Presented at the International Conference on Nutrient Recovery from Wastewater Streams, Vancouver, Canada, 10-13 May 2009

Social and economic feasibility of struvite recovery from urine at the community level in Nepal

E. Tilley, B. Gantenbein, R. Khadka, C. Zurbrügg and K.M. Udert

Eawag: Swiss Federal Institute of Aquatic Science and Technology, Überlandstrasse 133, 8600 Dübendorf, Switzerland
Corresponding author: kai.udert@eawag.ch, phone: +41 44 823 53 60, fax: +41 44 823 53 89

ABSTRACT

In the face of increasing phosphorus prices, Nepal, like all agrarian societies is in imminent need of a low-cost, sustainable source of phosphorus and nitrogen. The town of Siddhipur in the Kathmandu valley was selected as a study site to determine the feasibility of establishing a community-scale struvite processing centre using source-separated urine as a feedstock. Focus groups, workshops and household questionnaires were used to determine cultural acceptability and willingness to pay. Urine quality and quantity measurements, along with fertilizer cost analysis were used to determine the economic feasibility. A regression analysis using the current, local value of the nutrients was used to calculate the theoretical value of struvite; the estimated nutrient value of struvite was found to be 24 to 41 NRp per kilogram, which is in the same range as locally available Diammonium Phosphate (DAP). The production of struvite would currently cost about 25 NRp/kg due to high prices of available magnesium sources. Nevertheless, struvite precipitation can be economically feasible for at least three reasons. First, Nepal possesses its own magnesite deposits, which might allow it to produce cheaper magnesium sources. Second, customers are likely to pay more for locally produced struvite than for imported synthetic fertilizers. Third, the effluent from struvite precipitation can also be used as a valuable and efficient nitrogen and potassium fertilizer. Despite shadow-pricing based on the constituent nutrients, the true value of struvite can not be known until it is produced and sold.

KEYWORDS

magnesium ammonium phosphate (MAP); nutrient recovery; phosphorus; sustainable sanitation; struvite precipitation; urine separation;

INTRODUCTION

After a long period of a state regulated fertilizer supply in Nepal, the fertilizer market was liberalized by the government in 1997. The Nepalese government, in an attempt to control long lines and shortages, removed import duties and value-added tax on fertilizer products and granted other tax reductions. However, these small gestures were not enough to compensate for the dramatic increase, and a new black market of imported fertilizer from India emerged. India continues to subsidize fertilizer nationally, and thus a lucrative business of smuggling Indian fertilizer into Nepal has emerged to take advantage of the significant price gap. As of 2006, roughly 60% of the total fertilizer sold in Nepal came from informal sources and of that, the majority can be attributed to India (Thapa, 2006).

As fertilizer, especially phosphate, prices continue to rise at unprecedented rates (The Market, 2008), it is imperative for Nepal and other countries with low income to explore alternative sources for nutrient supply such as human urine (Lienert et al., 2003).

Struvite

A great deal of research over the past 20 years has optimized phosphorus recovery through struvite precipitation from different side streams in WWTPs, especially from digester supernatant (Ueno and Fujii, 2001; Britton et al., 2005; Forrest et al., 2008). Until recently, however, relatively little work has been done on the recovery of struvite from urine, although the body of work is growing (Ronteltap et al., 2007; Wilsenach et al., 2007; Tilley et al., 2008). Despite the fact that reactor design, dosing regimes and pH control can optimize the process and improve the product, the fundamentals of struvite recovery remain unchanged. A soluble magnesium source, a high pH value, a stirring mechanism and an effective method of solid separation are, essentially, the elements needed for struvite recovery with a high rate of phosphate recovery (490 % and usually higher). Due to the low technological requirements, phosphate recovery through struvite precipitation is an ideal process for low-tech applications, e.g. in decentralized setups or in the developing world.

Urine is often promoted as a liquid fertilizer although it has a strong smell, it is heavy to transport, it is voluminous, it requires a large amount of storage space and its nutrient content is often unknown. Application of urine as a fertilizer is further hampered by the volatilization of ammonia. Struvite, on the other hand, is odourless, dense, compact and efficient to transport, it can be stored during winter, or dry seasons and used when needed, and the nutrient quantity is consistent. Struvite from urine offers the simplicity and quality of chemical fertilizer without the high cost or technical requirements. However, struvite is essentially a phosphate fertilizer, with little nitrogen and no potassium except if struvite is precipitated from an ammonium free solution (Wilsenach et al., 2007).

Siddhipur

As of 2006, 73 % of people in Nepal still lacked access to improved sanitation, but between 1990 and 2004, intensive national and international projects increased the number of people with improved sanitation by 25 % (WHO, 2008). According to an ENPHO report (ENPHO, 2007) there are 481 Urine-Diverting Dry Toilets (UDDTs) in the Kathmandu valley, but informal information suggests it could be closer to 600.

Siddhipur is a farming village located about 10 km south east of Kathmandu. Of the 6000 residents, almost 90 % of them work in agriculture. Although there is a sewer network in Kathmandu proper, Siddihipur is not connected. Currently there are 100, family-owned UDDTs in Siddhipur. Because of the number of urine-collecting toilets, the proximity to agriculture, the tradition of nutrient reuse and the proven sensitivity to inter- vention programs, Siddhipur was selected as the study site for examining the possibility of community-scale struvite production.

METHODS

To determine the economic feasibility of collecting the urine generated at the household level and processing it into struvite at the community level, the quality, quantity and current uses of urine were determined. The cultural acceptability and willingness to pay was determined in focus group disccusions, in workshops and with household.

Urine quality

Urine samples were taken from 14 household urine containers. To determine the average concentration of nutrients, 10 samples were mixed together and analyzed for nitrogen, phosphorus and potassium. The remaining 4 samples were analyzed individually for phosphorus. Additionally, struvite was prepared with the mixed sample and the process effluent was subsequently analysed for N, P and K. The results are summarized in Table 1.

Table 1: *Urine analysis*

Parameter	pH	EC	PO_4-P	NH_4-N	K
		[mS/cm]	*[mg/L]*	*[mg/L]*	*[mg/L]*
Individual samples					
Sample 1	8.83	62.6	374	–	–
Sample 2	8.57	40.1	264	–	–
Sample 3	8.00	24.0	123	–	–
Sample 4	8.48	31.1	182	–	–
Mixed samples					
Untreated urine	8.67	38.2	259	2352	802
Mix struvite effluent	8.59	38.5	16.47	2240	744
Values from Ek et al. (2006)					
Stored urine	9.1	–	310	3600	900

Compared to literature data for stored urine (Udert et al., 2006; Vinnerås et al., 2004; Jönsson et al., 2005), the urine of Siddihipur is considerably less concentrated. Ek et al. (2006) monitored urine from UDDTs and found values that were more similar to those found in Siddhipur, although they attributed this to dilution of the urine with water. Citizens of Siddhipur also dilute the urine as a way to 'reduce smell', although the effectiveness of this technique, is not completely clear.

To assess the amount of urine that could be collected in Siddhipur, a questionnaire with 26 UDDT owners was conducted. People were asked how often they empty their urine tanks and based on that information, it was deduced that they collect, on average, 155 L of urine per person per year, which is one- third to one-half of the normally cited values (Ciba-Geigy, 1977). Some families claim as much as 355 L per person per year, while others reported as low as 51 L were collected per person per year. To verify these data, the urine tanks at six households were monitored continuously for six days. On average about 0.5 L per person and day was recorded, although some families are collecting close to 1 L per person and day.

Interviews about how the families use the urine indicated that people either pour the urine on their compost pile (the Nepalese 'saaga'), use it on a local plot, dump it in the drain or give it to someone for agricultural use. So while there is not a strong tendency to use it directly on fields, there is little doubt that the use of urine is well accepted.

FINANCIAL FEASIBILITY

To determine the perceived value of urine, people were asked to answer questions about how much they would consider paying for urine as a liquid fertilizer. The results were too erratic to obtain a useful data set. Some people reported that they would not sell their urine for any price (despite the fact that they were currently dumping it down the drain) while still another reported that he would pay 2000 NRp for 100 L of urine (where 100 NRp is approximately 1 €). This clearly illustrates that estimating or valuing the nutrient worth of urine or struvite is something that has no precedent in this community and therefore, will likely be unpredictable until the point of sale. The price of 16 different local fertilizers including NPK mixes, urea and diammonium phosphate were collected in local fertilizer shops. The fertilizers and their prices are listed in Table 2.

Table 2: *Currently available fertilizers*

Fertilizer	Prices (NRp/kg)
Urea $(NH_2)_2CO$	20, 29, 30, 20, 20
NP 20:20	29, 30, 27, 30
NPK 20:20:10	32
Diammonium Phosphate $(NH_4)_2HPO_4$	38, 44
Ammonium Sulfate $(NH_4)_2SO_4$	24, 25
Myriate of Potash KCl	22
Magnesium Sulfate $MgSO_4$	24

To determine the current value of each nutrient of interest, a regression model was used to disaggregate the price of each of the nutrients (N, P, K, S, Mg) from the total fertilizer price using the following:

$$\text{Price} = a_1[N] + a_2[P] + a_3[K] + a_4[Mg] + a_5[S]$$

The value for each element, as well as the standard error, for the determination of each, is shown in Table 3.

Table 3: *Regression estimates for nutrient values.*

Nutrient	Value (NRp/ kg)	Std. error (%)
Nitrogen	60	9
Phosphorus	159	10
Potassium	54	20
Magnesium	173	34
Sulfur	61	27

Phosphorus has more than twice the value of nitrogen, and nearly three times the value of potassium. The low standard error for

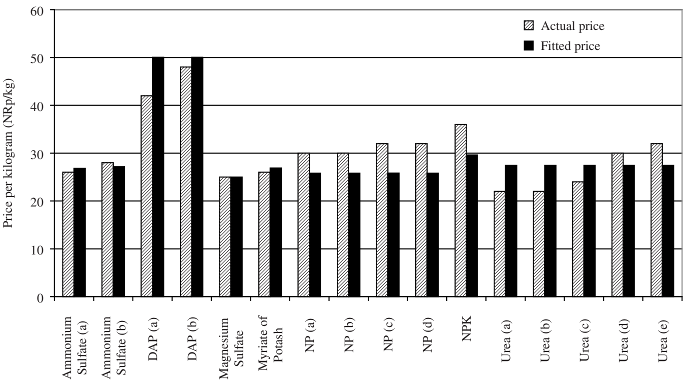

Figure 1: *Comparison of modelled and actual fertilizer prices.*

Table 5: *Regression estimates for value of struvite processing effluent. Upper and lower values are estimates for the limits of the 95 % confidence interval (average ± 2 standard deviation). A ratio of 16 g NH_4-N/g SO_4-S was used to estimate the sulfur content of urine (Udert et al., 2006).*

Parameter	N	P	K	S	water	NPK	NPK water
concentration (kg/m³)	2.24	0.017	0.74	0.14	1000	–	–
max value (NRp/m³)	157	3.1	56	13	100	229	329
est value (NRp/m³)	134	2.6	40	8.5	100	185	285
min value (NRp/m³)	111	2.1	24	3.8	100	141	241

nitrogen and phosphorus reflects the fact that all, except for 4 of the fertilizers used in the regression include nitrogen and phosphorus, whereas the calculations for K, S and Mg were based on only two, two and one fertilizer(s), respectively.

Using the values shown in Table 4, the price of fertilizers were calculated. Figure 1 shows a comparison between the calculated values for each fertilizer as determined by the regression analysis, and the actual prices. Clearly, the regression was able to predict the price of the elements such that the fertilizers prices could be estimated closely using the regression results. The same regression results were used to estimate the value of each of the elements in struvite as well as the total nutrient value of struvite. Although magnesium is not typically sought out by farmers, it is important for healthy soils; the value of struvite both including and not including the value of magnesium is presented in Table 4.

Table 4: *Regression estimates for nutrient value of struvite. Upper and lower values are estimates for the limits of the 95 % confidence interval (average ± 2 standard deviations).*

Parameter	**N**	**P**	**Mg**	**Struvite**	
Prices in NRp/kg				no Mg	incl. Mg
weight fraction (%)	5.7	13	10		
upper value	4.0	24	29	28	57
estimated value	3.4	20	17	24	41
lower value	2.8	16	5.5	19	25

The weight fraction for each element was based on the molecular weight of struvite being 245 g/mol; the upper and lower values were calculated using the percent standard deviation determined in the regression. The calculated value of 1 kg struvite is similar to locally available DAP (38 and 44 NRp/kg). The financial feasibility of struvite production strongly depends on the costs for the magnesium source. If the magnesium sulfate listed in Table 2 were used for struvite precipitation, the costs for 1 kg struvite would be at least 25 NRp/kg, which is close to the nutrient value of struvite. Nevertheless, we argue that there are at least three reasons why struvite precipitation is economically feasible. First, cheaper magnesium sources can be made accessible in Nepal, since the country has own magnesite deposits (USGS 2007). Second, it is very likely that customers are willing to pay more for locally produced struvite than for imported synthetic fertilizers. Third, the effluent from struvite precipitation is a valuable fertilizer, which might be especially suited for micro-irrigation. When struvite is produced, a nitrogen-rich, high pH solution remains. As noted in Table 1 there is over 2000 mg/L of nitrogen remaining in the effluent after struvite has been precipitated. Table 5 presents the theoretical nutrient values of the struvite effluent. Non-potable freshwater can be bought in Siddhipur for 100 NRp per cubic metre. Since the effluent could potentially serve as a drought- proof irrigation-water source, as well as a year-round fertilizer, the value for effluent including and excluding the value of water is shown. The use of the effluent as a fertilizer can strongly increase the economic feasibility of urine processing. Assuming a struvite yield of 1.92 kg struvite/m³ urine, the effluent values can be estimated as 149 NRp/kg struvite and 96 NRp/kg struvite with or without water, respectively (calculated with an ammonium to phosphate ratio in collected urine of 9 kgN/kgP).

Although untreated urine has a similar composition, effluent is arguably more suitable for modern fertilization methods such as micro-irrigation than untreated urine. Effluent, unlike untreated urine, does not have the ability to precipitate spontaneously the same way that full strength urine does (Tilley et al., 2008). Urine precipitation is one of the major problems facing urine-separating technologies and components: pipes, values, and fittings routinely become blocked and must be cleaned with acid or by hand (Udert et al., 2003). Although there is little published evidence, anecdotal evidence points to the same problem with using urine in micro irrigation. Micro irrigation is an attractive alternative to hand-application since it reduces lifting, carrying, smells, nitrogen losses and the fertilizer can be targeted to the ideal root zone. It is hypothesized that precipitates from urine would clog and disrupt the functioning of irrigation systems using urine: for this reason it is proposed to use the effluent generated as a precipitate/clog-proof source of irrigation water and nitrogen. Studies are currently underway to assess the technical feasibility of this solution, given that the economic feasibility has already been established.

CONCLUSIONS

Struvite recovery from urine in Siddhipur is both culturally and economically feasible.

The assessment of urine in Siddhipur indicates that most people are not using the UDDTs constantly, and therefore the current volume generated is less than initially thought. Public urinals and education campaigns about the hygienic, environmental and financial benefits of consistently using the UDDTs and collecting urine may be methods to improve the quality and quantity of urine, and therefore the amount of struvite that could be produced.

To reap increased value, future research will address the potential of using the nitrogen-rich processing effluent as a liquid fertilizer. If this is successful, the effluent could be used for free locally, while the struvite could be used, with any surplus sold for export, as a cash-earning product.

The methods used, i.e. shadow-pricing, do not, and can not, reflect the true 'value' of either the struvite or the effluent since there is inherent value which can not be numerically assessed. The fact that locally produced struvite will be made onsite, will be associated with a person or a group who is visible in the community, and that the product is consistently reliable (as opposed to foreign imports which are subject to natural disasters like in China, or foreign export rules) may add extra value. Alternatively, the reverse may hold true, if fears exist about the quality or if local fertilizer merchants see it as a threat to their business.

The price of magnesium has a large effect on the price of producing struvite, and it would be unrealistic to attempt producing struvite if a low cost source were not available. It is very likely that cheaper magnesium sources can be accessed in Nepal. Currently, a variety of local sources are being investigated.

Future work will examine the actual value given, in the current market, to both struvite and effluent which will become increasingly important if nutrient independence for Nepal is to be achieved.

ACKNOWLEDGEMENTS

The authors would like to thank the Swiss Development Corporation, the National Centres for Competence in Research North-South, UN-HABITAT Nepal, ENPHO, and the people of Siddhipur for their generous support.

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