How to cope with so much food !

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Challenges for nitrifying bacteria in urine

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Pictures from Eawag's main building

Forum Chriesbach, Dübendorf

Pictures from Eawag's main building

Urine collection tank

NoMix toilet

Waterless urinal

85,000 UDDTs in peri-urban Durban / South Africa

Pictures: Max Grau, Thomas Hug

Urine-diverting dehydration toilets (UDDTs)

Volume of feces is reduced, most pathogens are killed.

Usually, urine is infiltrated into the ground.

Picture: Linda Strande

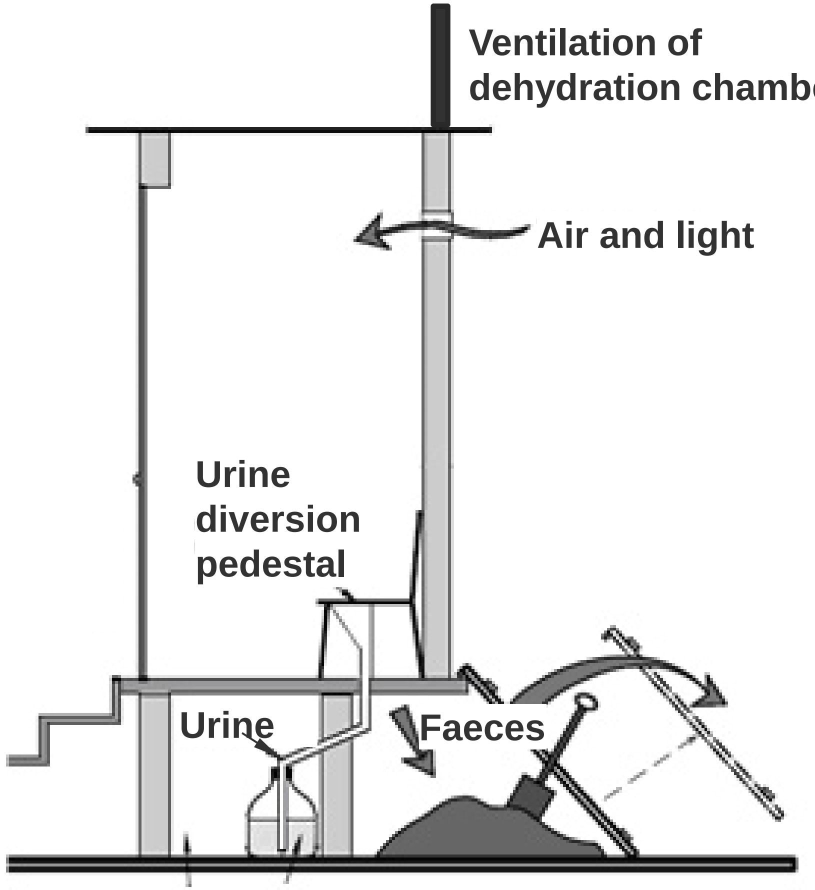

Figure: © WEDC

The VUNA project

Promoting sanitation by recovering nutrients from source-separated urine

1. Reactor technology

2. Management of dispersed urine tanks and reactors

3. Socio-economic boundaries

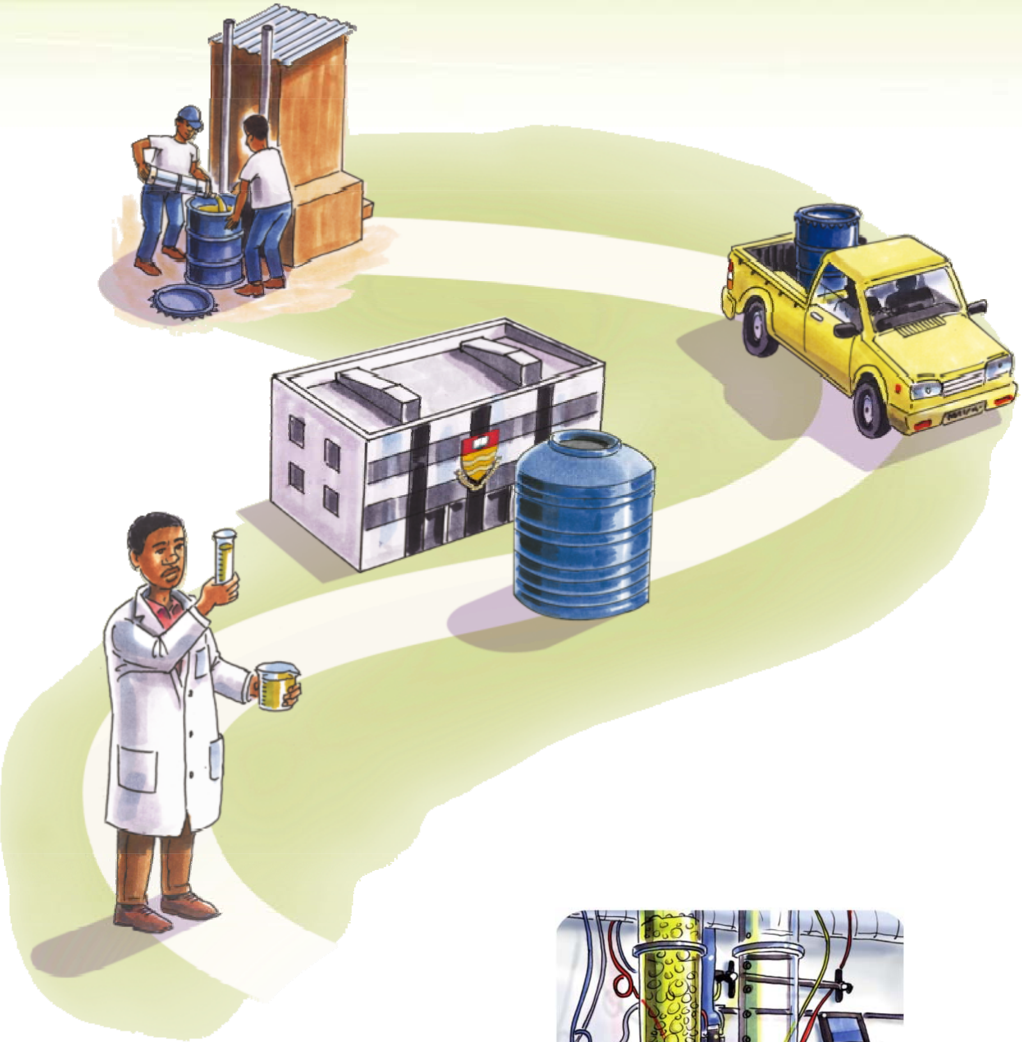

Figure: © Eawag

Complete Nutrient Recovery

Step 1

Stabilization by nitrification

$NH_4^+ + 2\ O_2 \rightarrow NO_2^- + 2\ H_2O + 2\ H^+$

$NO_2^- + 0.5\ O_2 \rightarrow NO_3^-$

Step 2

Water removal by distillation

Picture: Michael Wächter

Biological nitrification

Ammonia oxidizing bacteria (AOB)

$$NH_3 + 0.5\ O_2 \longrightarrow NH_2OH$$

$$NH_2OH + O_2 \longrightarrow NO_2^- + H_2O + H^+$$

Nitrite oxidizing bacteria (NOB)

$$NO_2^- + 0.5\ O_2 \longrightarrow NO_3^-$$

Two main effects
1.) pH decrease
2.) Nitrogen fixation as nitrite or nitrate

Picture: Kai Udert

Fertilizer production at Eawag

Nitrification

Destillation

Fertilizer product

Pictures: Kai Udert, Peter Penicka

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AURIN fertilizer

Zusammensetzung (Minimalgehalte)
Composition (teneurs minimales / minimum contents) [%]:

4.2	N	Gesamtstickstoff / Azote total / Total Nitrogen
0.4	P_2O_5	Phosphat / Phosphate / Phosphate
1.8	K_2O	Kaliumoxid / Oxyde de potassium / Potassium Oxide
1.7	Na	Natrium / Sodium / Sodium
0.8	SO_3	Schwefeltrioxid / Anhydride sulfurique / Sulphur Trioxide
3.1	Cl	Chlorid / Chlorure / Chloride
0.0015	B	Bor / Bore / Boron
0.0001	Fe	Eisen / Fer / Iron
0.0012	Zn	Zink / Zinc / Zinc
0.1	TOC	Ges. org. Kohlenstoff / Carbone org. tot. / Tot. Org. Carbon

Ausgangsmaterial: Separat gesammelter menschlicher Urin.
Als Blumen-, Rasen- oder Zierpflanzendünger verwenden.
Nur im Freien und in gut belüfteten Räumen verwenden. Nur auf aufnahmefähige Böden ausbringen. **Anwendung (1 Mal pro Monat):** Einzelpflanzen: 10 mL Flüssigdünger in 1 L Wasser verdünnen. Flächen (pro m^2): 50 mL Flüssigdünger in 5 L Wasser verdünnen. **Aufbewahrung:** Trocken und in verschlossenem Gebinde aufbewahren. **Entsorgung:** Restmengen der bestimmungsgemässen Verwendung zuführen. Leere Packungen können mit dem Hauskehricht entsorgt werden. **Sicherheit: Ausser Reichweite für Kinder und Tiere aufbewahren. Flüssigdünger (konzentriert oder verdünnt) nicht in freie Gewässer gelangen lassen.**

The substrate: changes during urine collection

		Fresh	Stored
Urea	$g_N\ m^{-3}$	5300	~ 0
Ammonium	$g_N\ m^{-3}$	270	**4100**
Phosphate	$g_P\ m^{-3}$	330	240
Potassium	$g_K\ m^{-3}$	2000	1500
Sulfate	$g_{SO4}\ m^{-3}$	890	710
COD	$g\ m^{-3}$	7600	6500
pH		6.4	**9.0**

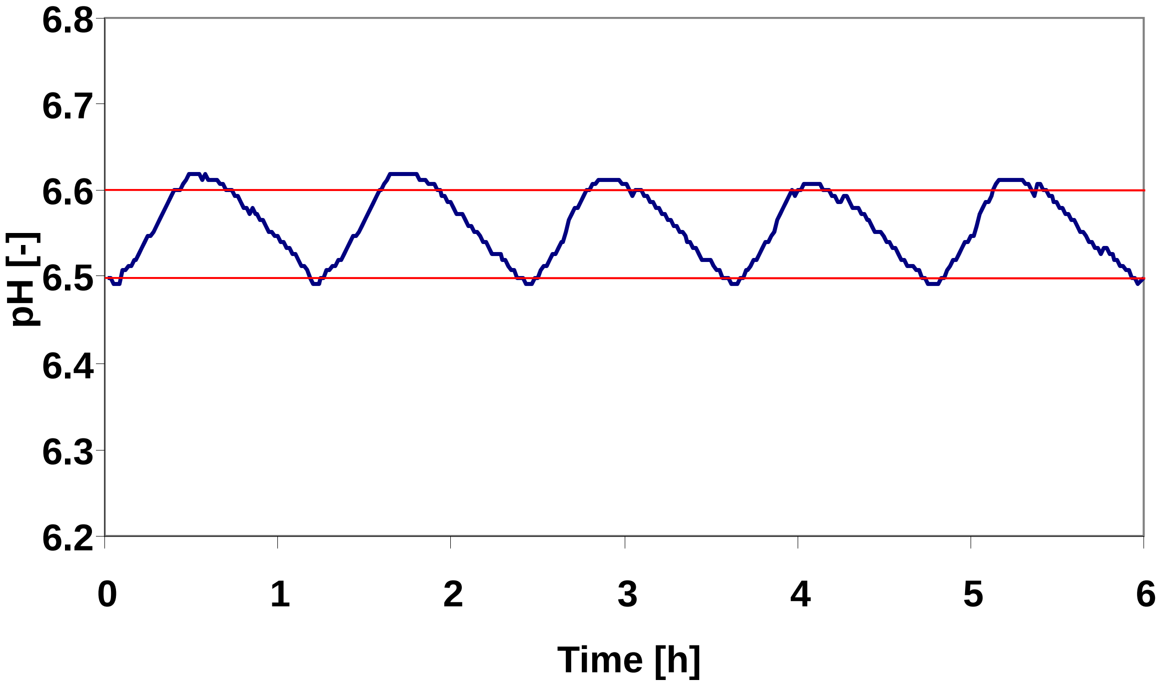
Values for men's urine at Eawag

Urine collection tank
Forum Chriesbach Eawag

Operation of nitrification reactor

pH critical for stable nitrate production

pH control with influent pump



Biofilm carriers

Picture: Bastian Etter

Three major failures

Case 1: Sudden and strong increase of urine load

- AOB inhibited by NH_3
- Complete cessation of nitrification

Case 2: Urine dosage too fast

- Elevated pH and elevated NH_3
- Nitrite accumulation
- NOB completely inhibited

Case 3: Low or no urine dosage

- Acid-tolerant AOB grow in
- No NOB, loss of nitrogen gases such as nitric oxide

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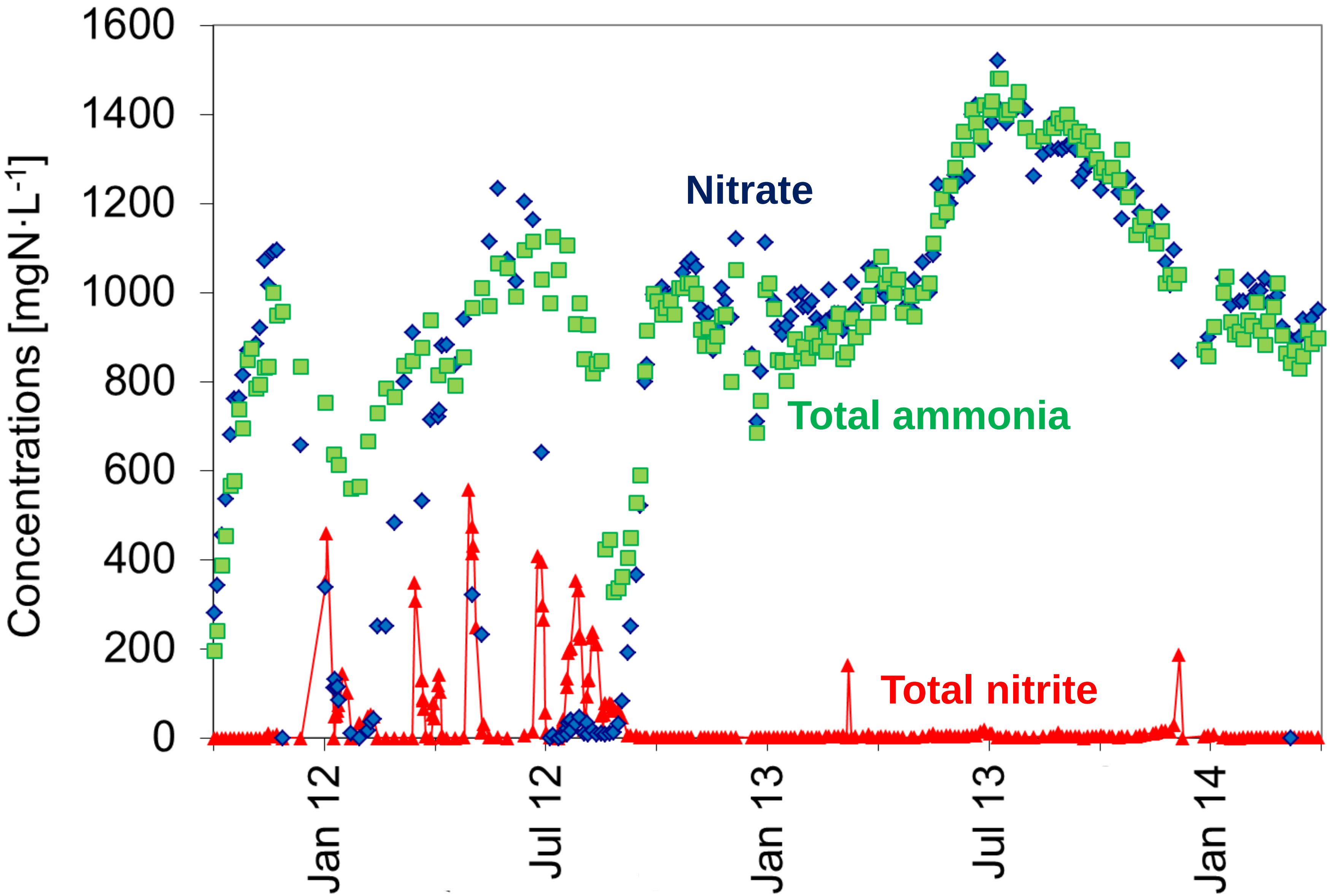
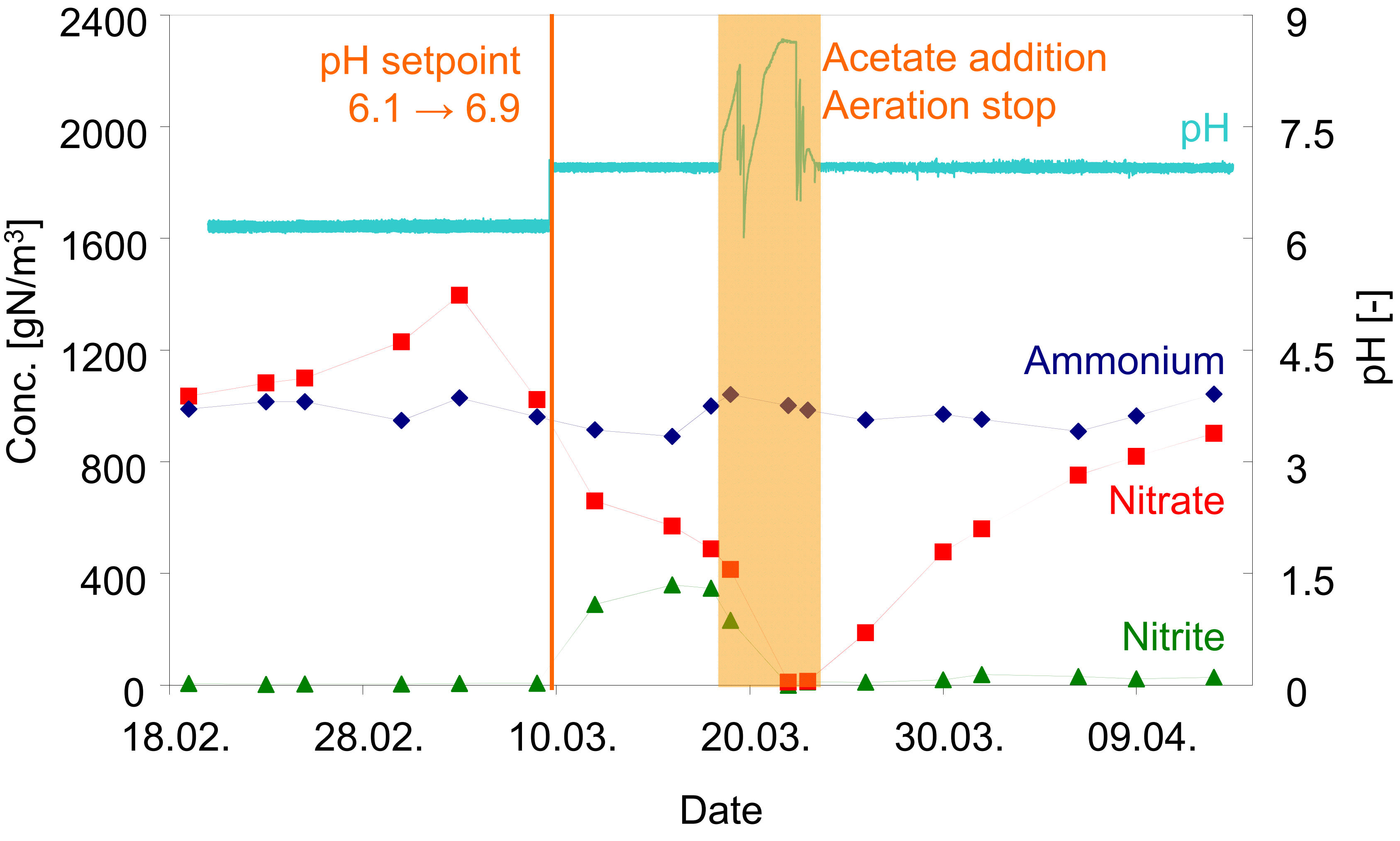
Case 2: Accumulation of nitrite

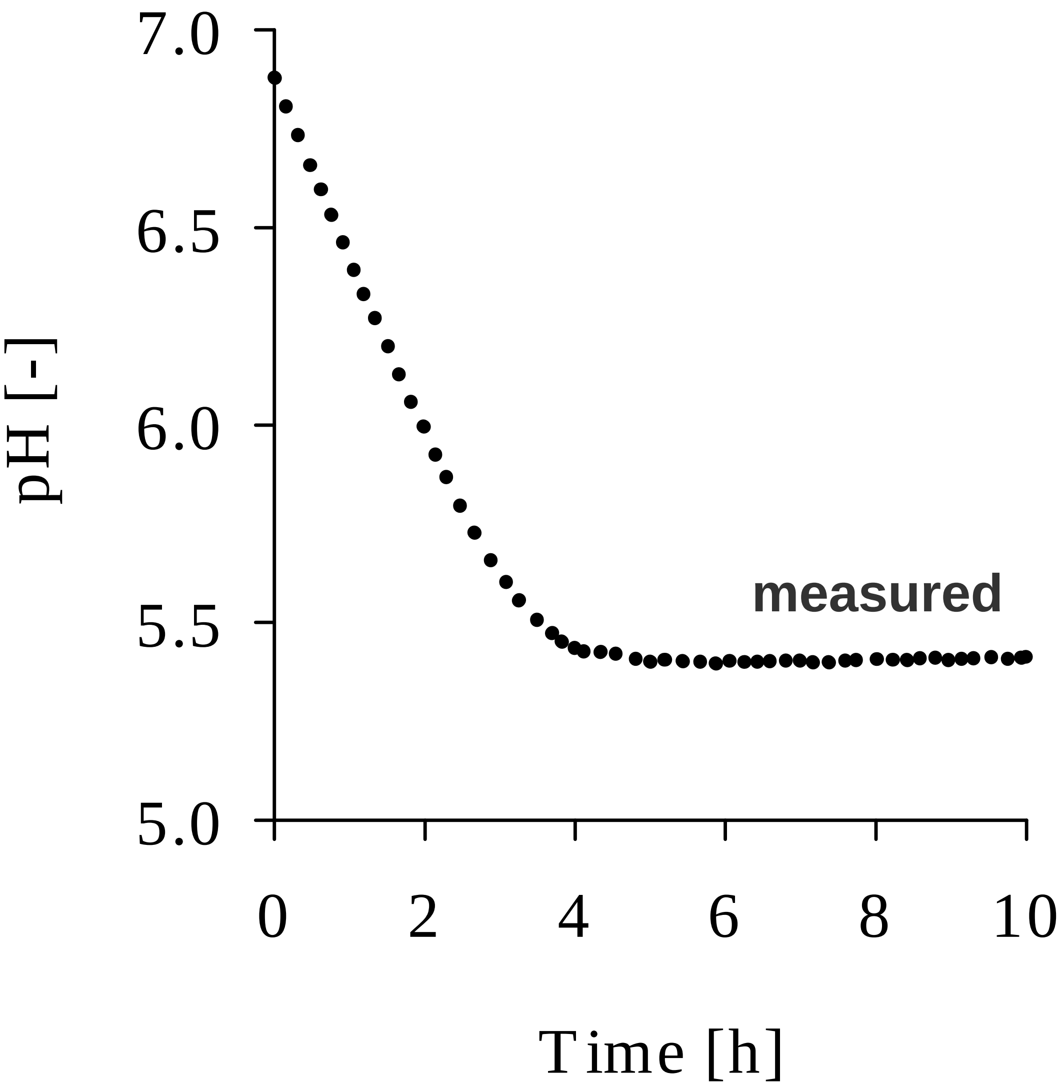


Case 2: Nitrite accumulation due to pH change



Udert, K.M. and Wächter, M. (2012)

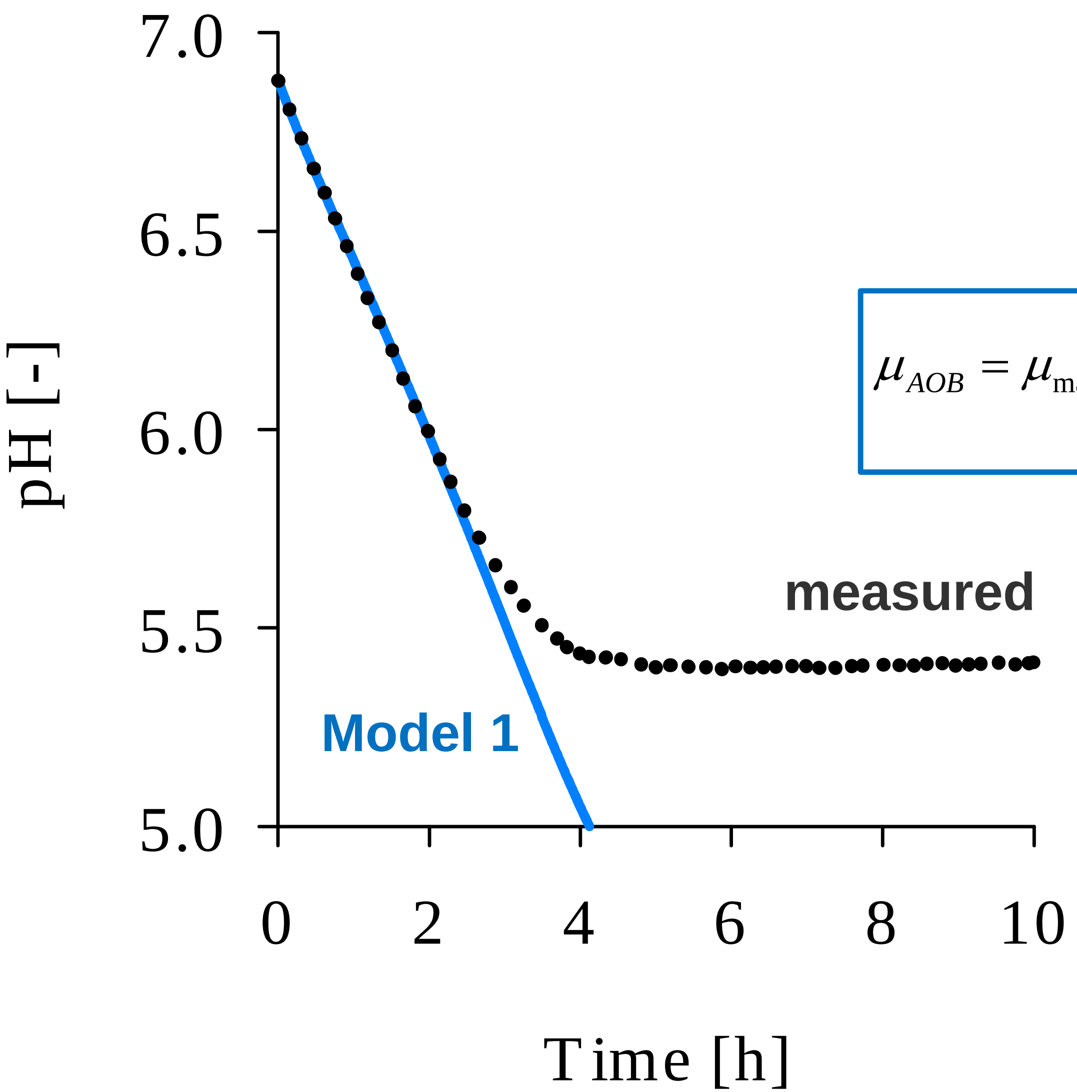
Case 3: pH limit of ammonium-oxidizing bacteria



Growth of *Nitrosomonas eutropha* decreases with pH and stops at pH 5.4

Fumasoli et al. (2015)

Case 3: Modelling of low pH value with Monod



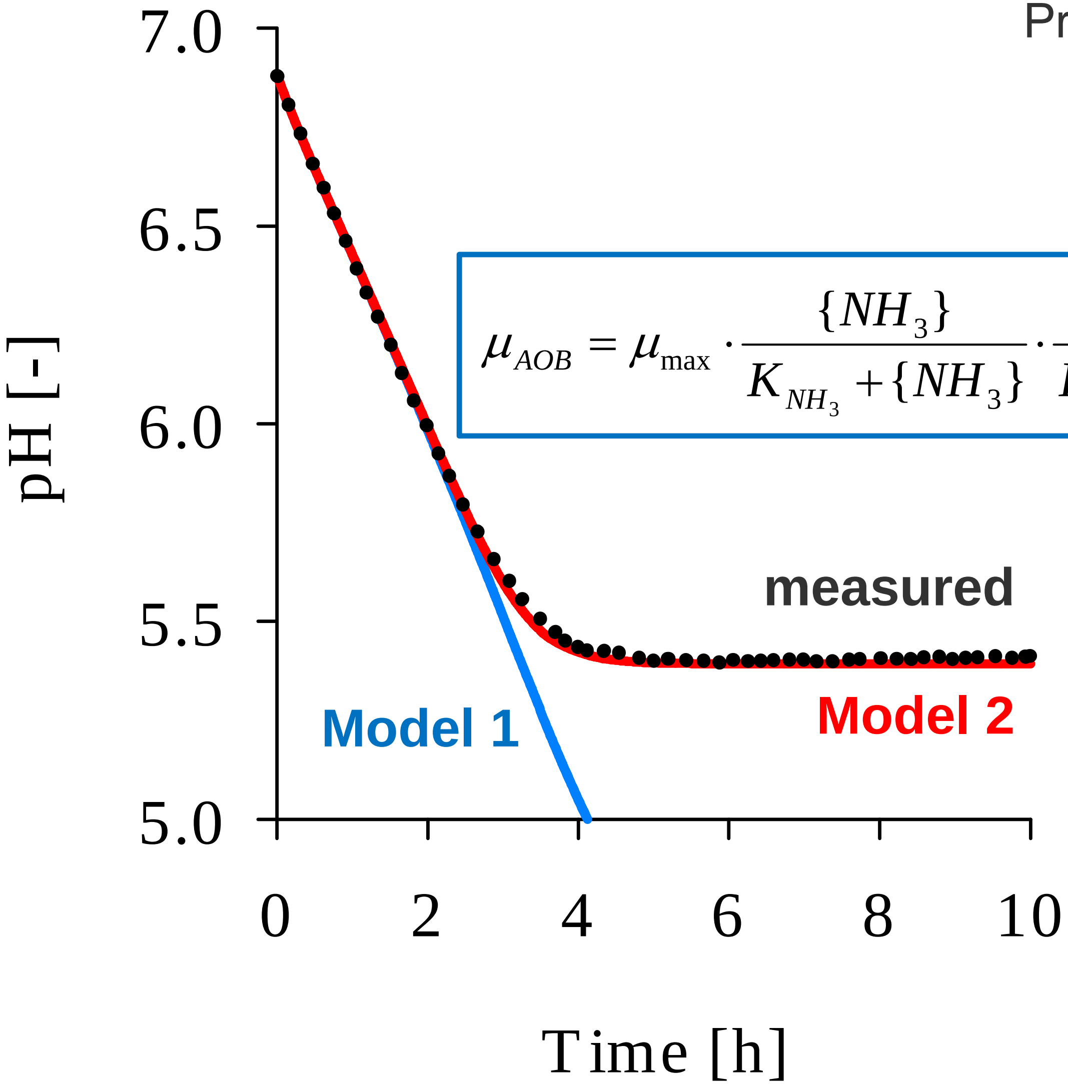
limitation by NH_3
or
inhibition by HNO_2

$$\mu_{AOB} = \mu_{max} \cdot \frac{\{NH_3\}}{K_{NH_3} + \{NH_3\}} \cdot \frac{I_{HNO_2}}{I_{HNO_2} + \{HNO_2\}}$$

Fumasoli et al. (2015)

Case 3: low pH value

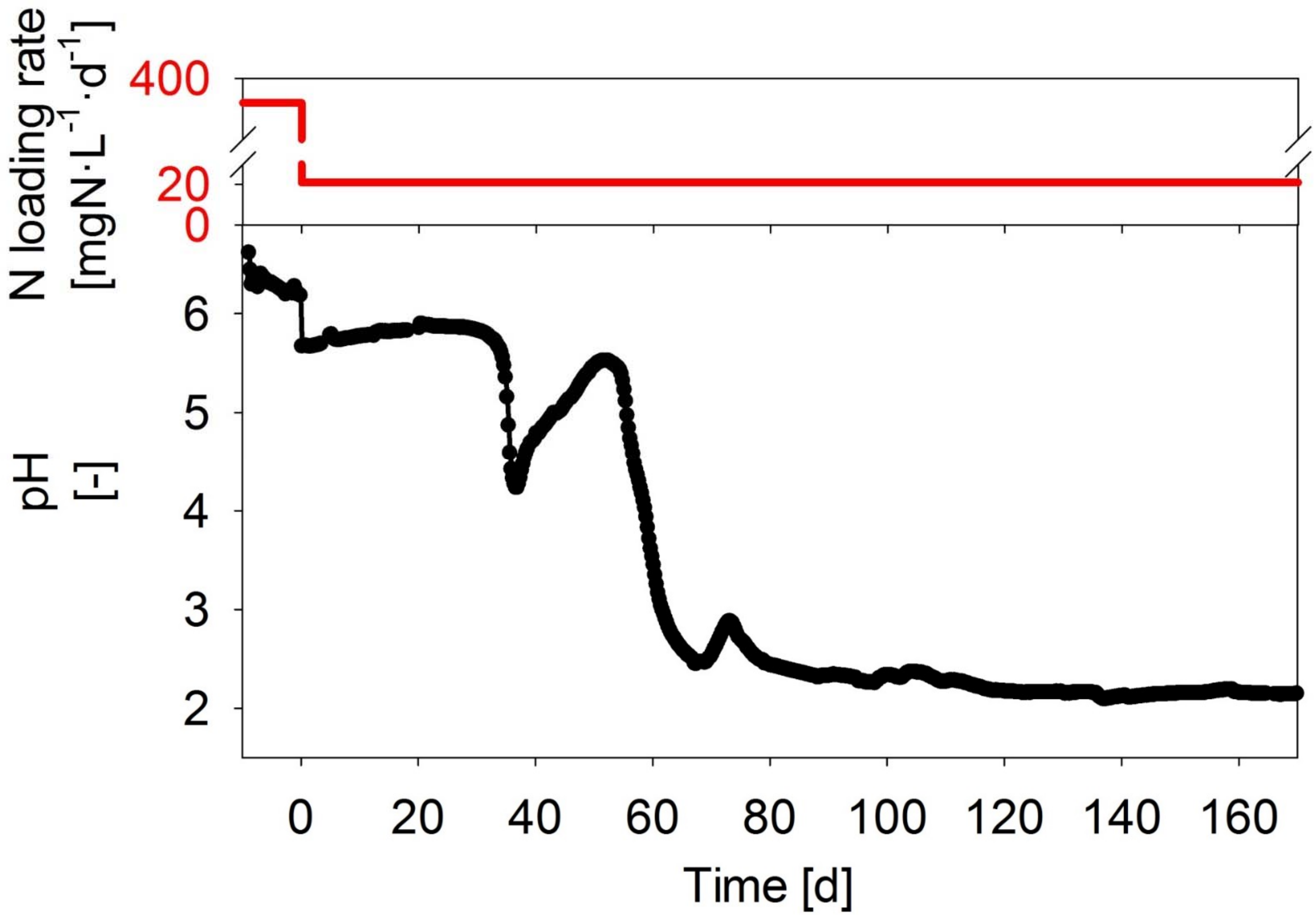
Proton-motive force becomes too small for NADH production



$$\mu_{AOB} = \mu_{\max} \cdot \frac{\{NH_3\}}{K_{NH_3} + \{NH_3\}} \cdot \frac{I_{HNO_2}}{I_{HNO_2} + \{HNO_2\}} \cdot \left(1 - 10^{(K_{pH}(pH_{\min} - pH))}\right)$$

Fumasoli et al. (2015)

Case 3: low pH value due to strong inflow decrease



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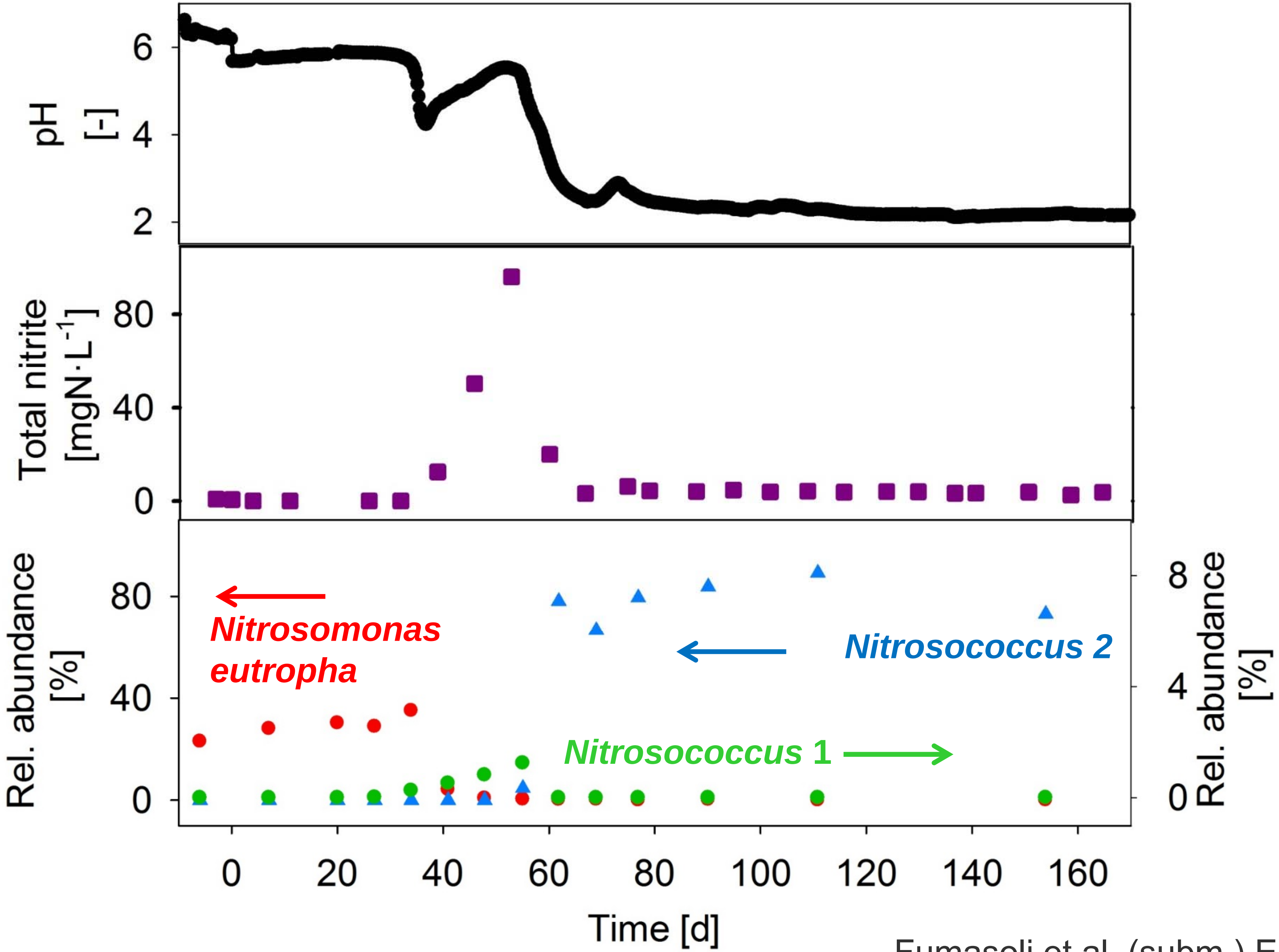
Case 3: low pH value due to strong inflow decrease



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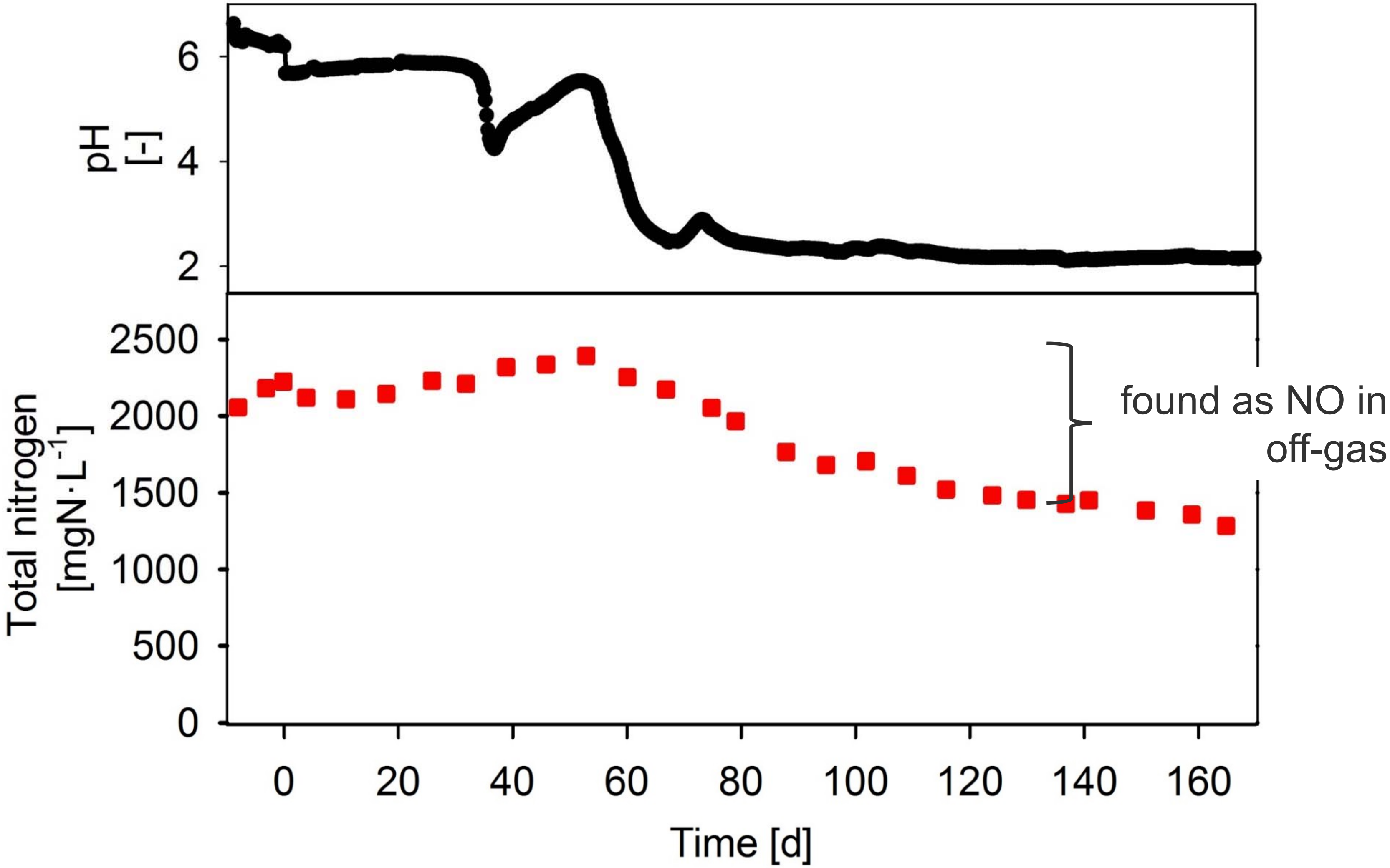
Case 3: Nitrogen losses as NO



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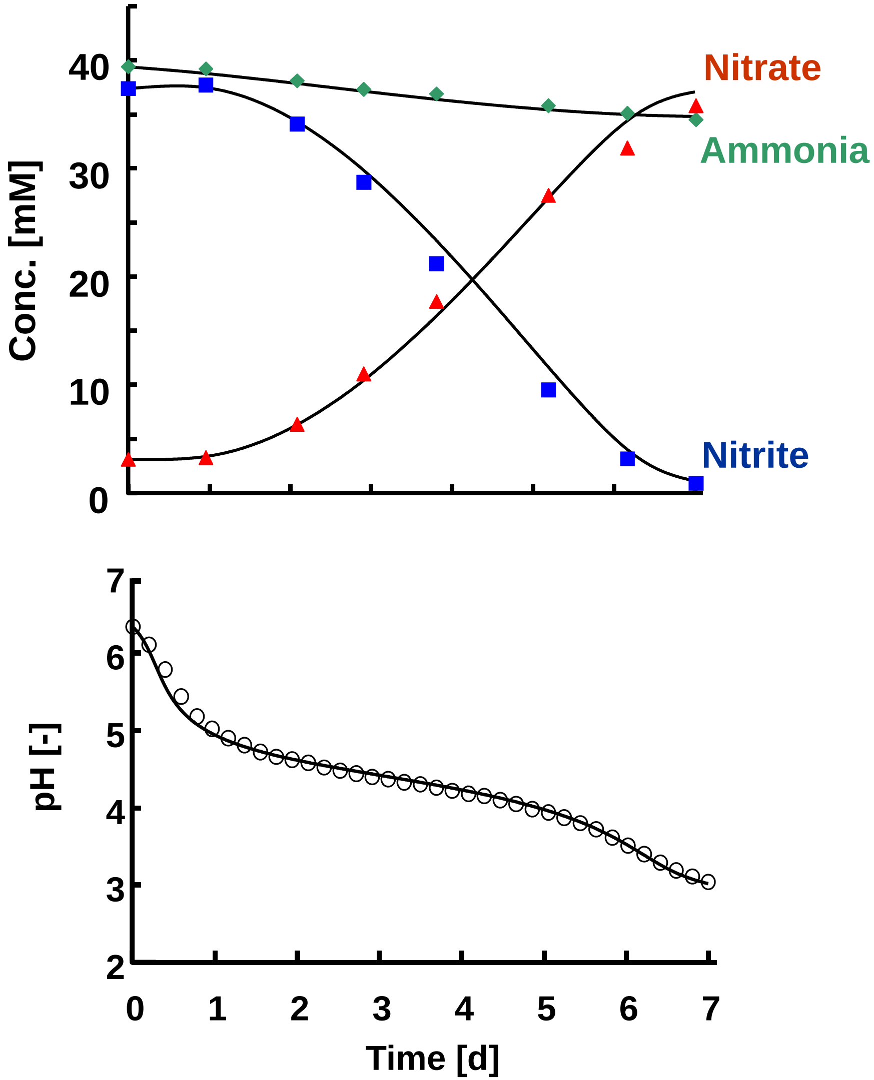
Case 3: Modelling low pH values



Microbial Ammonium Oxidation:

$NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + 2\ H^+ + H_2O$

Chemical Nitrite Oxidation:

$2\ HNO_2 \leftrightarrow NO + NO_2 + H_2O$

$NO + 0.5\ O_2 \rightarrow NO_2$

$2\ NO_2 + H_2O \leftrightarrow HNO_2 + NO_3^- + H^+$

Chemical Ammonium Oxidation

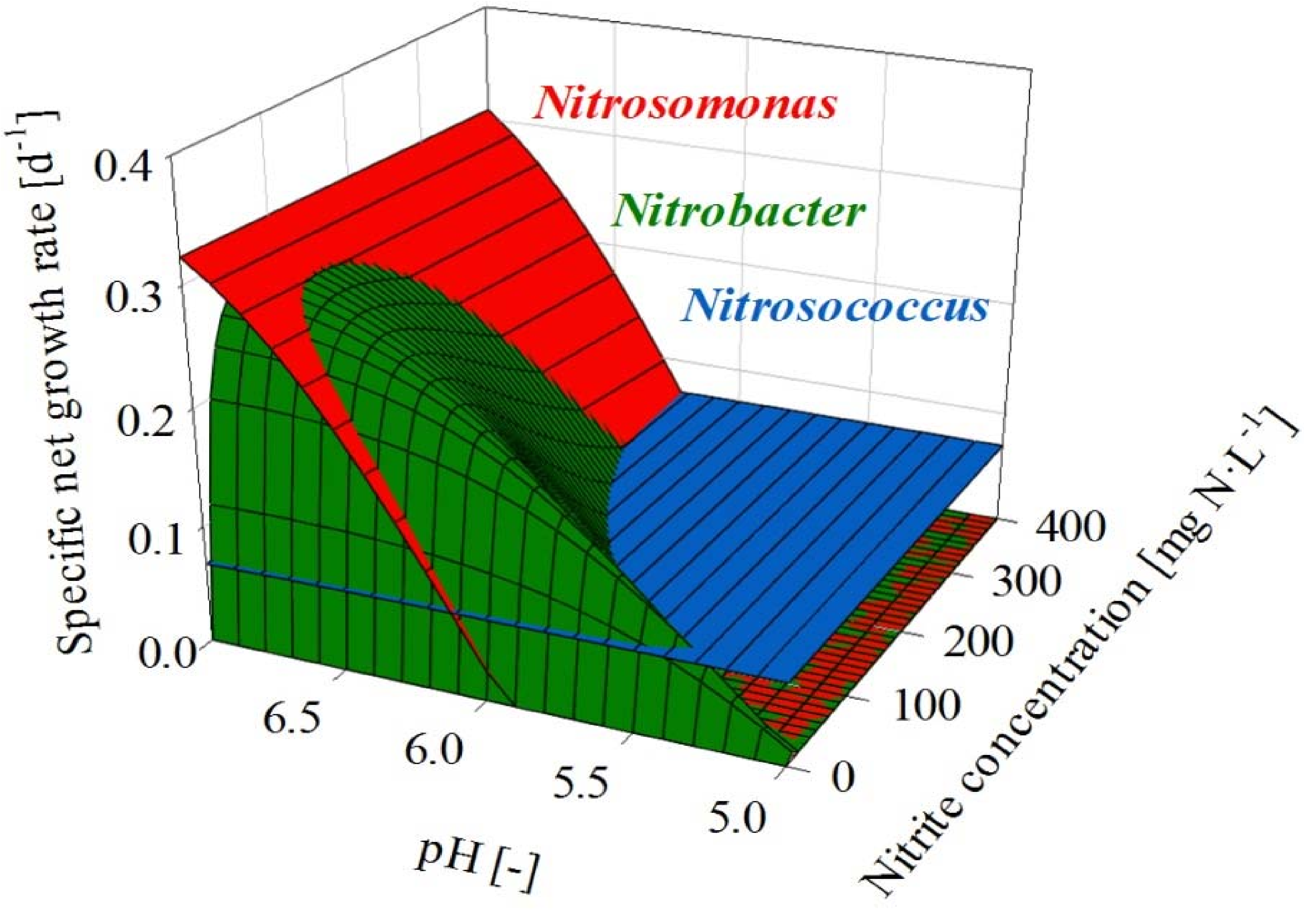
$NO + NO_2 \rightarrow N_2O_3$

$N_2O_3 + NH_3 \rightarrow N_2 + HNO_2 + H_2O$

Volatilization and acid-base equilibria

Udert et al. (2005)

Optimal range for urine nitrification at steady state



Fumasoli et al. (subm.) Water Research

Conclusions

Nitrification is a suitable process for **urine stabilization**.

Reliable **process contr**ol is needed to prevent fatal process failures.

Growth of **acid-tolerant ammonia oxidizing bacteria** is a new and challenging phenomena.

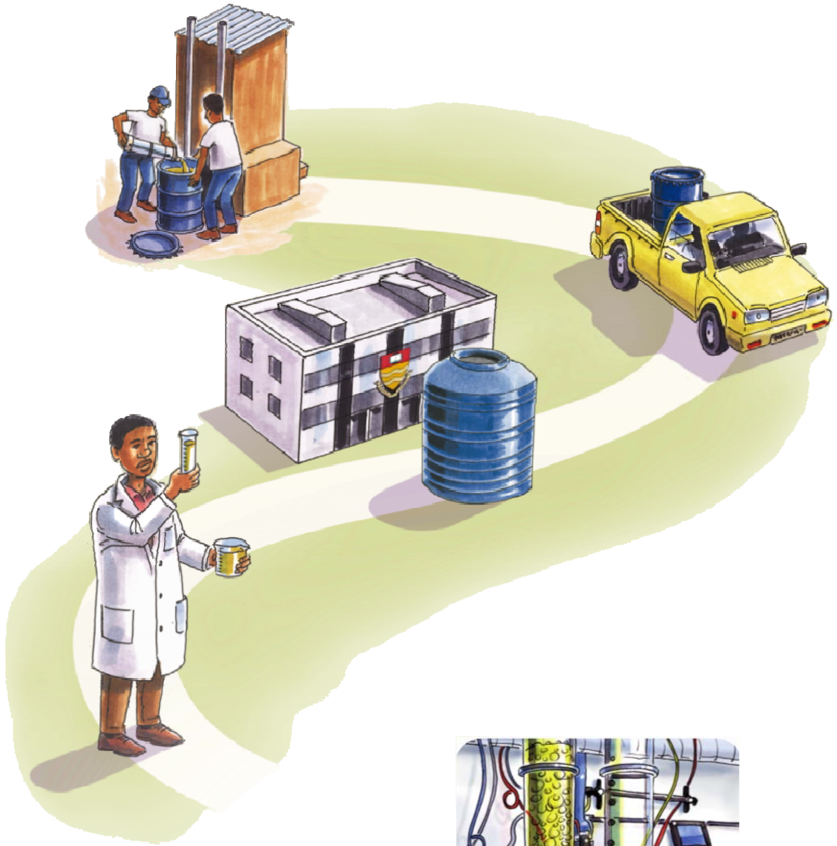
Picture: Kai Udert

Acknowledgements

All my coworkers and colleagues at Eawag and in the VUNA project, especially Alexandra Fumasoli for her work and many of the slides.

Most of the funding was provided by the Bill and Melinda Gates Foundation.

I also thank Eawag for discretionary funding.



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