Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Sanitisation of Faecal Sludge by Ammonia

Treatment Technology for Safe Reuse in Agriculture

PhD dissertation

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Background

- 1 billion people practice open defecation
- 3 billion have toilets with low degree of protection from pathogens[1]
  - User
  - Downstream population
- 1.9 million people die each year of unsafe water, lack of sanitation and poor hygiene[2]

Ref: 1 Baum et al. 2013 , 2 Lopez et al. 2006

Background

- Faecal sludge as fertilizer
  - Contain N,P,K and org.matter
  - Increase food production
  - Reduce depency on mineral fertilizers
- 800 million people in chronic hunger
  - Unsafe water and sanitation: 3.7 % of total loss of Disability Adjusted Life Years (DALY)
  - Mal- and Undernutrition: 15.4 % of total DALY loss [3]
- Risk of transmission of diseases
  - Diarrhea and intestinal worms decrease uptake of nutrients from food

→ *Need for faecal sludge treatment in terms of pathogen inactivation*

Ref: 3 Lopez et al. 2006

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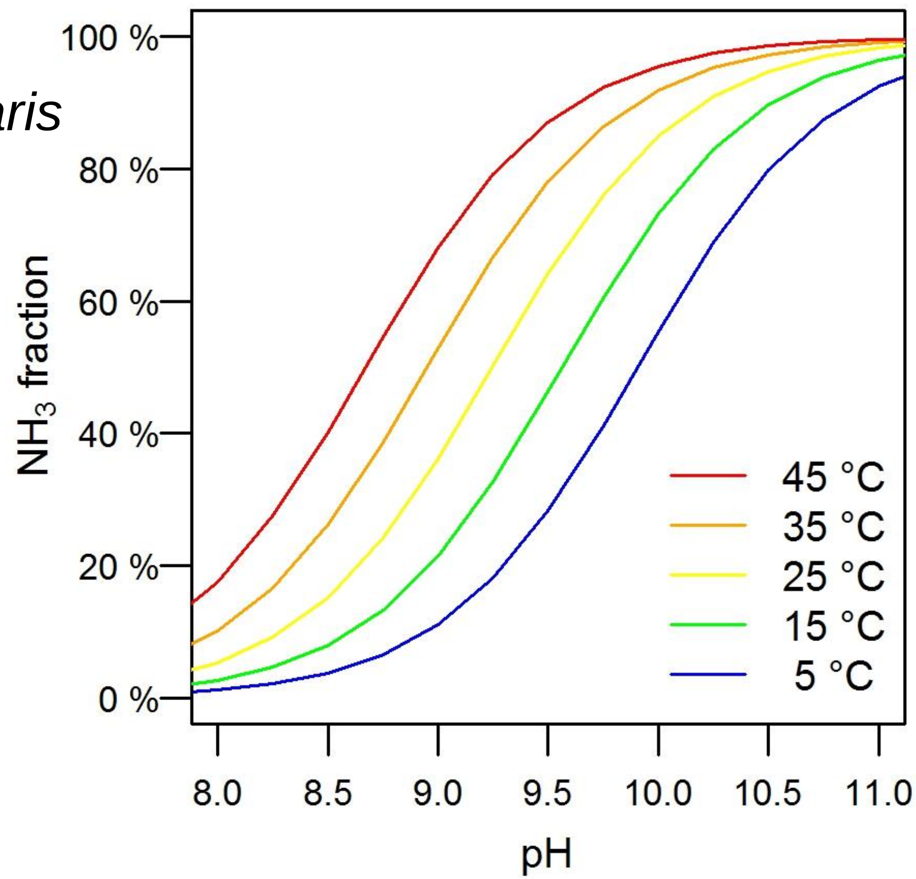
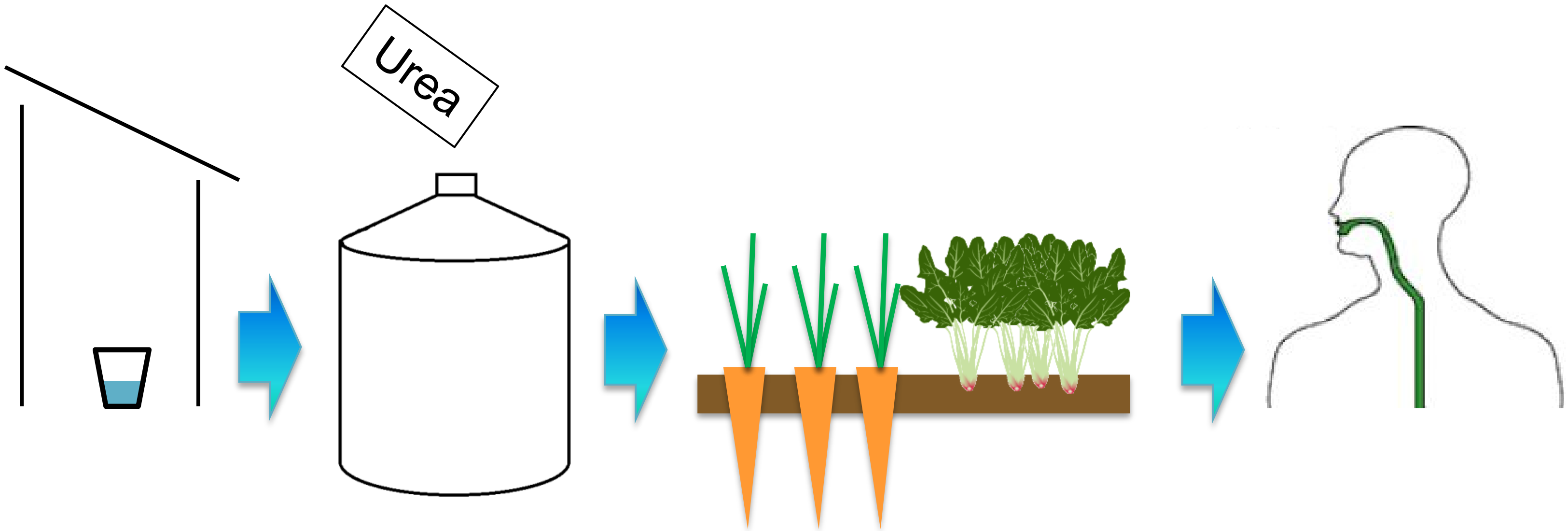
Ammonia sanitisation

- NH_3 inactivates:
  - Helmints eggs, e.g. *Ascaris*
  - Viruses
  - Bacteria
  - Protozoa
- Source of ammonia
  - Urine
  - Urea
- $NH_4^+ \rightleftharpoons NH_3 + H^+$
  - pH
  - Temperature
  - Other ions



Overall aim:

Give treatment recommendations



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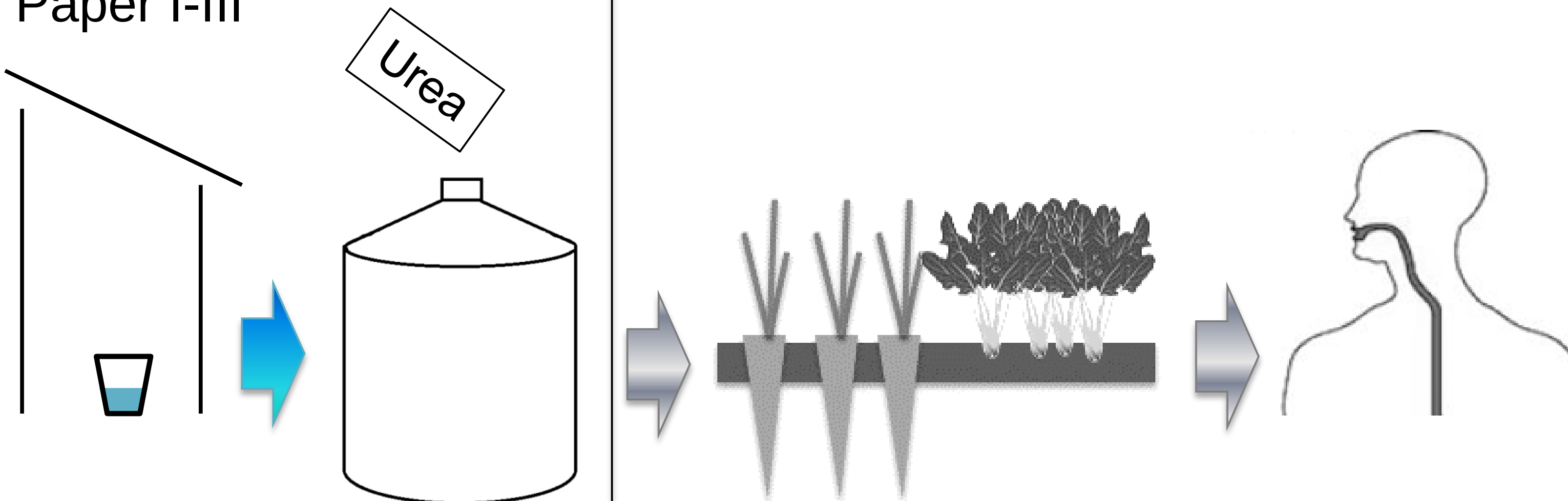
Paper I-III

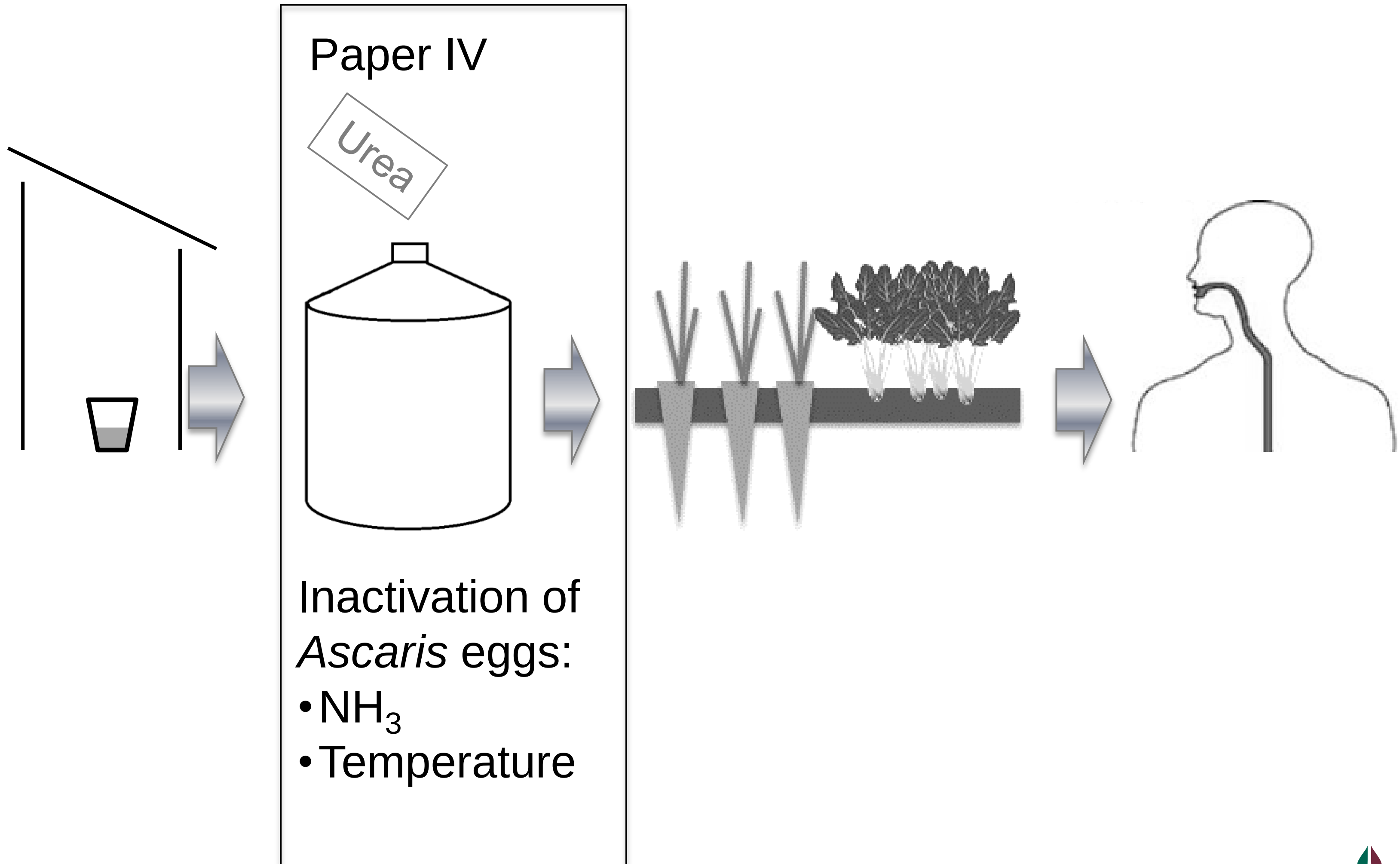


Inactivation of pathogens:

- Flushwater volumes
- Urine content
- Urea dose
- Temperature

Overall aim:

Give treatment recommendations



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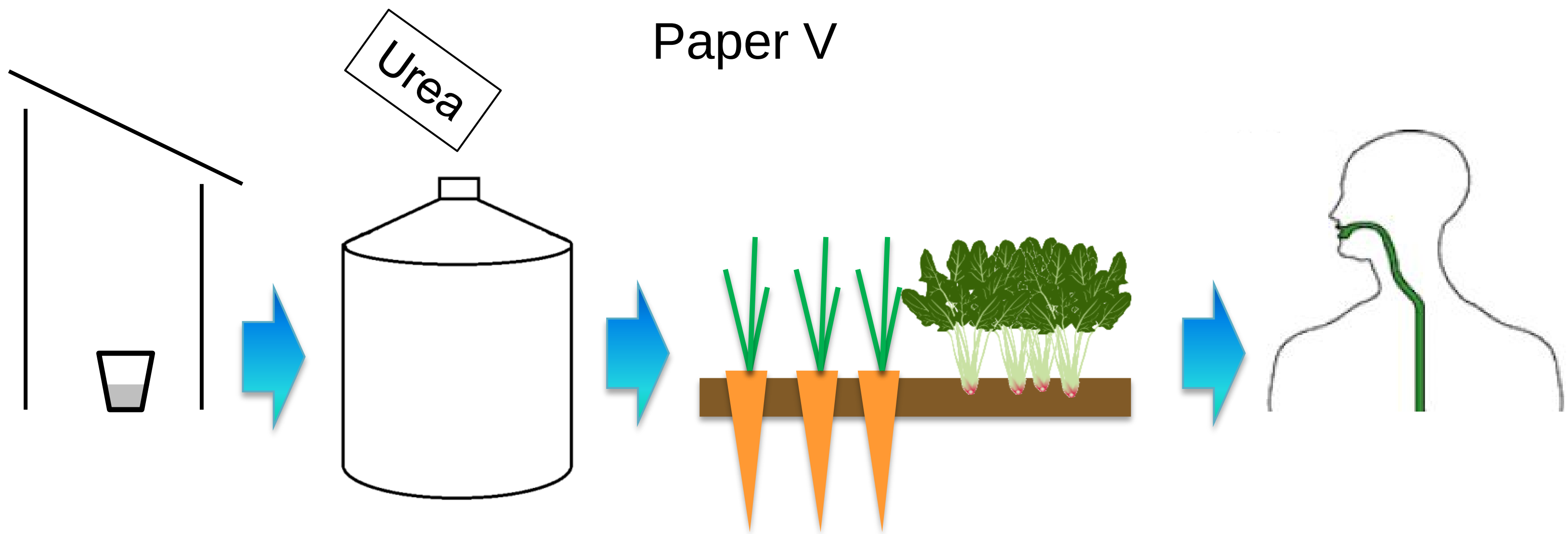
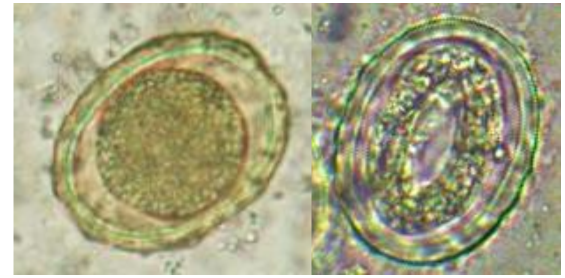


Pathogen inactivation impact the health risk

Lab studies (Paper I-III)

Organisms studied

- Helminths
  - *Ascaris suum*
- Bacteria
  - *Salmonella* Typhimurium
  - *Enteroccus faecalis*
- Viruses
  - Reovirus
  - Adenovirus
  - PhiX174
  - MS2
  - 28B



Lab studies (Paper I-III)

Treatment	Temp.	Salmonella, Enterococcus, MS2, PhiX	Ascaris, reovirus, adenovirus, 28B
UDDT1/ UDDT2	10 °C	x	x
Vacuum 1	10 °C	x	
Vacuum 2	10 °C	x	
Vacuum 3	10 °C	x	
Vacuum 4	10 °C	x	
Vacuum 5	10 °C	x	
Pour flush 1	10 °C	x	
Pour flush 2	10 °C	x	
UDDT1/ UDDT2	23 °C	x	x
Vacuum 1	23 °C	x	
Vacuum 2	23 °C	x	
Vacuum 3	23 °C	x	
Vacuum 4	23 °C	x	x
Vacuum 5	23 °C	x	x
Pour flush 1	23 °C	x	x
Pour flush 2	23 °C	x	x
UDDT1/ UDDT2	28 °C	x	x
Vacuum 1	28 °C	x	
Vacuum 2	28 °C	x	
Vacuum 3	28 °C	x	
Vacuum 4	28 °C	x	x
Vacuum 5	28 °C	x	x
Pour flush 1	28 °C	x	x
Pour flush 2	28 °C	x	x

Treatment	Temp.	Ascaris, Salmonella	Reovirus, adenovirus
10 % A	32 °C	x	x
0.4 % U	32 °C	x	x
0.15 % U	32 °C	x	x
0.05 % U	32 °C	x	
No additive	32 °C	x	x
1.5 % U	28 °C	x	x
0.75 % U	28 °C	x	x
0.4 % U	28 °C	x	x
0.15 % U	28 °C	x	x
0.05 % U	28 °C	x	
No additive	28 °C	x	x
10 % A	23 °C	x	
1.5 % U	23 °C	x	x
No additive	23 °C	x	x
3 % A	17 °C	x	
1.5 % U	17 °C	x	x
0.75 % U	17 °C	x	x
No additive	17 °C	x	x
10 % A	10 °C	x	
5 % A	10 °C	x	
1.5 % U	10 °C	x	x
No additive	10 °C	x	x
10 % A	4 °C	x	
5 % A	4 °C	x	
1.5 % U	4 °C	x	x
No additive	4 °C	x	x

Results – Inactivation, 28 °C

Toilet	Flush water Volume ($l\ p^{-1}\ d^{-1}$)	Additives	5 log_{10} *Salmonella* (days)	3 log_{10} reovirus (days)	3 log_{10} *Ascaris* eggs (days)
Flush toilet	30	Urea 1.5%	1	12	15
Flush toilet	30	Urea 0.75%	2	21	25
Flush toilet	30	Urea 0.4%	3	33	39
Flush toilet	30	Urea 0.15%	283	33	No red.
Flush toilet	30	-	No red.	200	No red.
UDDT	0	-	1	6	24
Vacuum	2	-	2	11	19
Pour flush	6	-	16	20	42

Impact of temperature

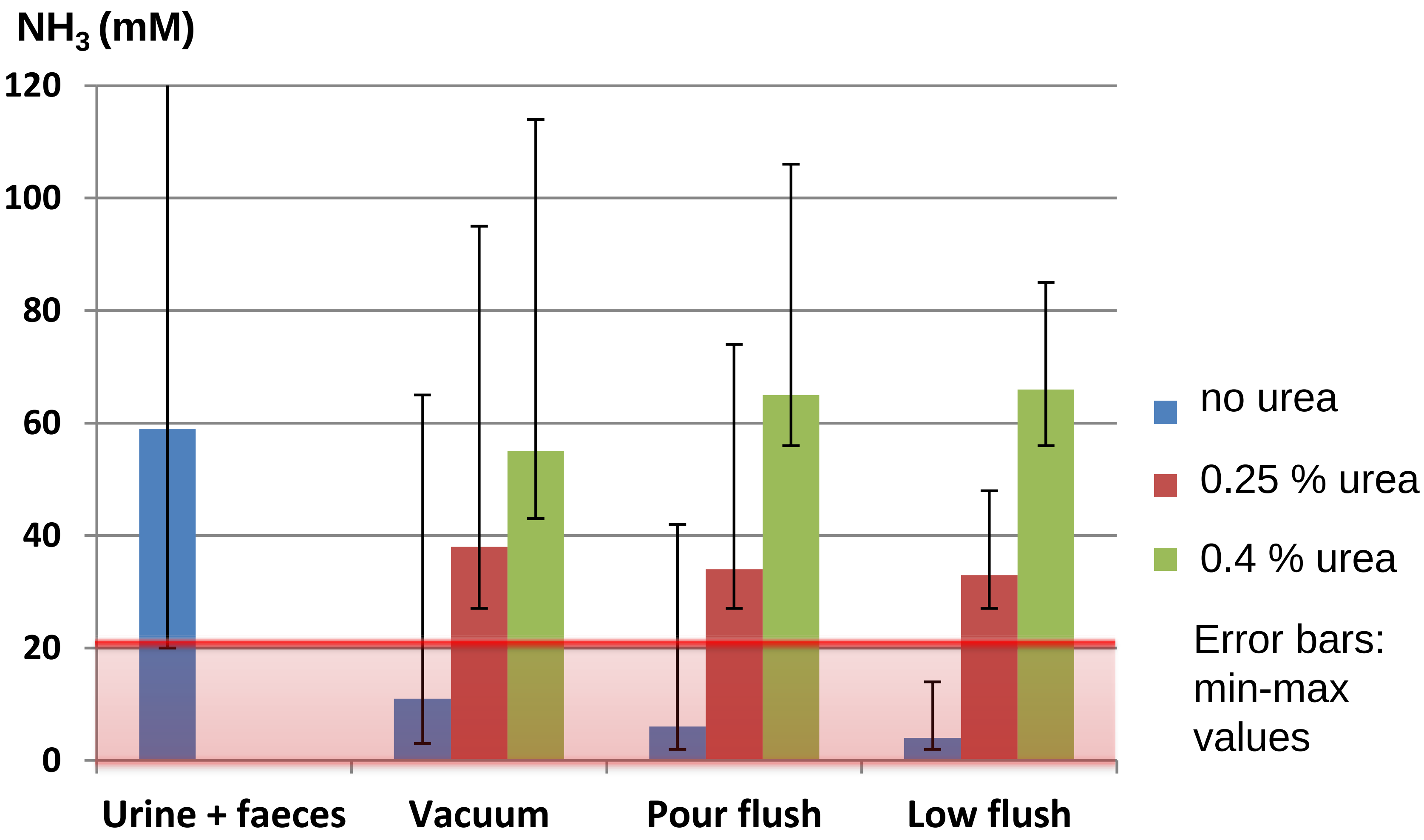
1.5 % urea

	Salmonella 5 $\log_{10}$ (days)	Reovirus 3 $\log_{10}$ (days)	*Ascaris* egg 3 $\log_{10}$ (days)
28 °C	1.0	12	15
17 °C	1.2	49	108
4 °C	2.4	182	No reduction

Is urine enough for pathogen inactivation?

- Estimation of sludge characteristics
  - Flush water consumption
    - Vacuum toilets
    - Pour flush toilets
    - Low-flush toilets
  - Ammonia concentration in urine
  - Amount of faeces
  - Toilet visits per day

Is urine enough for pathogen inactivation?



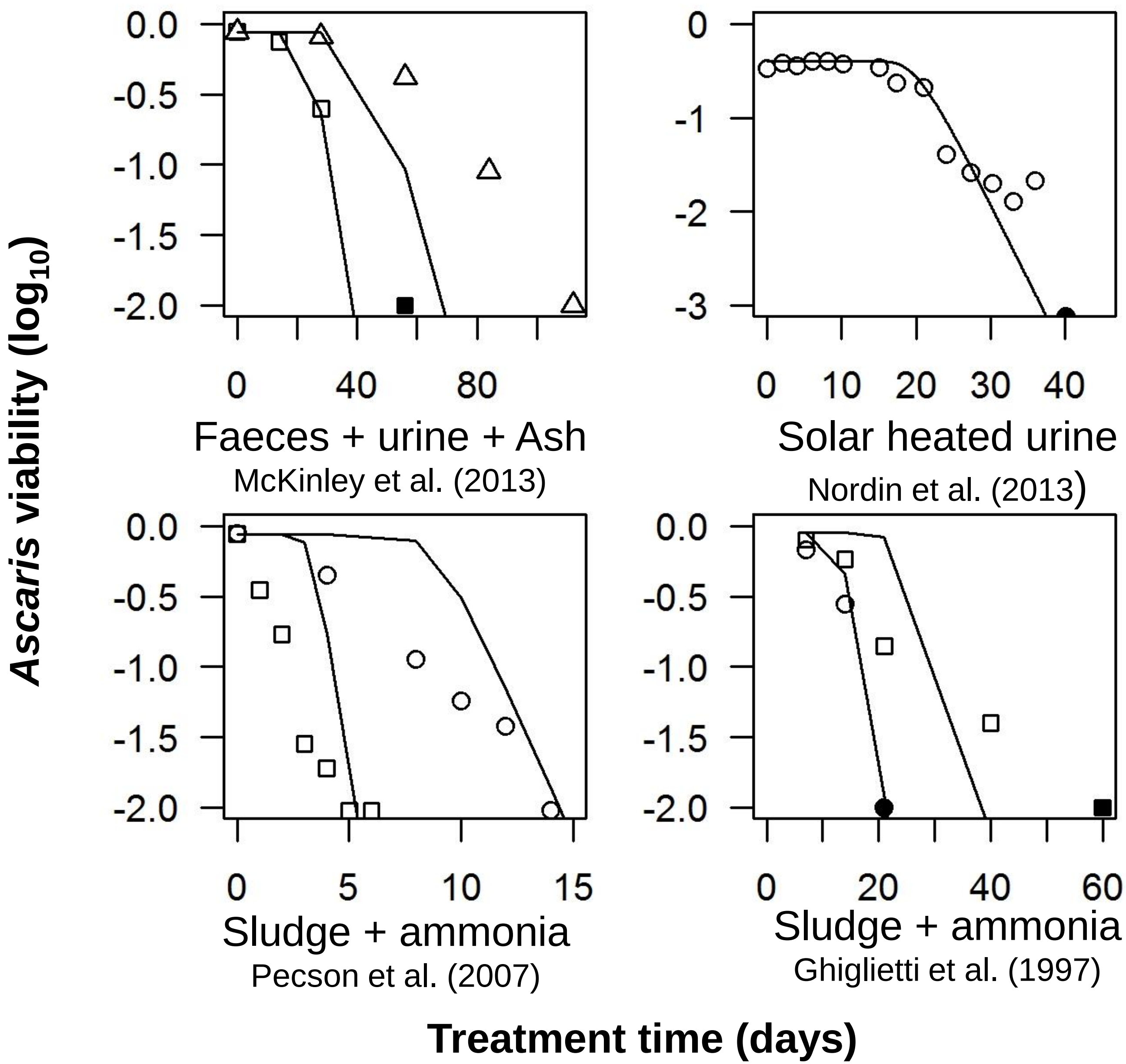
Ascaris egg inactivation model
(Paper IV)

- Method:
  - Non-linear regression on data from 4 studies:
    Paper I, Paper II, Nordin et al. 2009, Pecson et al. 2007
- Result
  - Prediction of treatment time required

$$t = \frac{3.2 + LRV}{10^{-3.7+0.062 \cdot T} \cdot NH_{3,Pitzer}{}^{0.7}} \cdot 1.15$$

- Other factors:
  - Carbonate, CO_3^{2-}
  - Dry matter
  - pH

Ascaris model validation



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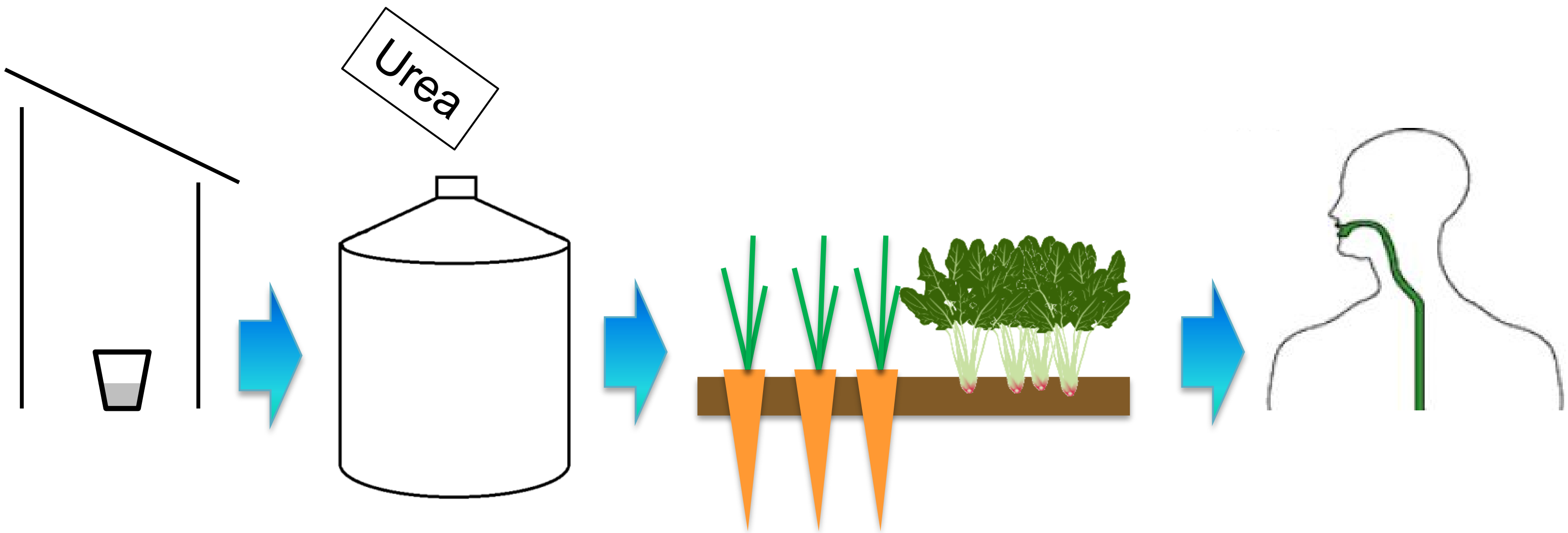
Microbial risk assessment

(Paper V)

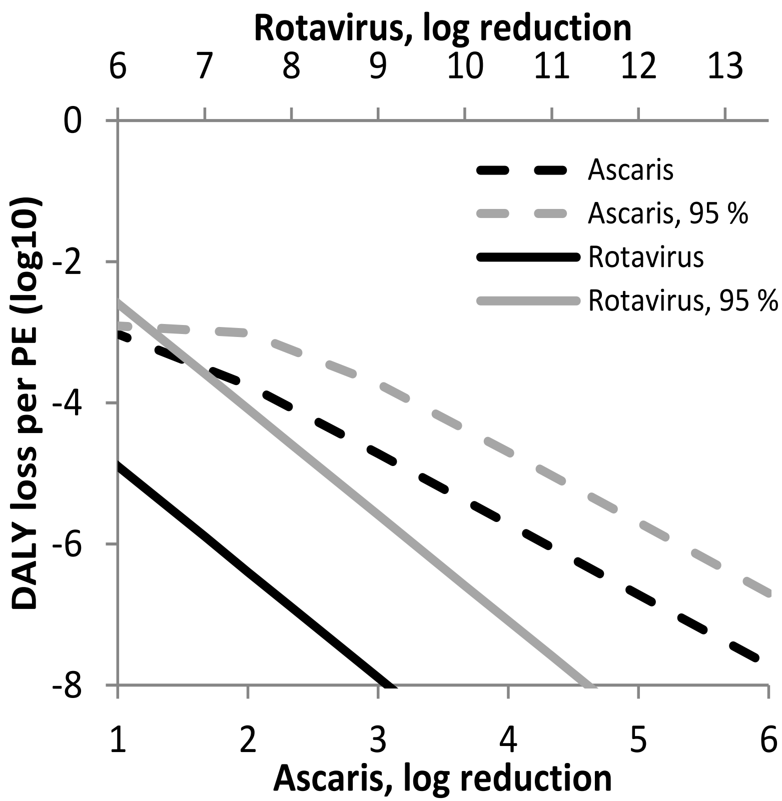


Inactivation required for acceptable median infection risk (10^{-6} DALY $person^{-1}$ $year^{-1}$):

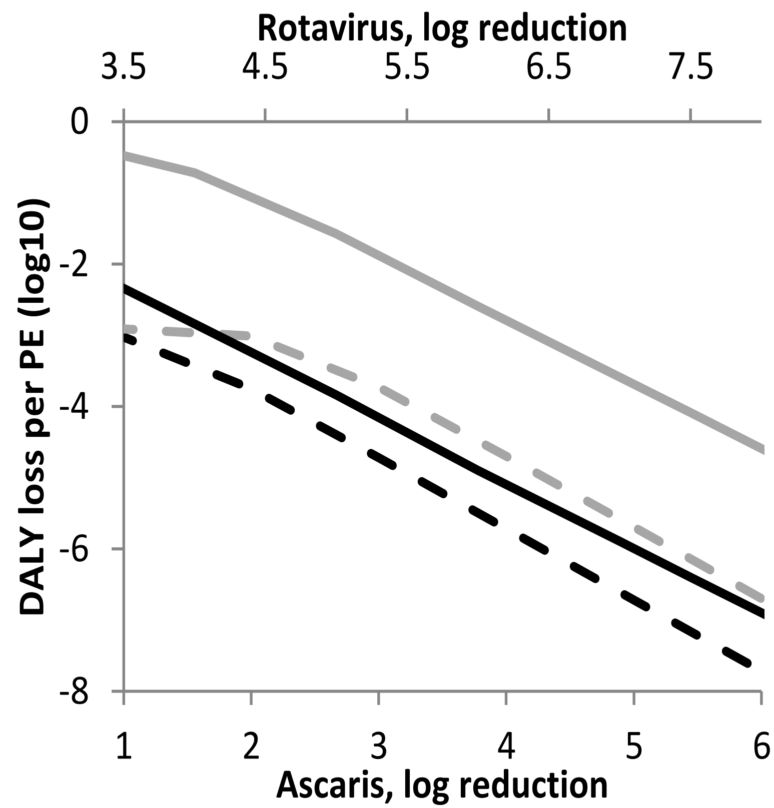
- *Ascaris*: 4.5 log
- Rotavirus: 7.5 log

Virus or *Ascaris* highest risk?

23 °C



28 °C



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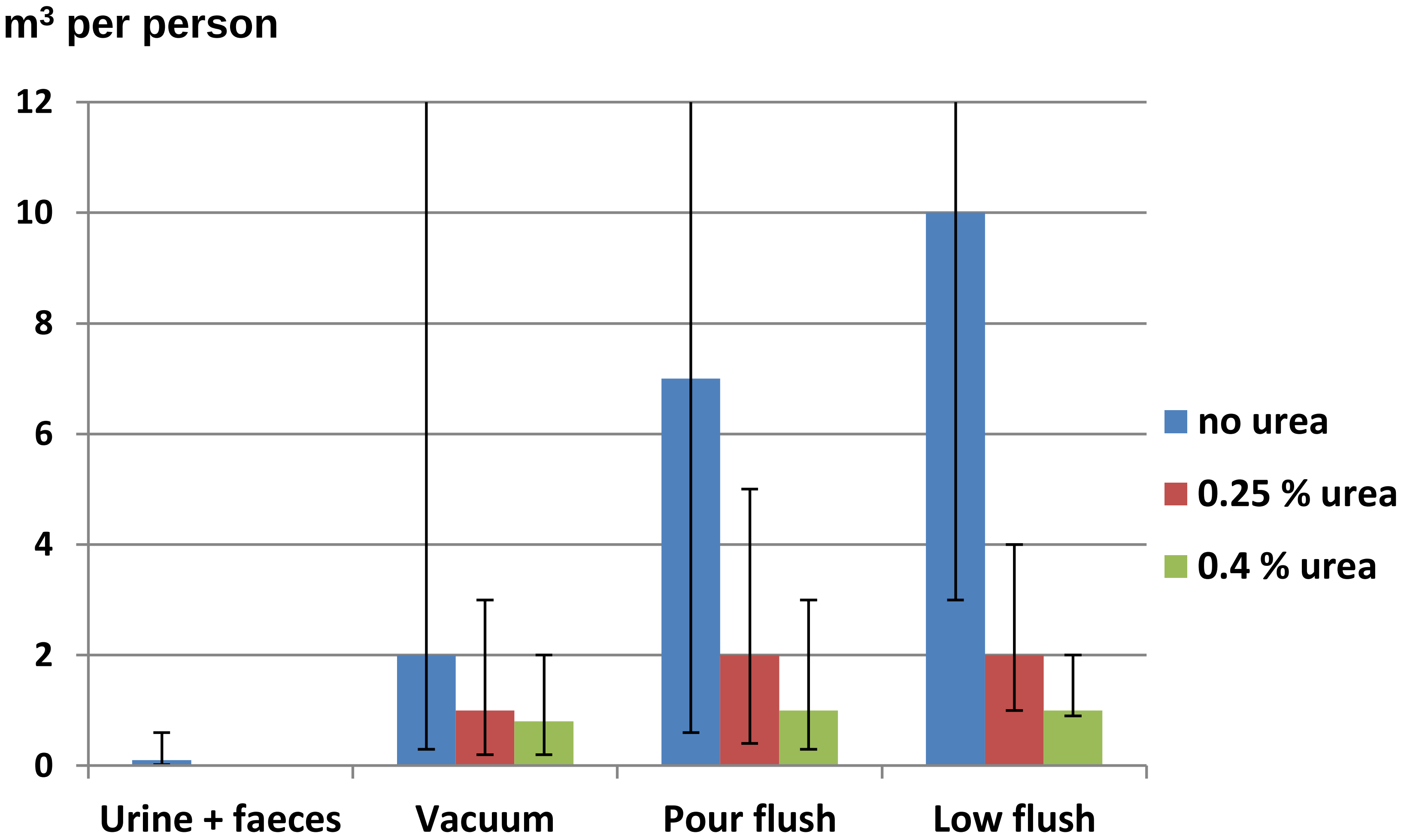
Estimation of storage capasity required



Conclusions

- Monitoring of pH & total ammonia → NH_3
  - Should have at least 20 mM NH_3
  - Treatment time dimensioning with *Ascaris* model
- Models for rotavirus and adenovirus are inactivated faster than bacteriophages
- Viruses and *Ascaris* eggs represent the largest health risk, and require 7.5 and 4.5 log reduction for acceptable risk
- Mixing urine and faeces from UDDT toilets give sufficiently high NH_3 concentration for pathogen inactivation
- Low doses of urea is probably required for pathogen inactivation in faecal sludge from toilets using flushwater

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Future studies and development

- Studies on full scale implementation:
  - How extensive monitoring is required?
  - Intrinsic NH_3 in sludge from different toilets
  - Time required for hydrolysis of urea
- Development of toilets using low or no volumes of water for flushing
- Modelling virus inactivation, distinguish between pH, NH_3 and other bases
- Studies on pathogen attachment to crop and removal during washing
- Inactivation of more pathogens, including more viruses, *Vibrio Cholera*, *Cryptosporidium*

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