implementing organisation:

gtz Partner for the Future. Worldwide.

Are pharmaceutical residues in urine a constraint for using urine as a fertiliser?

This paper provides an overview about pharmaceutical residues in urine and their potential role as constraint for reuse of the urine in agriculture.

Author: M. Winker

Abstract

Urine is an excellent, complete plant fertiliser (containing nitrogen, phosphorus and potassium), but also contains certain amounts of pharmaceutical residues even after prolonged storage as a treatment step. If those substances are polar and hardly biodegradable they can be taken up by plants and thereby possibly enter the human food chain. Research has shown that the low pharmaceutical concentrations provided with urine are unlikely to affect plant development and growth. A full evaluation of the potential toxic effects of pharmaceuticals ingested by humans via urine-fertilised crops is very difficult and has not yet been done. Perceptions of societies towards urine reuse vary widely and can work as a driver or a constraint for reuse.

Introduction

Urine can be used as an alternative fertiliser for agriculture. It contains large amounts of nutrients such as 80% of nitrogen, 50% of phosphorus, and 70% of potassium usually present in domestic wastewater as well as various micronutrients (Ciba Geigy AG, 1977; Larsen and Gujer, 1996; Otterpohl, 2002; von Münch and Winker, 2009). But this usage of urine includes the risk of transfer of pharmaceutical residues to agricultural fields (Lienert et al., 2007a; Winker et al., 2008b). Only recently the fate of pharmaceuticals regarding their accumulation in soils, transfer to groundwater, and incorporation by plants came into the focus of research. However, these effects cannot be excluded as fairly high concentrations of pharmaceuticals are expected in urine (Winker et al., 2008b).

The urine normally ends up in the domestic

Key message:

- Pharmaceutical residues are contained in urine but only in few investigations concentrations have been measured so far. Predicted (German) concentrations were in the range of 0.1 to 103 µg/l of urine and determined for 124 substances.
- Data from literature show that plants are generally able to take up pharmaceuticals. Concentrations in plant parts detected were very low (in the range of ng/kg) even though plants were exposed to high concentrations (mg/kg soil). Nevertheless, pharmaceuticals were also found in edible plant parts.
- Pharmaceuticals can also cause phytotoxic effects in dependence of the applied pharmaceutical concentration. Also here, it has to be mentioned that high concentrations were applied.
- Overall, different plant species have dissimilar sensitivity levels towards the same pharmaceutical as studies have shown. Unfortunately, it is impossible to extend these conclusions to long term effects in general.
- Exposure of rye grass to pharmaceuticals contained in urine at expected “natural” levels as well as at higher concentrations did not affect dry matter production during the growth period of three months either for single pharmaceuticals, or for the combination of carbamazepine, ibuprofen, and 17α-ethinylestradiol.
- Only carbamazepine was shown to be taken up by roots and aerial plant parts of rye grass. The concentrations in aerial rye grass parts were in the mean 4950 µg/kg DM (dry matter), and in roots 225 µg/kg DM. This leads to the assumption that only pharmaceuticals which are persistent in soil and not biodegraded are transferred to plants in measureable concentrations.
- Potential effect of pharmaceutical substances contained in urine towards plants cannot be determined in germination experiments. The urine matrix itself is much more affecting the seedlings due to its specific matrix than the active agents.
- Farmers and consumers are open to urine as fertiliser, although they are aware of the aspect of pharmaceutical appearance. The perception varies not only among the stakeholder groups but also between countries.

wastewater in conventional, sewer-based collection systems. Many of these pollutants are not removed in sewage treatment plants and are thus discharged into surface water bodies and can even reach the groundwater.

The collection, storage and reuse of urine include various challenges. This article provides an overview about recent research (excluding advanced treatment technologies for urine as an excellent overview on that is provided by Maurer et al. (2006)). Additionally, it is also explained why the uptake of pharmaceuticals in plants and the effects on plant physiology and development is of major interest when crops are fertilised with urine. The article is based on the results of the PhD thesis of Winker (2009).

Concentrations of pharmaceutical residues in urine and the effect of storage

Urine contains pharmaceuticals: around 70% of the pharmaceuticals taken in, are excreted via urine accounting for 50% of the overall ecotoxicological risk (Lienert et al., 2007a; Lienert et al., 2007b). Urine analysed in various occasions showed concentrations from 2200 ng/l (fenoprofen; Strompen et al., 2003) to 545000 ng/l (ibuprofen; Tettenborn et al., 2007) (Figure 1). Apart of these substances, substance belonging to various indication groups as well as natural hormones were detected in human urine (Winker et al., 2008b).

As analytics are sometimes difficult, Lienert et al. (2007a) and Winker et al. (2008b) established theoretical calculations to receive a potential overview for Swiss and German urine. Winker (2009) could determine average concentrations in general German urine for 124 active substances (for details see https://www.tu-harburg.de/aww/pharma/). Also pharmaceutical concentrations in the urine of single person under medication were calculated for 173 substances. Additionally, Lienert et al. (2007a) determined the

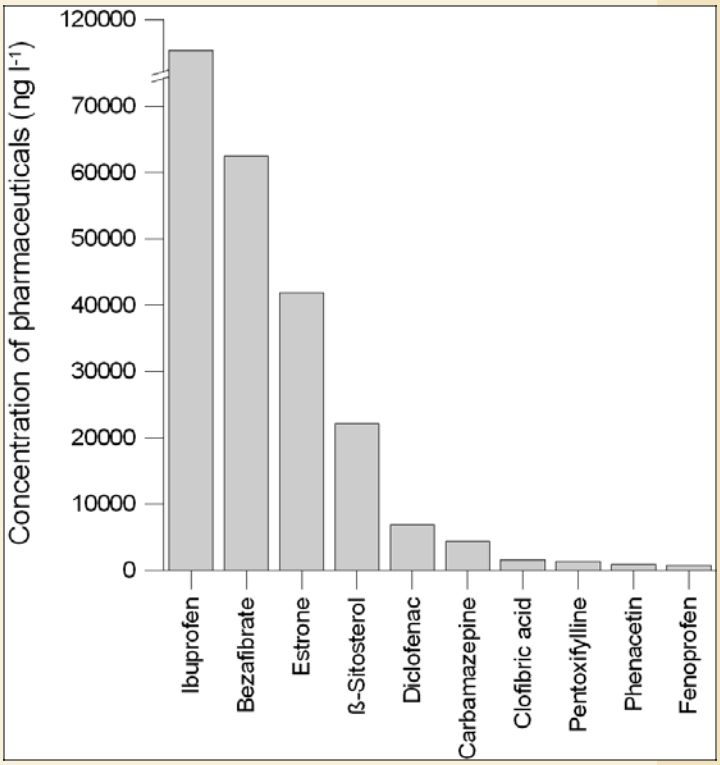

Figure 2. Measured mean concentrations of active agents in German source-separated urine done by Strompen et al. (2003) and Tettenborn et al. (2007) (Vinnerås et al., 2008).

excretion rates per person for 212 active substances along Swiss standards (**Fehler! Verweisquelle konnte nicht gefunden werden.** Table 1 shows roughly the variations of excretion possible among the different active agents as well as it points out the fractions of unchanged and metabolized substances.

Overall, it has to be pointed out that the effect of storage, induced by pH augmentation due to ureolysis (Udert et al., 2003), remains uncertain. Such as Butzen et al. (2005) detected efficient removal for diclofenac after six month; for further pharmaceuticals partial removal at different pH levels. In contradiction to these findings, Gajurel (2007) did not find any decay of clofibric acid, carbamazepine, diclofenac, and ibuprofen in spiked urine during a one year storage period under all investigated storage conditions. Preliminary sampling in the urine storage tanks in

Table 3. Excretion of 212 pharmaceuticals (Lienert et al., 2007a (modified)). Total percentages excreted via urine as well as substances excreted unchanged as parent compound as well as metabolized.

	Total			Unchanged			Metabolized		
	min	av	max	min	av	max	min	av	max
Excretion (%)	0	64	100	0.1	35	100	1	42	124
SD (N)	±27% (212)			±33% (132)			±28% (57)		

"av" determined average of the collected data (for details see Lienert et al., 2007a); "SD" stands for standard deviation; "N" stands for sample size.

the GTZ headquarters in Eschborn, Germany, indicated similar tendency. Several beta-blockers and antibiotics were found in urine stored for more than 1.5 years (Montag and Schürmann, 2010; Institute for Environmental Engineering, RWTH Aachen; personal communication). This finding will be followed up within investigations regarding the storage behaviour of active substances performed by the RWTH Aachen within the project SANIRESCH (2010). Hence, it has to be concluded that pharmaceutical residues are present in urine after storage and have to be kept in mind when it comes to reuse in agriculture.

Uptake and effects of pharmaceutical residues towards plants

Plant experiments

Greenhouse experiments in pots

The fertilising effect of urine is clearly documented (Muskolus, 2008; von Münch and Winker, 2009) but nearly no investigations focused on application of pharmaceuticals by urine except Schneider (2005) and Winker (2009). In the results presented here the focus is laid on uptake of certain pharmaceuticals by rye grass. Schneider (2005) applied diclofenac, sulfamethoxazole or sulfamethazine but in concentrations $5*10^5$ (diclofenac) and $9*10^5$ (sulfamethoxazole) higher than expected for an average German urine (AGU, Winker et al., 2008b) while sulfamethazine is not even present in AGU at all. Winker et al. (2010a) applied carbamazepine (CZ), ibuprofen (IBU), and 17α-ethinylestradiol (EE2) alone and in combinations in the expected natural as well as higher dosed concentrations of those in AGU.

f aerial plant matter (Figure 2) was identified for the entire 3 months experimental period. No visual effects were observed except Control 2 which received only irrigation water without nutrients and thus showed only about 25% of the biomass production compared to the fertilised grass. The lack of fertilisation led to a large weight reduction. The overall dry matter of all plants fertilised with urine did not show any effect irrespective of the kind and concentrations of added pharmaceutical (Figure 2).

IBU and EE2 could not be detected in any soil sample after the 3-month growing period. In contrast to IBU, CZ was detected in all pots irrespective the concentration level. On average, 49% of the applied CZ was recovered 3 months after application. In plants, only CZ could be

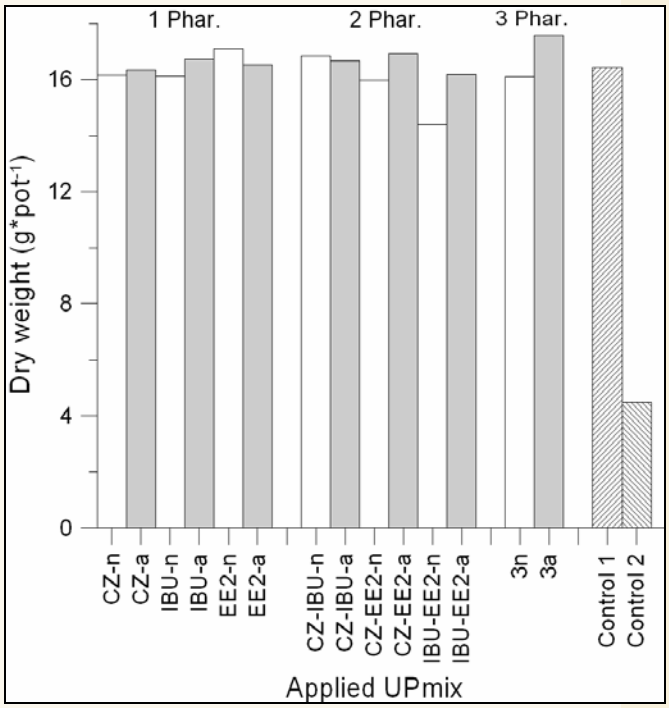

Figure 3. Overall dry weight of plant parts of rye grass determined during the full growth period. n = natural concentration (white bars), a = artificial concentration (grey bars). "Control 1" indicates plants treated with MeOH and urine, "Control 2" did not receive any application beside water; "3" is the designation for the combination of CZ, IBU, and EE2 (Winker, 2009).

detected at artificial concentrations (10 times higher than expected in AGU). CZ concentrations in roots showed a mean concentration of 225 µg/kg DM while a mean of 4950 µg/kg DM was reached in aerial plant parts. This correlates to an average of 0.21% of the total amount of CZ applied to each pot was found in the roots of rye grass, but 30% in the aerial plant parts.

Germination experiments

Plants show their highest sensitivity as seedlings. Therefore, this development stage is very appropriate for investigations regarding potential pollutants. Germination tests of cress and four different cereals (Winker et al., 2010b) were performed where the seeds were germinated in urine-water mix containing one up to five different pharmaceutical substances in raising concentration.

The seedlings show sensitivity against pharmaceutical agents (Table 2; Winker et al., 2008b). The sensitivity lies far above the concentration levels expected in average German urine. In the most cases the sensitivity lies even above the investigated range of concentrations. Apart, the urine matrix itself is much more

Table 4. Influence on dry weight of the seedlings by addition of one active agent. ">" indicates that the limiting concentration causing an effect was not reached and lies most likely above the tested level (Winker et al., 2010b).

Substance	Cress	Winter wheat	Winter rye*	Winter barley	Oat
EE2	>1.000.000 fold	> 1000 fold	>1000 fold	>1000 fold	> 1000 fold
E2	>10.000 fold	> 1000 fold	>1000 fold	> 1000 fold	> 1000 fold
CZ	>10.000 fold	> 1000 fold	AGU conc.	>1000 fold	> 1000 fold
PI	10 fold - better	> 1000 fold	1000 fold - worse	>1000 fold	> 1000 fold
IBU	>1000 fold	> 1000 fold	1000 fold - better	> 1000 fold	> 1000 fold

* "worse": the concentration let to a negative effect of the dry weight; "better": the concentration let to a statistically relevant increase of the dry weight.

affecting the seedlings due to its specific matrix than the active agents. Nevertheless, in certain cases reactions of seedlings towards the pharmaceutical substances could be observed. Overall, it can be concluded that the potential effect of pharmaceutical substances contained in urine towards plants cannot be determined in germination experiments.

Literature review

As already stated, nearly no literature is available on the uptake and effect of pharmaceuticals by plants spread via urine. Nevertheless, research was done regarding the uptake of several active substances and their effects. Data from literature show that plants are generally able to take up pharmaceuticals (Winker et al., 2008a). The concentrations usually detected in plant parts are in the range of ng/kg. Pharmaceuticals have also been found in edible plant parts such as carrot roots and cereal grains (Dolliver et al. (2007) and Boxall et al. (2006)). In addition, Brian et al. (1951) and Stokes (1954) reported excretion of griseofluvin via guttation drops at the leaf apex of wheat seedlings. The rate of movement in plants is influenced directly by rate of transpiration, which in turn is affected by air humidity and temperature. This finding leads to two contradictory assumptions. On the one hand, pharmaceuticals accumulate in leaves (Brian et al., 1951; Stokes, 1954), and higher uptake rates have been found in older leaves (Grote et al., 2004). On the other hand, leaves are able to secrete pharmaceuticals (Brian et al., 1951; Stokes, 1954) and to degrade organic chemicals taken up, in a process comparable to liver metabolism (Komoßa et al., 1995). Moreover, Kumar et al. (2005) reported that the correlation between the concentration applied and uptake is nearly linear, but it is currently impossible to generalise on these findings.

Pharmaceutical concentrations in plants depend on amounts of pharmaceuticals available in the respective growth medium. Mapping of naturally occurring concentrations in plant parts is nearly impossible. The literature screening performed (Winker, 2009) identified studies which could be split into 45 datasets (DS) reporting 9 pharmaceuticals. All studies were performed with concentrations above those expected by urine. In 18 datasets application rates were 2-182 times higher than those expected to be reached by urine fertilisation (see Table 3, ratio DS/AGU) and for 8 of these datasets bioaccumulation or phytotoxicity was reported. The others showed DS/AGU ratios between $2*10^3$ (chlorotetracylcine (Patten et al., 1980) and $2*10^8$ (chlorotetracycline (Jacobsen et al., 2004) and were thus too high to be of help for an evaluation of fertilization with urine.

Pharmaceuticals also cause phytotoxic effects depending on the concentration of the pharmaceutical substance resulting in a change of colour to darker green (Grote et al., 2004); lacking and incomplete colouring (von Euler, 1948; Rosen, 1954); lower chlorophyll content in leaves (von Euler and Stein, 1955); as well as hard and waxy leaves (Rosen, 1954). Moreover, Rosen (1954) reported a lack of lateral root development subsequent to pharmaceutical exposure and von Euler (1948) found thickened coleoptiles.

Studies have shown that different plant species have differing sensitivity levels towards the same pharmaceutical. However, it must be pointed out that many articles were published 20 to 30 years ago and the sensitivity and selectivity of chemical analyses at that time was somewhat lower. Furthermore, it is not possible to extend these conclusions to long-term effects in general, as most tests described in the literature did not last for a whole growing season.

Table 5. The 8 datasets reporting concentration similar to those in the case of urine fertilisation (DS/AGU ratio <200) which showed phytotoxic or bioaccumulative effects (Winker, 2009).

Substance	Plant species	Reported impacts1	Concentration applied	Ratio DS/AGU2	Ref.
Chloroquine	soybean	Phytotoxic: negative impact on w, h, r, s, l (13 d after germination)	8000 ng/kg	182	Jjemba, 2002
Chlorotetracycline	spring wheat	Phytotoxic: positive impact on h, r (27 d after germination)	160 ng/kg	82	Batchelder, 1982
Chlorotetracycline	pinto bean	Phytotoxic: negative impact on w, h, r, s, l (45 d after germination)	160 ng/kg	82	Batchelder, 1982
Chlorotetracycline	green onion	Uptake: 0.013 ng/kg FW in s and l (42 d after transplantation)	100 ng/kg	51	Kumar et al., 2005
Chlorotetracycline	cabbage	Uptake: 0.01 ng/kg FW in s and l (42 d after transplantation)	100 ng/kg	51	Kumar et al., 2005
Metronidazole	soybean	Phytotoxic: negative impact on w, h, r, s, l (13 d after germination)	2000 ng/kg DM	67	Jjemba, 2002
Oxytetracycline	spring wheat	Phytotoxic: positive impact on h, r (27 d after germination)	160 ng/kg	2	Batchelder, 1982
Oxytetracycline	pinto bean	Phytotoxic: negative impact on w, h, r, s, l (45 d after germination)	160 ng/kg	2	Batchelder, 1982

[1] Letters denote weight (w), height (h), roots (r), stalk (s), and leaves (l).
[2] "Ratio DS/AGU" describes the concentration applied in the specific investigation summarised in one dataset (DS) related to the pharmaceutical concentration calculated to be reached in case of urine application. DS/AGU = 1 describes equal conditions, <1/>1 implies that lower/higher concentrations would be applied by a fertilisation with urine under the described conditions. (March 16, 2008).

Importance of the topic in societies

The reaction of societies varies when they are confronted with the issue of urine-fertilised crops. The concerns regarding pharmaceutical residues differ between the different stakeholders. A very important stakeholder group are farmers. In Switzerland, a high percentage of farmers (57%) would accept urine as fertiliser (Lienert et al., 2003). For them, the fate of pharmaceuticals in the environment is one of the concerns mentioned. Approx. 80% of Swedish farmers were interested in using urine as fertiliser (Tidåker et al., 2004). The issue of spreading pathogens and pharmaceutical residues to the fields via any sewage product was the second highest concern after heavy metals and other organic compounds. Nevertheless, as pathogens or pharmaceutical residues were grouped it remained unclear which of the two aspect were in their major focus. Muskolus (2008) interrogated farmers around Berlin. They tend to react conservatively when confronted with the issue. Only one quarter of participating farmers expressed a positive attitude towards urine as fertiliser.

Users of urine-diverting systems or potential consumers of agricultural products fertilised with urine were interrogated in several studies. Amongst the users of urine diversion flush toilets at GTZ headquarters (Blume and Winker, 2010) a remarkable 90% of the participants (218 persons of 900 responded; Blume and Winker, 2010) were positive towards the idea of urine reuse in agriculture. 71% stated explicitly that they would buy crops which have been fertilised with human excreta according to WHO guidelines (WHO, 2006). Other studies showed similar results. Muskolus (2008) interviewed inhabitants in Berlin as well as people with an agricultural background, and 62% of both groups stated that they would buy food produced with urine as fertiliser.

Samwel (WECF, www.wecf.org; personal communication) reported a varying attitude in Easter European and Central Asian countries: Acceptance depends very much upon the awareness of the issue by involved authorities. In the Ukraine and Romania, members of the authorities responsible for hygiene and environment do reject the usage of urine due to the risk of spreading pharmaceutical residues. A major constraint is the lack of legal frameworks for UDDTs and reuse. In Central Asia and the Caucasian region, implementation of urine diversion systems and reuse of urine are well accepted by the authorities. For example in Western Georgia and Northern Kyrgyzstan urine diversion systems are very welcome due to high groundwater levels – normal pits simply fill up with water. Moreover, when a community is well informed, Samwel (2010; WECF, www.wecf.org; personal communication) observed also that groundwater protection can be a strong driver.

Sinar (2008) showed that apart from appearance of pharmaceutical residues in urine, it is important to investigate a societies' attitude on pharmaceutical consumption and that a difference between rural and urban areas might exist. In Ghana, the frequently used pharmaceutical groups (often referred to as indications) are antimalarials, antibiotics, analgesics, antifungals and antihelminthics; in urban areas pharmaceuticals addressing diabetes and cardiovascular diseases are also consumed (Sinar, 2008). While in Ghana, consumption of contraceptives is negligible, they most likely play a major role in Peru. 17α-ethinylestradiol is available for all women for free and very popular (Webb and Fernández Baca, 2006) as a result of the family planning below president Fujimori.

Conclusion

If urine is reused in agriculture, some of the pharmaceutical residues will be taken up by plants and thereby enter the human food chain. This is expected especially for polar and hardly biodegradable substances. A full evaluation of the potential toxic effects of pharmaceuticals ingested by humans via urine-fertilised crops is very difficult and has not yet been done.

Moreover, research carried out so far shows that the expected concentrations of pharmaceutical residues in average urine do not reach concentration levels which affect plant growth and development. This finding can be supported by the fact that the load of hormones and antibiotics in human urine are much lower than in animal manure which is already used in agriculture.

Overall, it can be concluded with the statement of Jörn Germer (cited in von Münch and Winker (2009)) that "*Drug residues in sustainable sanitation products used to supply plant nutrients can hardly be a serious issue in regions where malnutrition, groundwater and surface water pollution due to inappropriate sanitation and irrigation with untreated wastewater is a reality*".

References

Batchelder, A. (1982): Chlortetracyline and oxytetracycline effects on plant growth and development in soil systems. *J Environ Qual,* 11(4), 675-678.

Blume, S., Winker, M. (2010): Three years of operation of the urine-diversion system in GTZ headquaters in Germany; user opinions and maintenance challanges. In: *IWA Conference on Sustainable solutions for small water and waterwater treatment systems*, 19-22 April 2010, Girona, Spain.

Boxall, A., Johnson, A., Smith, E., Sinclair, C., Stutt, E., Levy, L. (2006): Uptake of veterinary medicines from soils into plants. *J Agric Food Chem*, 54(6), 2288-2297.

Brian, P., Wright, J., Stubbs, J., Way, A. (1951): Uptake of antibiotic metabolites of soil microorganisms by plants. Nature, 167(4244), 347-349.

Butzen, A., Werres, F., Balsaa, P. (2005): Aufbau und Einsatz einer problemorientierten Analytik mit dem Ziel eines Monitorings ausgewählter Pharmaka in Böden und Urin. Bonner Agrikulturchemische Reihe, 21, 25-54.

Ciba Geigy AG (1977): Teilband Körperflüssigkeiten. In: Lentner, C. (editor), Wissenschaftliche Tabellen Geigy, 8th edition, CIBA-GEIGY AG, Basel, Switzerland, pp. 51-97.

Dolliver, H., Kumar, K., Gupta, S. (2007): Sulfamethazine uptake by plants from manure-amended soil. J Environ Qual, 36(4), 1224-1230.

Gajurel, D. (2007): Investigation of elimination of selected pharmaceuticals in urine during storage, by UV irradiation and by ozonsation (in German), report, DFG-Förderkennzeichen: GA 1063/2-1, Institute of Wastewater Management and Water Protection, Hamburg University of Technology, Hamburg, Germany. URL: http://www.tu-harburg.de/aww/forschung/pdf/endbericht_dfg01.pdf

Grote, M., Freitag, M., Betsche, T. (2004): Antiinfektivaeinträge aus der Tierproduktion in terrestrische und aquatische Kompartimente, Ministerium für Umwelt und Naturschutz,L.u.V.d.L.N.-W., Germany.

Jacobsen, A., Halling-Sørensen, B., Ingerslev, F., Hansen, S. (2004): Simultaneous extraction of tetracycline, macrolide and sulfonamide antibiotics from agricultural soils using pressurised liquid excretion, followed by solid-phase extraction and liquid chromatography-tandem mass spectrometry. J Chromatogr, 1038(1-2), 157-170.

Jjemba, P. (2002): The effect of chloroquine, quinacrine, and metronidazole on both soybean plants and soil microbiota. Chemosphere, 46(7), 1019-1025.

Komoßa, D., Langebartels, C., Sandermann, H. (1995): Metabolic processes for organic chemicals in plants. In: Trapp, S. and Mc Farlane, J. (editors): Plant contamination, Lewis Publishers, Boca Raton, Florida, USA, pp. 69-103.

Kumar, K., Gupta, S., Chander, Y., Singh, A. (2005): Antibiotic use in agriculture and its impact on the terrestrial environment. Adv Agron, 87, 1-54.

Larsen, T., Gujer, W. (1996): Separate management of anthropogenic nutrient solutions (human urine). Water Sci Technol, 34(3-4), 87-94.

Lienert, J., Bürki, T., Escher, B. (2007a): Reducing micropollutants with source control: substance flow analysis of 212 pharmaceuticals in feces and urine. Water Sci Technol, 56(5), 87-96.

Lienert, J., Güdel, K., Escher, B. (2007b): Screening method for ecotoxicological hazard assessment of 42 pharmaceuticals considering human metabolism and excretory routes. Environ Sci Technol, 41(12), 4471-4478.

Lienert, J., Haller, M., Berner, A., Stauffacher, M., Larsen, T. (2003): How farmers in Switzerland perceive fertilizers from recycled anthropogenic nutrients (urine). Water Sci Technol, 48(1), 47-56.

Mauer, M., Pronk, W., Larson, T. (2006): Treatment processes for source-separated urine. Water Res, 40(17), 3151-3166.

Muskolus, A. (2008): Anthropogenic plant nutrients as fertiliser, PhD thesis, Institut für Pflanzenbauwissenschaften, Humboldt-Universität zu Berlin, Berlin, Germany. URL: http://edoc.hu-berlin.de/dissertationen/muskolus-andreas-2008-04-18/PDF/muskolus.pdf

Otterpohl, R. (2002): Options for alternative types of sewerage and treatment systems directed to improvement of the overall performance. Water Sci Technol, 45(3), 149-158.

Patten, D., Wolf, D., Kunkle, W., Douglass, L. (1980): Effect of antibiotics in beef cattle feces on nitrogen and carbon

mineralization in soil and on plant growth and composition. J Environ Qual, 9(1), 167-172.

Rosen, W. (1954): Effects of streptomycin on certain green plants. *The Ohio Journal of Science*, 54(2), 73-78.

SANIRESCH (2010): *Website of the BMBF project SanitaryRecycling Eschborn*, German Technical Cooperation, Eschborn, Germany, http//:www.saniresch.de (date of visit: 1 February 2010).

Schneider, R. (2005): Pharmaka im Urin: Abbau und Versickerung vs. Pflanzenaufnahme. In: *Bonner Agrikulturchemische Reihe*, 21, Bonn, Germany, pp.54-81.

Sinar, E. (2008): Pharmaceuticals in human sanitary products for use in tropical agriculture. *Master thesis*, University of Hohenheim, Stuttgart, Germany. http://www2.gtz.de/Dokumente/oe44/ecosan/en-pharmaceuticals-human-sanitary-2008.pdf.

Stokes, A. (1954): Uptake and translocation of griseofulvin by wheat seedlings. *Plant Soil*, 5(2), 132-142.

Strompen, S., Werres, F., Balsaa, P., Overath, H. (2003): Analytik polarer Arzneimittelrückstände in Urinproben einschließlich der Entwicklung der hierzu notwendigen adäquaten Verfahren mittels GC-MS/MS. In: *Wupperverband: Das Projekt Lambertsmühle: Zukunftsfähiges Abwassermanagement im ländlichen Raum?*, Remscheid, Germany, pp.32-53.

Tettenborn, F., Behrendt, J., Otterpohl, R. (2007): *Resource recovery and removal of pharmaceutical residues. Treatment of separate collected urine within the EU-funded SCST-project*, Institute of Wastewater Management and Water Protection, Hamburg University of Technology, Hamburg, Germany.

Tidåcker, P., Sjöberg, C., Jönsson, H. (2004): The use of sewage fertiliser products on arable land requirements from the farmers' perspective. In: Werner, C., et al. (editors): "Ecosan - closing the loop" - *Proceedings of the 2nd International Symposium on ecological sanitation*, 7-11 April 2003, Lübeck, Germany, pp.455-462.

Udert, K., Larsen, T., Biebow, M., Gujer, W. (2003): Urea hydrolysis and precipitation dynamics in a urine-collecting system. *Water Res*, 37, 2571-2582.

Vinnerås, B., Clemens, J., Winker, M. (2008): Non-metallic contaminants in domestic waste, wastewater and manures: constraints to agricultural use. In: *The International Fertiliser Society, Proceedings*, 641, United Kingdom, pp.1-31.

von Euler, H. (1948): Nukleinsäuren als Wuchsstoffe in Gegenwart von Colchicin und von Streptomycin. *Arkiv för kemi, mineralogi och geologi*, 25 A(8), 1-9.

von Euler, H., Stein, M. (1955): Einfluss von Streptomycin und von Tetracyclinen auf die Entwicklung keimender Samen. *Cell Mol Life Sci,* 11(3), 108-110.

von Münch, E., Winker, M. (2009): *Technology Review on Urine diversion components.* Overview of urine diversion components such as waterless urinals, urine diversion toilets, urine storage and reuse systems. German Technical Cooperation (GTZ) GmbH, Eschborn, Germany. URL: http://www.gtz.de/en/dokumente/gtz2009-en-technology-review-urine-diversion.pdf

Webb, R., Fernández Baca, G. (2006): *Anuario Estadístico: Perú en Números 2006*. Instituto Cuánto, Lima, Peru.

WHO (2006): WHO Guidelines for the Safe Use of Wastewater, *Excreta and Greywater*. Volume 4: Excreta and greywater use in agriculture. World Health Organisation, Geneva, Switzerland, http://www.who.int/water_sanitation_health/wastewater/gsuweg4/en/index.html (date of visit: 1 February 2010).

Winker, M. (2009): Pharmaceutical residues in urine and potential risks related to usage as fertiliser in agriculture. *PhD thesis*, Institute of Wastewater Management and Water Protection, Hamburg University of Technology, Hamburg, Germany. URL: http://doku.b.tu-harburg.de/volltexte/2009/557/

Winker, M., Behrendt, J., Otterpohl, R. (2008a): Pharmaceuticals in the environment - an overview via database (in German). In: *Fachhochschule Lübeck: 20.Norddeutsche Tagung für Abwasserwirtschaft und Gewässerentwicklung*, 20, Lübeck, Germany, pp.41-50.

Winker, M., Clemens, J., Reich, M., Gulyas, H., Otterpohl, R. (2010a): Ryegrass uptake of carbamazepine and iburpofen applied by urine fertilization. *Sci Tot Environ*, 408(8), 1902-1908.

Winker, M., Dimova, D., Ritter, K., Otterpohl, R., Clemens, J. (2010b): Effect of five pharmaceutical substances contained in urine on the germination of cress and cereal seedlings. In: *IWA Conference on Sustainable solutions for small water and waterwater treatment systems*, 19-22 April 2010, Girona, Spain.

Winker, M., Tettenborn, F., Faika, D., Gulyas, H., Otterpohl, R. (2008b): Comparison of analytical and theoretical pharmaceutical concentrations in human urine in Germany. *Water Res*, 42(14), 3633-3640.

Name: Martina Winker
Organisation: German Technical Cooperation (GTZ) GmbH, Sustainable sanitation – ecosan program
Town, Country: Eschborn, Germany
e-mail: martina.winker@gtz.de