Integrated, multi-process approach to total nutrient recovery from stored urine

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SUPPLEMENTAL MATERIALS

42 pages

6 equations

11 tables

3 Figures

1.1 Analytical methods

All samples were collected in triplicate, and the average and standard deviation of samples were calculated. Error bars in the figures represent one standard deviation of the triplicate samples. Samples were taken before and after each treatment process and analyzed. Samples that had greater masses than what was added to the solution were corrected to equal the added mass in solution. For example, K was never added during any treatment process yet some samples post struvite precipitation had K masses greater than the initial amount. For these samples, the amount of K post struvite precipitation was set equal to the amount of K pre struvite precipitation (initial). The pH was measured with an Accumet AB 15 pH meter, which was calibrated before use with pH 4, 7, and 10 buffer solutions (Fisher Scientific). Conductivity was measured using Orion Star A215 conductivity meter, which was calibrated before use with increasing calibration points of 1413µS cm^{-1}, 12900 µS cm^{-1}, and 100000 µS cm^{-1}. Total phosphate (TP) (as P) was measured following Standard Method 4500P ascorbic acid method (EPA 356.3) using a Hitachi U-2900 spectrophotometer at 880nm and a 1cm quartz cuvette.[1] Initial urine samples were diluted by 1:1000 and post struvite samples were diluted by 1:200 for TP analysis. Increasing calibration points of 0, 0.15, 0.30, 0.60, and 1.2 mg L^{-1} as P were used and the coefficient of determination (R^2) was greater than 0.995. Inorganic cations (Mg^{2+}, Na^+, K^+) were measured using inductively coupled plasma (ICP) Optical Emission Spectrometer (Thermo Fisher iCap 6000 ICP-OES). Samples were acidified using 2% trace metal grade nitric acid and analyzed using a standard calibration curve from 01mg/L to 100mg/L. Chloride and sulfate concentrations were measured using ion chromatography (Dionex ICS-3000) and an increasing calibration curve from 0.01 mg/L to 50mg/L. Samples for anion and cation analysis were diluted by 1:100. To measure total ammonia nitrogen (TAN) as NH_4^+ via flow injection analysis (Lachat's

QuikChem® 8500 Series 2 Flow Injection Analysis System), samples were diluted by 1:1000 and acidified to pH < 2. Increasing calibration points of 1, 2.5, 5, 10, and 20 mg L^{-1} as N were used and the coefficient of determination (R^2) was greater than 0.995.

Precision and accuracy of sample measurements were checked by measuring samples in duplicate and calculating the relative percent difference between samples as well as using an external known concentration solution and calculating the relative percentage difference between the measured and known concentrations. Values were below 10%

1.2 TP concentration for samples containing $MgCl_2 \cdot 6H_2O$

Samples containing $MgCl_2 \cdot 6H_2O$, post struvite, had TP values up to 0.001mg P /L which was below the first calibration point of 0.15mg P/L (EPA 356.3). Therefore, concentrations of TP in those samples were reported as being below 30mg/L (200*0.15=30). Samples containing $MgCl_2 \cdot 6H_2O$, post struvite, had residual magnesium (Mg) in the supernatant whereas samples with MgO and $MgCO_3$ barely did. This suggests less than 30 mg P/L remained in samples containing $MgCl_2 \cdot 6H_2O$, post struvite. Since Mg was added at 10% excess of the P concentration and the percent of excess magnesium ranged from 5.8-11.1%, it is likely that actual TP recovery ranged from 94-100%, not 91-94%.

		Pre treatment		Post treatment	
Urine solution	Mg precipitant	Initial TP (mmol P/L)	Mg addition (mmol/L)	Mg in solution (mmol/L)	Percent excess (%)
Synthetic hydrolyzed urine with no metabolites	$MgCl_2 \cdot 6H_2O$	13.3	14.6	0.846	5.78
	MgO	13.3	14.6	0.0602	0.411
	$MgCO_3$	13.3	14.6	0.0411	0.281
Synthetic hydrolyzed urine with metabolites	$MgCl_2 \cdot 6H_2O$	15.2	16.7	1.50	8.97
	MgO	15.2	16.7	0.0849	0.508
	$MgCO_3$	15.2	16.7	0.117	0.699
Real hydrolyzed urine	$MgCl_2 \cdot 6H_2O$	11.1	12.2	1.36	11.1
	MgO	11.1	12.2	0.0738	0.604
	$MgCO_3$	11.1	12.2	0.106	0.866

2. Results and Discussion

2.1 Calculation of TAN recovery

The mass of NH_4^+-N remaining in the urine post struvite precipitation and the sum of NH_4^+-N present in the stripping and absorption columns post ammonia stripping–acid absorption was expected to be the same. However, this was not the case and the sum of NH_4^+-N in the stripping and absorption column for control samples (no pH and temperature adjustments) exceeded the mass of NH_4^+-N post struvite precipitation by approximately 45-60%. Due to the setup of the experiment, no sources of additional NH_4^+-N entering the system were identified. Therefore, the % TAN recovered was calculated using Equation S1 (also located in the equations section).

Equation S1: TAN recovery efficiency was calculated as NH_4^+-N using the equation

$$\frac{mg\ N\ in\ absorption\ column}{mg\ N\ in\ stripping\ column + mg\ N\ in\ absorption\ column} x\ 100$$

2.2. Discussion of condition pH 9.2, 70°C: Operational issues

Although temperature had a greater effect on TAN recovery than pH, serious operational issues could arise based on experimental observation. Operational issues such as excess foaming, precipitation, and evaporation were observed when the sample was heated to 70°C. These operational issues resulted in lower than expected TAN recovery and cross contamination of potassium from the stripping column to absorption column. Since all of the stripping experiments were done with the same volume (urine and sulfuric acid) and flow rate (1LPM for 3 h), increasing the volume of oil added to each sample was tried to reduce the excess foaming which lead to cross contamination. This failed, as too much oil (> 5% of the sample volume) was needed to slightly reduce the foaming. Therefore, reducing the flow rate to approximately 0.9 LMP was attempted to solve the operation issues described. Sample and acid volume, experimental time, and volume of oil addition remain constant with previous ammonia stripping–acid absorption experiments. The reduction in flow rate most likely affected the TAN recovered, where <90% was recovered.

The reason for this experimental condition was only to compare the effect of pH and temperature on TAN recovery by comparing conditions pH 9.2, 70°C, pH 9.2, 22°C, and pH 10.2, 22°C. Therefore this condition was excluded from tables that reported potash purity (Table S11 and S10) and the cost analysis of NPK recovery from 10,000L of urine (Table 4).

2.3 Discussion of increased Cl^- and SO_4^{2-} post ammonia stripping–acid absorption

This explanation corresponds to section 3.2 in the manuscript. The original sources of Cl^- and SO_4^{2-} in the synthetic urine solutions were NaCl, KCl, and Na_2SO_4. Post struvite precipitation, $MgCl_2 \cdot 6H_2O$ was also a source of Cl^- and samples containing that Mg source contained higher Cl^- concentrations compared to the other samples. However, post ammonia stripping–acid absorption, all of the samples that required NaOH to increase the pH showed the same degree of concentration increase in these anions. The cation (Mg^{2+}, K^+, Ca^{2+}) concentration did not increase but remained either constant or decreased. Since the increase of Cl^- and SO_4^{2-} was only seen in samples that had NaOH added, contamination of NaOH was thought to be a reason. To test this, condition pH 10.5, 22°C was done with deionized (DI) water and samples were diluted 1:20. Due to the high buffering capacity of urine, all samples with pH>9.2 required approximately equal g/L NaOH. Therefore, only this condition was tested with DI water. Results from these experiments showed an increase of approximately 0.098 mg/L Cl^- and SO_4^{2-} in DI to 2 mg/L Cl^- and 5 mg/L SO_4^{2-}. The percent difference of Cl^- and SO_4^{2-} in DI water and experimental samples was similar to the increase seen amongst samples that required NaOH. Therefore, the increase of unexpected Cl^- and SO_4^{2-} in solution is attributed to experimental error.

2.4 Cost analysis: reference and price of each variation

Variation	Cost	reference
$MgCl_2 \cdot 6H_2O$	150 ($/metric ton)	www.alibaba.com (2017)
MgO	350($/metric ton)	www.alibaba.com (2017)
$MgCO_3$	500($/metric ton)	www.alibaba.com (2017)
NaOH	400($/metric ton)	www.alibaba.com (2017)
KOH	480 ($/metric ton)	www.alibaba.com (2018)
H_2SO_4 (98%)	0.46 ($/L)	www.alibaba.com (2017)
Struvite	350 ($/metric ton)	www.alibaba.com (2017)
Ammonium sulfate	314 ($/metric ton)	Agricultural Marketing Service. Data from December 14 2017, North Carolina prices.
Potash	336 ($/metric ton)	Agricultural Marketing Service. Data from December 14 2017, North Carolina prices.
Arizona electricity cost	0.11 ($/kWh)	https://www.eia.gov data used: September 2016 for all sectors

Equations:

Equation S1: TAN recovery efficiency was calculated as NH_4^+-N using the equation.

$$\frac{mg\ N\ in\ absorption\ column}{mg\ N\ in\ stripping\ column + mg\ N\ in\ absorption\ column} x 100$$

Equation S2: Percent N (w/w) in the liquid ammonium sulfate product.

$$\frac{g\ N}{30\ mL\ solution} x \frac{1cm3\ solution}{1.05\ g\ solution} x \frac{1\ mL}{1\ cm3}\ x\ \frac{100\ g\ solution}{1} = \%\ N\ (w/w)$$

Where: “solution” is 1M sulfuric acid solution

Equation S3: Maximum mass of N (g) that can be absorbed using 30mL of 1M H_2SO_4 solution.

$$\frac{1\ mol\ H2SO4}{1L} x \frac{30\ mL\ solution}{1} x \frac{1\ L}{1000\ mL}\ x\ \frac{1mol\ (NH4)2SO4}{1\ mol\ H2SO4} x \frac{2\ mol\ NH4}{1\ mol\ (NH4)2SO4} x \frac{1\ mol\ N}{1\ mol\ NH4} x$$

$$\frac{14\ g\ N}{1\ mol\ N} = 0.84\ g\ N$$

Equation S4: Maximum % N(w/w) that can be in the liquid ammonium sulfate product using 30mL of 1M H_2SO_4 solution.

$$\frac{0.84\ g\ N}{30\ mL\ solution} x \frac{1\ cm3\ \ solution}{1.05\ g\ solution} x \frac{1\ mL}{1\ cm3}\ x\ \frac{100\ g\ solution}{1} = 2.67\%$$

Equation S5: g N/L needed to produce commercial liquid ammonium sulfate fertilizer (8-0-0-9S). Density of 8-0-0-9S (8% N liquid fertilizer) is 1.2g/cm^3.[2]

$$\frac{8\ g\ N}{100g\ solution} x \frac{1.2\ g\ solution}{1\ cm3} x \frac{1000\ cm3}{1\ L} = \frac{96\ g\ N}{L}$$

Equation S6: : Volume of urine and concentration of sulfuric acid needed to obtain an ammonium sulfate product that is equivalent to market liquid ammonium sulfate fertilizers (8 % N).

(a) Assuming 5 g N L^{-1} urine and 90% TAN recovery, the mass of N/L urine is 4.5 g/L

$$\frac{96\ g\ N}{1\ L} x \frac{1\ L\ urine}{4.5\ g\ N} = \ 21.33\ L\ urine$$

(b) Concentration of H_2SO_4 needed to produce liquid ammonium sulfate containing 8% N

$$\frac{96\ g\ N}{1\ L} x \frac{1\ mol\ N}{14\ g\ N} x \frac{1\ mol\ H2SO4}{2\ mol\ N} = \frac{3.43\ mol\ H2SO4}{L}$$

Tables:

Table S1. Economic value of nutrients recovered from 10,000L of treated urine as fertilizer products assuming 100% recovery

Fertilizer	Cost ($/metric ton)[a]	Nutrient	Nutrient in fertilizer (% w/w)	Cost ($/metric ton nutrient)	Nutrient concentration (mg/L)[b]	Economic value ($ nutrient/10,000 L urine)
Potash	336	K	51.5	173	1560	2.70
Ammonium sulfate	314	N	21.0	65.9	7000	4.62
Struvite	350	P	12.6	44.1	434	0.19

[a]Bulk fertilizer prices for potash and ammonium sulfate obtained from Agricultural Marketing Service. Data from December 14 2017, North Carolina prices. Struvite fertilizer prices obtained from Alibaba.com

[b]Nutrient concentrations are based on the synthetic recipe used in the study (Table S2)

Table S2. Synthetic urine and synthetic urine with metabolites recipe in 1L 18.2 MΩ-cm ultra-pure water.

Chemical	Amount [g]	[mL]
NaCl	3.51	
Na_2SO_4	2.13	
KCl	2.98	
NH_4OH		15.9
NaH_2PO_4–P	1.68	
NH_4HCO_3	19.8	
Citrate[a]	0.478	
Creatinine[a]	1.39	
Glycine[a]	0.0928	
Hippurate[a]	0.502	
L-Cysteine[a]	0.0976	
Taurine[a]	0.124	

[a] added for urine solution with metabolites

Tables S3. a-e. All ANOVA two way with replication data analysis done with concentration or mass values

a. ANOVA two way statistical analysis with replication (α=0.05) for TP recovery

Nutrient	p-value factor i[a]	p-value factor ii[b]
P	1.13E-05	1.8E-10

[a]Factor i. Conducted for statistical significance between TP recovery (mg P/L) and varying urine solutions
[b]Factor ii. Conducted for statistical significance between TP recovery (mg P/L) and varying Mg sources

b. ANOVA two way statistical analysis with replication (α=0.05) for TAN recovery (mg N) in the absorption column after ammonia stripping–acid absorption experiments

Mg source	Nutrient	p-value factor i[a]	p-value factor ii[b]
$MgCl_2 \cdot 6H_2O$	N	2.43E-15	3.56E-02
MgO	N	3.21E-11	5.12E-03
$MgCO_3$	N	5.62E-07	2.84E-02

[a]Factor i. Conducted for statistical significance between TAN recovery (mg N) and varying ammonia stripping–acid conditions
[b]Factor ii. Conducted for statistical significance between TAN recovery (mg N) and varying urine solutions

c. ANOVA two way statistical analysis with replication (α=0.05) for TAN recovery (mg N) in the absorption column after ammonia stripping–acid absorption experiments

Urine solution	Nutrient	p-value factor i[a]	p-value factor ii[b]
Real urine	N	2.22E-15	2.71E-01
Synthetic urine with metabolites	N	1.93E-05	1.14E-01
Synthetic urine	N	1.22E-10	5.77E-06

[a]Factor i. Conducted for statistical significance between TAN recovery (mg N) and varying ammonia stripping–acid conditions
[b]Factor ii. Conducted for statistical significance between TAN recovery (mg N) and varying magnesium sources

d. ANOVA two way statistical analysis with replication (α=0.05) for K recovery (mg K) in the stripping column after ammonia stripping–acid absorption experiments

Urine solution	Nutrient	p-value factor i[a]	p-value factor ii[b]
Real urine	K	1.85E-13	9.35E-01
Synthetic urine with metabolites	K	9.46E-13	1.41E-01
Synthetic urine	K	2.41E-16	1.58E-01

[a]Factor i. Conducted for statistical significance between K recovery (mg K) and varying ammonia stripping–acid conditions
[b]Factor ii. Conducted for statistical significance between K recovery (mg K) and varying magnesium sources

e. ANOVA two way statistical analysis with replication (α=0.05) for K recovery (mg K) in the stripping column after ammonia stripping–acid absorption experiments

Mg source	Nutrient	p-value factor i[a]	p-value factor ii[b]
$MgCl_2\cdot 6H_2O$	K	2.28E-13	2.71E-13
MgO	K	8.39E-15	2.46E-14
$MgCO_3$	K	7.71E-15	3.88E-13

[a]Factor i. Conducted for statistical significance between K recovery and varying ammonia stripping–acid conditions

[b]Factor ii. Conducted for statistical significance between K recovery and varying urine solutions

Table S4. Results of preliminary Mg^{2+} solubility experiments showing percentage Mg dissolved in varying ionic strength solutions.

		Solid Mg dose[a] (mmol/L)		Mg in solution (mmol/L)	
Mg source	Solubility (g/100mL)	DI water	synthetic urine with no P	DI water	synthetic urine with no P
$MgCl_2\cdot 6H_2O$	52.9	15.4	15.4	15.3	17.0
MgO	0.009	15.4	15.4	0.579	16.2
$MgCO_3$	0.0139	15.4	15.4	1.31	4.21

[a] 1.1:1 Mg:P ratio. Initial concentration of TP in synthetic urine was approximately 14 mmol/L

Table S5. Economic cost analysis for struvite production from 10,000L of real urine.

Mg source	$/mol Mg[a]	Consumed cost ($)	$/mol P recovered[c]	Product[b] ($)	Net profit ($)
$MgCl_2\cdot 6H_2O$	0.0305	3.73	3.02	8.72	4.99
MgO	0.0141	1.73	1.93	7.44	5.72
$MgCO_3$	0.0422	5.15	4.93	8.80	3.65

[a] Cost ($/ton) of each magnesium source: $MgCl_2\cdot 6H_2O$ ($150), MgO ($350), $MgCO_3$ ($500)

[b] $/ton of struvite was $350

Struvite and magnesium prices obtained from www.alibaba.com.

[c] Based on experimental TP recovery of 91%, 66%, and 77% for $MgCl_2\cdot 6H_2O$, MgO, and $MgCO_3$ respectively

Table S6. Change in pH from each magnesium source during struvite precipitation

Urine solution	Mg source	Pre struvite precipitation	After Mg addition	Post struvite precipitation
Synthetic urine	$MgCl_2 \cdot 6H_2O$	9.2	9.3	9.3
	MgO	9.2	9.4	9.3
	$MgCO_3$	9.2	9.4	9.3
Synthetic urine with metabolites	$MgCl_2 \cdot 6H_2O$	9.2	9.1	9.1
	MgO	9.2	9.2	9.2
	$MgCO_3$	9.2	9.2	9.2
Real urine	$MgCl_2 \cdot 6H_2O$	9.2	8.9	8.9
	MgO	9.2	9.0	9.0
	$MgCO_3$	9.2	9.0	9.0

Table S7. Base (NaOH) addition (mL NaOH/100 mL urine) required for ammonia stripping–acid absorption samples

Urine solution	Condition	$MgCl_2 \cdot 6H_2O$	MgO	$MgCO_3$
Real urine	pH 9.6, 55°C	1.3	1.4	1.2
	pH 10, 40°C	2.4	2.3	2.4
	pH 10.5, 22°C	4.2	4.1	3.7
	pH 9.2, 70°C	0.0	0.0	0.0
	pH 9.2, 22°C	0.0	0.0	0.0
Synthetic urine with metabolites	pH 9.6, 55°C	1.0	1.1	1.0
	pH 10, 40°C	2.3	2.0	2.4
	pH 10.5, 22°C	3.7	3.5	3.7
	pH 9.2, 70°C	0.0	0.0	0.0
	pH 9.2, 22°C	0.0	0.0	0.0
Synthetic urine	pH 9.6, 55°C	1.2	1.1	1.0
	pH 10, 40°C	2.3	2.1	2.4
	pH 10.5, 22°C	3.5	3.4	3.7
	pH 9.2, 70°C	0.0	0.0	0.0
	pH 9.2, 22°C	0.0	0.0	0.0

Table S8. Consumed costs of producing ammonium sulfate from 10,000L of real urine

Condition[a]	NaOH	H_2SO_4	Energy	Total

	consumed cost ($)	consumed costs ($)	consumed cost[b] ($)	consumed costs ($)
pH 9.6, 55°C	20.80	40.13	42.35	103.3
pH 10, 40°C	38.40	44.10	23.10	105.6
pH 10.5, 22°C	67.20	27.34	0.0	94.54
pH 9.2 70C	0	38.47	61.60	99.97
pH 9.2, 22°C	0	13.67	0.0	13.67

[a] $MgCl_2 \cdot 6H_2O$ was used as Mg source for struvite precipitation

[b] Energy consumed costs defined as energy transferred as heat

Table S9. Average pH of samples after ammonia stripping–acid absorption experiments

Urine solution	Mg source	Post struvite precipitation	pH 9.6, 55°C	pH 10, 40°C	pH 10.5, 22°C	pH 9.2, 70°C	pH 9.2, 22°C
Real urine	$MgCl_2 \cdot 6H_2O$	8.93	9.57	9.91	10.41	9.22	nm
	MgO	9.02	9.52	9.92	10.03	9.13	9.18
	$MgCO_3$	9.02	9.53	9.99	10.07	9.17	9.21
Synthetic urine with metabolites	$MgCl_2 \cdot 6H_2O$	9.12	9.56	9.96	10.44	9.21	9.20
	MgO	9.21	9.57	9.95	10.41	9.18	9.19
	$MgCO_3$	9.18	9.59	10.00	9.92	9.19	9.20
Synthetic urine	$MgCl_2 \cdot 6H_2O$	9.25	9.57	9.95	10.44	9.22	9.19
	MgO	9.54	9.54	9.89	10.04	9.23	9.18
	$MgCO_3$	9.30	9.46	9.93	10.16	9.19	9.18

Table S10. Mass of potassium (K) recovered in samples post ammonia stripping–acid absorption for each Mg source.

		Stripping column	Absorption column	Unaccounted K

Mg source	Urine solution	Initial K^a	Condition	Avg. (mg)^b	R_k^c	Avg. (mg)^b	R_k^c	Avg. (mg)^d	R_k^c
$MgCl_2{\cdot}6H_2O$	Real urine	*105*	pH 9.6, 55°C	77.6	0.739	3.61	0.0344	23.8	0.226
			pH 10 temp 40	87.0	0.829	0.300	0.00286	17.7	0.168
			pH 10.5 temp 22	58.7	0.559	3.75	0.0357	42.6	0.406
			pH 9.2, 22°C	106	1.01	0.456	0.00435	-1.02	-0.00974
	Synthetic urine with metabolites	*158*	pH 9.6, 55°C	115	0.733	3.69	0.0234	38.3	0.243
			pH 10 temp 40	120	0.760	4.95	0.0314	32.9	0.209
			pH 10.5 temp 22	96.9	0.615	4.83	0.0307	55.8	0.354
			pH 9.2, 22°C	148	0.940	0.300	0.00190	9.13	0.0580
	Synthetic urine	*147*	pH 9.6, 55°C	103	0.698	3.80	0.0259	40.6	0.276
			pH 10 temp 40	110	0.751	4.11	0.0279	32.6	0.222
			pH 10.5 temp 22	104	0.704	5.89	0.0401	37.6	0.256
			pH 9.2, 22°C	147	0.999	0.300	0.00204	-0.20	-0.00136
MgO	Real urine	*104*	pH 9.6, 55°C	65.7	0.635	2.33	0.0225	35.5	0.343
			pH 10 temp 40	91.4	0.883	5.66	0.0546	6.45	0.0624
			pH 10.5 temp 22	64.6	0.624	3.45	0.0333	35.4	0.342
			pH 9.2, 22°C	102	0.982	0.300	0.00290	1.54	0.0148
	Synthetic urine with metabolites	*156*	pH 9.6, 55°C	112	0.717	2.49	0.0160	41.5	0.267
			pH 10 temp 40	117	0.748	3.45	0.0221	35.8	0.230
			pH 10.5 temp 22	102	0.652	2.56	0.0164	51.7	0.332
			pH 9.2, 22°C	146	0.937	0.300	0.00193	9.57	0.0614
	Synthetic urine	*147*	pH 9.6, 55°C	96.6	0.656	2.56	0.0174	48.0	0.326
			pH 10 temp 40	106	0.720	3.93	0.0267	37.2	0.253
			pH 10.5 temp 22	94.7	0.643	4.98	0.0339	47.5	0.323
			pH 9.2, 22°C	148	1.00	0.300	0.00204	-1.03	-0.00702
$MgCO_3$	Real urine	*106*	pH 9.6, 55°C	64.2	0.607	2.97	0.0281	38.5	0.365
			pH 10 temp 40	84.3	0.798	5.05	0.0478	16.3	0.155
			pH 10.5 temp 22	67.7	0.641	3.22	0.0304	34.7	0.328
			pH 9.2, 22°C	107	1.01	0.310	0.00293	-1.31	-0.0124
	Synthetic urine with metabolites	*158*	pH 9.6, 55°C	101	0.637	3.35	0.0212	54.0	0.342
			pH 10 temp 40	107	0.680	4.81	0.0304	45.9	0.290
			pH 10.5 temp 22	102	0.645	6.19	0.0391	49.9	0.316
			pH 9.2, 22°C	148	0.933	0.368	0.0023	10.3	0.0649
	Synthetic urine	*146*	pH 9.6, 55°C	93.9	0.641	4.17	0.0285	48.4	0.330
			pH 10 temp 40	106	0.722	3.06	0.0209	37.7	0.257
			pH 10.5 temp 22	98.2	0.670	3.14	0.0215	45.1	0.308
			pH 9.2, 22°C	145	0.992	0.324	0.0022	0.910	0.00621

[a] Data taken from samples post struvite precipitation. K mass calculated as (mg/L K) * (0.1 L) and reported as mg in 100mL of urine.

[b] K mass calculated as (mg/L K) * (volume in column after 3h experiment time)

[c] R_K calculated as (average mg K in column/ initial mg K)

[d] Average mass of K that was unaccounted for was calculated as ((mg K initial- (mg K in stripping column + mg K in absorption column))

Table S11. Composition (% w/w) of potash product via evaporation

Urine solution	Condition[b]	Mg source	Added NaOH (g)	K^+	[a]Cl^-	[a]SO_4^{2-}	Na^+
Real urine	pH 9.6, 55°C	$MgCl_2{\cdot}6H_2O$	0.52	4.4	12.0	6.2	31
		MgO	0.56	4.0	8.0	6.1	32
		$MgCO_3$	0.48	3.7	7.8	6.6	27
	pH 10, 40°C	$MgCl_2{\cdot}6H_2O$	0.96	5.0	12	6.2	39
		MgO	0.92	5.1	7.5	5.7	38
		$MgCO_3$	0.96	4.9	7.7	6.5	35
	pH 10.5, 22°C	$MgCl_2{\cdot}6H_2O$	1.7	2.6	11	6.0	40
		MgO	1.6	3.4	7	5.6	48
		$MgCO_3$	1.5	3.5	7	6.3	47
	pH 9.2, 22°C	$MgCl_2{\cdot}6H_2O$	0	6.5	13	6.6	8.5
		MgO	0	6.6	8.5	6.5	7.9
		$MgCO_3$	0	6.6	8.3	7.0	7.7
Synthetic urine with metabolites	pH 9.6, 55°C	$MgCl_2{\cdot}6H_2O$	0.40	6.6	21	6.9	29
		MgO	0.44	6.7	16	7.3	31
		$MgCO_3$	0.40	5.9	16	7.1	27
	pH 10, 40°C	$MgCl_2{\cdot}6H_2O$	0.92	7.1	21	7.2	43
		MgO	0.80	6.7	15	7.0	40
		$MgCO_3$	0.96	6.1	15	7.0	40
	pH 10.5, 22°C	$MgCl_2{\cdot}6H_2O$	1.5	5.3	20	6.9	49
		MgO	1.4	5.5	15	6.9	51
		$MgCO_3$	1.5	5.5	15	6.8	48
	pH 9.2, 22°C	$MgCl_2{\cdot}6H_2O$	0	8.9	22	7.3	14
		MgO	0	6.5	17	7.6	8.0
		$MgCO_3$	0	9.2	17	7.7	14
Synthetic urine	pH 9.6, 55°C	$MgCl_2{\cdot}6H_2O$	0.48	6.7	22	7.8	28
		MgO	0.44	5.5	15	6.8	25
		$MgCO_3$	0.4	5.2	15	6.6	25
	pH 10, 40°C	$MgCl_2{\cdot}6H_2O$	0.92	7.4	23	8.1	45
		MgO	0.84	6.2	15	7.0	40
		$MgCO_3$	0.96	6.6	16	7.4	45
	pH 10.5, 22°C	$MgCl_2{\cdot}6H_2O$	1.4	5.8	20	7.0	51
		MgO	1.4	5.2	15	6.8	49
		$MgCO_3$	1.5	5.2	14	6.5	47
	pH 9.2, 22°C	$MgCl_2{\cdot}6H_2O$	0	9.3	22	7.6	15
		MgO	0	9.2	16	7.5	15
		$MgCO_3$	0	9.1	16	7.4	14

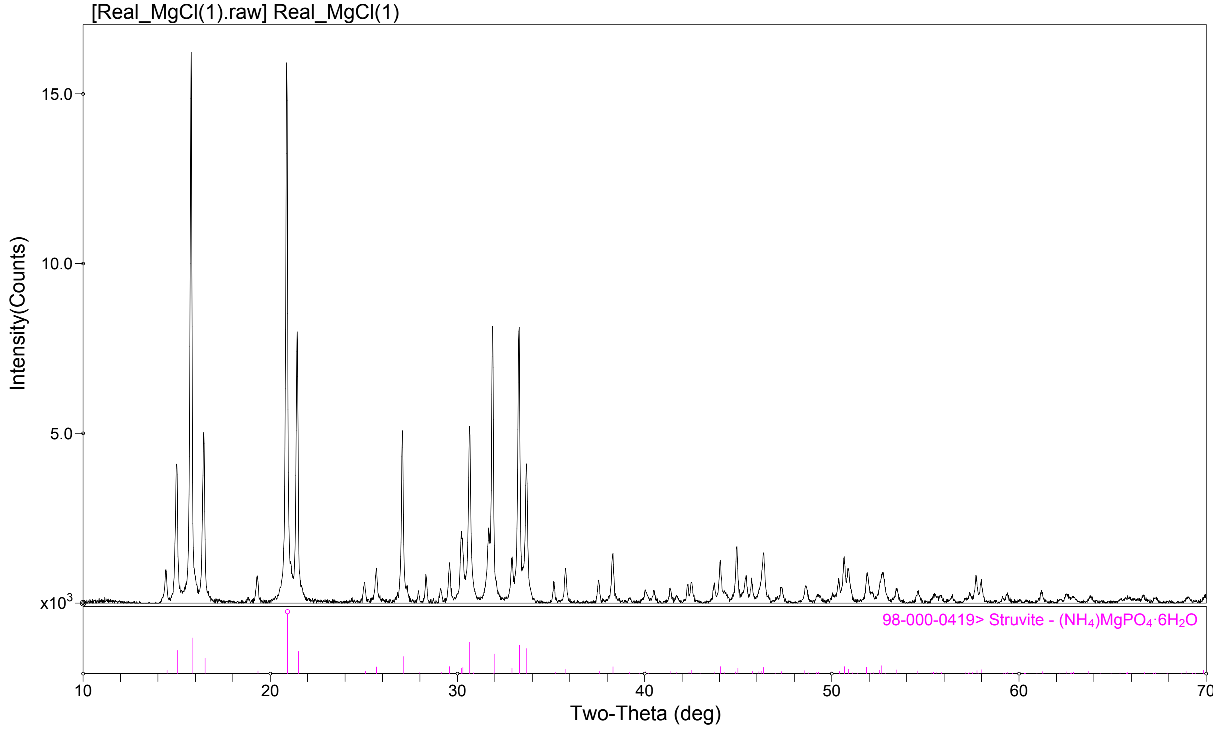
[a] Cl^- and SO_4^{2-} values taken from control samples (explained in ESI section 2.3)

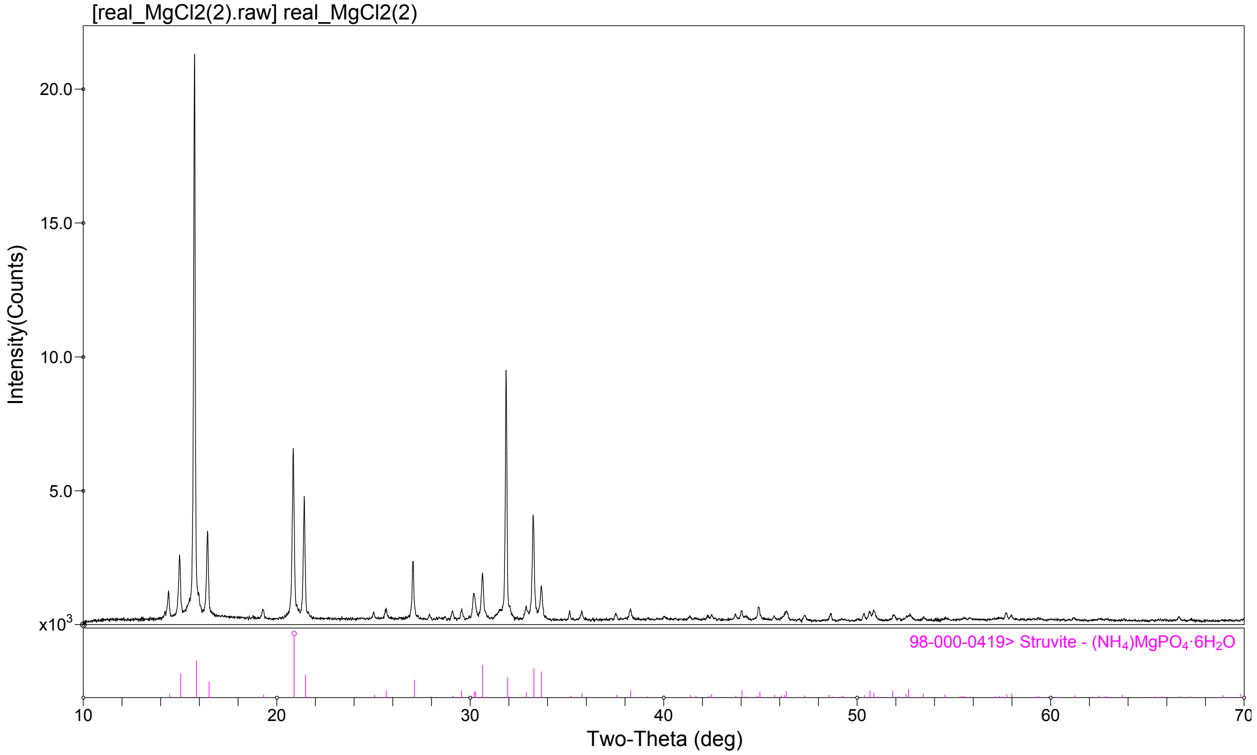
[b] Condition pH 9.2, 70°C was not included because of operation issues (explained in ESI section 2.2)

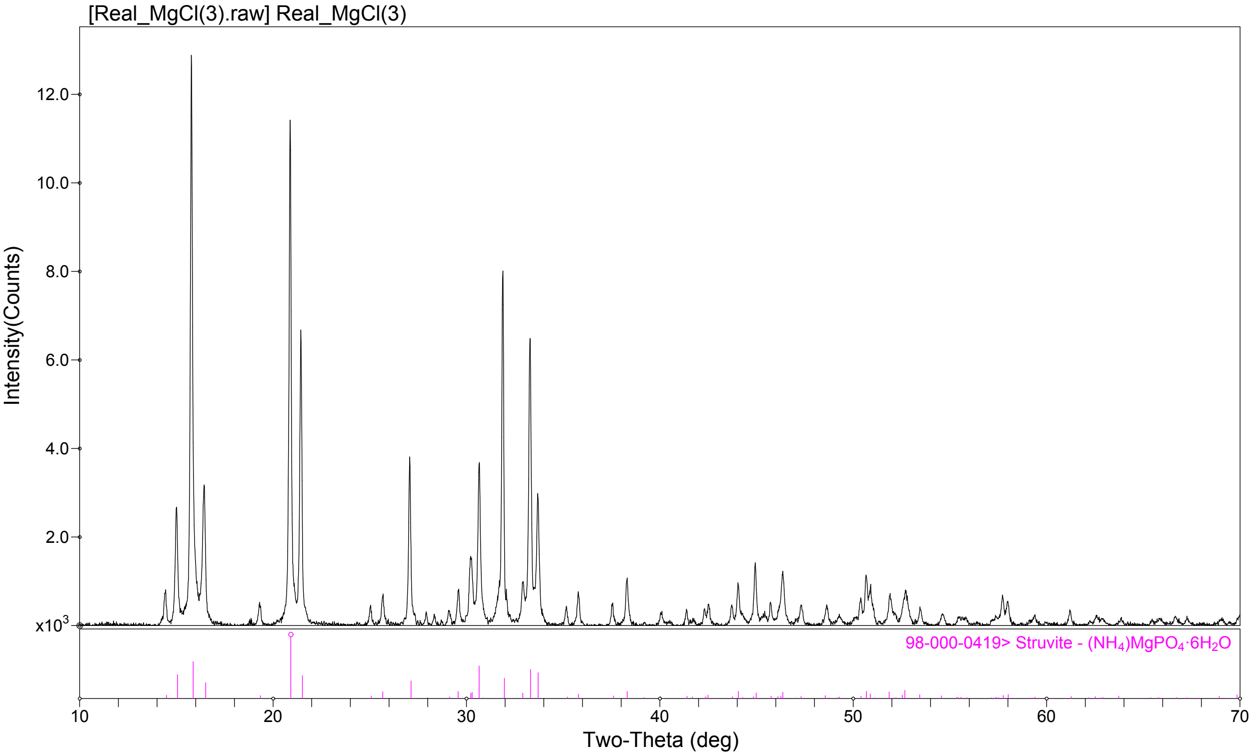
Figures:

Fig. S1. X-ray diffraction patterns of solid precipitates from synthetic and real hydrolyzed urine by Mg^{2+} addition. X-axis is two theta (degree) and y-axis is intensity (counts).

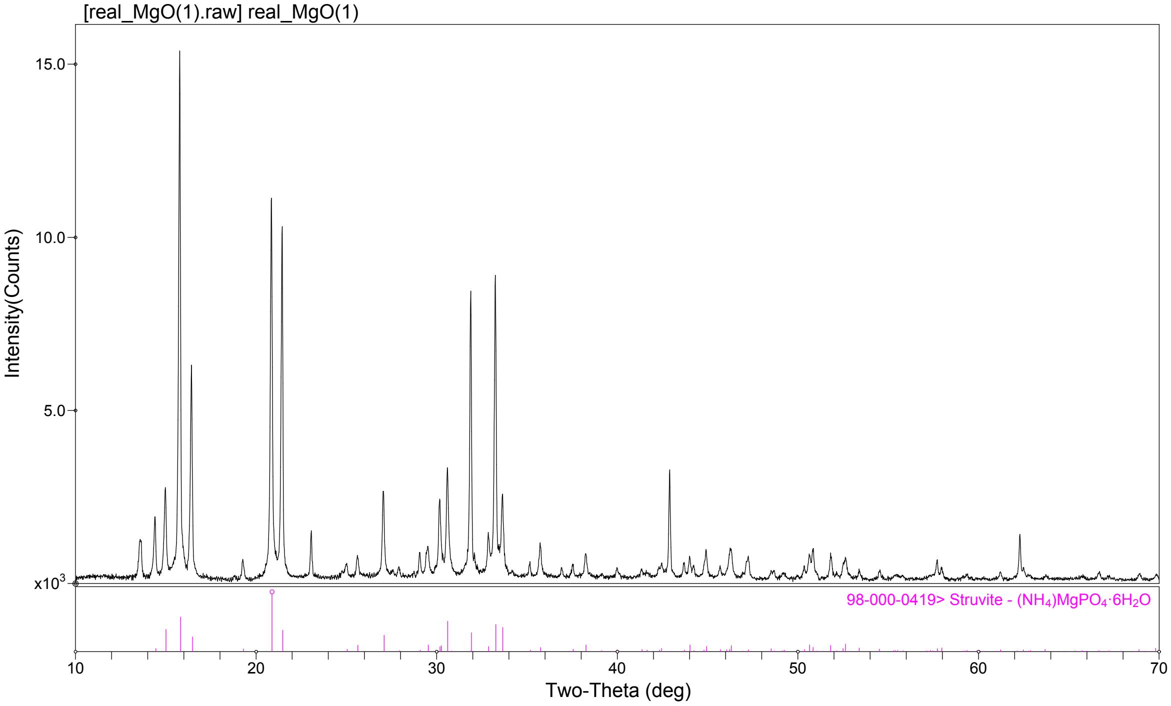
A. XRD for Real urine samples



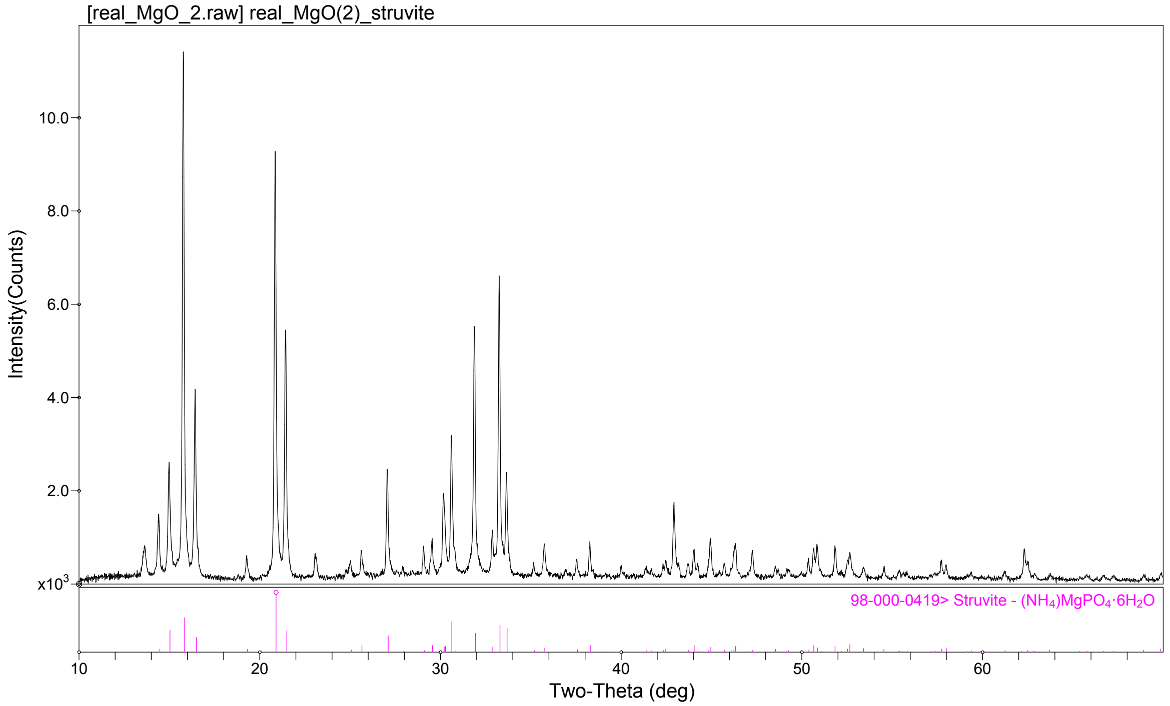


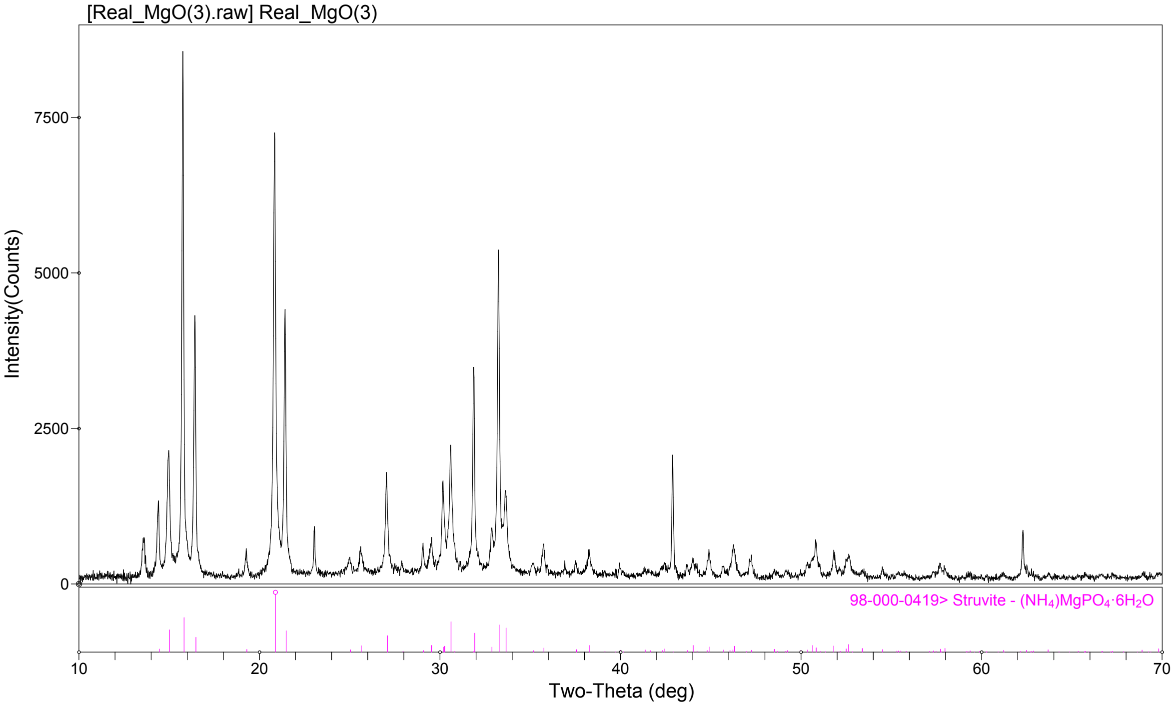

[Real_MgCl(3).raw] Real_MgCl(3)
Intensity(Counts)
12.0
10.0
8.0
6.0
4.0
2.0
x10^3
98-000-0419> Struvite - $(NH_4)MgPO_4·6H_2O$
10
20
30
40
50
60
70
Two-Theta (deg)

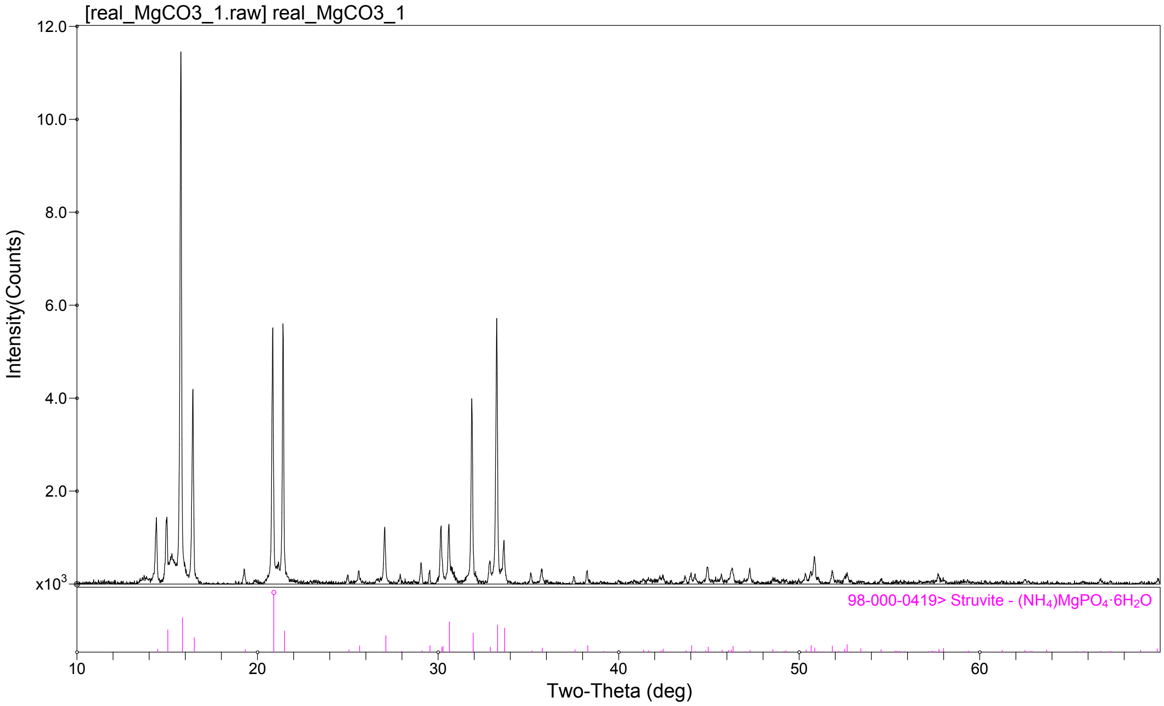
414


[real_MgO(1).raw] real_MgO(1)
Intensity(Counts)
15.0
10.0
5.0
x10^3
98-000-0419> Struvite - $(NH_4)MgPO_4·6H_2O$
10
20
30
40
50
60
70
Two-Theta (deg)

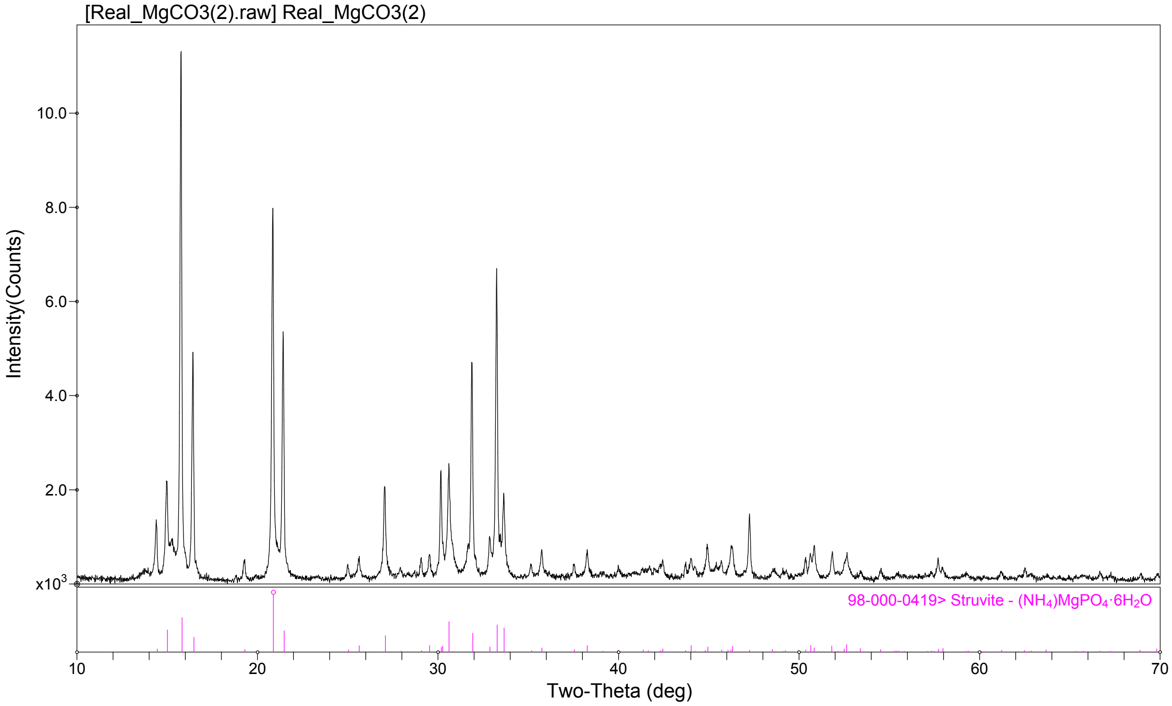
415


[real_MgO_2.raw] real_MgO(2)_struvite
Intensity(Counts)
10.0
8.0
6.0
4.0
2.0
x10^3
98-000-0419> Struvite - (NH4)MgPO4·6H2O
10
20
30
40
50
60
Two-Theta (deg)

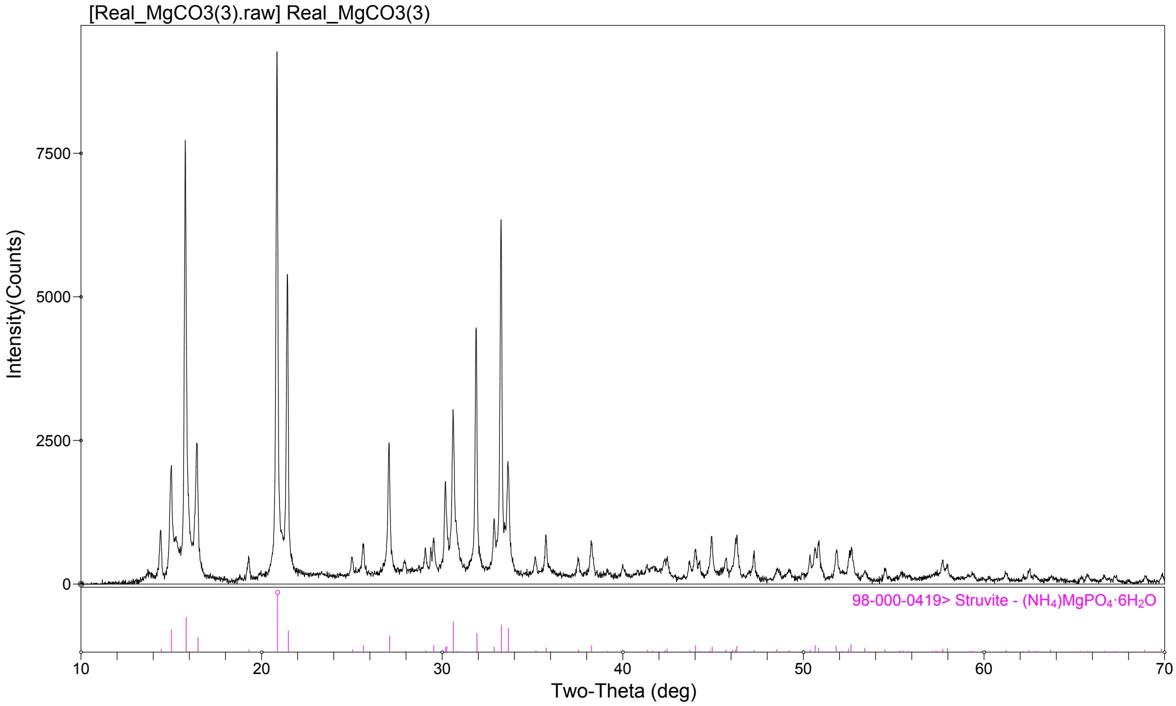

[Real_MgO(3).raw] Real_MgO(3)
Intensity(Counts)
7500
5000
2500
0
98-000-0419> Struvite - (NH4)MgPO4·6H2O
10
20
30
40
50
60
70
Two-Theta (deg)


[real_MgCO3_1.raw] real_MgCO3_1
Intensity(Counts)
12.0
10.0
8.0
6.0
4.0
2.0
x10³
98-000-0419> Struvite - (NH₄)MgPO₄·6H₂O
10
20
30
40
50
60
Two-Theta (deg)

418

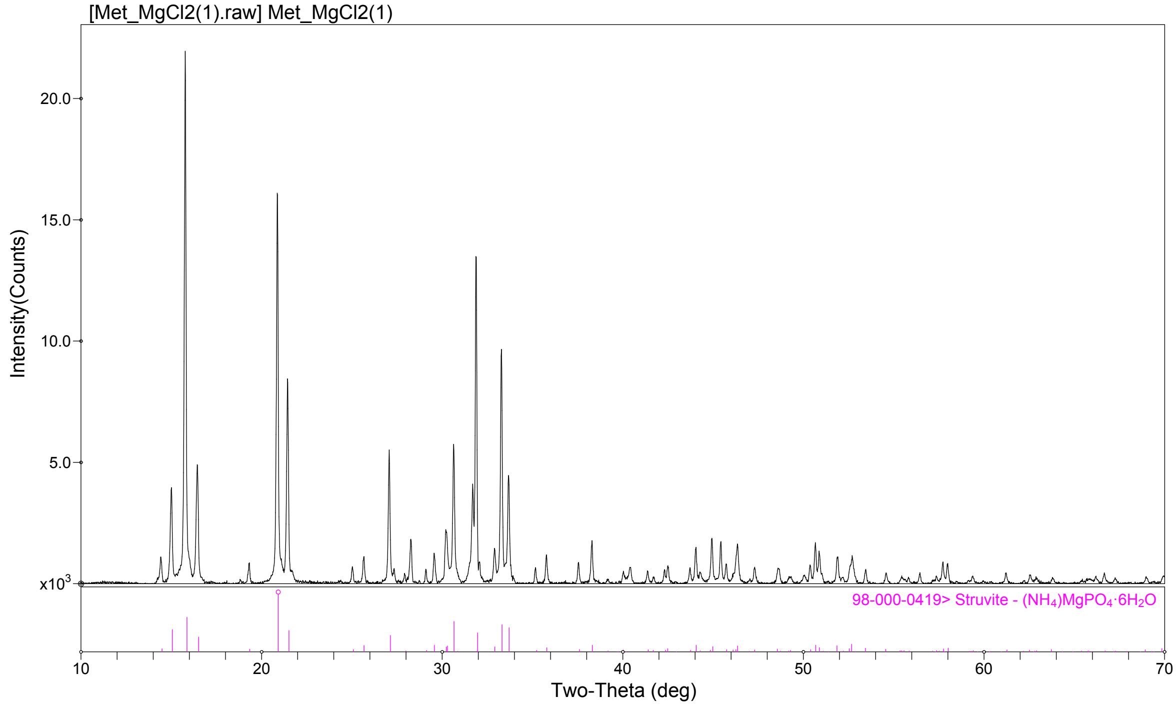

[Real_MgCO3(2).raw] Real_MgCO3(2)
Intensity(Counts)
10.0
8.0
6.0
4.0
2.0
x10³
98-000-0419> Struvite - (NH₄)MgPO₄·6H₂O
10
20
30
40
50
60
70
Two-Theta (deg)

419

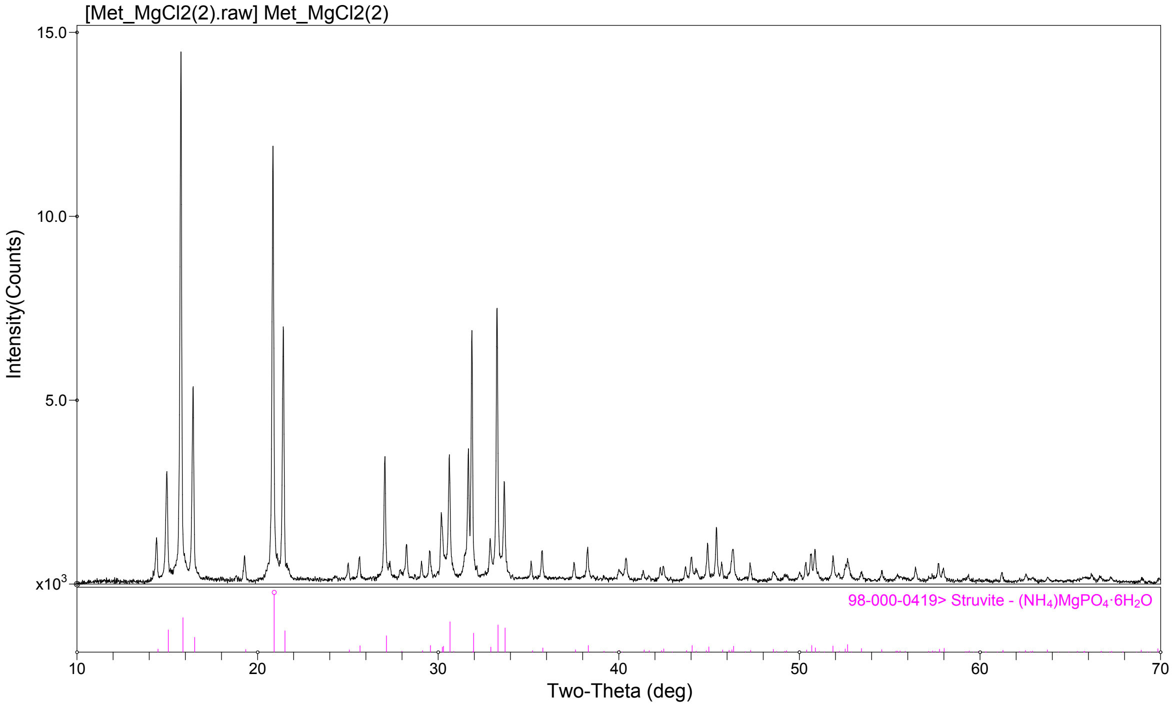


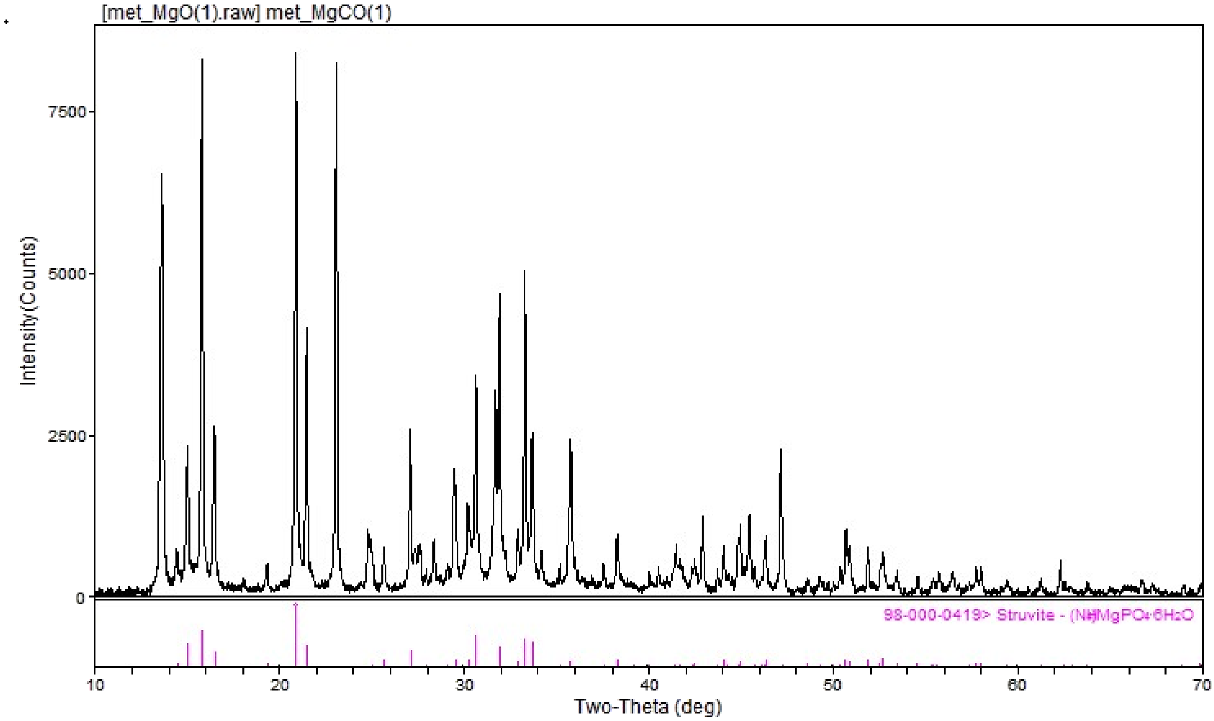
420

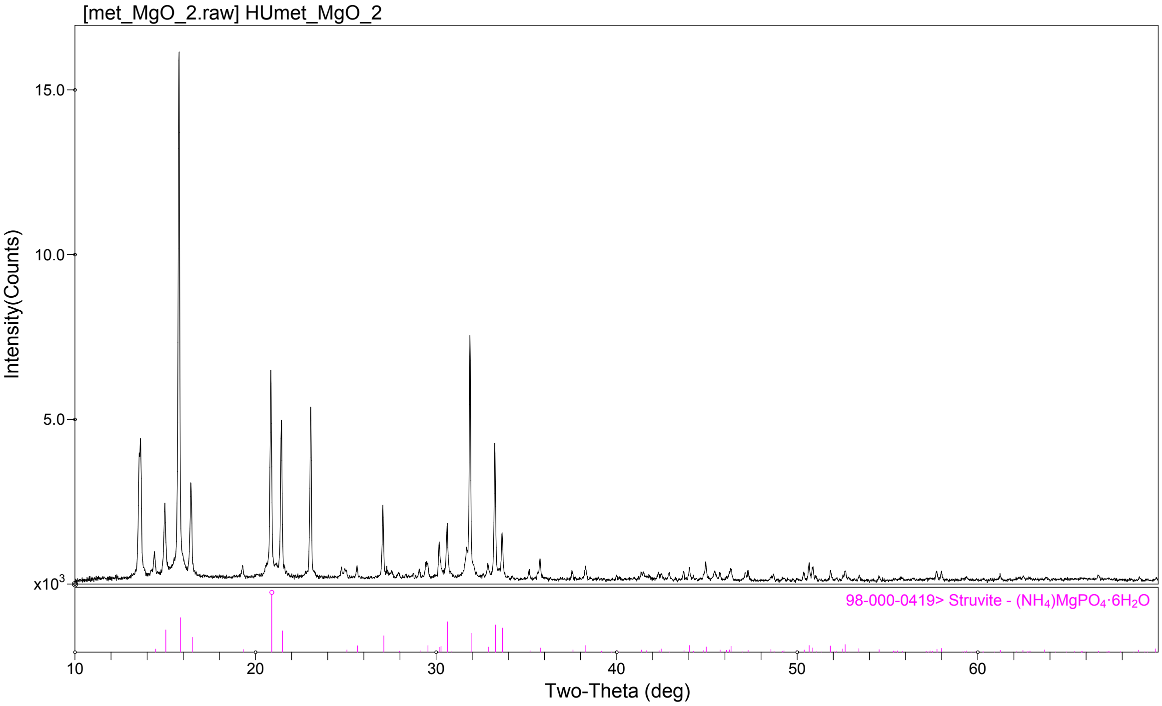
421 **B. XRD for Synthetic urine with metabolites samples**



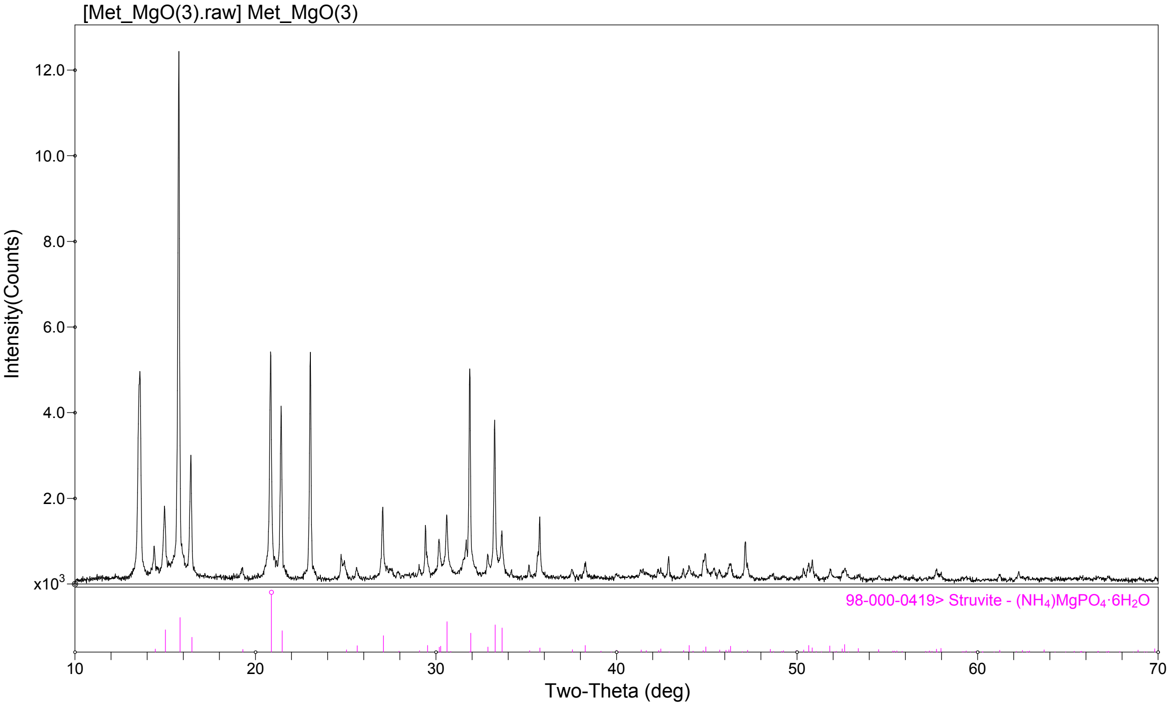
422


[Met_MgCl2(2).raw] Met_MgCl2(2)
Intensity(Counts)
15.0
10.0
5.0
x10^3
98-000-0419> Struvite - $(NH_4)MgPO_4{\cdot}6H_2O$
10
20
30
40
50
60
70
Two-Theta (deg)

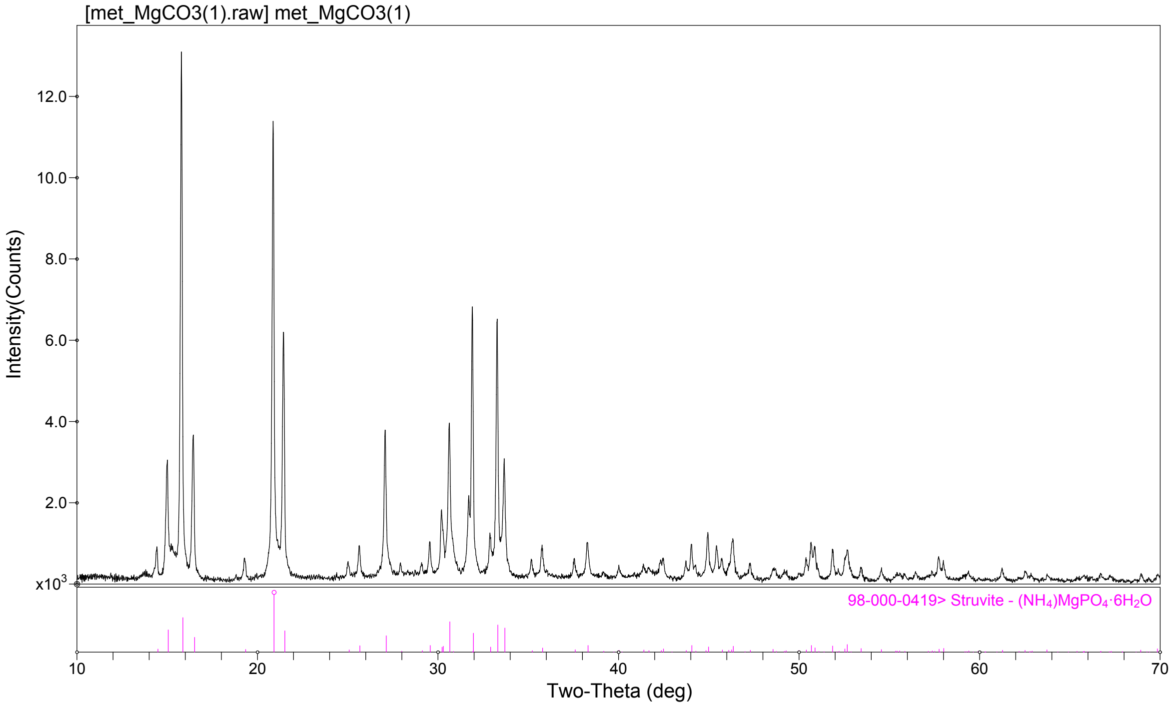

[met_MgO(1).raw] met_MgCO(1)
Intensity(Counts)
7500
5000
2500
0
98-000-0419> Struvite - (NH)MgPO4·6H2O
10
20
30
40
50
60
70
Two-Theta (deg)


[met_MgO_2.raw] HUmet_MgO_2
Intensity(Counts)
15.0
10.0
5.0
x10^3
98-000-0419> Struvite - $(NH_4)MgPO_4·6H_2O$
10
20
30
40
50
60
Two-Theta (deg)

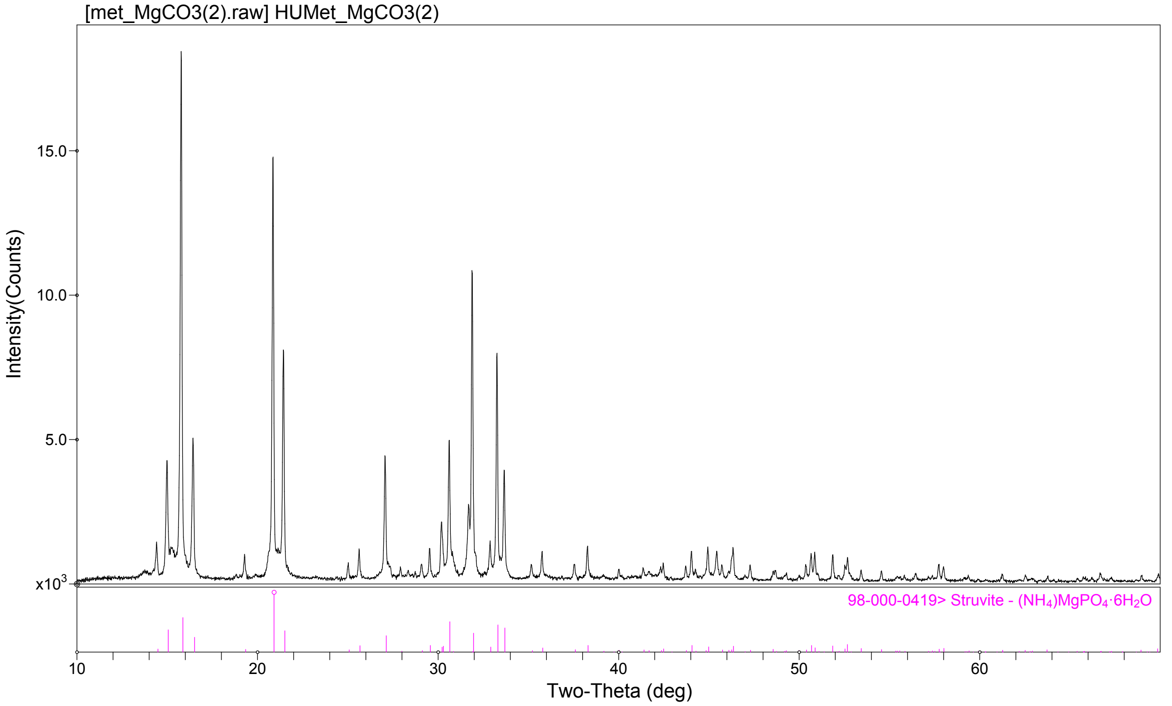
425


[Met_MgO(3).raw] Met_MgO(3)
Intensity(Counts)
12.0
10.0
8.0
6.0
4.0
2.0
x10^3
98-000-0419> Struvite - $(NH_4)MgPO_4·6H_2O$
10
20
30
40
50
60
70
Two-Theta (deg)

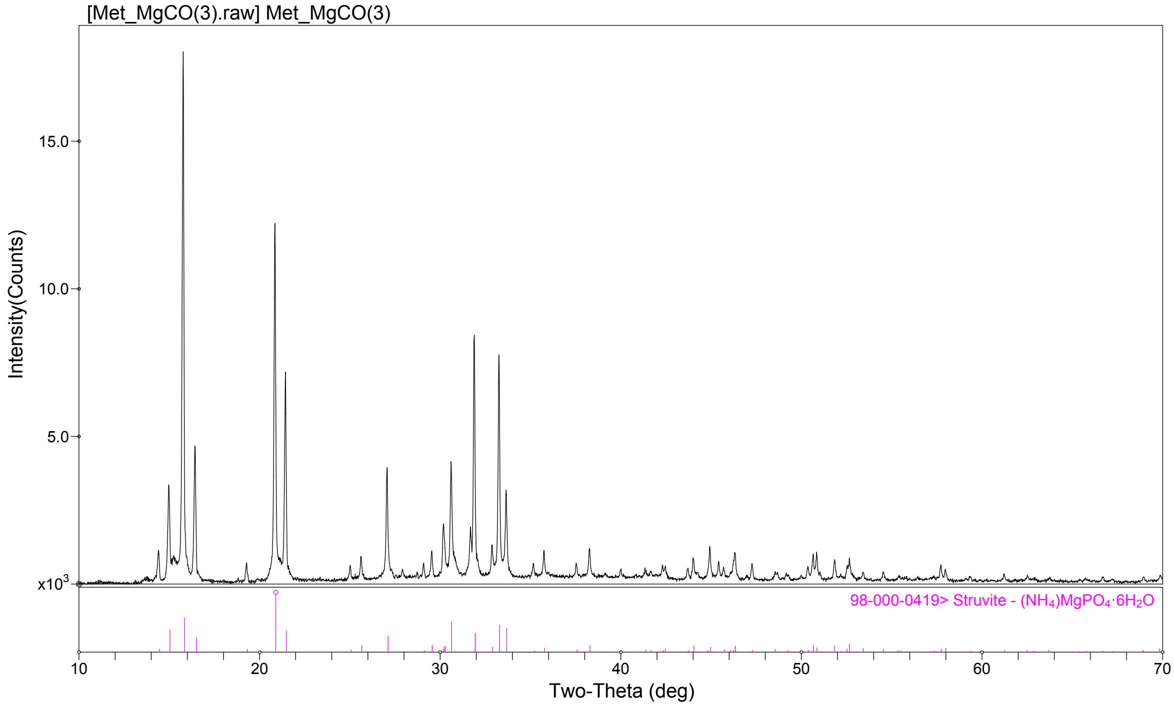
426


[met_MgCO3(1).raw] met_MgCO3(1)
Intensity(Counts)
12.0
10.0
8.0
6.0
4.0
2.0
x10^3
98-000-0419> Struvite - $(NH_4)MgPO_4 \cdot 6H_2O$
10
20
30
40
50
60
70
Two-Theta (deg)

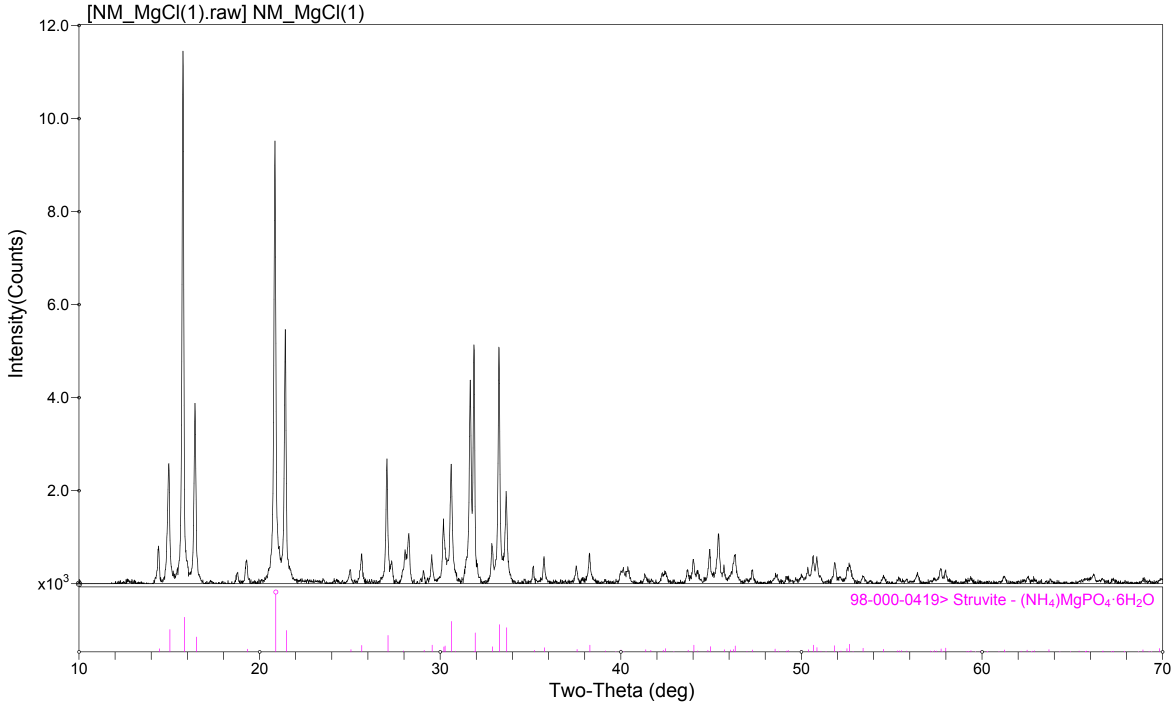
427

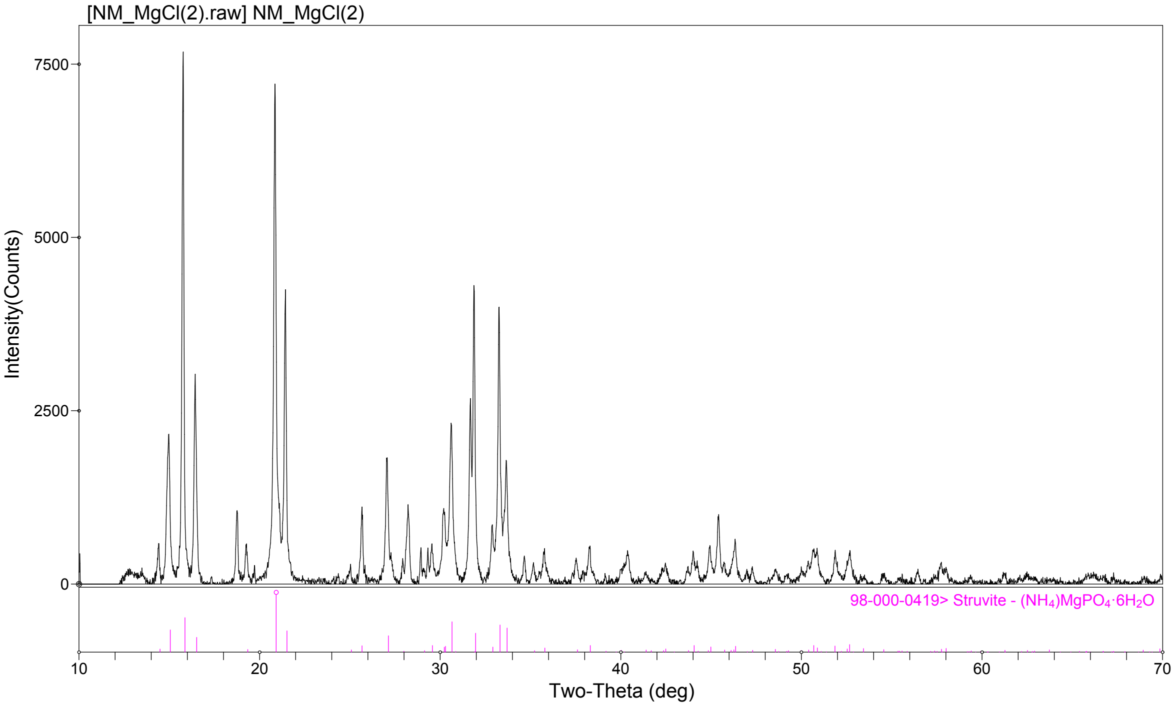

[met_MgCO3(2).raw] HUMet_MgCO3(2)
Intensity(Counts)
15.0
10.0
5.0
x10^3
98-000-0419> Struvite - $(NH_4)MgPO_4 \cdot 6H_2O$
10
20
30
40
50
60
Two-Theta (deg)

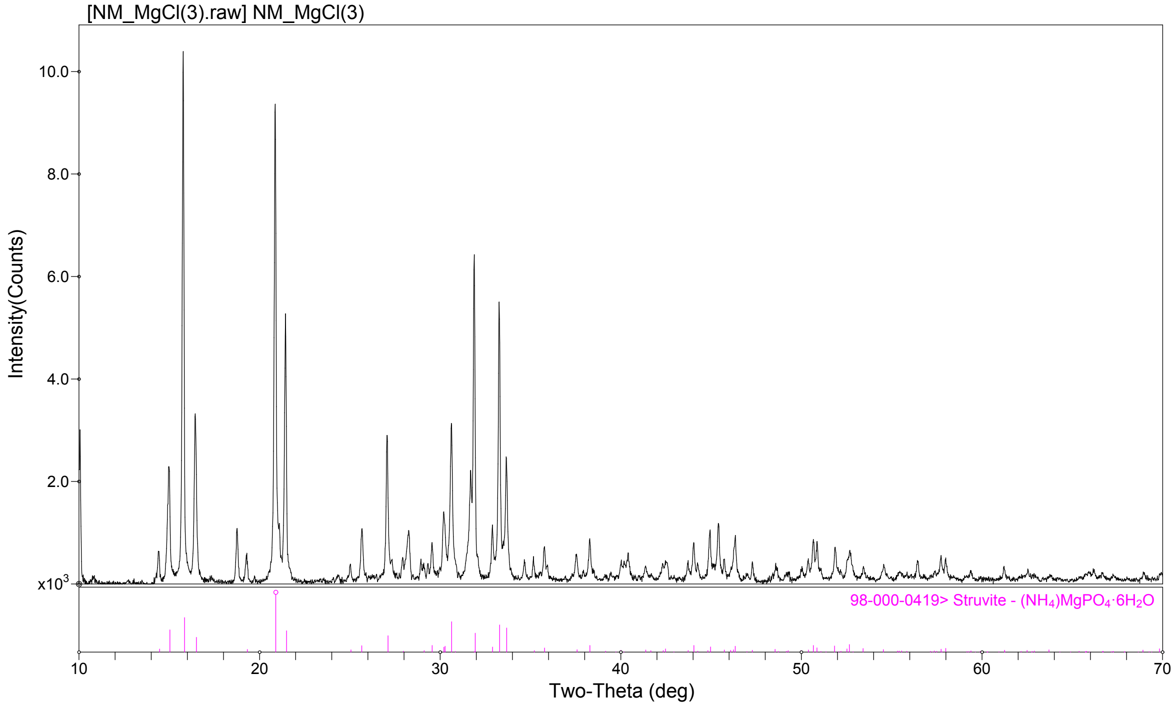
428

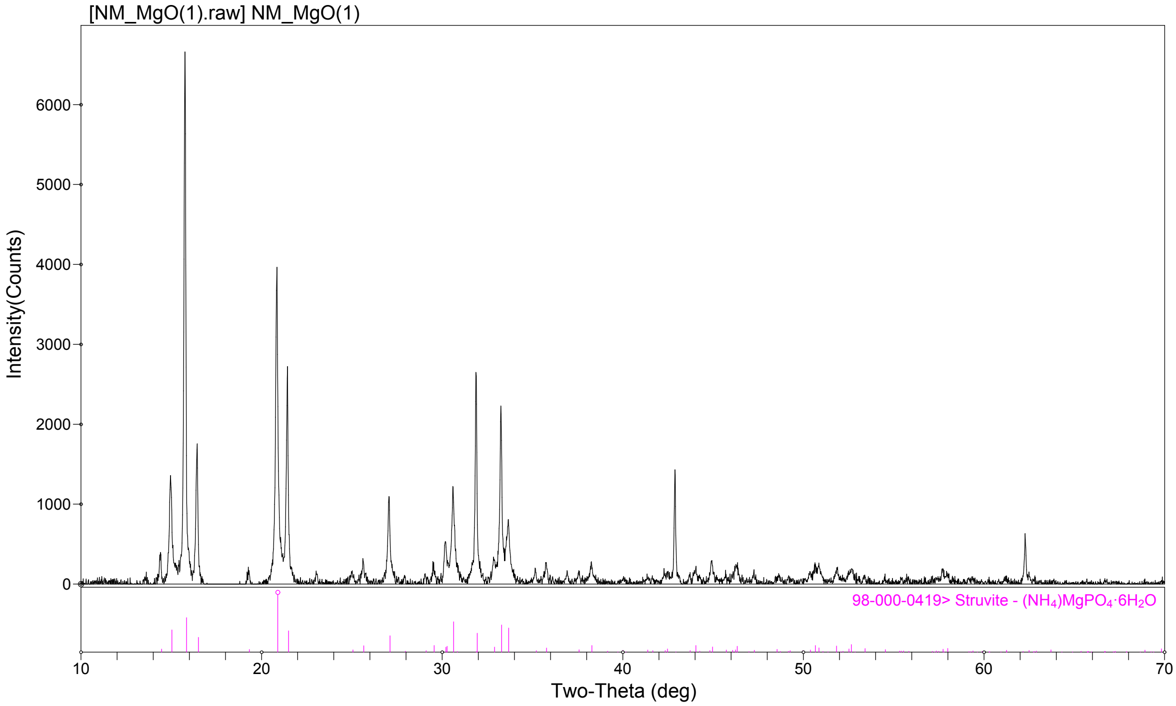


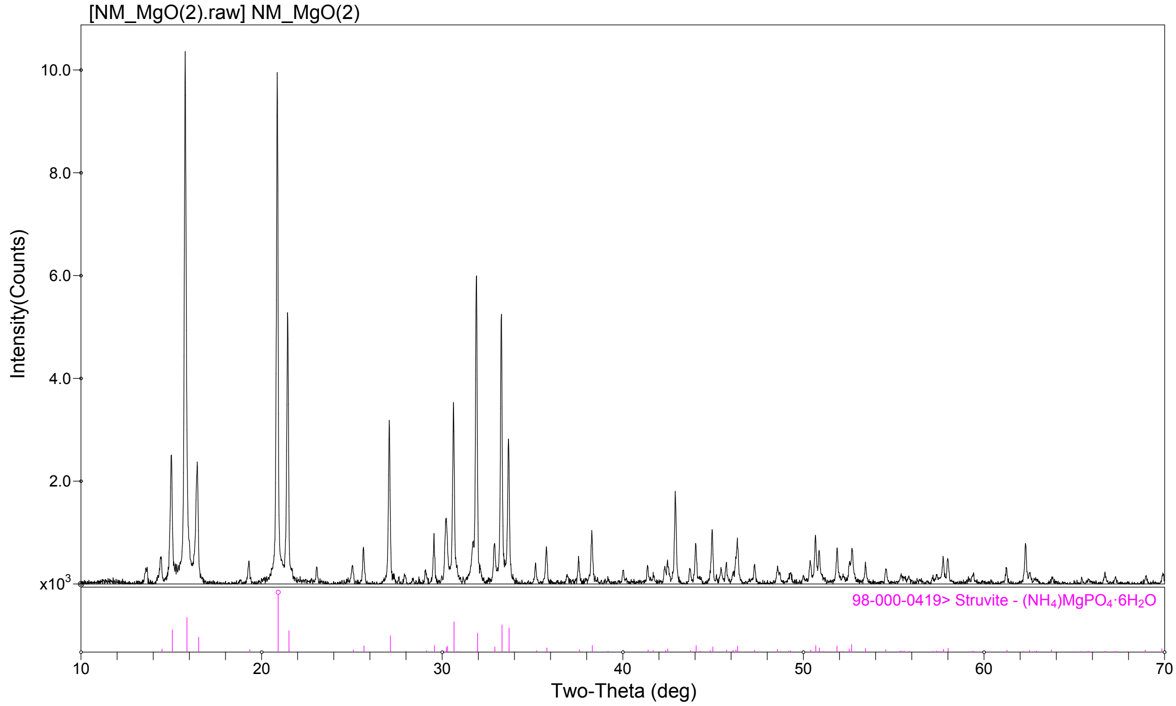
C. XRD for Synthetic urine samples

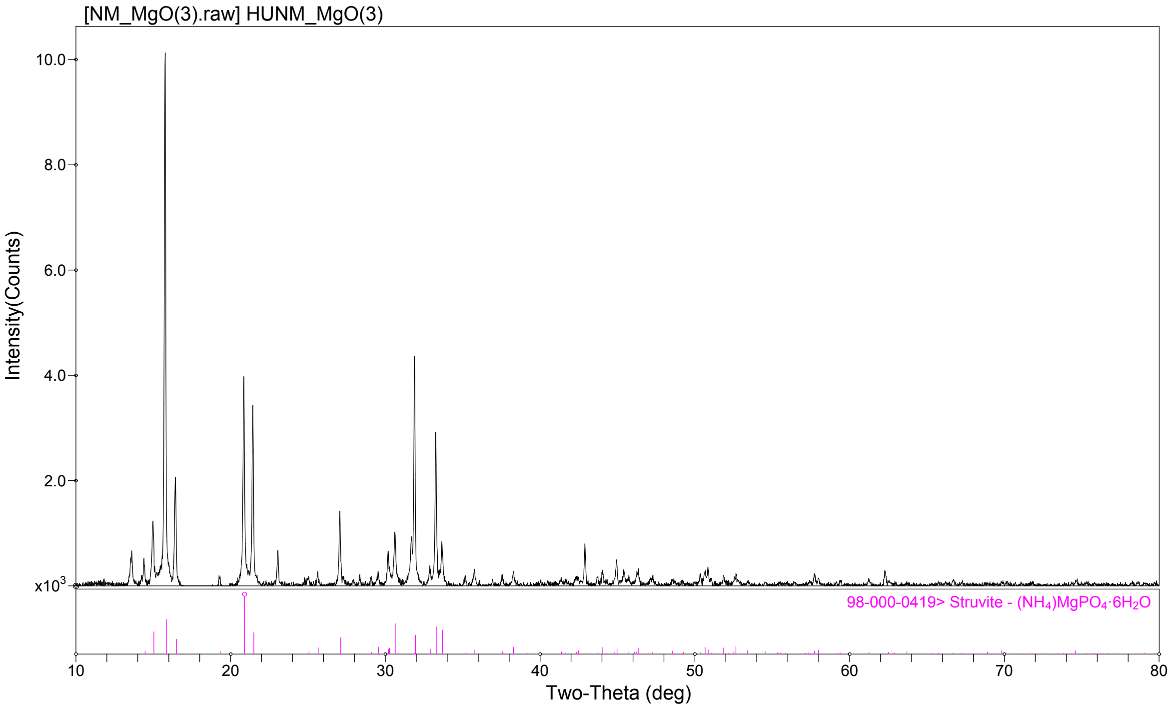


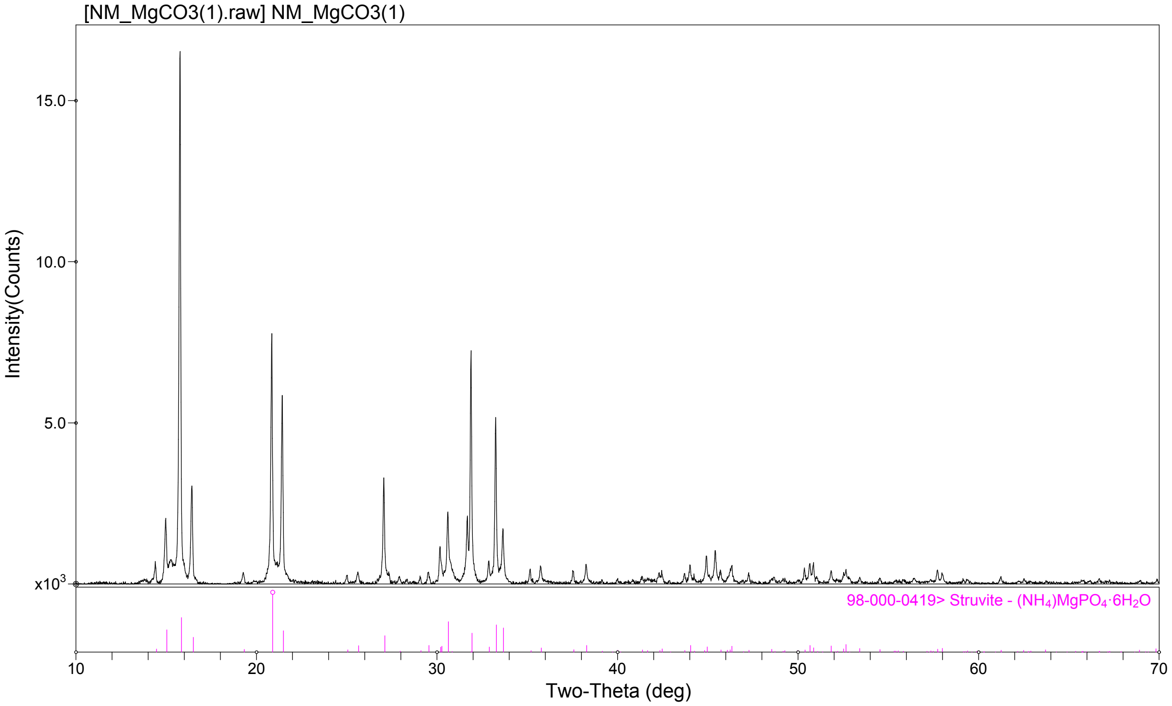

[NM_MgCl(2).raw] NM_MgCl(2)
Intensity(Counts)
7500
5000
2500
0
98-000-0419> Struvite - (NH4)MgPO4·6H2O
10
20
30
40
50
60
70
Two-Theta (deg)

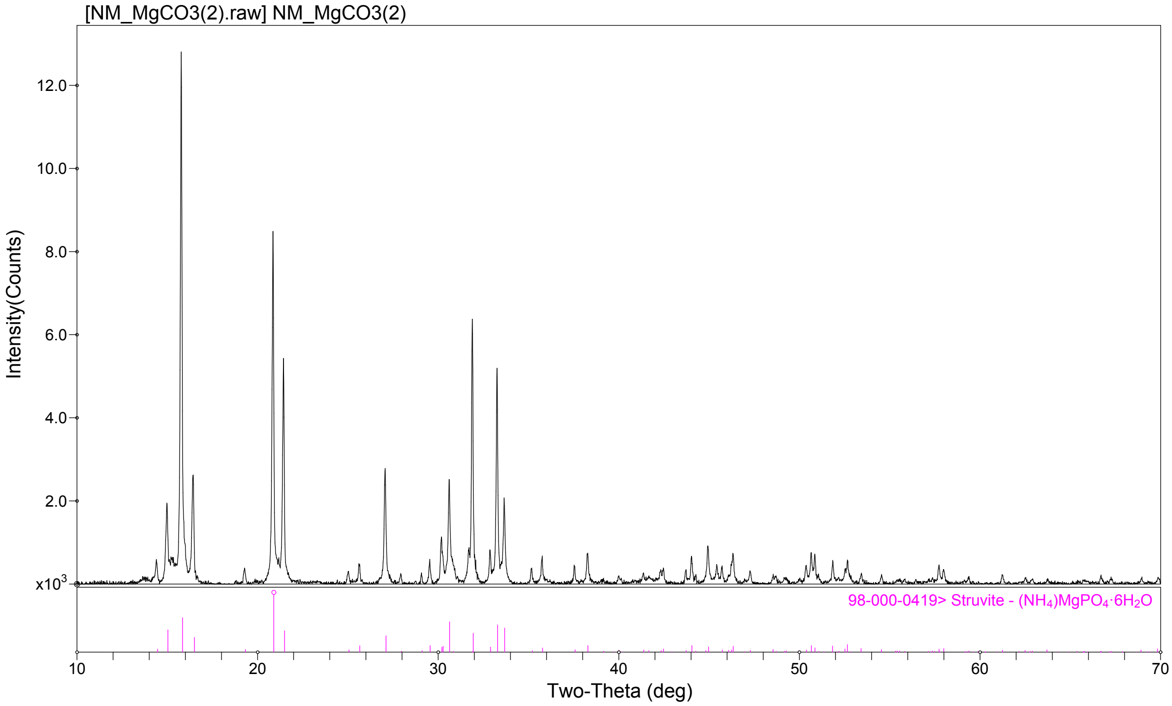

[NM_MgCl(3).raw] NM_MgCl(3)
Intensity(Counts)
10.0
8.0
6.0
4.0
2.0
x10^3
98-000-0419> Struvite - (NH4)MgPO4·6H2O
10
20
30
40
50
60
70
Two-Theta (deg)


[NM_MgO(1).raw] NM_MgO(1)
Intensity(Counts)
6000
5000
4000
3000
2000
1000
0
98-000-0419> Struvite - $(NH_4)MgPO_4{\cdot}6H_2O$
10
20
30
40
50
60
70
Two-Theta (deg)


[NM_MgO(2).raw] NM_MgO(2)
Intensity(Counts)
10.0
8.0
6.0
4.0
2.0
$x10^3$
98-000-0419> Struvite - $(NH_4)MgPO_4{\cdot}6H_2O$
10
20
30
40
50
60
70
Two-Theta (deg)


[NM_MgO(3).raw] HUNM_MgO(3)
Intensity(Counts)
10.0
8.0
6.0
4.0
2.0
x10^3
98-000-0419> Struvite - $(NH_4)MgPO_4{\cdot}6H_2O$
10
20
30
40
50
60
70
80
Two-Theta (deg)


[NM_MgCO3(1).raw] NM_MgCO3(1)
Intensity(Counts)
15.0
10.0
5.0
x10^3
98-000-0419> Struvite - $(NH_4)MgPO_4{\cdot}6H_2O$
10
20
30
40
50
60
70
Two-Theta (deg)


[NM_MgCO3(2).raw] NM_MgCO3(2)
Intensity(Counts)
12.0
10.0
8.0
6.0
4.0
2.0
x10^3
98-000-0419> Struvite - $(NH_4)MgPO_4 \cdot 6H_2O$
10
20
30
40
50
60
70
Two-Theta (deg)

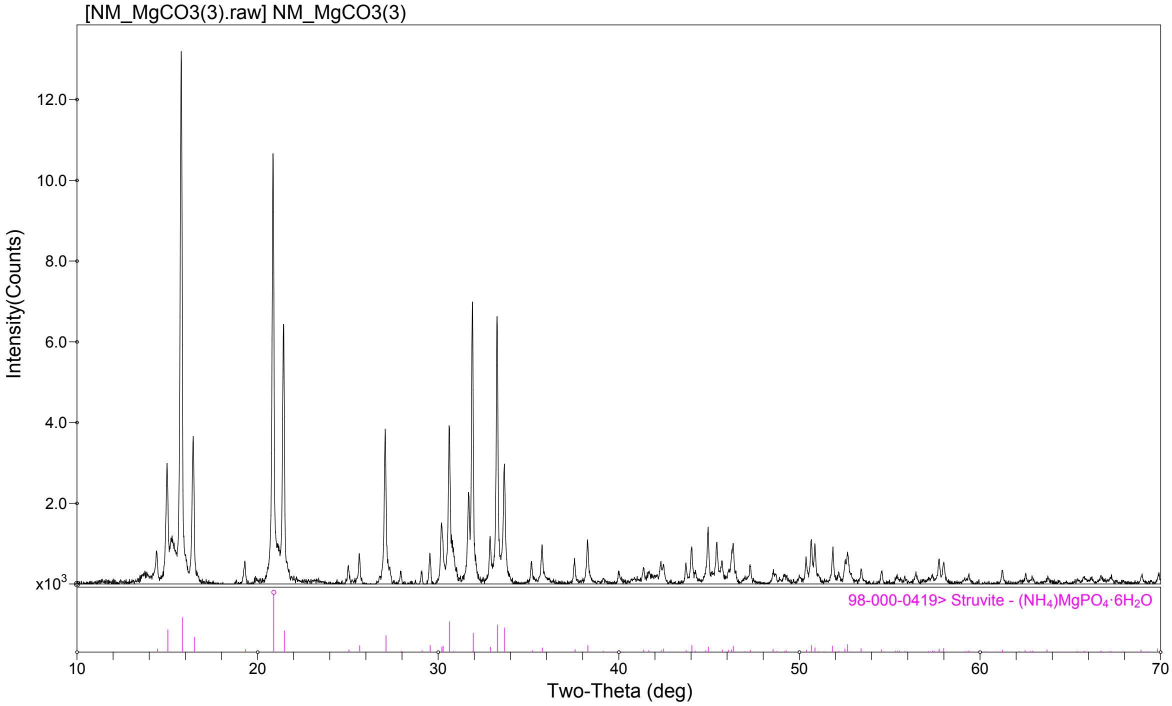
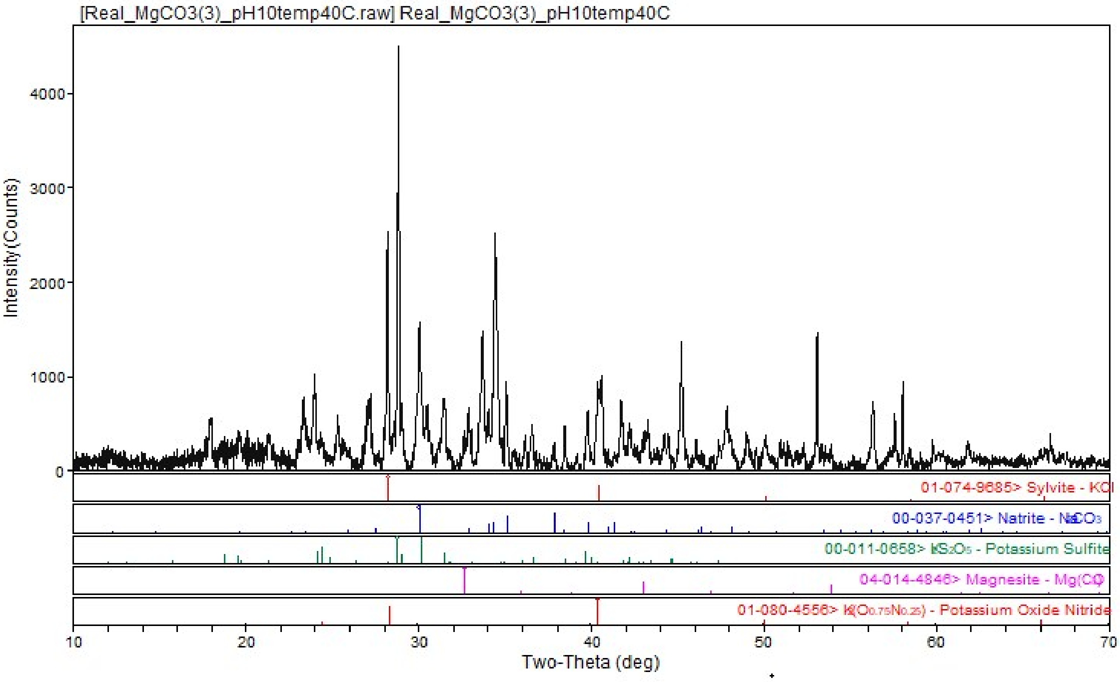
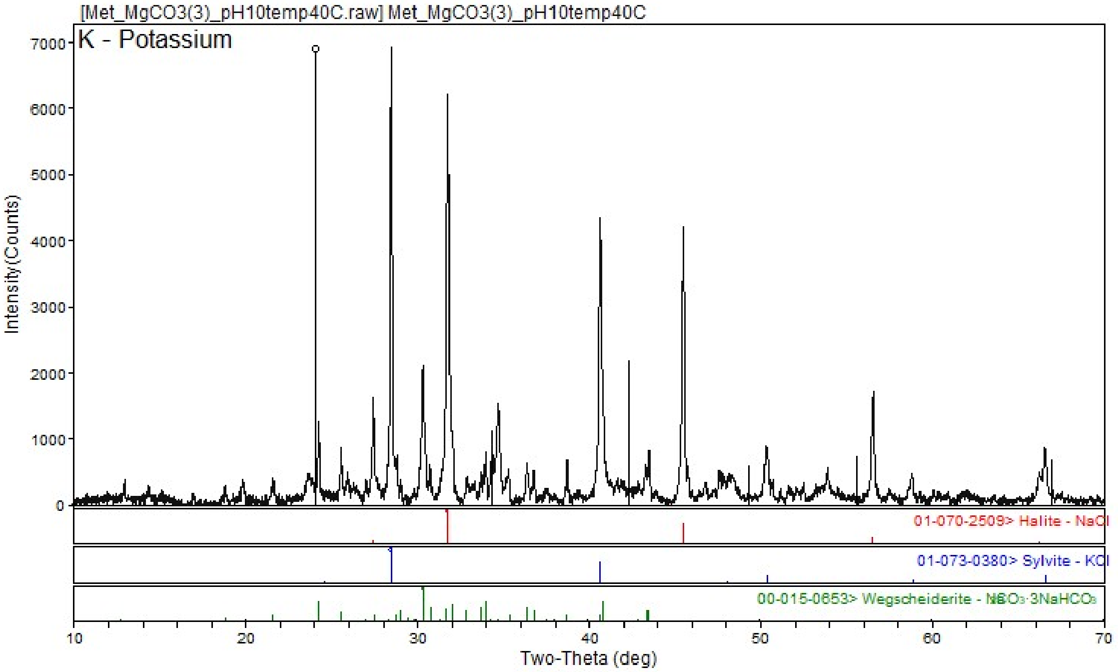
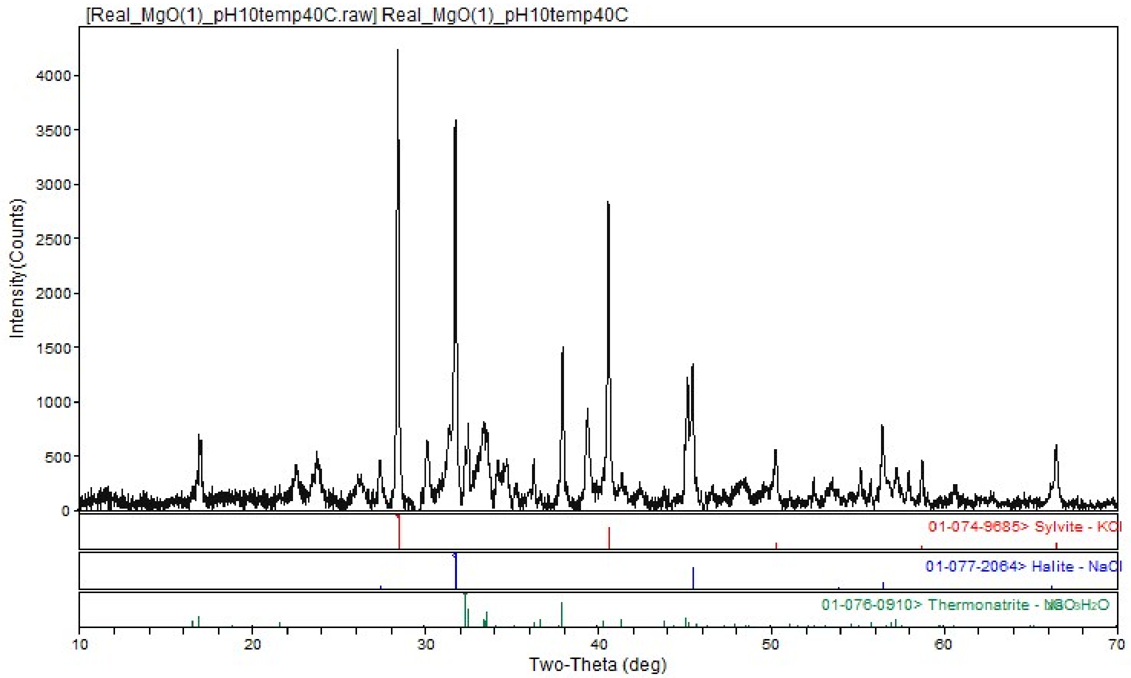
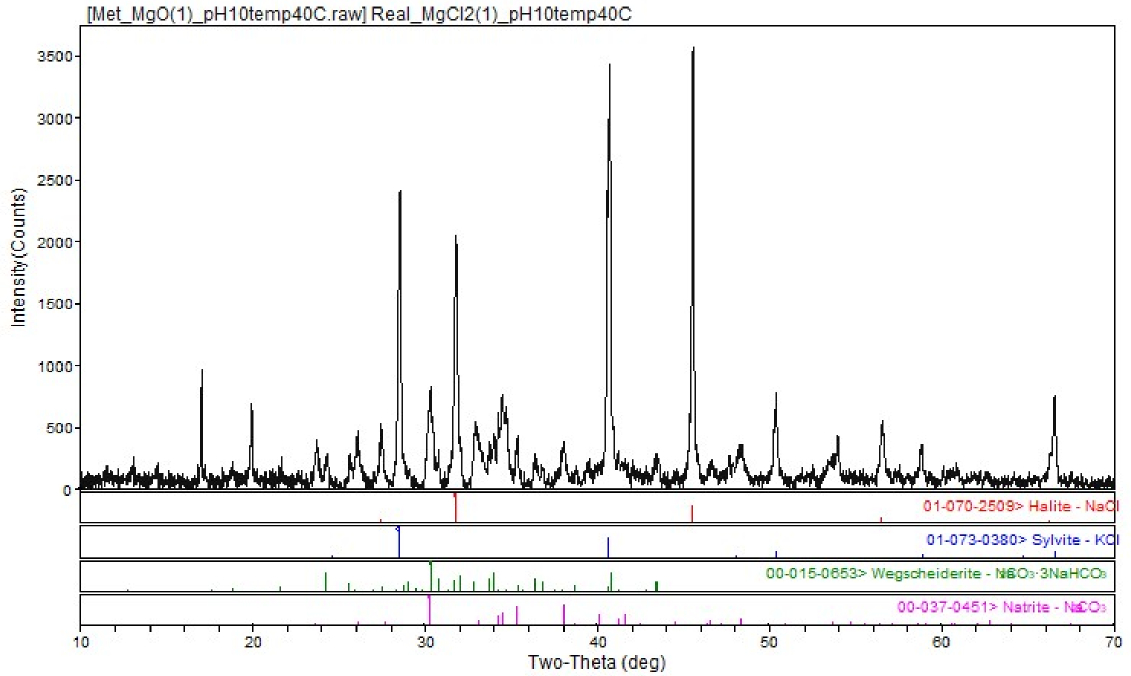

[NM_MgCO3(3).raw] NM_MgCO3(3)
Intensity(Counts)
12.0
10.0
8.0
6.0
4.0
2.0
x10^3
98-000-0419> Struvite - $(NH_4)MgPO_4 \cdot 6H_2O$
10
20
30
40
50
60
70
Two-Theta (deg)

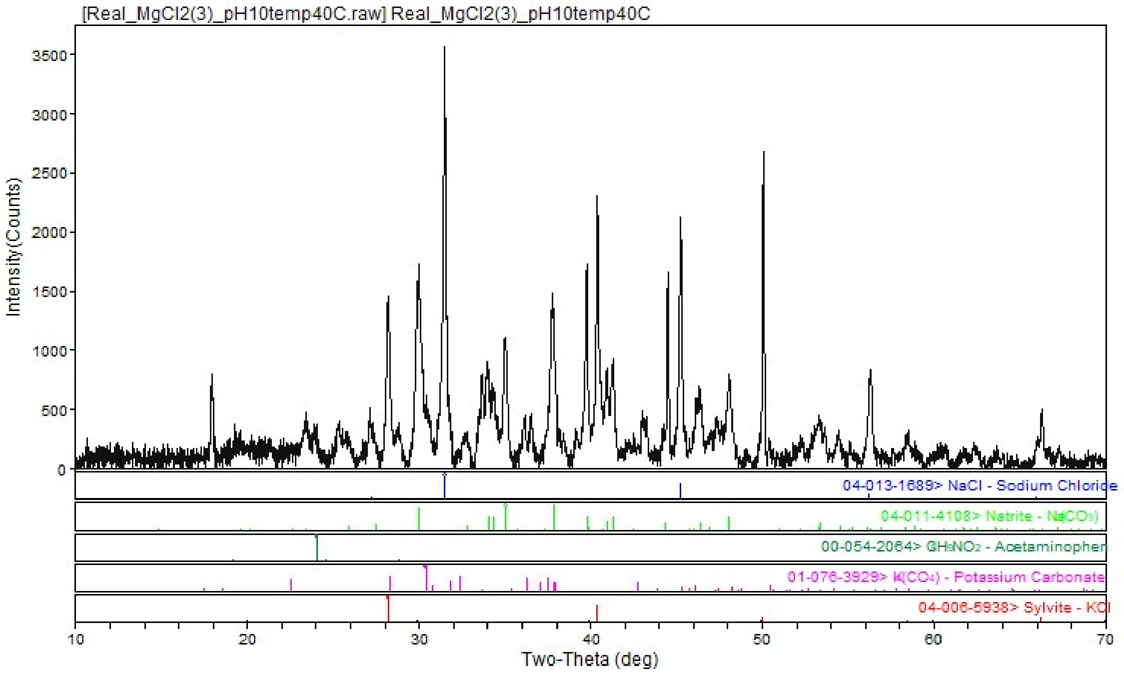
Fig. S2. X-ray diffraction patterns of synthetic and real hydrolyzed urine post evaporation. Previous ammonia stripping–acid absorption condition was pH 10 40°C. Patterns presented are representative samples of triplicates. X-axis is two theta (degree) and y-axis is intensity (counts).

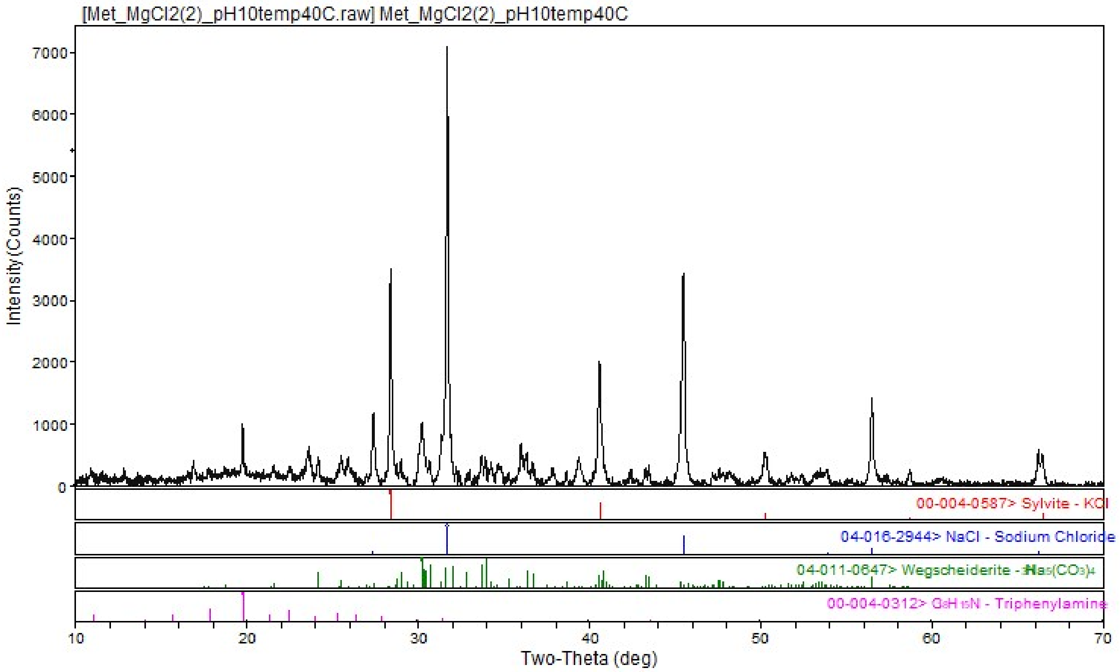





[Real_MgO(1)_pH10temp40C.raw] Real_MgO(1)_pH10temp40C
Intensity(Counts)
4000
3500
3000
2500
2000
1500
1000
500
0
01-074-9685> Sylvite - KCl
01-077-2064> Halite - NaCl
01-076-0910> Thermonatrite - Na2CO3·H2O
10
20
30
40
50
60
70
Two-Theta (deg)


[Met_MgO(1)_pH10temp40C.raw] Real_MgCl2(1)_pH10temp40C
Intensity(Counts)
3500
3000
2500
2000
1500
1000
500
0
01-070-2509> Halite - NaCl
01-073-0380> Sylvite - KCl
00-015-0653> Wegscheiderite - Na2CO3·3NaHCO3
00-037-0451> Natrite - Na2CO3
10
20
30
40
50
60
70
Two-Theta (deg)


[Real_MgCl2(3)_pH10temp40C.raw] Real_MgCl2(3)_pH10temp40C
Intensity(Counts)
3500
3000
2500
2000
1500
1000
500
0
04-013-1689> NaCl - Sodium Chloride
04-011-4108> Natrite - $Na(CO_3)$
00-054-2064> $C_8H_9NO_2$ - Acetaminophen
01-076-3929> $K(CO_4)$ - Potassium Carbonate
04-006-5938> Sylvite - KCl
10
20
30
40
50
60
70
Two-Theta (deg)


[Met_MgCl2(2)_pH10temp40C.raw] Met_MgCl2(2)_pH10temp40C
Intensity(Counts)
7000
6000
5000
4000
3000
2000
1000
0
00-004-0587> Sylvite - KCl
04-016-2944> NaCl - Sodium Chloride
04-011-0647> Wegscheiderite - $Na_5H_3(CO_3)_4$
00-004-0312> $C_{18}H_{15}N$ - Triphenylamine
10
20
30
40
50
60
70
Two-Theta (deg)

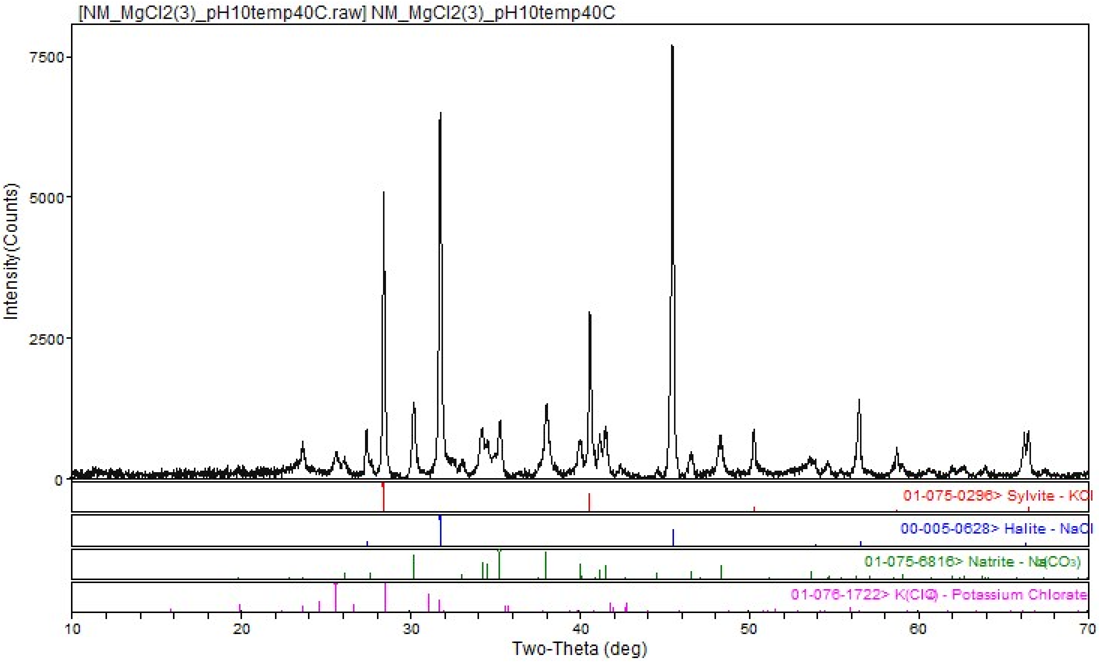
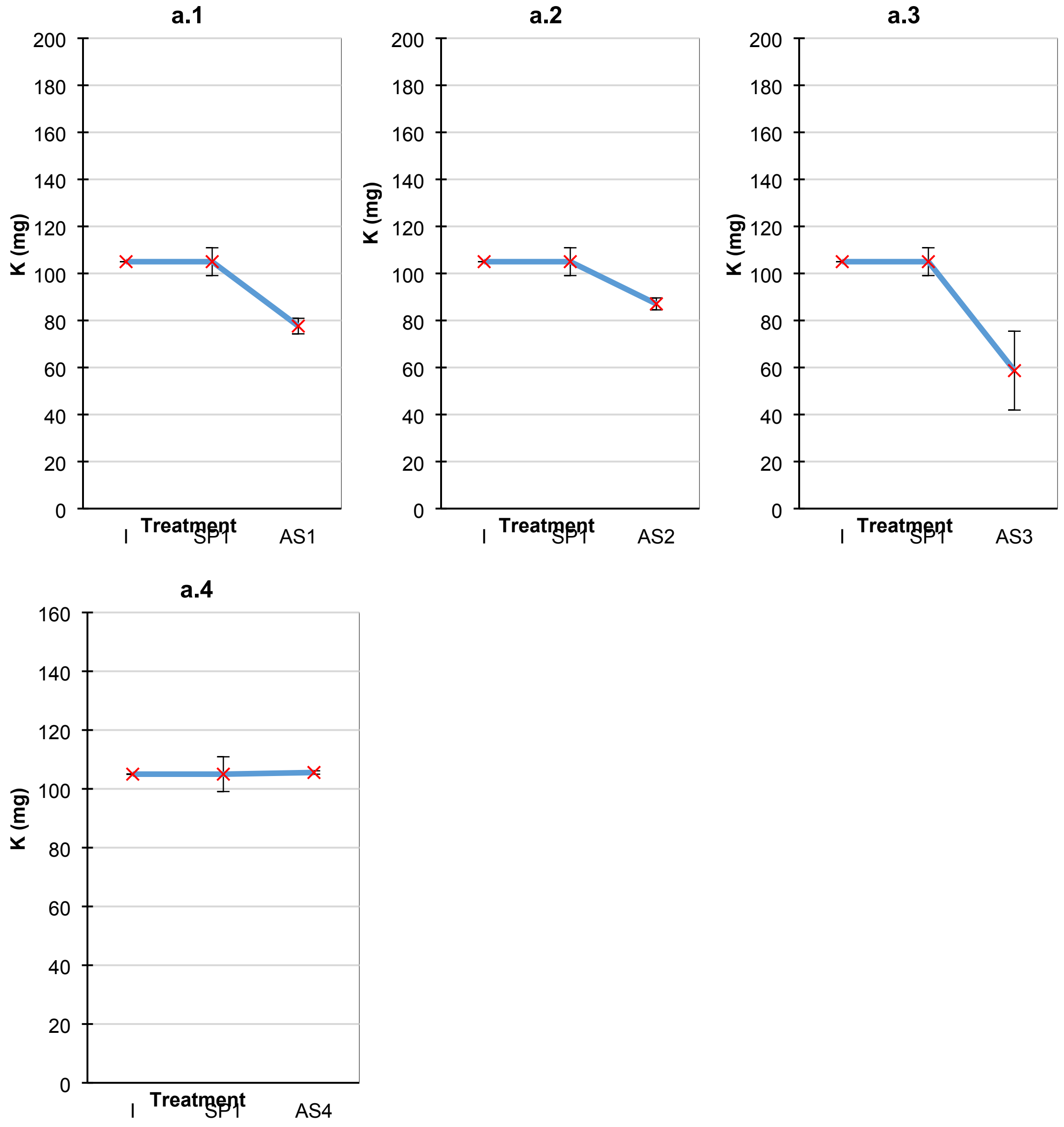


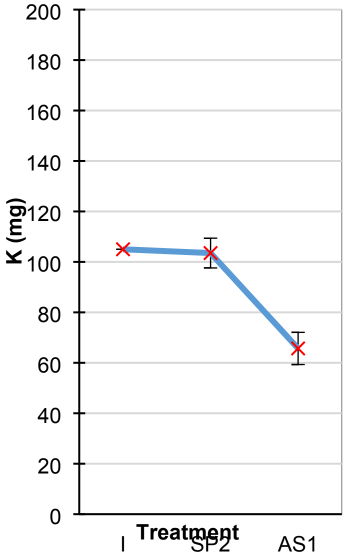
Figure 2 XRD further explanation:

Characterizing the potash product via XRD was not sufficient. Eight XRD patterns are included below to give an example of identified and unidentified peaks. Although a significant portion of peaks could not be identified, KCl and NaCl consistently corresponds with 10% of the peaks followed by $NaHCO_3$ and other sodium and carbonate species, which corresponds with 20% of the defined peaks.

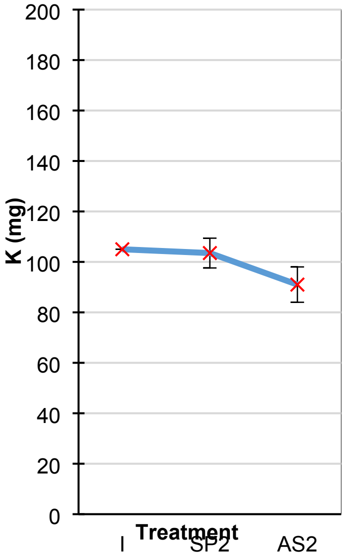
Figure 3. Mass of potassium in (a) real urine, (b) synthetic urine with metabolites, and (c) synthetic urine after each treatment process. Treatment processes are reported on the x-axis labels: Pre struvite precipitation (I), post struvite precipitation (SP), and post ammonia stripping and acid absorption (AS). A volume of 100mL (the experimental volume used for ammonia stripping and acid absorption experiments was used to calculate the mass of K for the treatment processes of pre struvite precipitation (I) and post struvite precipitation (SP). The volume remaining in the stripping column post AS was used to calculate the mass of K for that process. Each treatment process condition is reported in the legend. All measured data, except data for pre struvite precipitation, are values of triplicate samples with error bars showing one standard deviation.



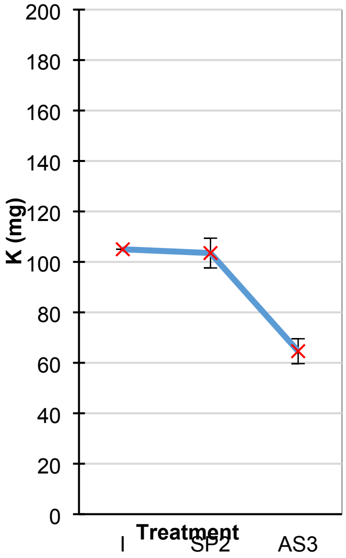
a.5


K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP2
AS1

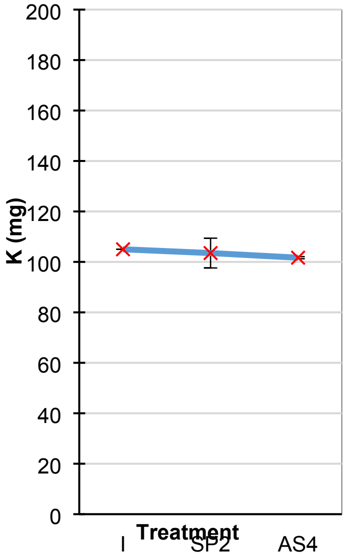
a.6

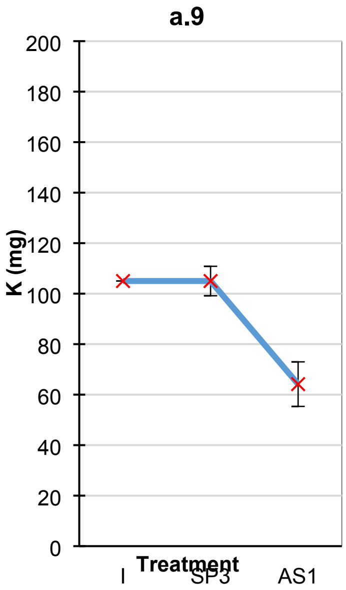

K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP2
AS2

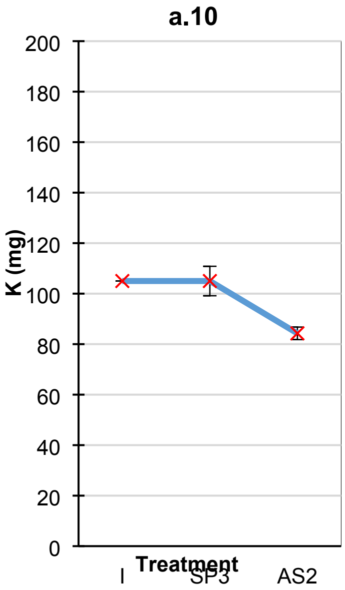
a.7

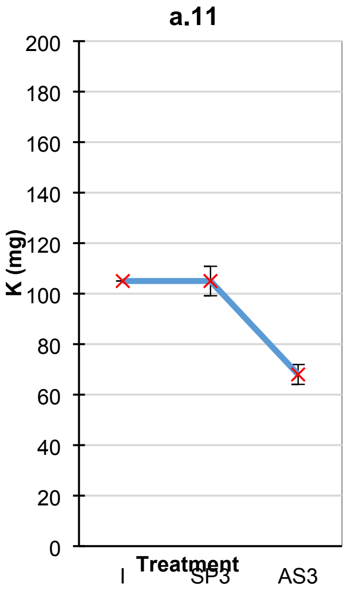

K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP2
AS3

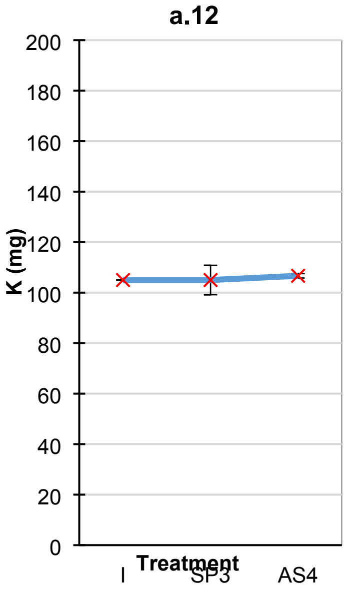
a.8

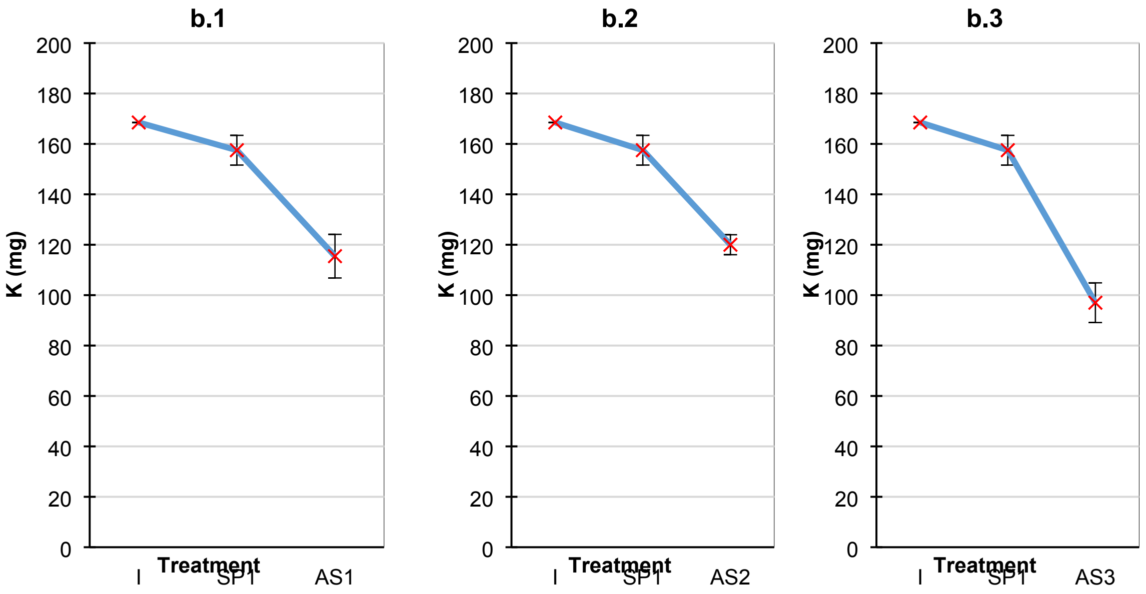

K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP2
AS4

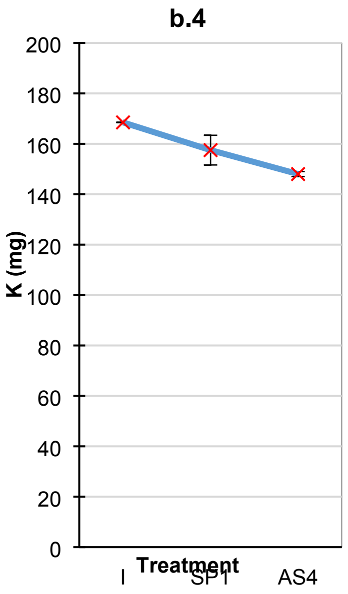

a.9
K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP3
AS1

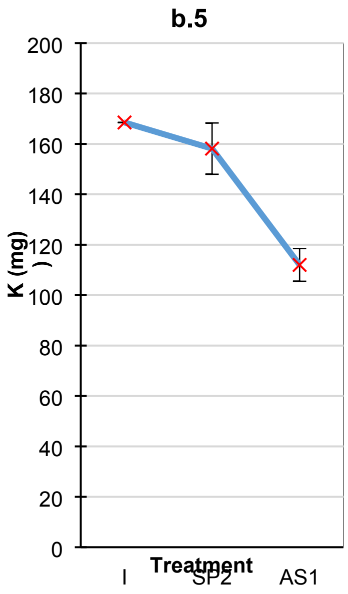

a.10
K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP3
AS2

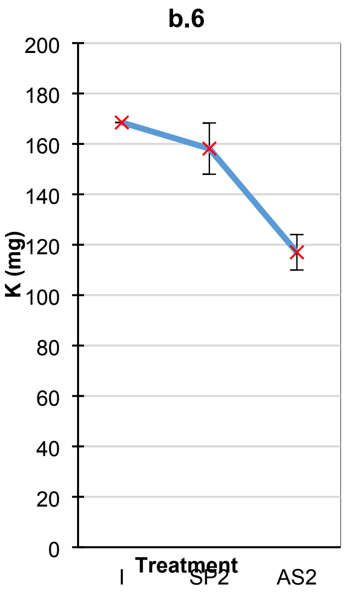

a.11
K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP3
AS3

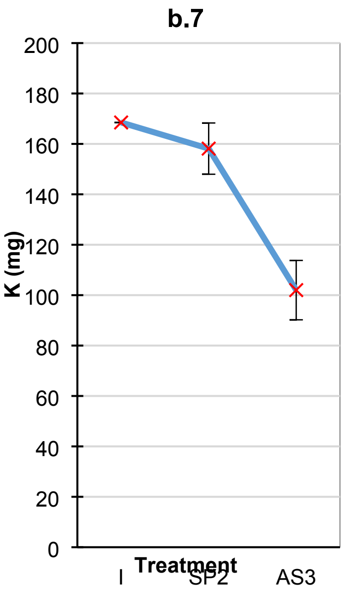

a.12
K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP3
AS4

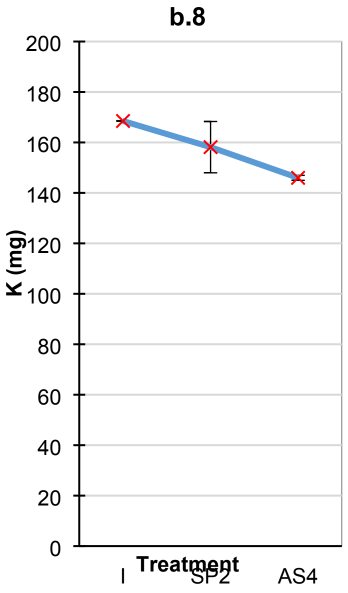

b.1
K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP1
AS1
b.2
K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP1
AS2
b.3
K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP1
AS3

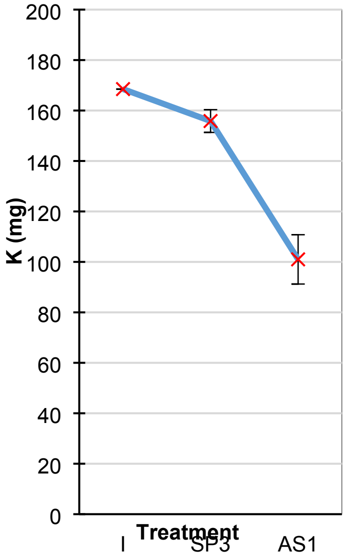

b.4
K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP1
AS4

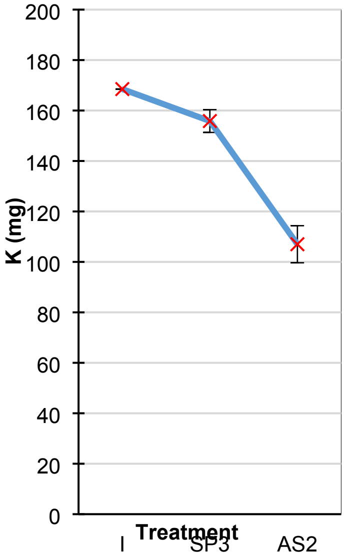

b.5
200
180
160
140
120
100
80
60
40
20
0
K (mg)
Treatment
I
SP2
AS1

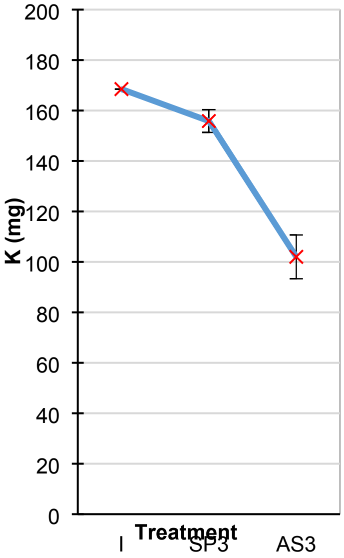

b.6
200
180
160
140
120
100
80
60
40
20
0
K (mg)
Treatment
I
SP2
AS2

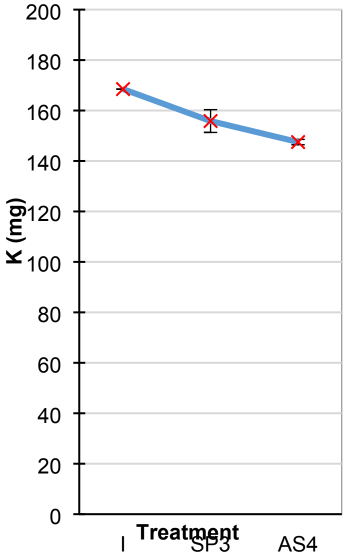

b.7
200
180
160
140
120
100
80
60
40
20
0
K (mg)
Treatment
I
SP2
AS3

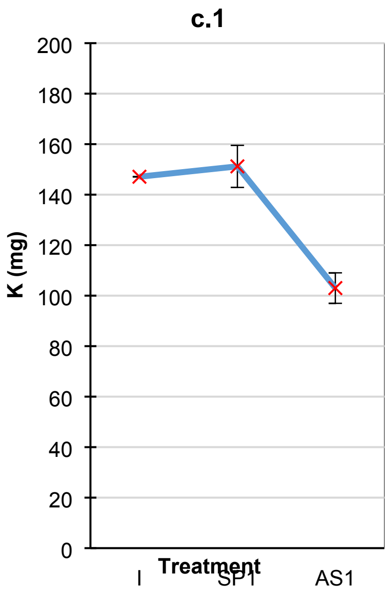

b.8
200
180
160
140
120
100
80
60
40
20
0
K (mg)
Treatment
I
SP2
AS4

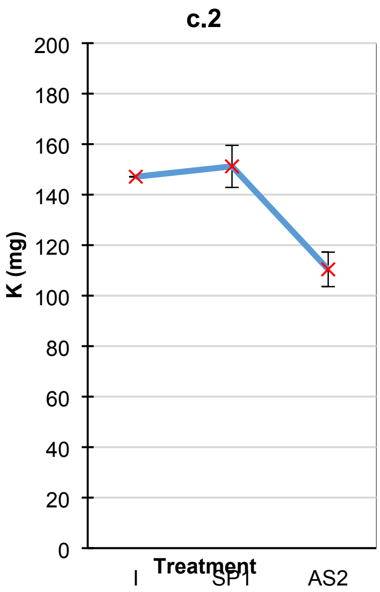

b.9

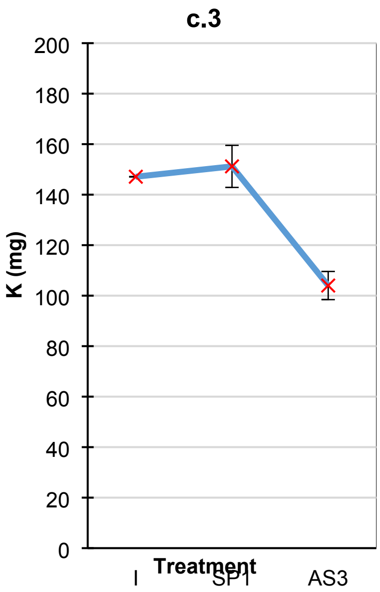

b.10

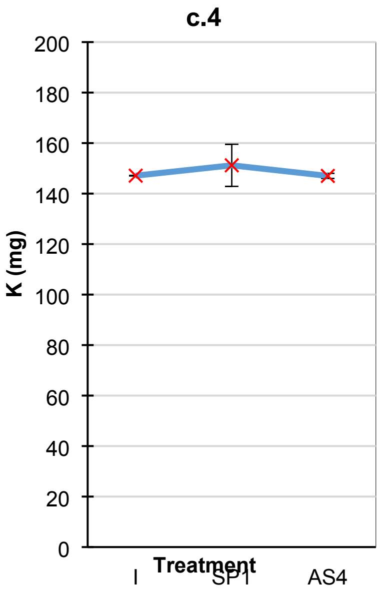

b.11

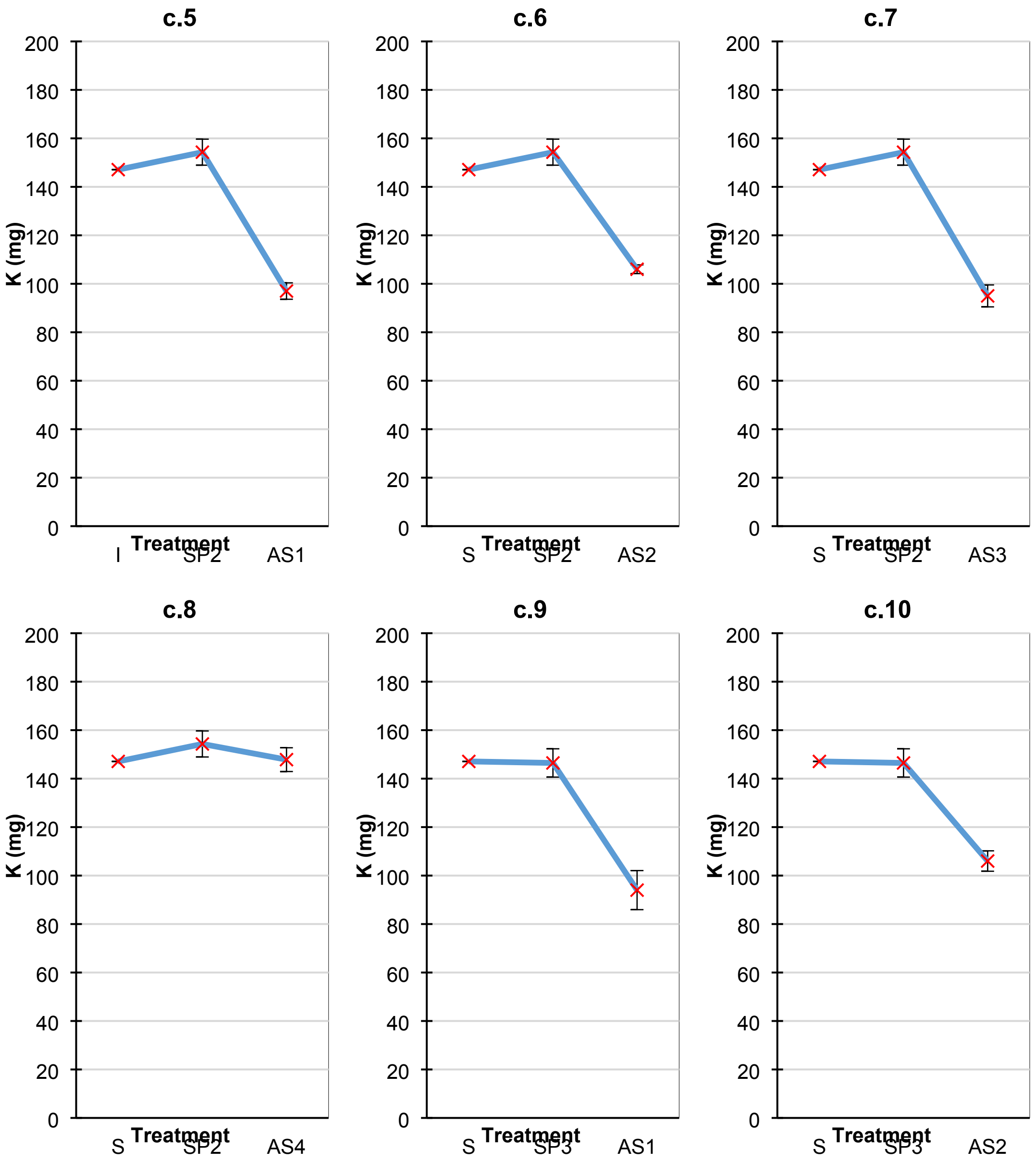

b.12

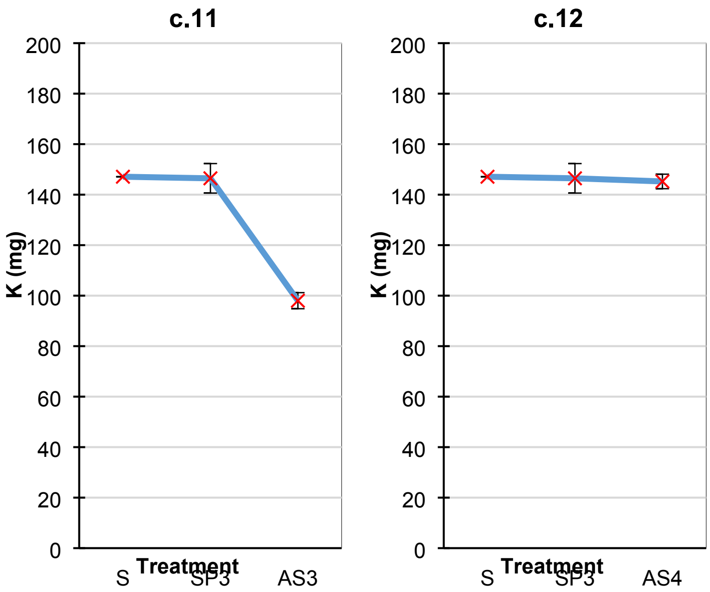

c.1
K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP1
AS1


c.2
K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP1
AS2


c.3
K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP1
AS3


c.4
K (mg)
200
180
160
140
120
100
80
60
40
20
0
Treatment
I
SP1
AS4


c.5
c.6
c.7
c.8
c.9
c.10
K (mg)
0
20
40
60
80
100
120
140
160
180
200
Treatment
I
S
SP2
SP3
AS1
AS2
AS3
AS4



X-AXIS TREATMENT:
I= pre-struvite precipitation
SP1=struvite precipitation using $MgCl_2 \cdot 6H_2O$
SP2= struvite precipitation using MgO
SP3= struvite precipitation using $MgCO_3$
AS 1= ammonia stripping under pH 9.6, 55°C
AS 2= ammonia stripping under pH 10, 40°C
AS 3= ammonia stripping under pH 10.5, 22°C
AS 4= ammonia stripping under pH 9.2, 22°C

1. U. E. P. Agency, *Methods for chemical analysis of water and wastes*, EPA-600/4-79-020, Washington, DC, 1979.
2. D. F. Leikam, *Fluid Fertilizer Foundation*, 2016.