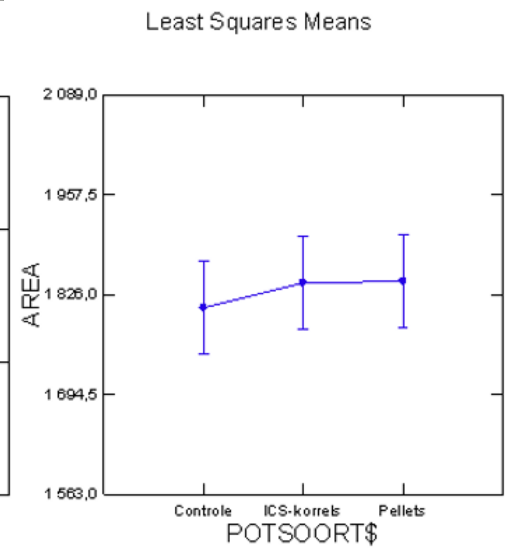
- 1. Control
- 2. 30% ICS grains
- 3. 30% pellets

Trial 2020

Trial 2020

Flowering on the 15th of October: left standard, middle 30% pellets and right 30% ICS grains





Other possibilities to use ICS?

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Standard N + standard P	Standard N without P	Standard N without P + 30% ICS

Thank you

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