Fertilizer products from human urine

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Human urine as a resource

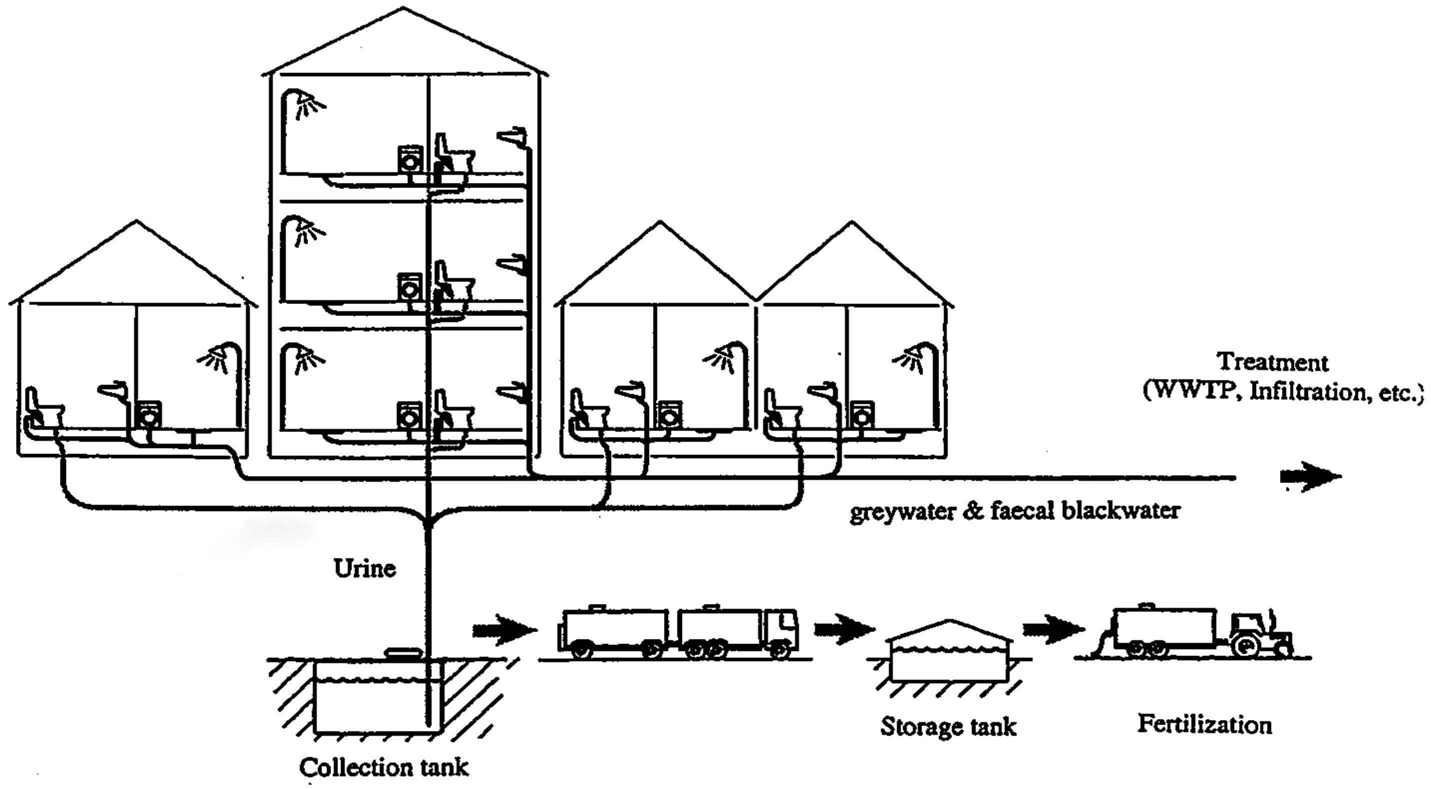
Nutrients in human excreta (one year) and the fertilizer need to produce 250 kg grain/year (Wolgast, 1993).

Most important nutrients	Urine 500 l	Faeces 50 l	Total	Fertilizer need for 250 kg grain
N	5.6 kg	0.09 kg	5.7 kg	5.6 kg
P	0.4 kg	0.19 kg	0.6 kg	0.7 kg
K	1.0 kg	0.17 kg	1.2 kg	1.2 kg
N + P + K	7.0 kg (94%)	0.45 kg (6%)	7.5 kg (100%)	7.5 kg

Metals in urine and faeces compared with manure from organic farming in Sweden (Jönsson, *et al.*, 2004)

Material	Unit	Cu	Zn	Cr	Ni	Pb	Cd
Human urine	µg/kg ww	67	30	7	5	1	0
Human faeces	µg/kg ww	6667	65000	122	450	122	62
Cattle manure org. farming	µg/kg ww	5220	26640	684	630	184	23

20 years of experimenting, research and use of urine separation systems in Sweden



Urine separating system for dwelling-houses or residential quarters

(From: Jönsson H, et al., Källsorterad humanurin i kretslopp, VA-FORSK Report 2000/1)

Working at eco-village level…

Urine separating toilets in Sweden

WM-Ekologen

Dubletten

Urine collection (right tank, 20 m3)
Mjölnartorpet eco-village
www.mjolnartorpet.com/eko/vadekoby.htm

Urine collection in Västervik
www.vatervik.se Photo: Anders Fröberg

Urine spreading
www.grappa.nu Photo:Henrik Andersson

… but what about in larger scale?

Problems connected with urine separation and urine recirculation to arable land

- Handling and storage
- Transport (greenhouse gases)
- Nutrient (N) loss to the atmosphere
- Spreading on arable land (time, dosage, machines)
- Pharmaceuticals and synthetic estrogen spreading

Today the recycling loop between urine collecting and reuse in agriculture is still broken.
We in Sweden are very good in collecting but not in reusing!

Urine can be processed for efficient nutrient recovery and reuse in agriculture by:

Struvite precipitation

and

Zeolite adsorption

Plant available nutrients (N in NH_4^+-form and P in $P0_4^{3-}$-form) are turned into solid fertilizers, much easier to

- **handle and store,**
- **transport,**
- **spread on arable land.**
- **Prohibiting atmospheric and soil N-losses,**
- **improving hygiene and safe management.**

New research (e.g. EAWAG, Swiss, 2007) shows that the struvite is

- **heavy metal, estrogen and pharmaceutical free**

Struvite

$[Ca, Mg)(K,NH_4)(PO_4)*6H_20]$

as problem in ”human pipes” (kidney stone):

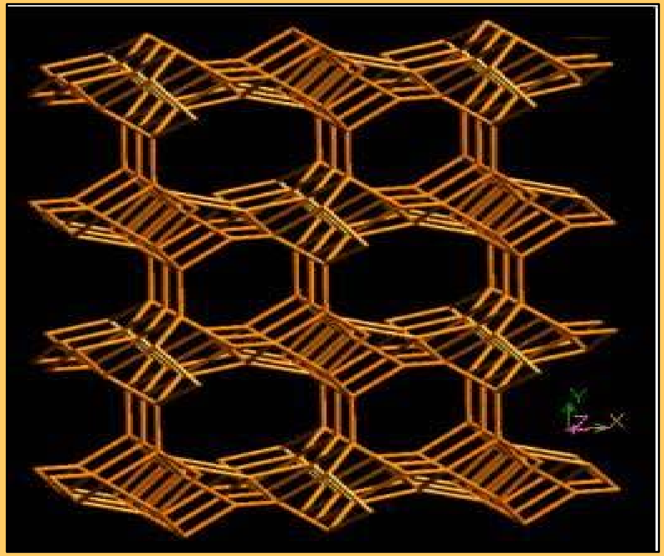
Source: http://www.calculilab.com/art/pix/struvite.jpg

as problem in pipes in wastewater treatment plants:

Source: www.crystalenv.com/struvite_pipe_256x192.jpg

Zeolite (clinoptilolite)

$[(Na_3K_3)(Al_6Si_{40}0_{96}) * 24\ H_2O]$



Source: Database of zeolite structures: www.iza-structure.org/databases/

Source: www.zeolitanatural.com/images/powder.jpg

Results from 15 years of research

- By addition of small amounts of MgO to human urine macronutrients as N, P, K, Ca and S could be recovered in solid form, mainly as struvite.

  Efficiency of nutrient recovery:
  - 98-100 % P
  - 25-30 % N
  - 22-64 % K
  - 2-5.6 % Ca
  - some S (amount not determined)

- The zeolite alone could recover:
  - 18 % P (probably due to adsorption)
  - 15-60 % N (due to ion exchange)

- The combined process with simultaneous struvite precipitation and zeolite adsorption is a simple and efficient process resulting in an improved nutrient recovery both for N and P.

  Efficiency:
  - 100 % P
  - 83 % N

Two products from processed urine: struvite (S) and struvite - zeolite mix (SZM)

When struvite precipitates from a complex solution like human urine co-precipitates like montgomeriyte [$Ca_4MgAl_4(PO_4)_6(OH)_4{*}12H_2O$], brushite [$CaHPO_4{\cdot}2H_2O$], epsomite [$MgSO_4{*}7H_2O$], K-struvite, apatite, etc. are also formed. The precipitate called STRUVITE here contains *mainly* struvite, according to XRD and element analysis made on the precipitates.

Testing the fertilizer value of the struvite (S) and the struvite - zeolite mix (SZM)

Common wheat in climate chamber tested in two different systems.
At the left, in automatic, closed drip-system.
At the right, in manually watered system.
Plant biomasses, plant mineral status, substrates and irrigation water were analyzed in all experiments.

Testing struvite (S)

in strictly controlled climate chamber conditions and with automatic, closed drip-system for irrigation and 4 replicates for each treatment.

*** The substrate was vermiculite, sand and a mixture of sand-vermiculite.**
*** Struvite precipitated from urine and analyzed for elemental composition was added to the substrates in optimal amount for 22 days of balanced plant growth.**
*** The controls were fertilized with an optimal nutrient solution.**

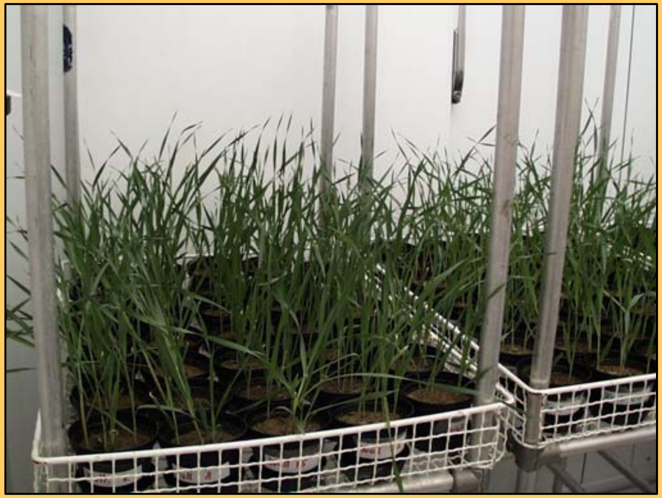
Wheat grown in sand, fertilized with struvite (pots with red mark) compared to the controls.

Wheat grown in vermiculite, fertilized with struvite (pot with red mark) compared to the controls.

Testing struvite (S)

in strictly controlled climate chamber conditions with manual irrigation (5 replicates for each treatment).

*** The substrate was sand, vermiculite and sand-peat-dolomite mix. Even a series of commercially available nutrient enriched soil was parallel-tested.**
*** The controls were fertilized with an optimal nutrient solution mixed in the substrate (OPT) and a negative control (OPT-P).**
*** Struvite precipitated from urine and analyzed for elemental composition was added to the substrates in optimal amounts for 33 days of balanced plant growth.**



The experimental setup with 5 replicates for each treatment

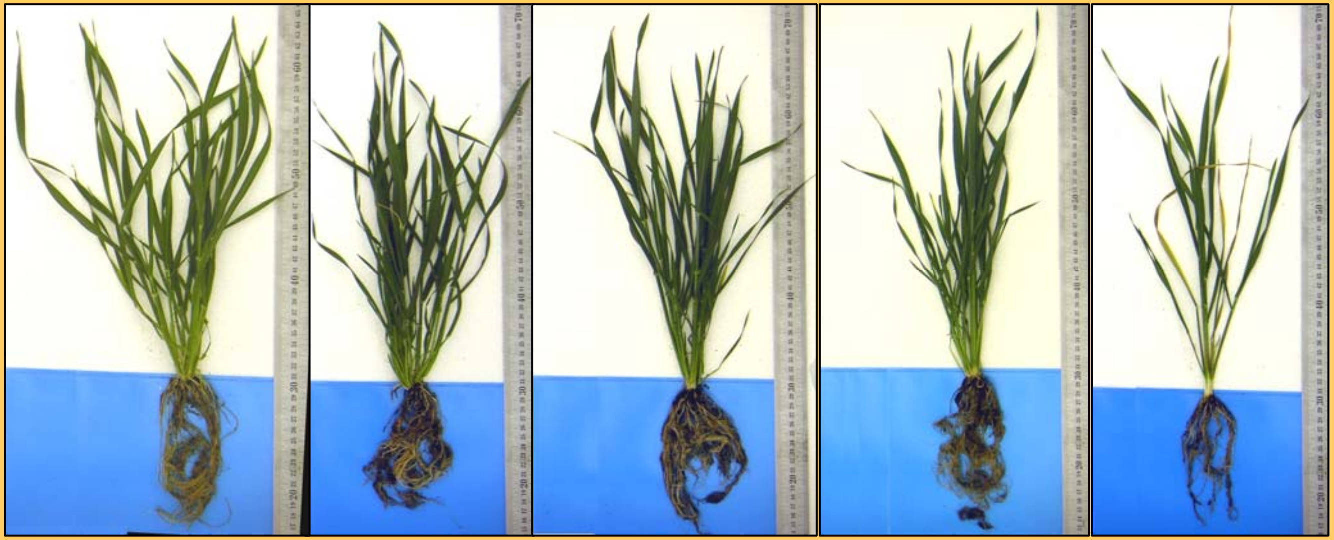
OPT-P Soil OPT Struvite
(in sand - peat - dolomite as substrate)

Testing struvite – zeolite mix (SZM)

in strictly controlled climate chamber conditions with manual irrigation (5 replicates for each treatment).

*** The substrates were sand-dolomite, sand-vermiculite, vermiculite and sand-peat-dolomite mix.**
*** The controls were fertilized with an optimal nutrient solution mixed in the substrate (OPT) and a negative control (OPT-P).**
*** Two commercial fertilizers were parallel-tested: DAP (di-ammonium hydrogen orthophosphate) and Ca-P (mono-calcium-phosphate monohydrate).**
*** The solid mix from simultaneous struvite ppt. and zeolite adsorption made from urine and analyzed for elemental composition was added to the substrates in optimal amounts for 33 days of balanced plant growth. Analyses on plant mineral status was made along biomass DW.**

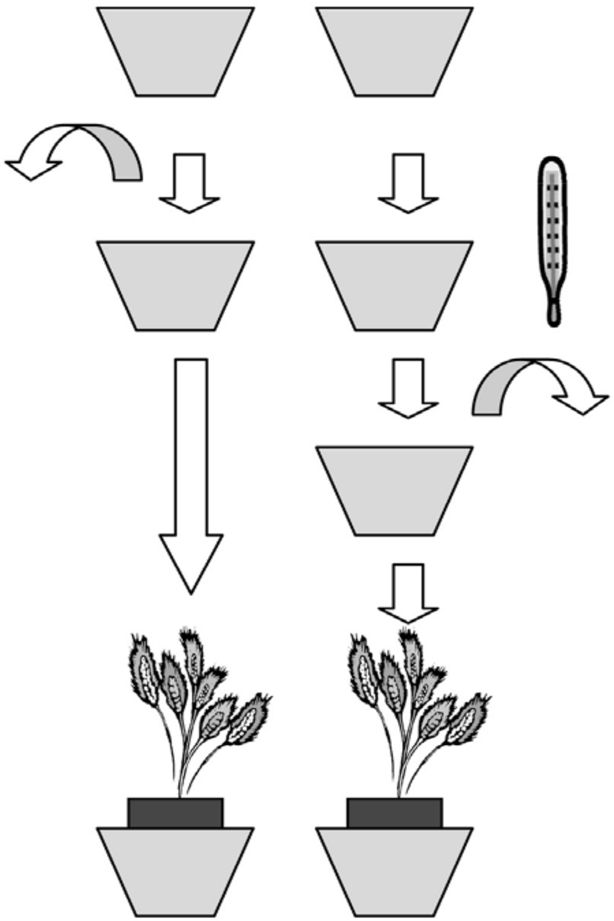
Photos from the last harvest: common wheat grown in sand-peat-dolomite substrate mix.



OPT DAP SZM Ca-P OPT-P

The experimental set-up for SZM combined with freezing and nutrient availability tested on common wheat during 30 days

in strictly controlled climate chamber conditions with manual irrigation



Three different amounts (7.5, 15 and 30 g) of untreated and pre-treated (washed and washed + heated) zeolites, plus 0.04 g MgO were added to each of 18 replicates of 150 ml of urine. The solutions were stirred manually and left to settle for 72 h in enclosed beakers.
Two series of this experimental setup was started. Totally 36 samples were used in pot trials.

The supernatant from half of the beakers (left) were removed and later chemically analyzed and tested for toxicity. The other half (right) was frozen to -18 ºC for 24 h.

The frozen samples were partially thawed and the supernatants were removed for chemical analysis and toxicity tests.

Plastic pots filled with washed quarts sand were placed in the beakers. Four sprouted seeds of common wheat were planted in each pot. As negative controls three replicates only sand and three replicates as positive controls with commercial fertilizer (NPK 14-4-21) were used. The pots were placed in a climate chamber and irrigated with deionised water and harvested after 10, 20 and 30 days.

Plant mineral status was not analyzed.

Results from the plant experiments

P availability from struvite (S) and SZM

• good nutrient (P) availability from struvite (S)
• very good nutrient availability from SZM
• the SZM showed better nutrient release than struvite alone, probably due to a synergistic effect between the struvite dissolution and zeolite ion exchange
• both struvite and SZM acted as “slow-release” fertilizers and
• SZM from urine acts similarly to DAP and Ca-P commercial P-fertilizers and the P-availability was comparable even with NPK 14-4-21 in the tests with not frozen SZM.

Plant development

* Plant biomass production was generally higher when P was supplied from struvite (S) recovered from urine compared to controls
• Plant biomass production was generally higher when P was supplied from SZM recovered from urine compared to DAP, Ca-P and controls.
• No deficiency symptoms or nutrient unbalance was detected for plants fertilized with SZM compared to DAP, Ca-P or control.

Scientific articles related to solid fertilizers recovered from human urine:

* Ganrot, Zs., Broberg, J., Bydén, S. (2009). Energy efficient nutrient recovery from household wastewater using struvite precipitation and zeolite adsorption techniques. A pilot study in Sweden. In: Achley, K., Mavinic, D., Koch, F. (eds): International Conference on Nutrient Recovery from Wastewater Streams. IWA Publishing, 511-521.

* Ganrot, Zs., Dave, G., Nilsson, E. (2007). Recovery of N and P from human urine by freezing, struvite precipitation and adsorption to zeolite and active carbon. Bioresource Technology 98, 3112-3121.

* Ganrot, Zsofia (PhD Thesis, May 2005). Urine processing for efficient nutrient recovery and reuse in agriculture, ISBN 91 88376 29X, Göteborg University (available as pdf file on www.melica.se/zsofia.htm).

* Ban, Zs., Dave G. (2004). Laboratory studies on recovery of N and P from human urine through struvite crystallization and zeolite adsorption. Environmental Technology 25, 111-121.

* Adamsson M., Ban, Zs., Dave G. (2003). Sustainable utilization of human urine in urban areas – practical experiences. Peer reviewed paper published in Conf. Proceedings: 2nd International Symposium on ecological sanitation, Lübeck, Germany, April 2003, 643-650.

* Lind, B-B., Ban, Zs., Bydén, S. (2001). Volume reduction and concentration of nutrients in human urine. Ecological Engineering 16, 561-566.

* Lind, B-B., Ban, Zs., Bydén, S. (2000). Nutrient recovery from human urine by struvite crystallization with ammonia adsorption on zeolite and wollastonite. Bioresource Technology 73, 169-174.

Scientific articles related to plant experiments testing the fertilizer value of recovered solids from urine:

* Ganrot, Zs., Wallin, G., Dave, G., Nilsson, E., Li, B. (2009). Plant availability of P recovered as solids from human urine compared to two commercial fertilizers and a liquid fertilizer in four substrates tested on *T. aestivum* L. (Under processing in J. of Plant Nutrition and Soil Science)

* Ganrot, Zs., Slivka, A., Dave, G. (2008) Nutrient recovery from human urine using pre-treated zeolite and struvite precipitation in combination with freezing-thawing and plant availability tested on common wheat. CLEAN, 36(1), 45-52.

* Ganrot, Zs., Dave, G., Nilsson, E., Li, B. (2007). Plant availability of nutrients recovered as solids from human urine tested in climate chamber on *Triticum aestivum* L. Bioresource Technology 98, 3122-3129

Thank You

and please visit the poster session
to see the pilot projects I am working with today:

The SplitBox-household **(processing household wastewater)**
and
The SplitBox-Agri **(processing animal manure)**

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