HUMBOLDT-UNIVERSITÄT ZU BERLIN
LANDWIRTSCHAFTLICH-GÄRTNERISCHE FAKULTÄT
INSTITUT FÜR PFLANZENBAUWISSENSCHAFTEN

FACHGEBIET ACKER- UND PFLANZENBAU

Humboldt-Universität zu Berlin • Unter den Linden 6 • 10099 Berlin

Final report for task 8 of the demonstration project
"Sanitation Concepts for Separate Treatment
of Urine, Faeces and Greywater " (SCST)

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Fertilizer usage

A. Muskolus
F. Ellmer

Humboldt-University of Berlin
Department of Agronomy
and Crop Production
Albrecht-Thaer-Weg 5
14195 Berlin

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Content

1. Introduction

The recycling of plant-nutrients as nitrogen, potassium and phosphorus from human nutrition is considered to be a preposition towards sustainable agriculture. Commonly, human excreta are collected together with waste water and other liquid wastes from households and small industries. During the treatment in central sewage-works the valuable nutrients cannot be separated from potentially harmful substances such as heavy metals. Therefore, the application of sewage-sludge on agricultural fields is strongly limited. Today, in Germany a major amount of sewage sludge is burned in waste incineration plants. This means a dissemination of phosphorus, potassium and nitrogen into the atmosphere. Phosphorus and potassium fertilisers are extracted in mines and as such non-renewable. A shortage of phosphorus to be used as fertiliser is expected to arise within the next 80 years (STEEN, 1998).

Alternative Sanitation Concepts such as the separate collection and treatment of urine and faeces prevent the contamination of the plant nutrients with potentially harmful or unwanted substances from other liquid wastes. The main feature of this concept is the use of a separation toilet. It can be used in the same way as any other common flushing-toilet but has a special valve for separate urine collection. The urine can easily be stored in containers e.g. in the basement of a house and used as fertiliser. A composting process ensures hygienisation of the solid faeces separated from flushing water. Due to its low content of nitrogen all remaining waste water can be treated in a constructed wetland.

The studies introduced followingly were carried out within the scope of the SCST (Sanitation System of Separate Treatment) research project. This EU-Life demonstration project is a result of the cooperation of the KompetenzZentrum Wasser Berlin, Berliner Wasserbetriebe, Veolia Water and Anjou Recherche. It contains a setup of a complete Alternative Sanitation system including the conversion of 10 private households and two office-buildings as well as a biogas-plant and a constructed wetland in Berlin-Stahnsdorf.

It was the aim of the SCST-project to demonstrate the feasibility of an alternative sanitation system working with separation toilets. Apart from the technical questions to be answered it was necessary to know how urine and faeces are to be used in agriculture. The following four questions point out the aspects which needed to be investigated in detail:

1. How are the fertilising effects of urine und faeces compared to conventional mineral fertiliser?
2. What impact has urine to soil organisms?
3. How much gaseous nitrogen is lost after application?
4. Would farmers and consumers accept urine as fertiliser?

In this report you will find the four mentioned aspects investigated. This was done by carrying out laboratory or field experiments as well as acceptance studies for each of them accordingly. You will find a detailed description of the methods and materials used as well as the results and statistical evaluation as appropriate.

Regardless of the advantages possibly reached by a treatment of urine in the presented studies it was assumed that pure urine was used. It is still not known what kind of processing is suitable to reduce the water content of urine or any unwanted substances and whether the energy input during the treatment is justifiable or not. However, some results of the studies followingly presented may change if treated urine instead of pure urine was used.

2. Fertilising effect

The fertilising effect describes the influence of a substance containing plant nutrients on the growth and development of plants. Today in Germany, in conventional agriculture mainly mineral fertiliser and organic fertiliser from animals are used. Nitrogen, potassium and phosphorus are known to be the main plant nutrients. If plant matter is removed from fields (e.g. by harvest) the contained nutrients need to be replaced by organic or mineral fertiliser to ensure equal availability in the following years.

If human urine is used to substitute mineral fertiliser it is necessary to know what yield can be reached and which amount needs to be applied. To investigate the fertilising effect of urine it was compared with mineral fertiliser usually applied in Brandenburg. Both fertilisers had equal total amounts of nitrogen, potassium and phosphorus. This was ensured by mixing three mineral fertilisers in a way that it contained the same amounts of the three main nutrients as found in human urine. The mixtures needed to be adjusted slightly as the contents in the urine changed. The urine was delivered from the storage tank in Stahnsdorf using a 1000 l container. Urine from each container was analysed to know the actual content of nutrients.

Ammonium nitrate was the mineral fertiliser used at the pot experiments and calcium ammonium nitrate (CAN) was used for the field experiments. The mineral fertiliser was in solid form and its nitrogen concentration (CAN 27 % N) was much higher than the one from urine (0.4 % N). It also did not contain the same shares of nitrate and ammonium but the same total content of nitrogen. Ammonium is partly converted into nitrate before it is taken up by plants. This can potentially lead to a delay in the uptake of nitrogen. The fertilising effect of ammonia is generally slower than the one of nitrate. However, at dry weather conditions human urine as a liquid infiltrates into the soil quickly and becomes plant available faster than the solid mineral granulate. It was also aim of the pot and field experiments to investigate the effects on the plant growth resulting from these differences.

At first, pot experiments were set up in 2004 to investigate the fertilising effect of urine. Pot experiments allow controlled conditions in terms of water supply and other external influences like diseases or amount of soil and space available per plant. Therefore, potential differences in the fertilising effect can become more evident than under field conditions. Due to the daily water supply the mineral fertiliser reaches the soil solution quicker than under field conditions.

However, if the aim is to apply urine on agricultural fields, it finally needs to be tested under field conditions. Field experiments have been carried out in 2005 and 2006.

Urine was tested at a range of crops reaching from such intended for industrial use to feed crops and crops for the production of human food. This was chosen because provisos may exist against human or animal food produced with urine. Pot experiments were carried out with maize, spring wheat, hemp and oats. For the field experiments winter rye, winter oil seed rape, sprig wheat and maize were chosen.

2.1 Pot experiments 2004

Materials and methods

The first series of pot experiments was carried out in 2004. It dealt with the fertilising effect of urine. Special standardised "Mitscherlich" experimental pots were used for the experiment. They allow a filling height of 18 cm, are 20 cm in diameter, and made from metal with an enamel coat. All pots were equal in size and shape and contained the same amount of homogenised soil (6500g). The pots had small openings at the bottom to allow water running through the soil. This did prevent the water content being raised above its optimum.

With the crops spring wheat *(Triticum aestivum)*, oats *(Avena sativa)*, hemp *(Cannabis sativum)* and maize *(Zea mays)* in three replications each, a number of 96 pots was used in total. They were exposed to the weather but protected from birds. The crops were cultivated in a light and sandy soil as it is typically found in Brandenburg and are provided with an optimum amount of water. Special water was used which contained almost no minerals to prevent nutrient intake from that side. The amount of water consumed, was established for each single pot. This gave evidence of different efficiencies of water use. During plant growth the soil moisture was kept between 50-70% water-capacity by daily watering.

The Fertiliser application was split into two equal halves to prevent acid burn. 50 % of the urine and mineral fertiliser was incorporated into the soil while filling the pots and the application of the remaining dosage followed at the main period of growth. After establishment of the stand, a decollation was carried out to reach the number of 10 individual plants (spring wheat, oats) and 3 plants respectively (maize, hemp).

Table 1: Nutrients applied in pot experiment 1 (2004)

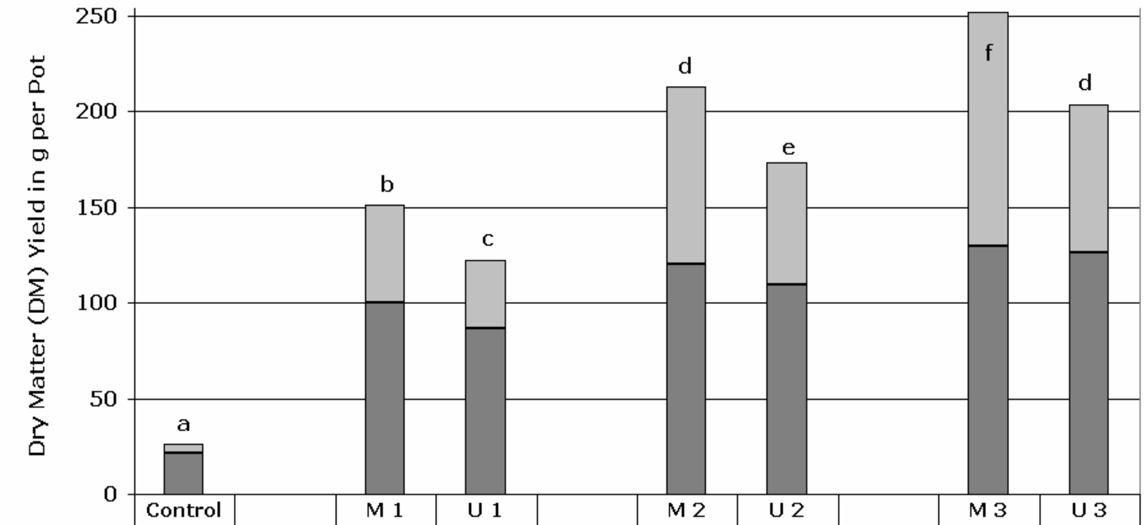
Treatment	Nitrogen in mg N per pot	Potassium in mg K per pot	Phosphorus in mg per pot	Amount of urine in ml
Control	0	0	0	0
M 1, U 1	1000	467.3	88.8	0.234
M 2, U 2	2000	934.6	177.6	0.467
M 3, U 3	3000	1004.9	266.4	0.701

The experiment was designed in 8 fertiliser treatments, 4 of urine and 4 of mineral fertiliser in steps of 0, 1, 2, 3 g total N per pot. In table 1 is shown how much nutrients were applied in the treatments. Including 3 replications the total number of pots added up to 96.

Not only was the yield per pot established but also growing parameters like plant height or leave colour index (using an optic N-tester). Furthermore the nutrient content in the soil before and after the experiment as well the nutrient contents of the plant matter were analysed. However, not all of these numbers will be presented in the following as not all were considered to be important. For comparison of the fertilising effect the yield was seen as the main factor to look at. In cases were the results needed some more explanation other data is mentioned additionally.

<u>Results</u>

Followingly the dry matter (DM) yield of each crop is presented.

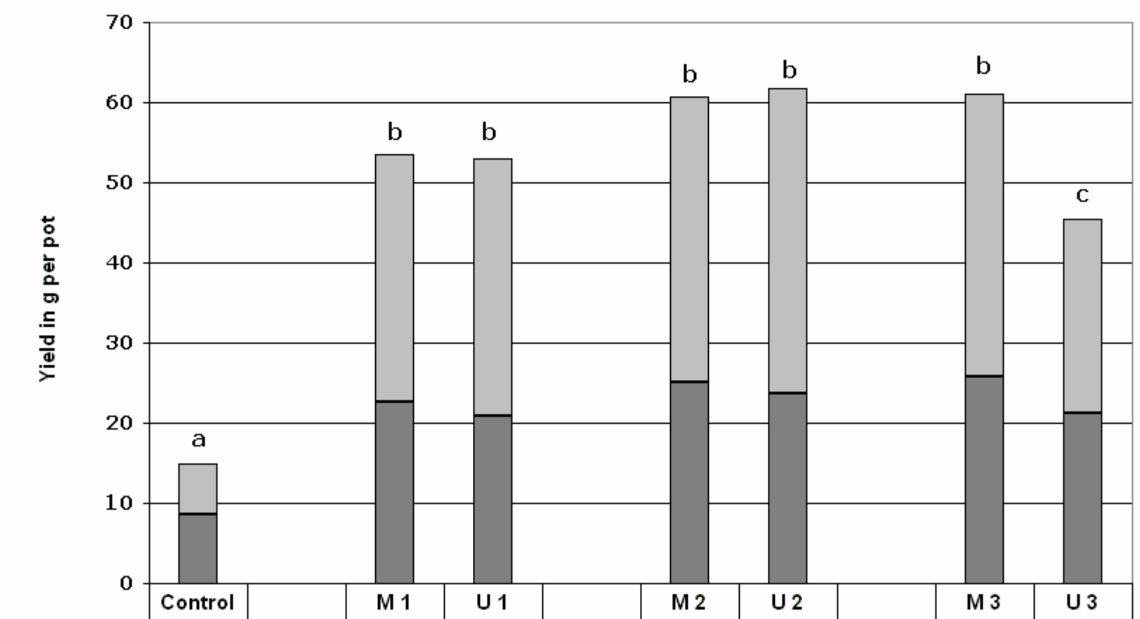


	Control		M 1	U 1		M 2	U 2		M 3	U 3
DM Cop	4.9		51.0	35.3		92.3	63.7		122.0	77.3
DM Plant	21.1		100.0	86.6		120.2	109.1		129.7	126.1

Figure 1: Dry matter yield of maize; pot experiment 1 (2004); M1 = mineral fertiliser 1 g N, U3 = urine 3 g N per pot; ANOVA: LSD 5 % of total DM per treatment = 21.1 g pot^{-1}; Different letters mean significantly different treatments

As visible in figure 1, the yield of maize did vary significantly between the mineral and the urine fertilised treatments. Only the M 2 and the U 3 treatment are statistically not different. This means that in the mentioned experiment urine had a lower fertilising effect than mineral fertiliser. To explain the result it is helpful to look at the plant development. Apart from the control the treatments did not show a different plant height at any time (appendix 1). However, the leave colour index did show clear differences between the treatments (appendix 2). This can be seen as an evidence for a different nutrient supply. Because of its physiology maize as a C4 plant takes up large amounts of nitrate within a short time. In addition to that, the 3 maize plants per pot produced far more plant matter than other crops of the experiment. Obviously the maize in the urine treatments could not be supplied with nitrogen sufficiently because the conversion of ammonia to nitrate via nitrite did not happen fast enough. This is supported by the fact that far less nitrogen was removed by the plants in the urine treatments than in the mineral fertiliser treatments not only due to a smaller amount of plant matter but also by lower concentrations of nitrogen (appendix 3).

A different situation was found at the experiment with spring wheat (figure 2). No statistical difference could be established within the treatments 1 g N and 2 g N. However, the yield of the 3 U-treatment (3 g nitrogen from urine) was significantly lower than the one of the 3 M (3 g nitrogen from mineral fertiliser).



	Control		M 1	U 1		M 2	U 2		M 3	U 3
DM Grain	6,2		30,8	32,1		35,5	38,1		35,3	24,3
DM Straw	8,7		22,7	20,9		25,2	23,7		25,8	21,2

Figure 2: Dry matter yield of spring wheat; pot experiment 1 (2004); M1 = mineral fertiliser 1 g N, U3 = urine 3 g N per pot; ANOVA: LSD 5 % of total DM per treatment = 9.99 g pot^{-1}; Different letters mean significantly different treatments

In general, urine did have an equal fertilising effect as mineral fertiliser but at high dosages plant growth was repressed. This effect is known in the literature from mineral fertiliser also. At certain dosages nitrogen can not be taken up anymore and even acts poison. Compared to maize, the dosages applied for 10 plants of spring wheat per pot was far higher. For comparison: Three plants of maize in the same kind of pot (figure 1) can produce four times the amount of plant matter produced from 10 individual plants of spring wheat (figure 2). Maize can cope with higher dosages of nitrogen in the soil. It must be assumed that the point, were the concentration of nitrogen or other components found in urine repressed the plant growth, was reached earlier with spring wheat than with maize. As displayed in figure 2, the fact that ammonia is a slow acting fertiliser did not influence the plants in terms of the reached yield. Except from the 3 g nitrogen dosage, with urine the same yields could be reached with spring wheat.

Figure 3 shows the dry matter yields of hemp *(cannabis sativum)* reached after application of 1 g, 2 g and 3 g nitrogen from urine as well as mineral fertiliser. Higher yields were found in the treatments with 1 g nitrogen per pot compared to the control but no difference between the two kinds of fertiliser. The 2 g treatments clearly differed. Here, the mineral fertiliser application resulted in a higher yield compared to the urine application. No increase of yield was observed from the additional 1 g nitrogen per pot in the 2 g N urine treatment but in the mineral fertiliser variant. In the 3 g treatments a larger difference between the fertiliser variants was found. Only half of the DM yield was reached in the urine treatments compared to the 2 g nitrogen variant while the two mineral treatments did not differ significantly. In general, hemp did show the same effects as observed at maize and spring wheat. The same yield was found after urine application as after mineral

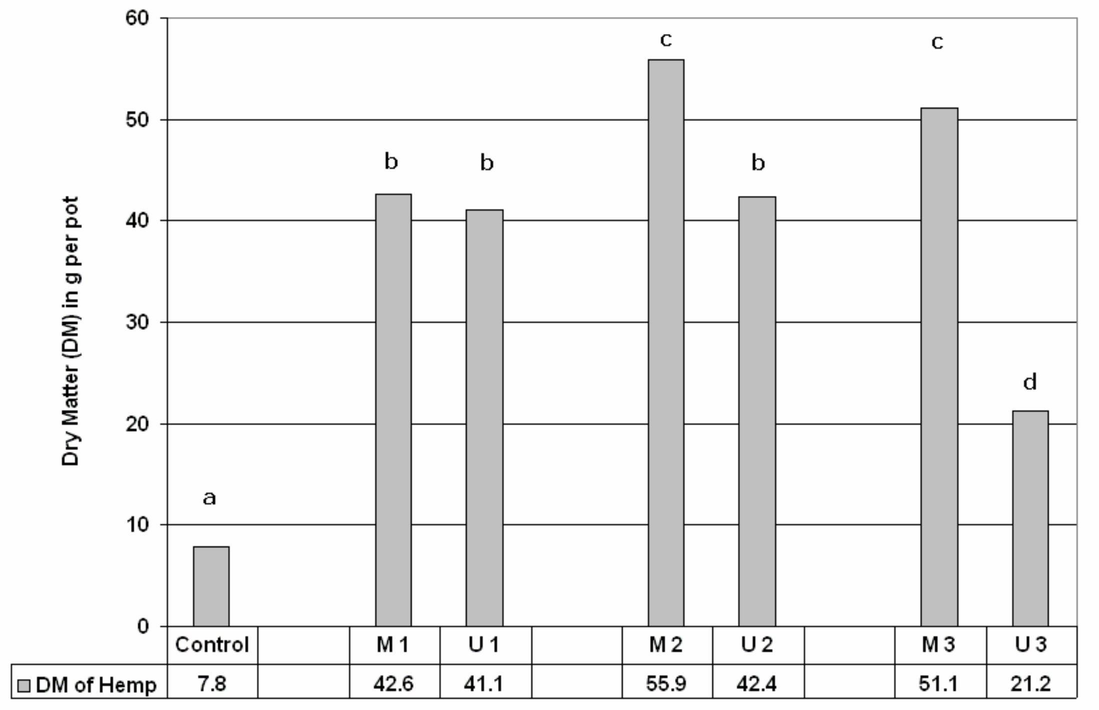


Figure 3: Dry matter yield of hemp; pot experiment 1 (2004); M1 = mineral fertiliser 1 g N, U3 = urine 3 g N per pot; ANOVA: LSD 5 % of total DM per treatment = 8.05 g pot^{-1} Different letters mean significantly different treatments

fertiliser application, but only to a certain extend. The point were any higher fertiliser dosage had a negative effect to plant growth was reached earlier with urine than with mineral fertiliser. Also, more nitrogen could be applied in total with mineral fertiliser than with urine without causing harm to the plants.

In Figure 4, the yield of oats is displayed. A significantly higher yield was reached in all fertilised treatments compared to the control. No statistical difference was found between the M 1, U 1, M 2 and the U 2 variants. The U 3 treatment had a lower yield than the M 3 but no statistical difference could be established between them. A slightly lower yield of dry matter was found at the 3 g nitrogen treatments compared to the 2 g and 1 g treatments. Obviously, the point were any additional nitrogen did not have a positive effect on the yield was exceeded. In this experiment oats showed very similar reactions as spring wheat.

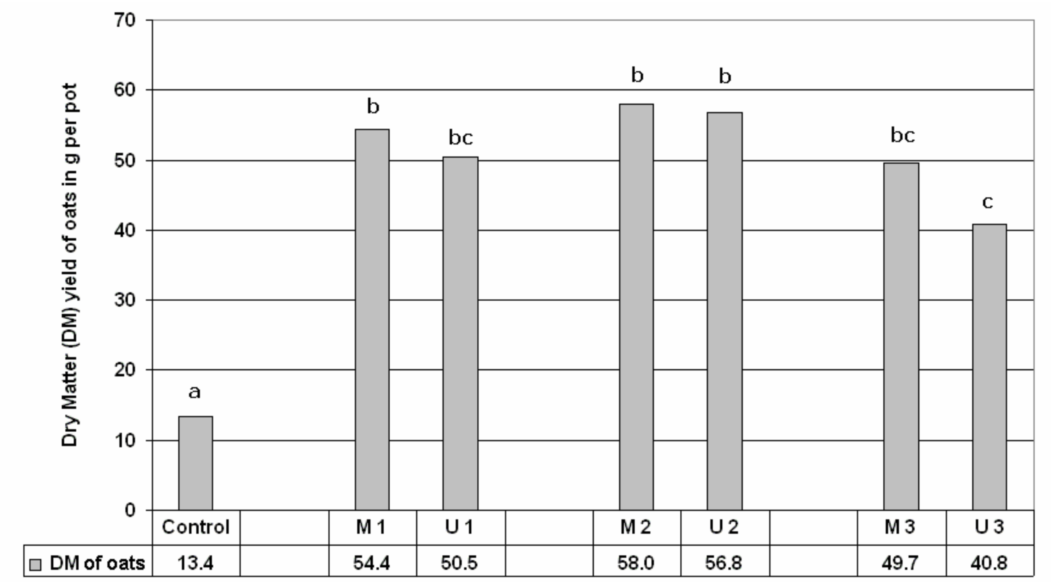


Figure 4: Dry matter yield of oats; pot experiment 1 (2004); M1 = mineral fertiliser 1 g N, U3 = urine 3 g N per pot; ANOVA: LSD 5 % of total DM per treatment = 12.16 g pot^{-1}; Different letters mean significantly different treatments

Despite the fact that four very different crops were tested in pot experiment 1, a clear statement regarding the fertilising effect of urine can be made. Urine did show the same fertilising effect as mineral fertiliser if applied in dosages useful for the plants. It became evident that the crops tested could cope with higher dosages of mineral fertiliser in a better way than with urine. Only in the case of maize a sufficient nutrient supply from urine could not be secured. This may be a result of the very high nutrient uptake from the maize plants. Compared to the amount of dry matter it produced, maize needed to cope with the lowest amounts of soil and nutrients.

2.2 Pot experiments 2005

In the year 2005, pot experiment 2 dealt with the fertilising effects of faeces as well as compost of faeces. Again, both substances were compared with mineral fertiliser containing ammonia and nitrate.

Materials and methods

After collection of the faeces in separation toilets the composting process was carried out using compost worms *(Eisenia fetida).* During the process the material lost water until a Dry Matter content of approximately 40 % was reached. The other substance tested was faeces with flushing water. Due to technical reasons no separation between solid and liquid matter was carried out. That means the water content strongly depended on the amount of water used for flushing the toilet. A particular problem was the homogenisation before analysing and fertilising. The effort of mixing larger contents was undertaken to secure best results possible.

In table 2 the contents of nitrogen, potassium and phosphorus are presented. Due to analytical reasons the amount of ammonia and organic nitrogen is not given for the compost of faeces. The Amount of Kjeldahl- nitrogen is given for compost only. This value contains all organically bound N and ammonia N.

Table 2: Nutrient contents of faeces with flushing water and compost of faeces

Parameter	Compost of faeces	Faeces with flushing water
Total N	2.73 %	0.025 %
Ammonia-N		160 mg l^{-1}
N org.		91 mg l^{-1}
Kjeldahl-N	13,600 mg kg^{-1}	
Total P	3,400 mg kg^{-1}	48 mg l^{-1}
Total K	2,800 mg kg^{-1}	100 mg l^{-1}

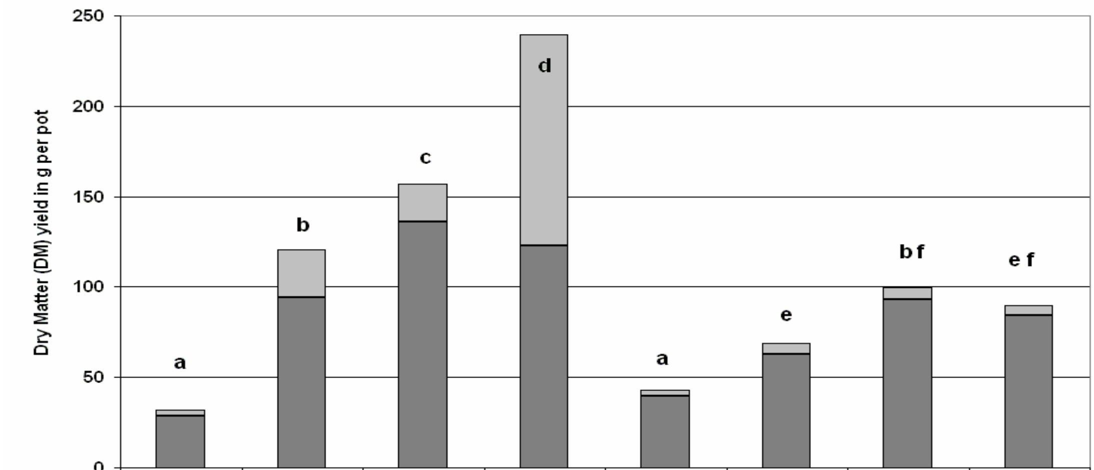
Compost of faeces was compared with mineral fertiliser in the dosages of 1 g, 2 g and 3 g total N per pot. The mineral fertiliser was split into two equal halves. The first share was mixed into the soil during the setup of the pots. The second share was added during the main growing stage. In difference to that, all compost was incorporated into the soil during the setup of the pots. A later incorporation of a share was not expected to be possible without damaging the roots of the already developed plants.

The faeces with flushing water (Brown Water) contained only a small amount of nitrogen and more than 99 % of water. To add 1 g total N to a pot the amount of 4 l brown water was needed. Not all of this faeces-water mixture could be added during the setup of the pots. The remaining liquid needed to be added during the following weeks when the pots had lost water due to evaporation. No dosages higher than 1 g nitrogen per pot were possible because of the high water content.

The experiment was carried out with maize and spring wheat. Three plants per pot of maize and ten plants of spring wheat were established. All treatments were carried out in tree replications.

Results

In figure 5 the dry matter yield of maize is given. The yield reached with mineral fertiliser was significantly higher than in any other treatment. With the amount of 1 g nitrogen per pot a higher yield was reached in the mineral fertiliser variant (M 1) than in the faeces variant (F 1). The yield in the compost treatment (K 1) was even below that. No difference was established between it and the control. However, the compost 3 g treatment (K 3) was at the level of the mineral 1 g (M 1) treatment. This means, compost did show a fertilising effect in general but it was lower than the one of mineral fertiliser. The effect of brown water was higher, but not as high as the one of mineral fertiliser. Unfortunately the distribution of ammonia and organically bound nitrogen was not given for the compost as the Kjeldahl-value contains both. But is has to be assumed that most



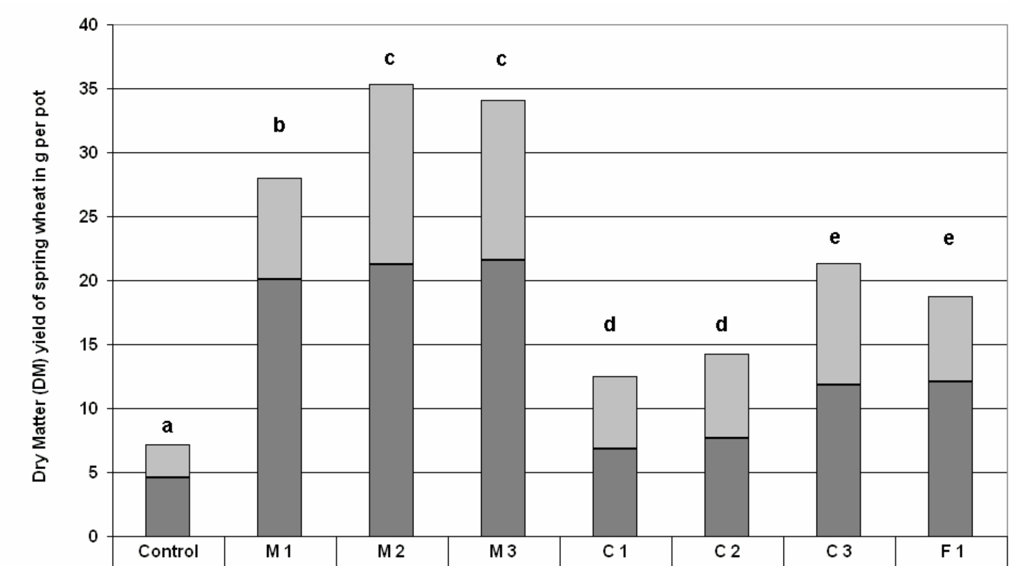
	Control	M 1	M 2	M 3	K 1	K 2	K 3	F 1
Cop	3.5	26.9	21.1	116.4	3.6	6.0	6.4	5.6
Plant	28.4	93.9	135.9	122.9	39.6	62.8	93.1	84.4

Figure 5: Dry matter yield of maize; pot experiment 2 (2005); M 1 = mineral fertiliser 1 g N, K 3 = compost of faeces 3 g N per pot, F 1 = Faeces 1 g N per pot; ANOVA: LSD 5 % of total DM per treatment = 24.12 g pot^{-1}; Different letters mean significantly different treatments

of the nitrogen contained was organically bound. The higher amount of ammonia in the faeces is presumably lost during the composting process. This would explain why the fertilising effect of the compost was low. Organically bound nitrogen is converted into forms of nitrogen which can be taken up by plants but this process of mineralization needs time.

In faeces the largest part of nitrogen is contained in the form ammonia. The conversion into nitrate takes less time than the mineralization. Therefore, the fertilising effect was higher at the F 1 treatment than at the K 1. However, due to the time delay of the conversion process and also the amount of organically bound nitrogen in the faeces the fertilising effect is not as high as after mineral fertiliser application.

In figure 6 the results of the second fertilising experiment with faeces and compost of faeces are shown. It was carried out with spring wheat.



	Control	M 1	M 2	M 3	C 1	C 2	C 3	F 1
Grain	2.6	8.0	14.1	12.5	5.7	6.6	9.5	6.7
Straw	4.6	20.1	21.2	21.6	6.8	7.7	11.9	12.1

Figure 6: Dry matter yield of spring wheat; pot experiment 2 (2005); M 1 = mineral fertiliser 1 g N, K 3 = compost of faeces 3 g N per pot, F 1 = Faeces 1 g N per pot; ANOVA: LSD 5 % of total DM per treatment = 4.18 g pot^{-1}; Different letters mean significantly different treatments

In figure 6 at all fertiliser treatments higher yields were reached than in the control. As in the experiments with maize the highest yields were measured after mineral fertiliser application. The yields reached after fertilising with compost of faeces were significantly lower. Similar to the experiment with maize, a higher yield was measured after fertilising with liquid faeces than after adding compost. No increase of dry matter yield was reached from the 2 g mineral treatment to the 3 g mineral fertiliser treatment. This effect could also be observed in the experiment with urine and spring wheat in the year 2004. Here, the limit were any more nitrogen did not add to the yield anymore was exceeded. Despite the same amounts of nutrients were applied to both crops, the potential uptake from spring wheat was lower.

In general, it can be concluded that compost of faeces did show a fertilising effect lower than the one from mineral fertiliser. The Brown Water (faeces and water) did also show a fertilising effect lower than mineral fertiliser but greater than compost. The faeces with flushing water used for the test could only be applied in a small dosage because of the high content of water.

2.3 Field experiments 2005

Material and Methods

In the year 2005 field experiments with urine in comparison to mineral fertiliser were carried out. The trials were located at the experimental field station of the Humboldt University of Berlin in Dahlem. Its geographical position is: latitude: 52° 28′′ N, longitude: 13° 18′′ E, altitude: 51 m above sea level. The sandy soil found here is typical for the light soils of Brandenburg. It contains about 72 % of sand, 25 % of silt and 3 % of clay. In the German soil classification scheme the location is evaluated with around 35 points. The mean annual precipitation is 545 mm and the mean annual temperature is 9.3 °C.

The experiment to test the fertilising effect of urine was carried out with a hybrid variety of winter oil seed rape *(Brassica napus)* and a new breed of winter rye *(Secale cereale)* as well as with spring wheat *(Triticum aestivum L.)*. Maize *(Zea mays)* was used for the experiment dealing with the fertilising effect of faeces (Brown Water).

Each Crop was cultivated at an area of approximately 600 m². It was divided into 32 parcels (8 treatments and 4 replications), arranged in a Latin- square design. Every parcel extended to 6 m in length and 2 m in width. To prevent edge-effects a core of 5 m in length and 1.5 m in width was harvested only. Each field was also surrounded by an edge of at least 2 m in width.

Beside a control, the urine and grained mineral fertiliser was applied in steps of 50kg, 100 kg and 150kg of total nitrogen per hectare. The used mineral fertiliser was a compound of Calcium Ammonium Nitrate (CAN) with 27 % N, Triple Super Phosphate (46 % P_2O_5) and Potash (40 % K_2O) mixed according to the nutrient contents of urine. Within the range of the treatments the amounts of fertiliser usually spread in Brandenburg were covered. The 150 kg per hectare treatment was even beyond the amount farmers would use at comparable locations. In each treatment the total amount of urine or mineral fertiliser was divided in two equal halves. The first was applied when spring temperatures just allowed plant growth. The second share was spread at the main growing season when nutrient uptake was at its peak.

Pesticides were applied at all crops to prevent weeds, insects or fungal pathogens taking influence on the results. In autumn 2004, a herbicide treatment was carried out at the winter crops. Maize and spring wheat were treated with selective herbicides after germination in spring 2005. Furthermore, a fungicide was spread on the cereals except of maize and an insecticide was spread on the oil seed rape during infestation of the rape beetle at early flowering.

No irrigation was carried out. The fields of oil seed rape as well as spring wheat needed to be protected from birds by a net cover.

From spring 2005 to harvest the leave colour as well as the leave area index being parameters of growth and development were measured in each parcel weekly. The contents of nitrate, potassium and phosphorus were also established for each treatment before planting and after harvest. Together with plant analyses this enables a retrace of nutrients. The yield was established for each parcel and corrected to 9 % and 14 % for oil seed rape and cereals respectively to enable comparability. The dry matter yield (DM) was determined for the cops of maize and the stems and leaves separately. Also, the structure of yield was established by counting the plants per square meter as well as the number of pods per plant (oil seed rape only) and measurement of the thousand seed weight (TSW). The protein content as a measure of quality was established for the cereals.

Results

Despite a large amount of data was collected during the experiment only the yield and some quality parameters will be presented in the following. In this experiment the yield was the parameter to be compared by definition. As long as no significant differences in quality can be established and the crops are not prone to pests and diseases in another way, yield is the main factor of interest for the farmer.

In figure 7 the seed yield of oil seed rape is presented. The lowest yield was reached in the unfertilised control. A significantly higher yield could be harvested in the M 50 (Mineral fertiliser with 50 kg ha^{-1} N) and in the U 50 treatment (50 kg ha^{-1} N from urine). However, there was no significant difference between them. The same picture presented itself in the 100 kg ha^{-1} N treatments and in the 150 kg ha^{-1} N treatments. Despite a slightly lower yield harvested in the urine treatments the difference was not above the statistical difference (LSD 5%) of 3.3 dt per hectare. In general, no difference in yield could be established.

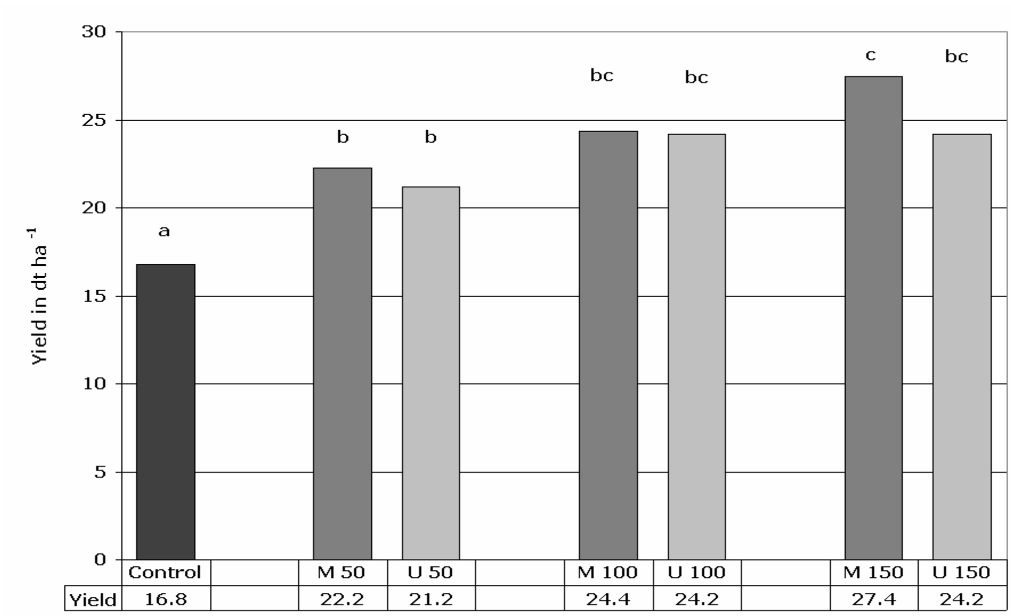


Figure 7: Seed yield of winter oil seed rape in 2005; M = mineral fertiliser (CAN), U = urine; 50 = 50 kg total nitrogen per ha; ANOVA, $p < 0.05$, LSD = 3.3 dt ha^{-1}; Different letters mean significantly different treatments

Figure 8 shows the grain yield of winter rye harvested in 2005. Again, the control was the lowest and no statistical differences were found between the mineral fertiliser and the urine treatments.

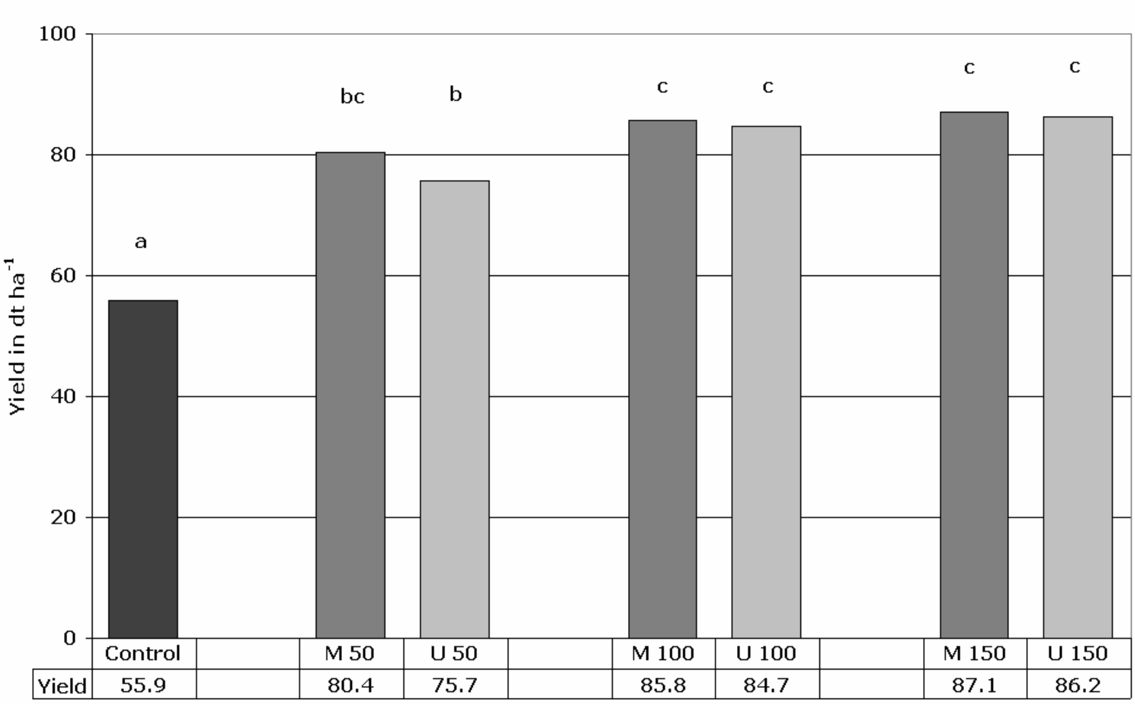


Figure 8: Grain yield of winter rye in 2005; M = mineral fertiliser (CAN), U = urine; 50 = 50 kg total nitrogen per ha; ANOVA, $p < 0.05$, LSD = 7.6 dt ha^{-1}; Different letters mean significantly different treatments

The increase of fertiliser between the 100 and the 150 kg ha^{-1} treatments was barely converted into a higher yield. For local measures the yield was in general high. Taking into account the statistical evaluation, no differences in yield were established after mineral fertilisation and the spreading of urine.

Spring wheat is planted in March and therefore does not have the advantage of having developed a stand before winter. This is the reason for generally lower yields of spring crops compared to such planted before winter in central Europe. In figure 9 the yield of spring wheat in 2005 is shown. No differences in yield were established between the mineral fertiliser and the urine treatments. Due to the high variation (LSD 10.4 dt ha^{-1}) no statistical difference could be established between the control and the U 50 treatment (50 kg ha^{-1} N from urine). However, the difference of the average yield between these variants was almost 10 dt ha^{-1}. The very high variance in this experiment was caused by birds reaching the plants were the net cover was partly removed by a storm. The birds decreased the yield at some palaces but not evenly over the whole experiment. Still, the results are useful and contain clear information. Within the 100 kg ha^{-1} N treatments a slightly higher yield was reached in the urine variant. This is against the general trend of a usually slightly lower yield after urine application. However, the difference is within the LSD. Generally no difference in grain yield between the both fertiliser was found.

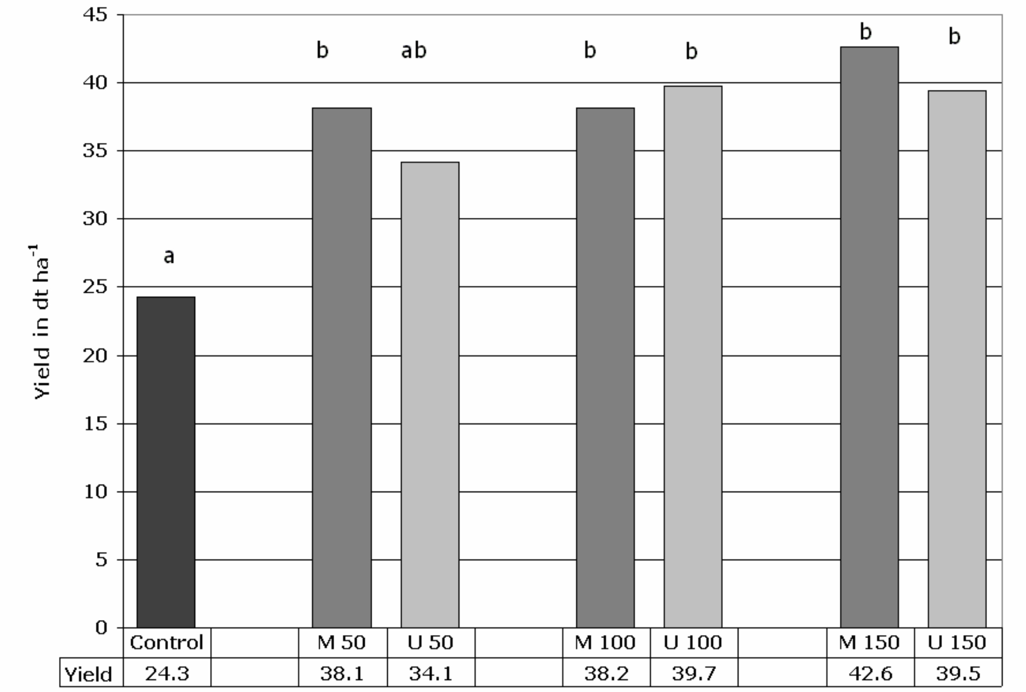
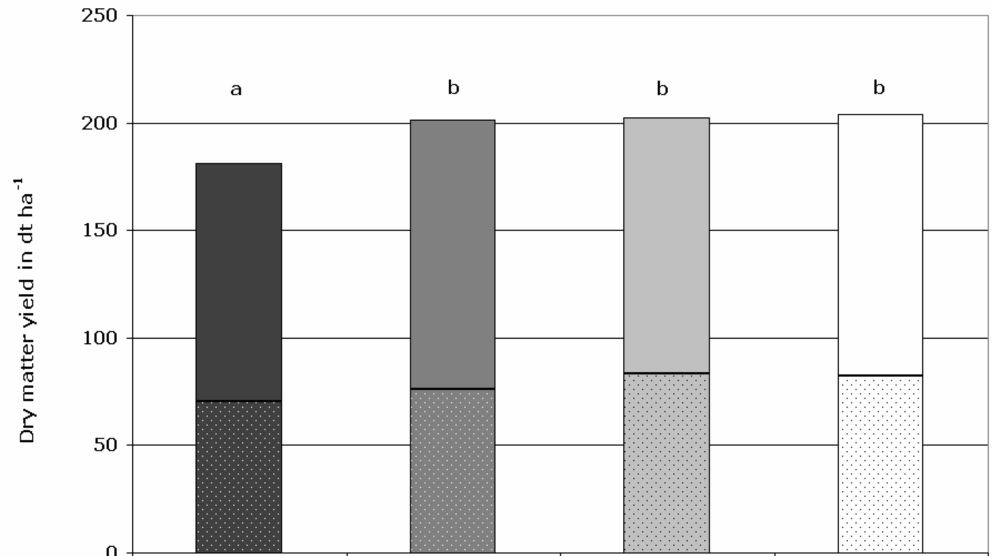


Figure 9: Grain yield of spring wheat in 2005; M = mineral fertiliser (CAN), U = urine; 50 = 50 kg total nitrogen per ha; ANOVA, $p < 0.05$, LSD = 10.4 dt ha^{-1}; Different letters mean significantly different treatments

In 2005, the fertilising experiment with liquid faeces was carried out with maize. In difference to the experiments with urine exclusively, the amount of fertiliser applied was 50 kg ha^{-1} only because of the high content of water in the faeces. In total more than 20 l per m^2 needed to be spread to reach an amount of 50 kg ha^{-1} of N. In figure 10 the yields after application of CAN, urine and faeces are displayed. No statistical difference could be established within the fertilised treatments but the control was different to any of them. The average yield values in all fertilised treatments differed only very little. However, the yield in the control was only about 10 % below. The reason for the difference being only little can be seen in the relatively low amount of nitrogen applied. Secondly, the soil status of nutrition was relatively high. It cannot be clarified if the differentiation of yield was higher in treatments of higher applications. For this reason the results from the experiment have to be handled with care.



	Control	Mineral	Urine	Faeces
Maize Cop	111	125	119	122
Stem + Leaves	70	76	83	82
Total	181	201	202	204

Figure 10: Dry matter yield of maize after applying mineral fertiliser (CAN), urine and faeces in 2005; ANOVA, $p < 0.05$, LSD = 10.8 dt ha^{-1}; Different letters mean significantly different treatments

One statement can be made without risk: The amount of nutrients contained in Brown Water as applied was to low to enable the application of a reasonable amount of nitrogen for maize. It also seems not to be justifiable to spread more than 200 m³ of liquid per hectare. From the experiment can be concluded that a pre-treatment of faeces is a preposition of an application as fertiliser on agricultural fields. However, the content of water in Brown Water may also vary with different types of toilets.

From the field experiments in the year 2005 it can generally be concluded that under the conditions of Brandenburg the fertilising effect of urine proved to be equal to the one of mineral fertiliser (CAN). The restriction has to be made that this is valid for comparable weather condition as in the year of the experiment only.

2.4 Field experiments 2006

Materials and methods

The field experiments in 2006 were carried out with the same type of crops and at the same location as in 2005. For the details please refer to section 2.3. However, the location of the crops was changed without changing the actual places and distribution of the parcels. At the field were oil seed rape was planted in 2005, winter rye was grown in 2005. Spring wheat followed after winter rye and the field were spring wheat had been was planted with oil seed rape. The field experiments in 2006 were no replication of the ones from 2005 in the narrower sense of the word. The main difference was that at each parcel the same treatment had been in the year before but with another crop. There were no even conditions within the parcels of a field in terms of the soil nutrient contents. Theoretically an accumulation-effect of the tested fertilisers would have been possible. Off cause the contents of N, P and K were determined before planting to assess the effect. The compost of faeces used in the experiment with maize was incorporated into the soil shortly before the maize was planted.

Results

As displayed in figure 11 the yield of oil seed rape was higher in 2006 than in 2005 (Figure 7) but the distribution was similar.

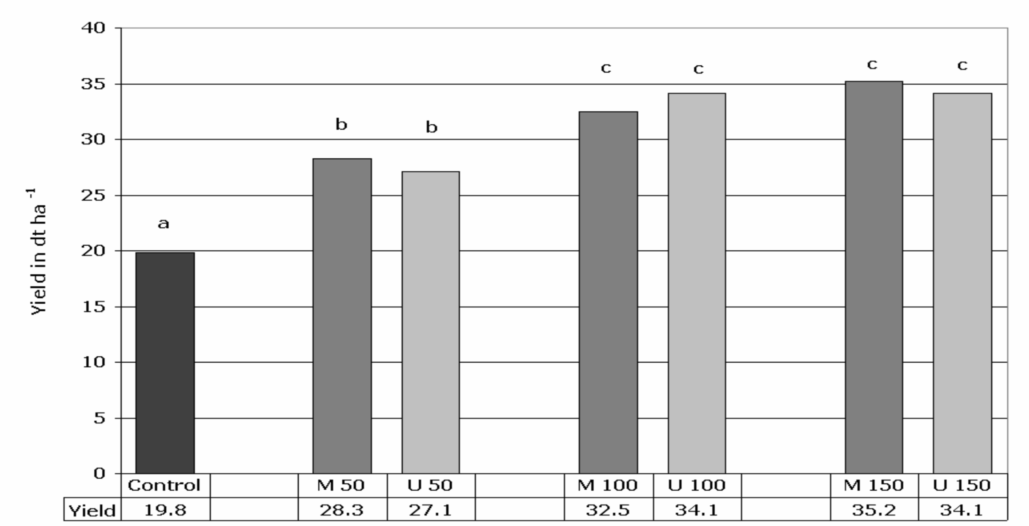
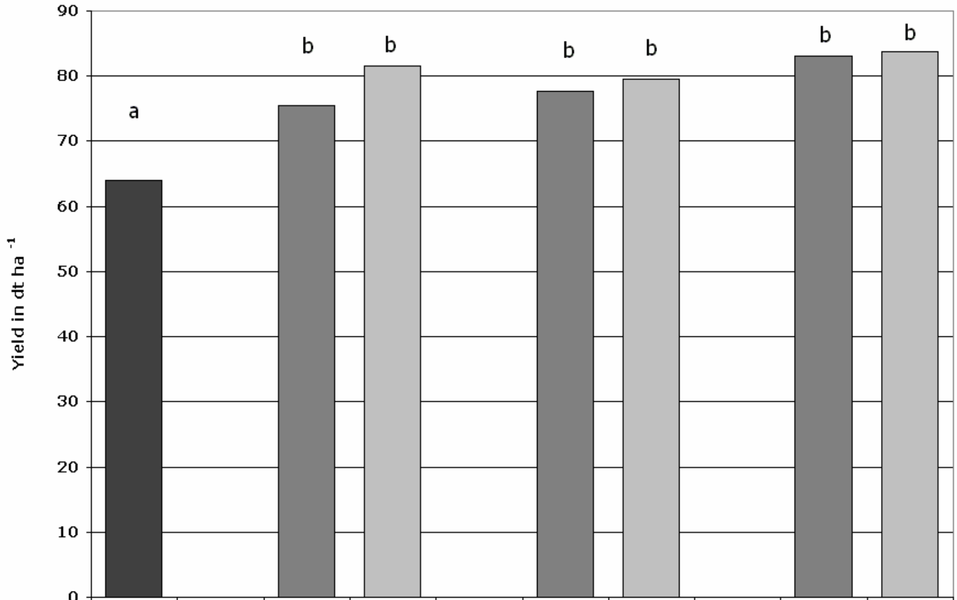


Figure 11: Seed yield of winter oil seed rape in 2006; M = mineral fertiliser (CAN), U = urine; 50 = 50 kg total nitrogen per ha; ANOVA, $p < 0.05$, LSD = 3.96 dt ha^{-1}; Different letters mean significantly different treatments

The lowest yield was reached at the unfertilised control. Only a slight difference in the average of the two 50 kg ha^{-1} N treatments was measured but could not be supported statistically. The mean of the U 100 treatment was even slightly higher than the one of the M 100 treatment. No significant differences were found between the two variants of 150 kg ha-1 total nitrogen.

The yield of winter rye is presented in figure 12. Apart from the control no statistical difference was found between the treatments.



	Control		M 50	U 50		M 100	U 100		M 150	U 150
Yield	64.0		75.5	81.6		77.6	79.5		83.1	83.8

Figure 12: Grain yield of winter rye in 2006; M = mineral fertiliser (CAN), U = urine; 50 = 50 kg total nitrogen per ha; ANOVA, $p < 0.05$, LSD = 9.5 dt ha^{-1}; Different letters mean significantly different treatments

However, in average a slightly higher yield was harvested after urine application than after spreading of CAN decreasing from the 50 to the 150 kg ha^{-1} nitrogen treatments. The overall yield was in general slightly lower than in the year 2005.

In figure 13 the grain yield of spring wheat is displayed as harvested in the year 2006. Again, the lowest yield was reached in the unfertilised control. The yield of the U 50 treatment was 6.2 dt per hectare higher than the control but not significantly different (LSD = 6.3 dt ha^{-1}). All other fertiliser variants were higher in yield. Also no statistical difference was found between the two kinds of fertiliser within the same total amounts of nitrogen.

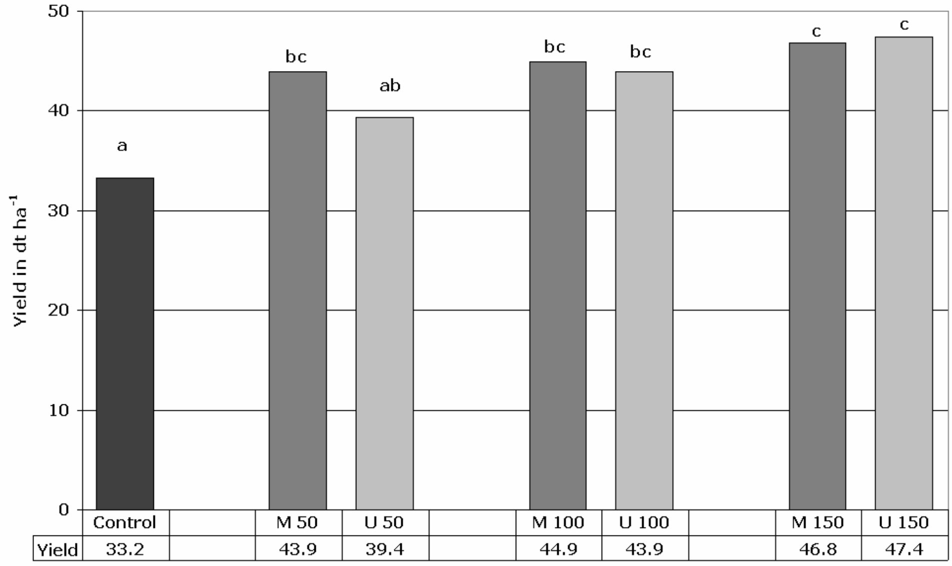


Figure 13: Grain yield of spring wheat in 2006; M = mineral fertiliser (CAN), U = urine; 50 = 50 kg total nitrogen per ha; ANOVA, $p < 0.05$, LSD = 6.3 dt ha^{-1}; Different letters mean significantly different treatments

Figure 14 shows the dry matter yield of the field experiment to establish the fertilising effect of compost from faeces. It was carried out with maize in 2006. The yield was increasing slightly from the control over the compost treatment to the mineral fertiliser treatment but no statistical difference could be proved between any of the variants.

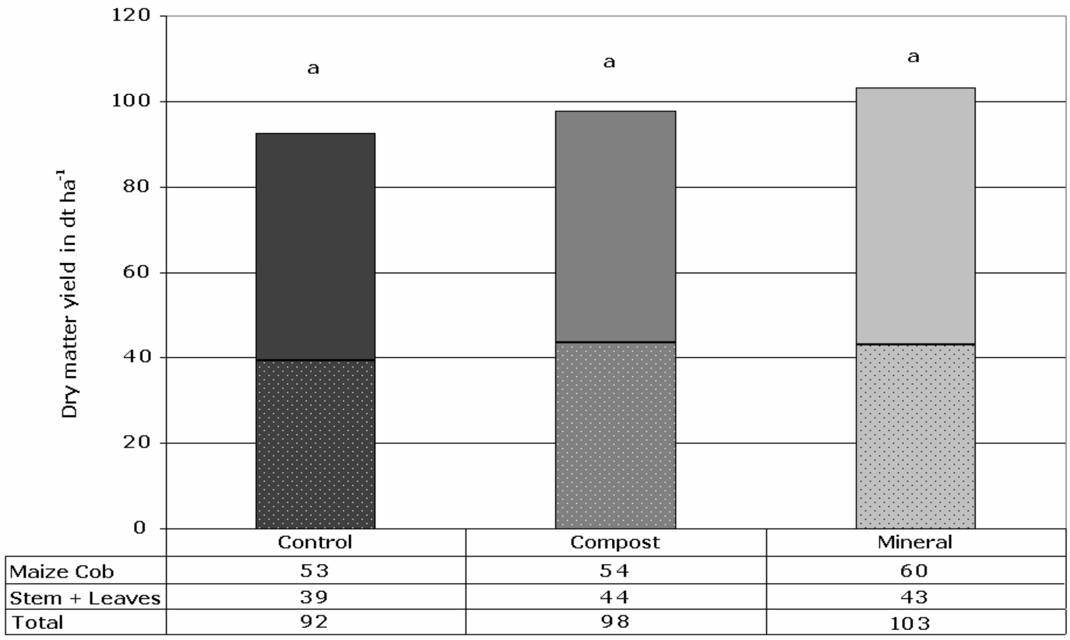


Figure 14: Dry matter yield of maize after applying mineral fertiliser (CAN), and compost of faeces in 2006; ANOVA, $p < 0.05$, LSD = 21.7 dt ha^{-1}

Generally no statistically different yield was measured after the spreading of mineral fertiliser (CAN) than after urine application. In some cases the mean yield was slightly lower, in others it was higher. The slight differences might be caused by the time delay due to the conversion of ammonia to nitrate and the loss of ammonia into the atmosphere after application. For further information regarding the extent of that influence please refer to chapter 4. Both years of experiments support that statement. If only the yield is taken into account no accumulating effect could be observed in the second year. For the tested crops and under the local conditions of Brandenburg, urine could substitute Calcium Ammonia Nitrate. However, it needs to be considered that urine and CAN are two different kinds of fertiliser. At first the CAN is granulated and the urine is liquid. This means that urine infiltrates into the soil quicker and reaches the soil nutrient solution faster. The granulated CAN needs water to be solved. At dry weather conditions it may happen that a main share remains at the surface after spreading for several days or even weeks. But secondly, the mineral CAN already contained nitrate which is the form of nitrogen mainly taken up by plants. Urine contains 95 % of its nitrogen in the form of the slow acting ammonia. The conversion means a delay in time. Due to the weather conditions during the winter in central Europe an earlier application was not possible.

3. Soil-Biological Effects – Experiments with Earthworms

The influence of urine to the soil life of agricultural fields is of great importance in terms of sustainable soil protection. Experiments investigating the effect of urine to the soil biology mean a contribution towards the realisation of the German Soil Protection Act (BBodSchG 1998). For the evaluation of urine recycling in agriculture its impact to the soil life is an essential criterion. Investigations dealing with this can prevent harmful changes of the soil.

Earthworms are considered to act as key-indicators in the assessment of soil contaminations. Due to their function of decomposing soil organic matter and with this releasing plant available nutrients they are of special importance. Earthworms also arrange for the balance of air and water in the soil and contribute to the development of a soil structure. Because of these functions the OECD and the EU consider earthworms to be key-indicators for environmental contaminations. Standardised test methods have been developed (EDWARDS et al. 1996). The avoidance response test is one of them. It provides the fast assessment of negative influences from the tested substances. The avoidance-response test is a test of the behaviour of worms based on the assumption that even little chemical stress leads to reactions. In this experiment earthworms are put into the situation to be able to choose between different types of substrates. Their reaction towards thus different types of habitats is reported. This screening test is considered to be of high sensitivity (LINDEMANN 2004).

The earthworms used for the two avoidance-response tests were from two different varieties. For the first test a species was used which is usually applied for laboratory experiments. Their natural habitat is the compost. For the second test a species was used which is found in agricultural soils.

Two different approaches have been used in the two avoidance response tests. At first, the reactions of the earthworms were investigated if confronted with urine incorporated into the soil with different spans of time between incorporation and insertion of the animals. This was done to give evidence for a chemical fate of urine. In the second experiment the earthworms were confronted with urine and compositions of urine which were ammonia and pharmaceutical substances to clarify the reasons for the response found in the first experiment.

The influences on earthworms at agricultural fields are far more complex than the ones in the laboratory test. Field experiments enable more practical statements but the explanation of the found results is also more difficult. In difference to laboratory tests, field tests enable to evaluate the influence of urine to earthworm populations. However, factors like drought can hinder the observations. Earthworm populations are very flexible and in case of water scarcity they move into deeper soil layers were investigations are not possible.

The field observations were carried out at the place were the fertilising effect was studied. In both years the parcels with winter rye were investigated after fertiliser application and after harvest. In principle the approach was to compare the urine treatments with the control and the treatments of mineral fertiliser application. All urine used in the experiments was stored for at least 6 months.

3.1 Avoidance-response test with different residence time of urine

The aim of this first experiment with earthworms was to carry out a screening test of how earthworms generally react to urine. In this test the compost-worm (*Eisenia fetida)* was used to investigate the general impact of urine on worms. The effect of a changing impact over time was included into the experiment by confronting the animals with substrates of different age after incorporation of the urine. The test established their behaviour but not the harmfulness of urine to them.

Materials and methods

Beside an unfertilised control, one treatment included soil and urine incorporated 24 hours before. The other two treatments contained soil and urine incorporated 14 days and 28 days before. In all treatments the locally found sandy soil was used and the water contend was adjusted to an equal level. Wooden boxes were used for the experiment. A picture can be found in appendix 10. The earthworms have been placed into the box in a way enabling them a free choice between the four substrates. The whole experiment contained four replications. 20 individuals were used in each of them giving a total number of 80 earthworms. All animals have not been in contact with urine before. The same amount of urine was used in all boxes. It corresponded to the 150 kg ha^{-1} nitrogen treatments applied in the field experiments. After 24 hours the boxes were opened and the earthworms in each substrate were counted.

Results

The numbers of earthworms found in the substrates are presented in table 3. The highest number (35) was counted in the controls but total avoidance was observed for the substrate consisting of soil and urine mixed into it 24 hours ago. In total 18 worms were counted in the treatments with urine incorporated 14 days ago and the number of 27 animals was found to be the total in the treatment "urine incorporated 28 days ago".

Stored urine freshly incorporated obviously affected the earthworms. The effect decreased in time. A statistical difference could only be established between the control and the treatment with 24 hour holding time.

Table 3: Distribution of *Eisenia fetida* in the treatments of Avoidance Response Test I

	Treatments			
Replication	Control	Urine incorp. 24 hours ago	Urine incorp. 14 days ago	Urine incorp. 28 days ago
1	9	0	0	11
2	8	0	3	9
3	5	0	11	4
4	13	0	4	3
Total	35^{a}	0^{b}	18^{ab}	27^{ab}

(Different letters mean significant differences, p ≤ 0.05)

The results show that the species *Eisenia fetida* avoids urine. This does not provide information about the fact if it would actually do any harm to them on a long term basis. However, the results suggest that a process of change or reduction of the urine starts after it was mixed with soil. The main part of this process obviously happens within the first two weeks. This theory is supported by the fact that the pH-value of the substrate increased from 6.6 to 7.7 after the alkaline urine was added. After 14 days the original pH-value was restored.

In an Avoidance Response test, a substrate is considered to be toxic if a difference to the control of more than 80 % can be established (HUND-RINKE et al. 2002). In this meaning the substrate with freshly incorporated soil was toxic to earthworms. From the experiment it could not be answered what the reason for this short-term effect is. A second Avoidance Response test was carried out to answer this question.

3.2 Avoidance-response test with urine and components of urine

The detection that earthworms avoid freshly incorporated stored urine was the base of this second Avoidance Response Test. It was the aim of this experiment to test if certain components of urine are the reason for the avoidance. It was assumed that either ammonia or pharmaceutical residues generate the response. Therefore, beside a control and a urine treatment a variant with a mixture of soil and ammonia was well as one with soil and pharmaceutical substances were incorporate in the experiment. A response to one of the treatments with components of urine would have given an indication for the reason of the reaction. In difference to the first Avoidance Response test the species *Aporrectodea caliginosa* was used. This field-species is the most found at the soils in Brandenburg. The animals were collected locally and had not been in contact with urine before. Pharmaceutical residues found in urine are to a large extend excreted unchanged; that means as pharmaceutical agent. In the experiment two substances were used in the form and amount of their appearance in the urine applied.

Materials and methods

The experiment included four variants: A control, an urine treatment, a treatment with ammonia and one with pharmaceutical substances. Again, the soil was from a local field. It was homogenised and its water content was adjusted to an equal level. In the ammonia treatment ammonium hydroxide was used and diluted according to the content of ammonia in urine. The scientific institute IWW in Mühlheim/Ruhr supplied the pharmaceutical agents Ibuprofen and Bezafibrate bound at inert sea sand. They were applied according to their appearance in the urine. Inert sea sand without pharmaceuticals was added at the other variants in the same amount. As in the first Avoidance Response test wooden boxes were used but this time only 16 animals per box were applied. With four replications, a total number of 64 individuals of the species *Aporrectodea caliginosa* were used which were found at local agricultural sites. The moisture content of all four kinds of substrates was levelled. Between the mixing of the substrates and the insertion of the animals was a residence time of 24 hours. The enumeration was carried out 48 hours after the worms were placed into the boxes.

Results

In table 4 the distribution of worms found after 48 hours is presented. Avoidance was observed at the urine treatment only. Neither pharmaceuticals nor ammonia did cause a negative response. An even distribution was established between them and the control.

Table 4: Distribution of *Aporrectodea caliginosa* in Avoidance Response test II

	Treatments			
Replication	Control	Urine	Pharmaceuticals	Ammonia
1	5	0	6	4
2	4	0	8	4
3	5	0	3	8
4	7	0	4	5
Total	21	0	21	21

The total avoidance of the urine treatment corresponds to Avoidance Response test I (Chapter 3.1). Avoidance effects of earthworms towards organic fertiliser containing urine from animals are reported in the literature (Curry 1976, quoted in Edwards & Bohlen 1996). In the cited article ammonia gas which is developed during the decomposition of animal urine is considered to cause the avoidance response. A concentration of 0.5 mg ammonia g^{-1} is reported to be toxic to earthworms (Edwards & Bohlen 1996). However, in the presented Avoidance

Response test II the corresponding reaction was not proofed. The ammonia variant was accepted by the worms. Ammonia votalisation occurring during the setup of the experiment and resulting in an actually lower content of ammonia in the substrate might have been the reason for this. A loss of gaseous ammonia was observed during preparation of the solution but cannot reliably be proved to be the reason.
In conclusion, in Avoidance Response Test II it was demonstrated that *Aporrectodea caliginosa* avoid freshly incorporated urine but accept the tested substrate including pharmacies and the tested substrate of soil and ammonia.

3.3 Field experiment with earthworms 2005

In 2005 field investigations concerning the abundance of earthworms after urine application were carried out. The experiment should show whether urine has an effect to earthworm populations on agricultural fields or not. Because of their function as bio-indicator an impact on earthworms is considered to be a crucial factor for the application of urine on a farm scale. A long-ranging disturbance of the sensitive bio-system was associated with a number of unwanted negative effects.

Materials and methods
The experiment was carried out at the experimental field station in Berlin-Dahlem. At this site the typical light and sandy soil of Brandenburg is found. The experiment did consist of two investigations. The first took place in May 2005, 14 days after the application of the second share of fertiliser at a field with winter rye. The second was carried out at the same parcels in October 2005. Investigations included the following treatments: Control, 150 kg ha^{-1} N from mineral fertiliser (CAN) and 150 kg ha^{-1} N from urine. Eight replications were included at the parcels of each treatment covering an area of 1 m² in total per treatment. At these 24 places the soil was excavated up to a depth of 20 cm. Each replication was searched for worms and their cocoons. This very labour intensive work was carried out by 4 to 6 people in 4 days. At all points the excavation was completed within 8 hours. All worms and cocoons found were determined according to their species. Also, the soil moisture content was measured at each place of excavation.

Results
In the area of investigation earthworms are fully active in spring and autumn as long as soil moisture is above 14 %. In dryer conditions they are found in a resting state at deeper soil layers only. To a wide extend this was the case in May at the time of the first investigations. The soil was too dry to allow a larger number of animals to be found. The averages of the soil moistures were 13.7 %

in the control, 12.1 and 12.0 in the urine treatments and the mineral fertiliser treatment respectively. The lower soil moisture in the fertilised variants was a result of the higher uptake of water by plants producing more biomass due to a higher supply of nutrients. In table 5 the abundances of earthworms are presented as found in the experiment. A total number of 53 earthworms were counted in May. 28 of them were found in the control, 19 in the mineral fertiliser treatments and 11 after urine application. A statistical difference could be established between the control and the urine treatment (Dunnet-test, one way). An overall number of 140 individuals were counted in October. The differences in the treatments were only small and no significance could be established between them.

Table 5: Abundance of earthworms in 2005, total numbers in individuals per m²

Species	May 2005			October 2005		
	Control	Mineral-fertiliser	Urine	Control	Mineral-fertiliser	Urine
A. caliginosa	10	7	1	31	16	18
A. chlorotica	14	6	2	14	20	18
A. icterica	2	1	2	1	0	0
A. species	1	1	6	2	5	6
A. longa	1	4	0	4	0	3
Total numbers	28	19	11	53	42	45

The largest increase was observed at the populations of *Aporrectodea caliginosa* and *Aporrectodea chlorotica.* Numbers of other species were not significantly raised.

In general, an impact of urine to the population of earthworms was observed. The effect was of short term only. In October an equal number of individuals was found in all treatments.

3.4 Field experiments with earthworms 2006

In the year 2005 a short term effect of urine on earthworms was determined. In 2006 the field investigations with earthworms were repeated. Earthworm populations are influenced by many factors. To come to more general conclusions it is necessary to observe their development over a longer period of time. In this meaning field experiment 2006 was meant to help finding more reliable statements regarding the effect of urine on the soil life. One of the main influences to the population of earthworms is considered to be the soil moisture which varies over the year but also between different years.

Materials and methods

Again, the experiment was carried out parallel to the fertilising experiment with winter rye. It did not take place at the same field as due to crop rotation winter rye was grown at a nearby field. The soil conditions have not been changed by the rotation. Also, the same treatments were included in the test as in the year 2005. Furthermore the same method was applied. In difference to the first field investigations there was only one week of time between the application of the second share fertiliser and the start of the experiment. The second investigation in October 2006 was carried out after harvest.

Results

Earthworms stay active at upper soil layers above a soil moisture of 14 %. A higher differentiation of soil water contents was found in the year 2006 than in 2005. Mean values of 9.9 %, 7.5 % and 7.1 % were measured at the control, the mineral fertiliser treatment (CAN) and the urine treatment respectively. The values were also generally lower than in the year before. However, the dry period had just begun and the total number of worms found was still higher than in the previous year.

Table 6: Abundance of earthworms in 2006, total numbers in individuals per m²

Species	May 2006			October 2006		
	Control	Mineral-fertiliser	Urine	Control	Mineral-fertiliser	Urine
A. caliginosa	20	15	4	21	12	10
A. chlorotica	5	1	4	8	3	0
A. terrestris	2	1	1	0	2	0
A. icterica	0	0	0	1	0	0
A. species	0	2	3	4	1	2
A. longa	4	4	0	5	3	1
E. fetida	0	0	0	2	0	1
Total numbers	31	23	10	41	21	14

In May, 31 individuals were found in the control, 23 in the mineral fertiliser treatment and 10 worms after urine application. These values approximately correspond to the numbers counted in May 2005. A significant difference was established between the control and the urine treatment only. The weather conditions in the year 2006 were generally dry. At the time of the second investigation in October the soil moisture was still far below the optimum for earthworm activity. The value of 7.8 % soil moisture was measured in the control and 7.4 % in both fertiliser treatments. In the October enumeration 41 individuals were found in the control, 21 in the mineral fertiliser treatment and 14 in the urine variant. A statistical difference was established between the control and the urine treatment using the ANOVA-test. The relations approximately correspond to the numbers of earthworms found in May. This means the population did not significantly recover since May. Also the relatively low total number in October shows that there was little development during the year. The low soil moisture is presumably the cause for this effect. At a nearby field free of vegetation it was constantly below 14 % (refer to Appendix 11. No soil moisture values have been obtained directly at the field of the earthworm experiment. However, the uptake of water by plants usually causes even lower soil water contents. In the year 2006 the earthworm population did not have the opportunity to recover due to the soil conditions. From these facts a long term degradation of the earthworm population after urine treatment cannot be concluded.

4. Gas emissions after application of urine

Human urine contains nitrogen mainly in the form of ammonia. In contact with air gaseous nitrogen emissions are possible. Depending on the type of gas either greenhouse gases (nitrous oxide, methane) or otherwise harmful gases (ammonia) can develop. Gaseous ammonia in the atmosphere together with nitrogen oxides or sulphur causes acid rain, eutrophication and N-depletion. Ecosystems as woodlands, upland moors and nutrient poor meadows are especially affected. Furthermore, secondary aerosols are formed by ammonia in the air. Listed as fine particles (PM10) they are hazardous to humans (FRIEDRICH et al.). A reduction of ammonia emissions from agriculture was claimed to be a political goal in Germany (Düngeverordnung 1996) and the EU. Emissions of nitrogen from agricultural sites also mean an unwanted loss of plant available fertiliser. At this point ammonia emissions have an economical aspect for the farmer. Furthermore it is necessary to know how much nitrogen is lost to correct fertiliser calculations accordingly. For this reasons, ammonia emissions resulting from the application of urine on agricultural fields need to be assessed before a possible introduction of urine as fertiliser.

It is known from the literature that ammonia emissions after the spreading of slurry vary with temperature, soil moisture and wind speed. The greatest influence is considered to have the application technique. Slurry application using a broadcast spreader cause higher emissions than trailing shoes or injectors.

4.1 Measurement concept and equipment

A number of ammonia measurement techniques have been developed during the last 30 yeas. All of them are considered to provide special advantages but also disadvantages. Today on lager fields mainly micrometeorological methods are applied. The method consists of measuring the wind speed and wind direction and the concentrations of ammonia at different heights around a certain place. From these data the total loss is calculated. However, this method is not suitable at an experimental field with small parcels. An open-chamber method was used in the experiment presented followingly. It mainly consists of a cover chamber which is placed at the field shortly after application, a gas measuring device and a vacuum pump to create an air flow in the cover. From the concentrations of the inlet and the outlet air as well as the air flow the emissions are calculated. The method enables controlled conditions close to real nature. However, it covers a small area only and special variations have to be compensated using a number of replications.

Materials and methods

An open-chamber method was used to measure ammonia, nitrous oxide and methane at the same time. The chambers were sealed at the bottom and had an air inlet at the height of 1 m above the ground. Air was pumped from the chambers via vacuum pumps during the measurements constantly. Between the chamber and the pump the air was analysed by a Photoacoustic Multigas-monitor. Also, in the incoming air a measurement of the mentioned gases was carried out. At each measurement point the concentration was reported every 10 to 15 minutes providing a high frequency set of data. In figure 15 the measurement system is presented. It contains four gas chambers each connected to a flow meter and a vacuum pump. At the air inlet and air outlet of each chamber a measuring point was installed connected to the Multipoint-sampler and further to the Multigas-Analyser for gas concentration establishment. A computer was used as data logger.

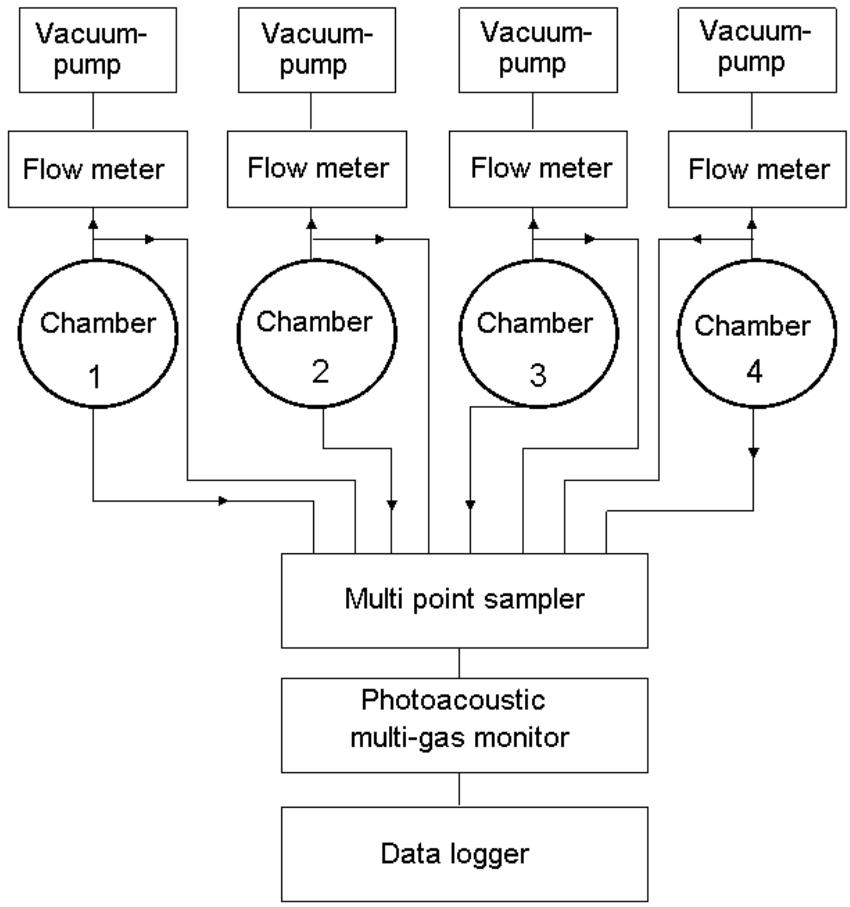


Figure 15: Scheme of the open chamber gas measurement system

Find a description of the used chamber in figure 16 and a picture in appendix 20.
The Multigas-monitor enables the determination of gas concentrations over a wide range and with high accuracy. Its measurement principle is based on the

photoacoustic infra-red detection method. A description of the used devices is listed in the following:

- Multigas-Monitor:
  INNOVA 1302, Photoacoustic infra-red detection method, Accurate – compensates for temperature fluctuations, water-vapour interference and interference from other known gases
- Multipoint-Sampler:
  Innova 1303, Full remote-control from a personal computer over an interface, 12 sample-input channels
- Flow meter:
  AALBORG GFM37, 0-50 l/min
- Vacuum pumps:
  HARTMANN&BRAUN AG, Membrane-Pump „2-Wisa“, 2..10 l/min
- Gas chamber:
  Self constructed from polyethylene (PE), Area covered: 0,075 m², Height of the fresh air inlet over ground: 100 cm, (Refer to Figure 16 + Appendix 20)
- Flexible tubes, each from the same length (10 m) and made from PTFE were used to connect the Multipoint-Sampler and the measuring points.

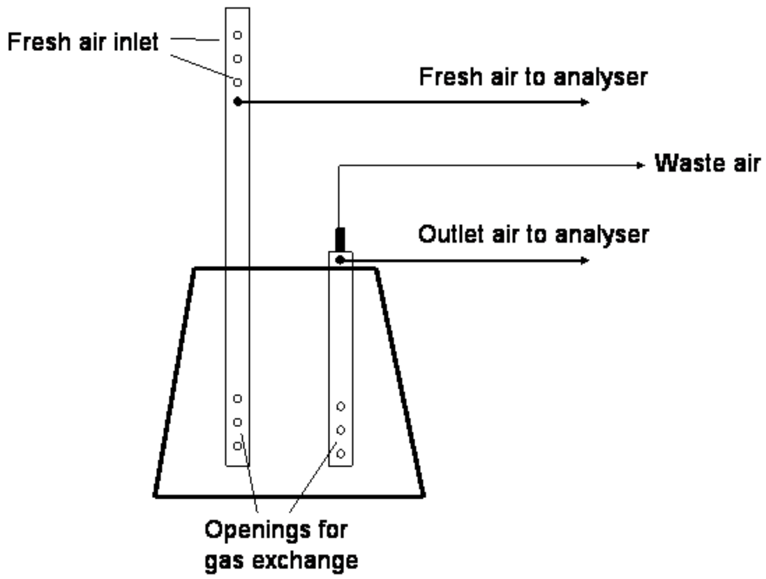


Figure 16: Gas chamber used in the experiment

The measurements were mainly carried out at the fields of the mentioned fertilising experiments (chapter 1) on spring wheat and maize in the years 2005 and 2006. Some additionally took place at nearby grassland. The urine was spread using a garden standard watering can. The method corresponds to a band spreader application without incorporation of the manure. For each gas chamber an area of 1 m² was spread and the hood was placed at the centre.

4.2. Ammonia emissions – Results

Six measurements have been carried out to determine the amount of nitrogen which was lost in form of ammonia emissions after application of urine. The results of each measurement are presented in the following.

The first measurement was carried out in May 2005. The four gas chambers were placed on a field with maize. Because of the wide distance of rows at a maize field the chambers did not cover any plants but were placed between them on bare soil. An amount of 150 kg ha^{-1} N was applied in one share which did not correspond to any treatment in the fertilising experiment. The result is presented in Figure 17.

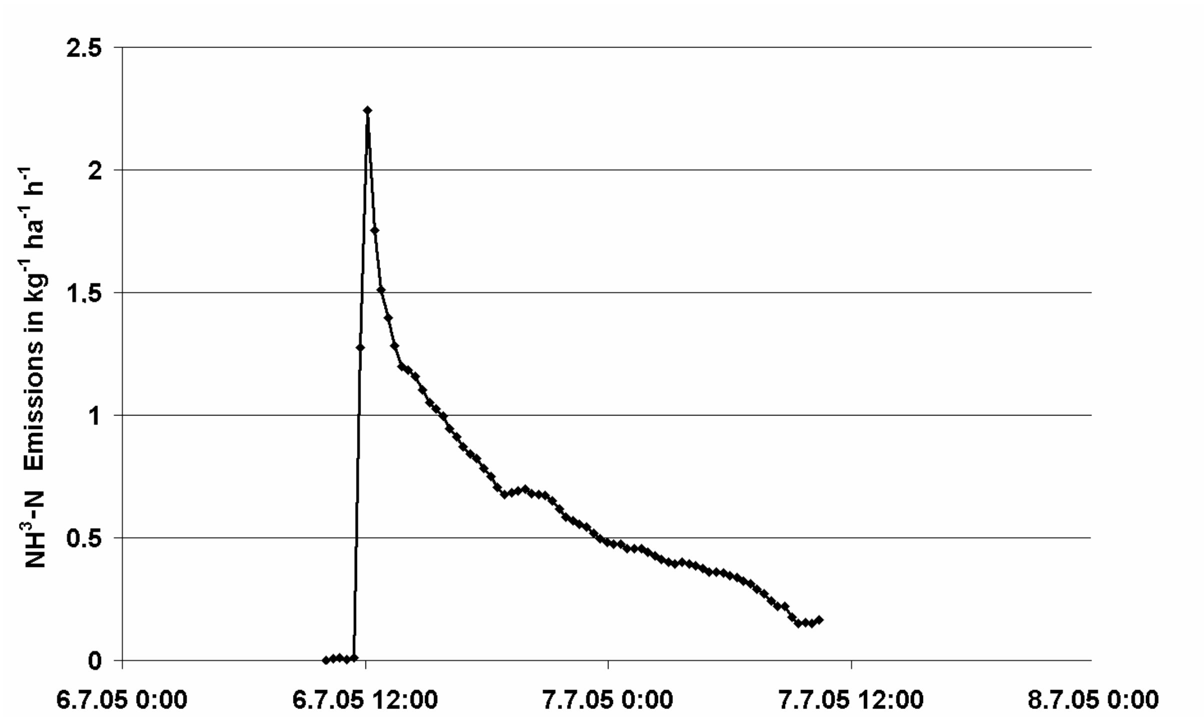


Figure 17: Ammonia emissions after application of urine with 150 kg ha^{-1} N between maize plants

From the 6th to the 7th of May 2005 total ammonia emissions of 14.8 kg ha^{-1} N were established. This means of loss of 9.9 % of the amount of nitrogen totally applied. After application a rapid raise in emissions to more than 2 kg ha^{-1} N could be observed. A release was observed within the following 24 hours.

The next measurements were carried out in June 2006 on a field with spring wheat. An amount of 75 kg ha^{-1} from urine was applied under the four spatial replications. The mean values of the emissions per hour are presented in figure 18. After application the loss per hour per hectare rose to 1.2 kg but soon decreased. A total loss of 4.8 kg of gaseous ammonia was found. This corresponds to 3.9 kg of nitrogen. Therewith 5.2 % of the totally applied nitrogen was emitted to the atmosphere within 12 hours after application.

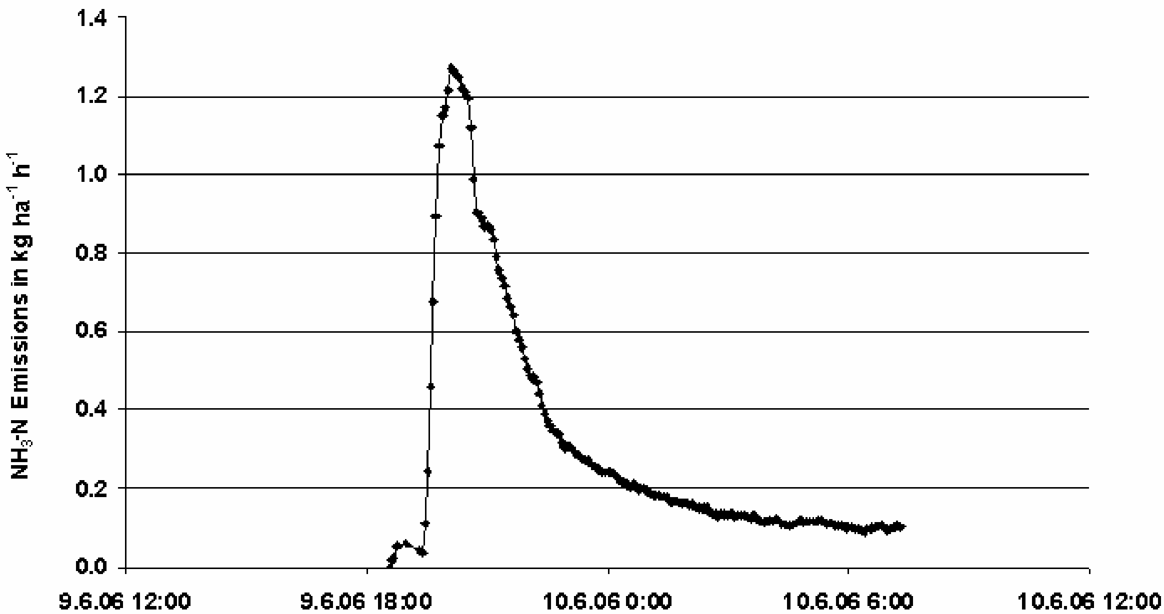


Figure 18: Average ammonia emissions after application of urine with 75 kg ha^{-1} N on spring wheat

Below the results from the gas measurements during the 12th to the 13th of July are presented. At this date an amount of 75 kg ha^{-1} N was applied on spring wheat. As presented in figure 19 emissions of up to 2.3 kg per hectare per hour were established shortly after application. Again, after a short peak the amount of ammonia which was lost to the atmosphere declined within the following 24 hours. In total 3.4 kg nitrogen were emitted which is equivalent to 4.6 % of the amount applied in form of urine.

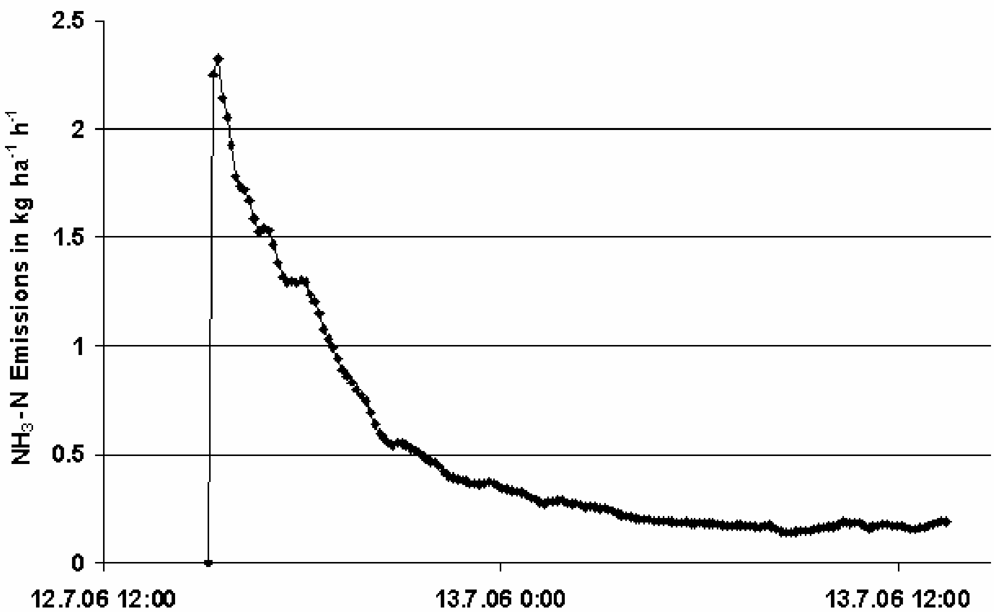


Figure 19: Average ammonia emissions after application of urine with 75 kg ha^{-1} N on spring wheat

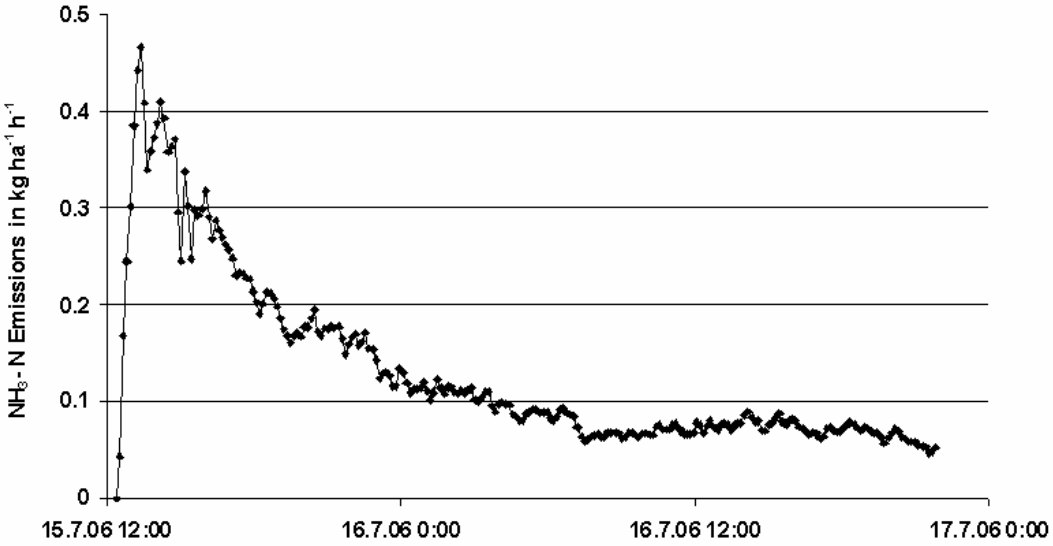


Figure 20: Average ammonia emissions after application of urine with 50 kg ha^{-1} N on maize

In figure 20 the emissions of ammonia are presented as measured from the 15th to the 17th of July 2006. An amount of 50 kg of nitrogen per hectare from urine was applied on a field with maize. An average emission rate of 2.4 kg of ammonia was established. This means a loss of 1.9 kg per hectare or 3.9 % of the amount totally applied.

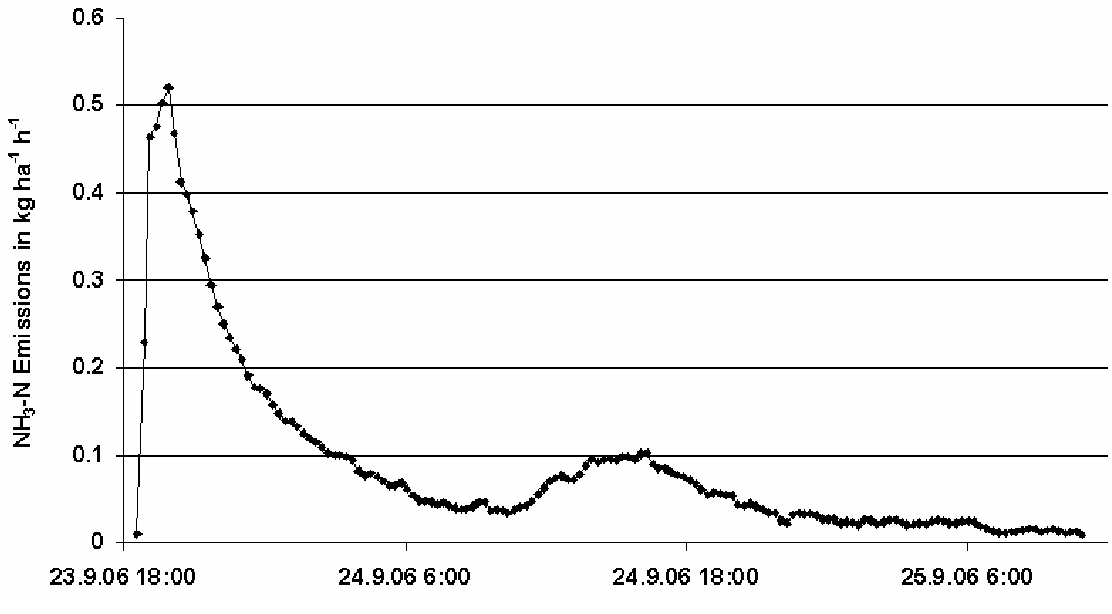


Figure 21: Average ammonia emissions after application of urine with 50 kg ha^{-1} N on grass

The results of the ammonia emission measurements from September 2006 are presented above. The experiment was carried out on grassland with urine containing 50 kg ha^{-1} nitrogen. Total emissions of 1.1 kg ha^{-1} nitrogen in form of ammonia were determined. This is an equivalent of 2.7 %.

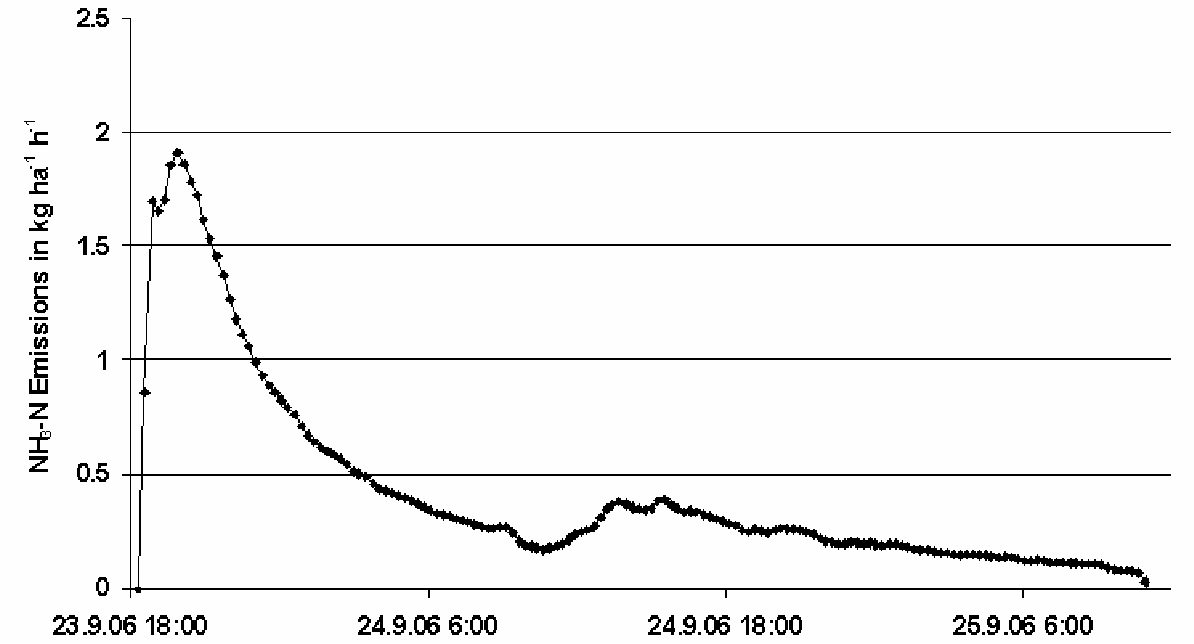


Figure 22: Ammonia emissions

Above, the results of a gas emission measurement are presented which were carried out parallel to the one presented before. Here, urine containing 100 kg ha^{-1} of nitrogen was applied. The gradient of ammonia emissions found in this experiment is presented in figure 22. In total 5.2 kg ha-1 of nitrogen was lost to the atmosphere. This approximates to an emission rate of 5.2 %.

In table 7 a summary of all measurements carried out is presented. Two main influencing factors (namely the amount applied and the type of plant cover) are also presented. However, when comparing the results it needs to be taken into account that other factors which are not presented (e.g. Weather) may also influence the emission rate.

Table 7: Summarised results of the six ammonia emission measurements

Date	Amount of N applied in kg ha^{-1}	Type of plant cover	Ammonia-Emission in %
July 06, 2005	150	Maize	9.9
June 09, 2006	75	Spring wheat	5.2
July 12, 2006	75	Spring wheat	4.6
July 15, 2006	50	Maize	3.9
September 23, 2006	50	Grass	2.7
September 23, 2006	100	Grass	5.2

In the summarised results a tendency can be observed: Higher percental emission rates were established at higher amounts applied. This leads to the conclusion that a splitting into two dosages reduces the emissions compared to an application of the whole amount at ones. In general, the emissions rates were below the ones from slurry presented in the literature (LEICK, 2003; FERM

2000). Furthermore the urine was not incorporated into the soil. A reduction of the ammonia emissions was reached with slurry due to the use of incorporating application techniques. This effect is also to be expected if these techniques are used for urine application.

The reason for the relatively low emission rate may be seen in the low dry matter content of urine. It infiltrates quickly and nearly completely into the soil without causing larger emissions.

4.3 Nitrous oxide – Results

The emissions of Nitrous oxide were measured with the same techniques in the same way as the ammonia emissions.

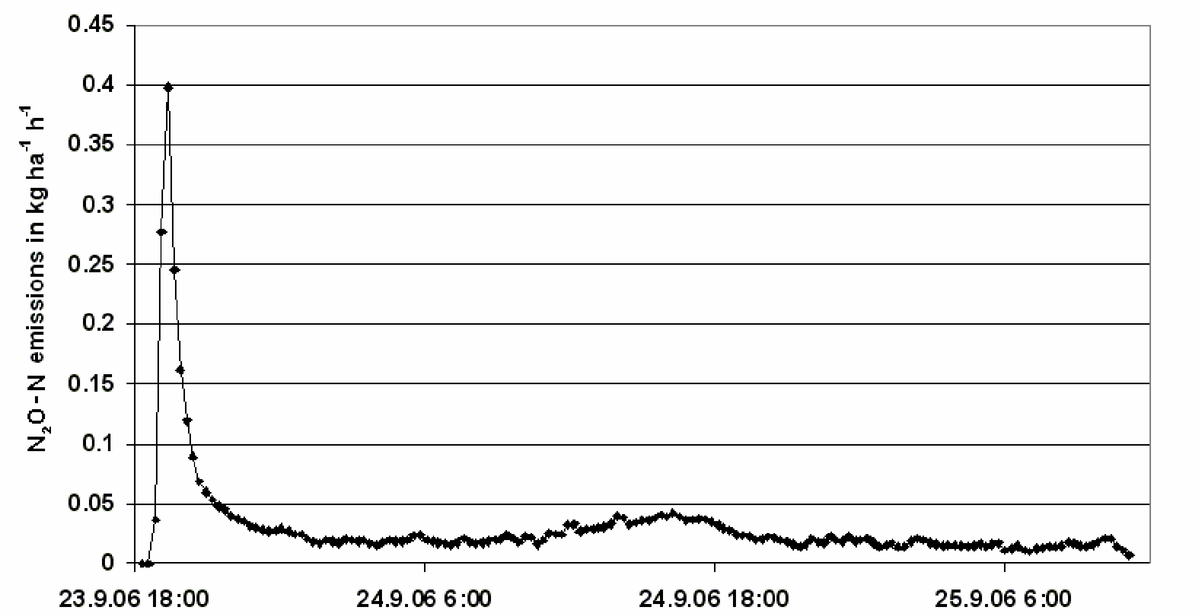


Figure 23: Emissions of N_2O after application of urine with 100 kg N per hectare

In figure 23 the emissions of nitrous oxide are presented as measured at the 23rd of September 2006. In total, 0.28 % of the amount totally applied was emitted. This relatively low number corresponds to data found in literature (LEICK, 2003). N_2O -emissions are more dependent on tillage measures, weather conditions and type of soil.

4.4 Methane – Results

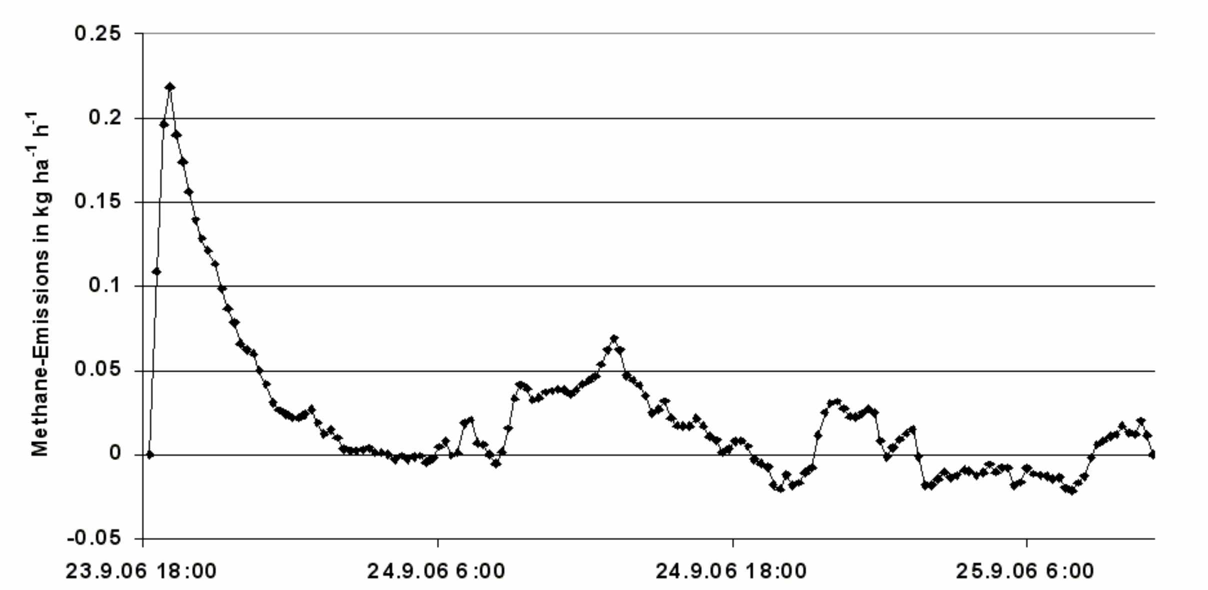


Figure 24: Methane emissions after application of urine with 100 kg ha^{-1} N

Raising methane emissions were measured after application of urine (figure 24). They were not long-lasting but at a zero-level 12 hours after spreading. At the next day, another peak of emissions was measured about at noon time. This second peak was lower than the first one. During the following time the values partly even dropped below the zero-point. This can be a result of the measuring variance at very low concentration values or an insertion of methane into the soil. A total amount of 0.32 kg methane per hectare was established within the time of measurement. Agriculture is considered to cause a main part of the global methane-emissions but from animal husbandry. Compared to these values, the emission rate found after spreading of urine was low (Petersen et al., 2004).

5. Acceptance of Urine as fertiliser

The acceptance of urine as fertiliser is a preposition for successful implementation of the Alternative Sanitation Concept. Attitudes and perceptions about health hazards and revulsion to urine vary between cultures and generations. TANNER (1995) describes that every social group has a social policy for excreting; some codes of conduct which will vary with age, marital status, gender, education, class, religion, locality, employment and physical capacity. After CROSS (1985) the human dimension is a severely neglected concern in environmental health and yet one that is of central importance to a full understanding of the potential reuse of nutrients in human waste. In the case of Germany, urine and faeces have widely been used as fertiliser before modern sanitation systems were introduced. In East Germany sewage from rural communities was applied to agricultural fields until the 1980^{ths}. This may lead to the assumption that the public acceptance of this "natural" fertiliser may be relatively high. In opposition to that, people may have provisos against the spreading of untreated urine on fields because of hygienic or just emotional concerns. Potential aversions against the idea may result form news-information about pharmaceutical residues in urine and their negative influence to fish populations.

Most acceptance studies concerning Alternative Sanitation in Europe deal with the use of the toilet itself. But for the introduction of the system not only the acceptance of the toilet-users would be needed. A broad based agreement of the consumers was necessary because the system would affect many people via the food cycle. However, some questionnaires included a general question of how the participants like the idea of using urine in agriculture. An investigation in Switzerland found that "the acceptance of individual citizens for the new technology proved to be quite high. The majority of the citizens expressed their willingness to […] buy food fertilized with urine." (Pahl-Wostl at al., 2003)

5.1 Consumer acceptance study

A questionnaire was developed to be completed within 3 minutes containing the following questions:

- How do you like the idea of applying urine on agricultural fields?
- If the system was introduced, would you be concerned about the following aspects: Hygiene, pharmaceutical residues, diseases, smell, over-fertilisation?
- Would you accept food produced with urine?
- Would you prefer to buy such products in the meaning of sustainable agriculture?

The lack of information regarding the existence of Alternative Sanitation systems and source-separating toilets was a major problem when the acceptance study was carried out. People just did not take the questions serious because they did not consider it to be possible to separate urine and faeces in a toilet. To overcome that problem, people were asked in front of a life-size model of a separation toilet. At first they were introduced into the working principles of the toilet and then they were asked to answer a questionnaire regarding the use of urine on farmland. The investigations took place at three exhibitions with considerable different types of visitors. At first, 108 questionnaires were completed at the Green Week Agricultural Exhibition 2006. Secondly, 27 returns were achieved at an open door event of the agricultural scientific campus Berlin-Dahlem ("Lange Nacht der Wissenschaften") in May 2006. 40 more answered questionnaires were collected at a local farmer's exhibition in the countryside of Brandenburg ("BraLa").

Results

In total, 175 participants answered the questionnaire. The results of the question "How do you like the idea of applying urine on agricultural fields?" are displayed in figure 25.

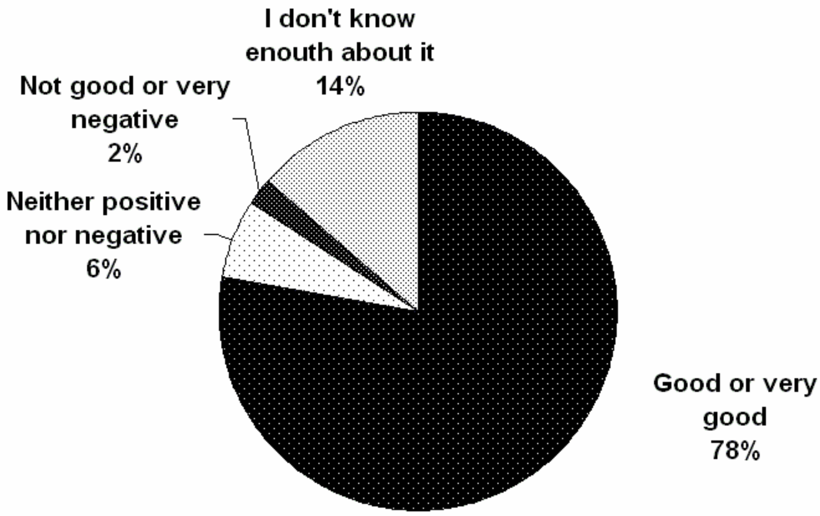


Figure 25: Distributions of answers to the question: "How do you like the idea of applying urine on agricultural fields?"

A broad majority liked the idea of urine recycling in principle. However, some concern was expressed in the answers of the following questions: More than 61 % felt worried about pharmaceutical residues in urine. About one forth expressed concern regarding the potential transmission of diseases but only 12 % considered hygiene as a potential problem. The smell during and after application was expected to be very unpleasant by 15 % of the participants, 11 % considered urine recycling as not necessary because of the "already existing over-fertilisation".

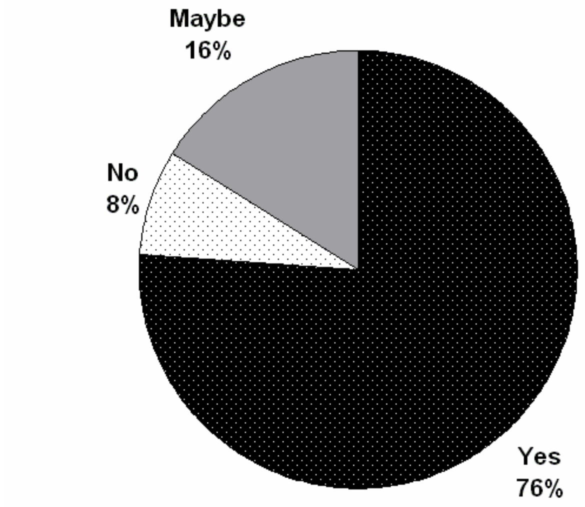


Figure 26: Distribution of answers to the question: „Would you accept food produced with urine as fertiliser?"

Above, in figure 26 the answers regarding the acceptance of food produced with urine as fertiliser are presented. Three quarter of the participants agreed, 8 % would not accept such products. The last question focused on the buying behaviour of the consumers. "Would you prefer to buy such products in the meaning of sustainable agriculture?" was asked and the following options were given: "Yes", "No", "Maybe" and "Only if these products would not be more expensive than others". With 62 % the majority stated that they would buy food produced with urine as fertiliser. 11 % constricted that the products would have not to be more expensive than others. Slightly different answers were recorded between the different locations. While at the open door day in Berlin-Dahlem only 7 % restricted the purchase at a not higher price, 20 % did so at the exhibition in a rural area (BraLa). Refer to Appendix 30 for the full questionnaire and detailed answers.

5.2 Farmer acceptance study

The acceptance of urine as fertiliser among farmers is a preposition for the introduction of the described Alternative Sanitation concept. Farmers in Brandenburg are considered to play a key role in recycling urine if relevant amounts could be supplied. Only if they would agree to apply urine on their fields the system could be introduced on a broad basis. On one hand urine could mean the source of an alternative fertiliser which is considered to become even more attractive with raising energy costs and prices for mineral fertiliser. By the other hand farmers might be concerned about their reputation if the application was not supported by the public. At present urine is not registered as marketable fertiliser in Germany. By law farmers are not allowed to spread urine on their fields. A license is not expected to be published within the next time. However, the technical possibilities and a demand of urine from the farmers' side could put pressure on the discussion to change the legal regulations. No comparable investigations are known from the literature carried out in Germany yet.

At first, six expert-interviews with selected farmers or farm-mangers were carried out to identify relations and factors potentially influencing the farmer's decision whether to use urine as fertiliser or not. A number of hypotheses set up afterwards were evaluated by a two-page questionnaire. They dealt with the following aspects: Smell and manageability, fertilising effect, price and value, safety and micro pollutants, product saleability and emotional concerns. The participants were also asked to rank the mentioned aspects in order of importance. Only rural districts directly surrounding Berlin were chosen because they were seen as potential purchasers for urine from the city. Local governments from these areas supplied the post addresses of 400 farmers. An answering possibility via FAX was given, however some returns were made by post. Additional information regarding sex and age of the participant as well as farm size, management type and distance to Berlin were asked for statistical evaluation.

Results

68 replications enabled a clear identification of crucial factors. Only selected results will be presented in the following. Generally asked if they would apply urine on their fields, the major part was not sure. As given in figure 27 only one quarter gave a clear "Yes" statement. 72 % answered that present legal regulations would prevent them from implementing the alternative fertiliser.

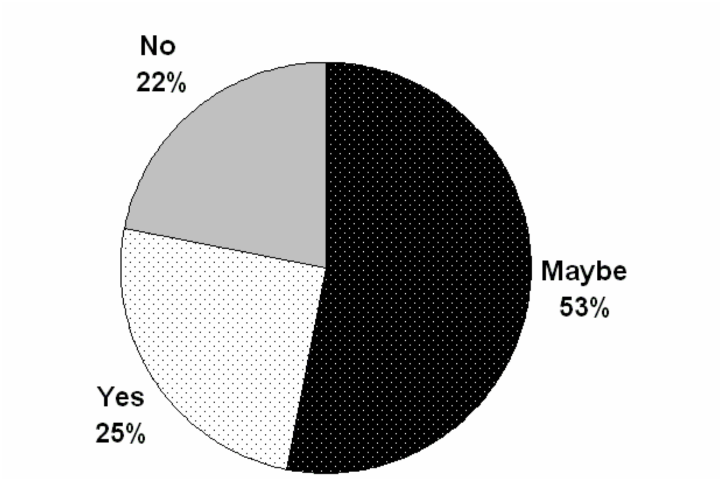


Figure 26: Distribution of answers to the question: "Would you apply urine on your fields?"

Only 10 % would apply urine on food crops, half of the participants would use it at energy crops. 63 % were worried about the saleability of their products if vegetables (including potatoes) would be fertilised with urine. The closer the farmland to Berlin the more concern was mentioned regarding the smell. In total, half of the farmers consider a smell worse than the one usually found after slurry application as a reason not to apply urine. The participants did not feel ecological concern or considered logistical reasons potentially preventing them from spreading urine on a farm scale basis. When asked for a ranking the farmers considered the legal regulations as well as the price as being most important in that concern (table 8).

Table 8: Distribution of answers when farmers were asked: "Please rank the following aspects on order of their importance!", Values in %, Numbers in grey background if more than 20 %

	Ranking: 1 = very important; 8 = not important at all							
Aspects	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Ecology	8.2	8.3	13.1	11.5	4.9	15.0	13.3	39.3
Hygiene	8.2	16.7	3.3	9.8	18.0	26.7	11.7	1.6
Pharmaceutical residues	18.0	16.7	21.3	6.6	8.2	3.3	13.3	9.8
Smell after application	0.0	5.0	13.7	24.6	21.3	13.3	13.3	9.8
Application technology	1.6	6.7	8.2	9.8	8.2	8.3	30.0	26.2
Saleability of products	19.7	11.7	14.8	11.5	14.8	10.0	5.0	8.2
Legal liability	26.2	15.0	14.8	16.4	13.1	8.3	1.7	1.6
Price and fertilising value	18.0	20.0	11.5	9.8	11.5	15.0	11.7	3.3

The saleability of their products as well as potential hazards resulting from micro-pollutants were ranked lower but still more important than logistical issues or the impact to the ecosystem. For the full questionnaire with answers please refer to appendix 31.

6. Conclusions

Fertilising experiments have been carried out with different types of crops in form of pot experiments and field experiments. A difference in fertilising effect could only be observed in one case: Significantly lower Dry Matter yields of maize were harvested after urine application compared to mineral fertiliser application. This was explained by the temporary high nutrient uptake of maize and the high amount of plant matter produced per pot. In all other cases a difference in the fertilising effect between urine and ammonium nitrate or calcium ammonium nitrate respectively was not established. It can be concluded that under the conditions of Brandenburg urine has an equal fertilising effect as mineral fertiliser. This could be proved even despite the fact that urine contains a different composition of nitrate and ammonia than the CAN (calcium ammonium nitrate) or AM (ammonium nitrate) used. In some case especially in the year 2006 higher mean yields were reached after urine spreading. This was explained due to the granulated form of the CAN resulting in a high retaining time at the soil surface during dry weather conditions. Furthermore it can be stated that obviously the ammonia emissions after urine spreading do not cause measurable lower yields. The composition of urine regarding the three main plant nutrients nitrogen, potassium and phosphorus is to be seen as suitable for many types of crops. However, under practical conditions the exact time and amount of application of urine needs to be determined case by case. From the fertilising point of view, the use of urine as fertiliser is recommended if relevant amounts of could be collected. Lower yields are not to be expected.

Fertilising experiments were also carried out with faeces and compost of faeces. In both cases lower yields have been found in pot experiments with maize and spring wheat. Under field conditions only the compost had a lower fertilising effect than mineral fertiliser. However, only a small amount of nutrients were applied from liquid faeces due to the high content of flushing water. Without a separation of the flushing water a use of the Brown Water as fertiliser in not recommended. The low contents of nutrients do not allow relevant amounts to be applied.

The effect of urine to soil biological life was investigated using earthworms. Two avoidance response tests were carried out and field investigations in the years 2005 and 2006. It can be concluded that earthworms totally avoid freshly incorporated urine. Under laboratory conditions the effect was only short-term. After two weeks of residence time earthworms do not avoid urine anymore. It could not be finally clarified what mechanisms cause the avoidance. Under field conditions a decrease of the earthworm population was observed after urine application. In 2005 the number of worms found in autumn was equal in all three treatments (control, mineral fertiliser and urine). In 2006 the population did not recover due to the dry weather condition. It can be concluded that urine has an impact to soil life. The effect proved to be only of short term. A persisted negative impact from urine to earthworms is not to be expected.

Gaseous emissions of ammonia, nitrous oxide and methane were measured to assess the impact of urine application to air pollution and greenhouse effect. Different application amounts between 50 and 150 kg ha^{-1} N resulted in ammonia emissions between 2.7 and 9.9 %. Higher emissions were established after the application of higher dosages. In general compared to slurry the ammonia emissions after urine spreading were low even without incorporation into the soil. The loss of ammonia could even be decreased by using incorporating application techniques. It can be concluded that in the total system of urine application on fields the ammonia emissions are negligible.

Nitrous oxide (also called laughing gas) is considered to act as greenhouse gas and cause global warming. Only little emissions have been found after urine application. N_2O emissions after urine application can be seen as negligible. A similar picture was found in terms of methane emissions. Only 0.32 kg of methane was lost within the first two days after application of urine with 100 kg ha^{-1} nitrogen. Considering other sources of methane emissions in agriculture this amount is very small. Compared to slurry urine infiltrates into the soil quickly and can be taken up by plants. In general, relevant extends of negative gas emissions after urine applications are not to be expected.

The opinions of 175 consumers were investigated regarding the use of urine in agriculture. The majority supported the idea. Even food produced with urine as fertiliser was widely accepted. However, about two thirds feel worried about the spread of pharmaceutical residues from urine. The participants proved to be open-minded to the new sanitation system and up to a certain extend they admit to carry more personal risk or disadvantages if that would contribute to sustainable agriculture. Comparable results were recorded in other acceptance studies in Europe but never before in the region of Berlin.

More concern was found at the farmer’s side. Only 25 % clearly agree with the idea. The major part is not sure. Most doubts seem to be a result of the legal regulations in Germany. They were not expected to be changed easily. Furthermore farmers showed to be worried about the reputation of their products. Off cause, the price was considered to be a crucial factor. If urine in Germany was a marked-able fertiliser and it would be offered to a reasonable price, farmers would use urine on their fields.

Taking into account the aspects investigated it can be fully recommended to use urine as fertiliser on agricultural fields.

7. Literature

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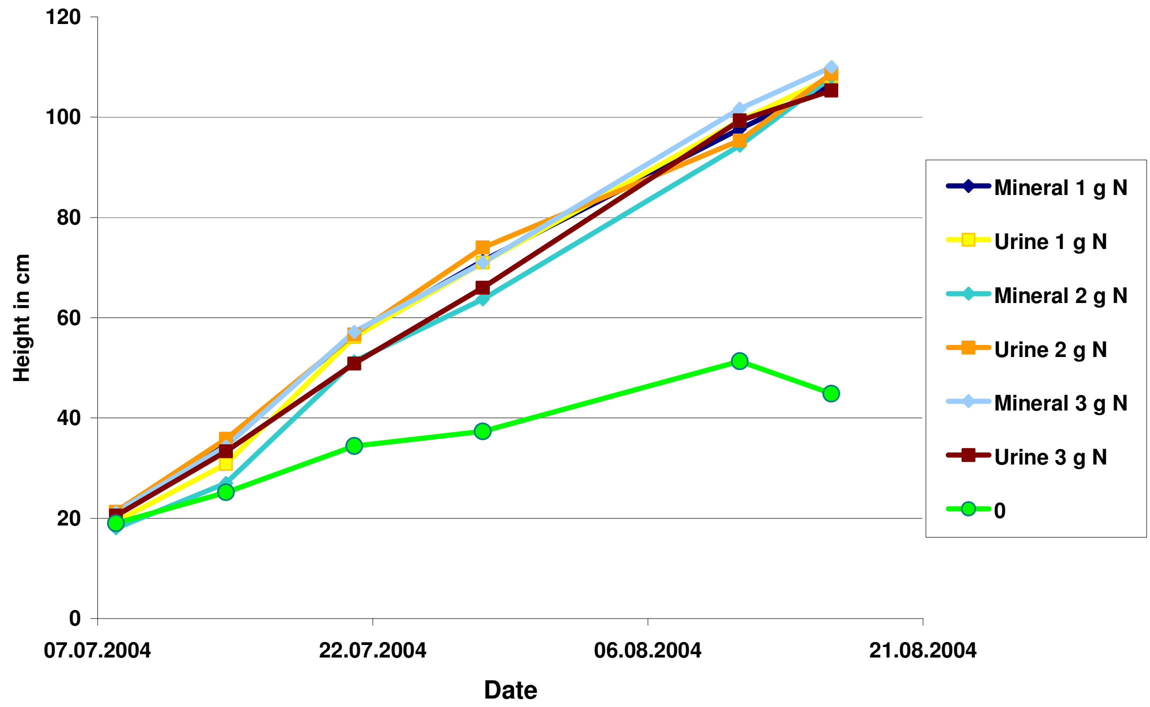
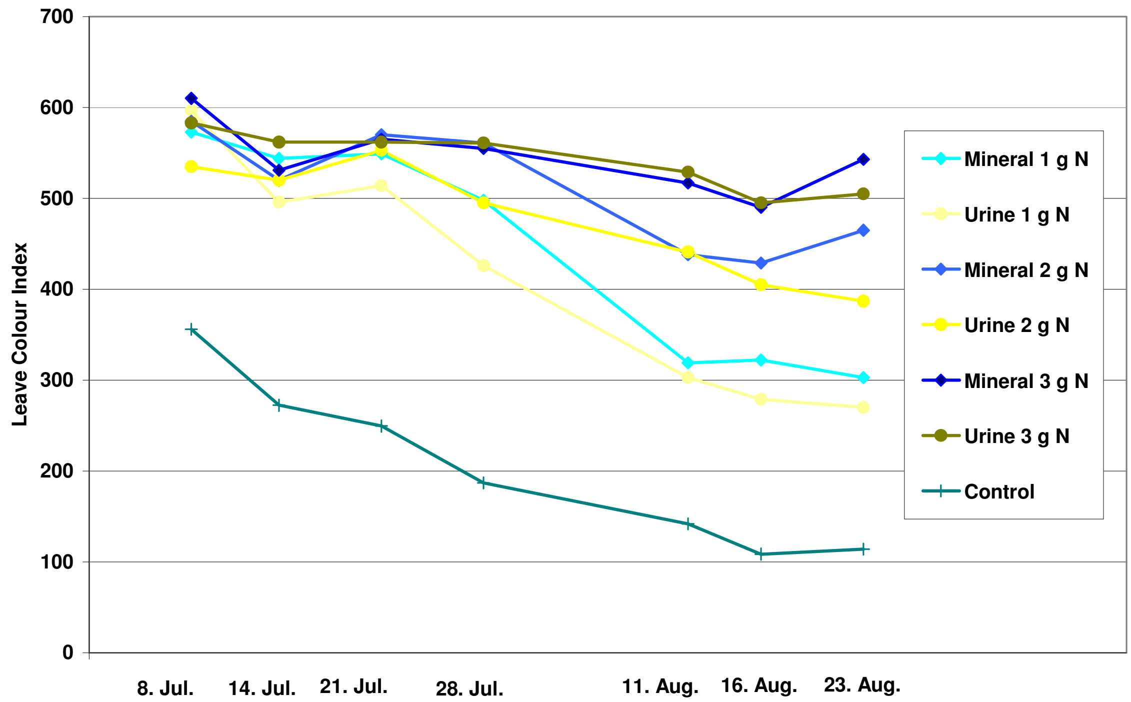
8. Appendix

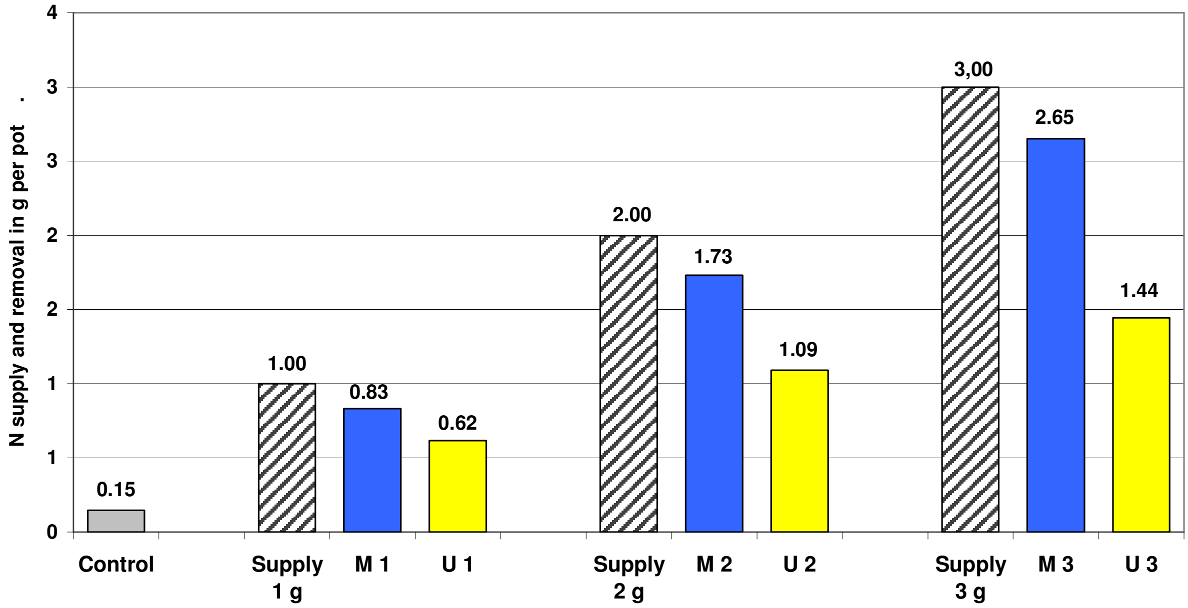
Appendix 1: Development of height of maize plants in pot experiment 1 (2004)



Appendix 2: Leave colour index pot experiment 1 (2004) Maize

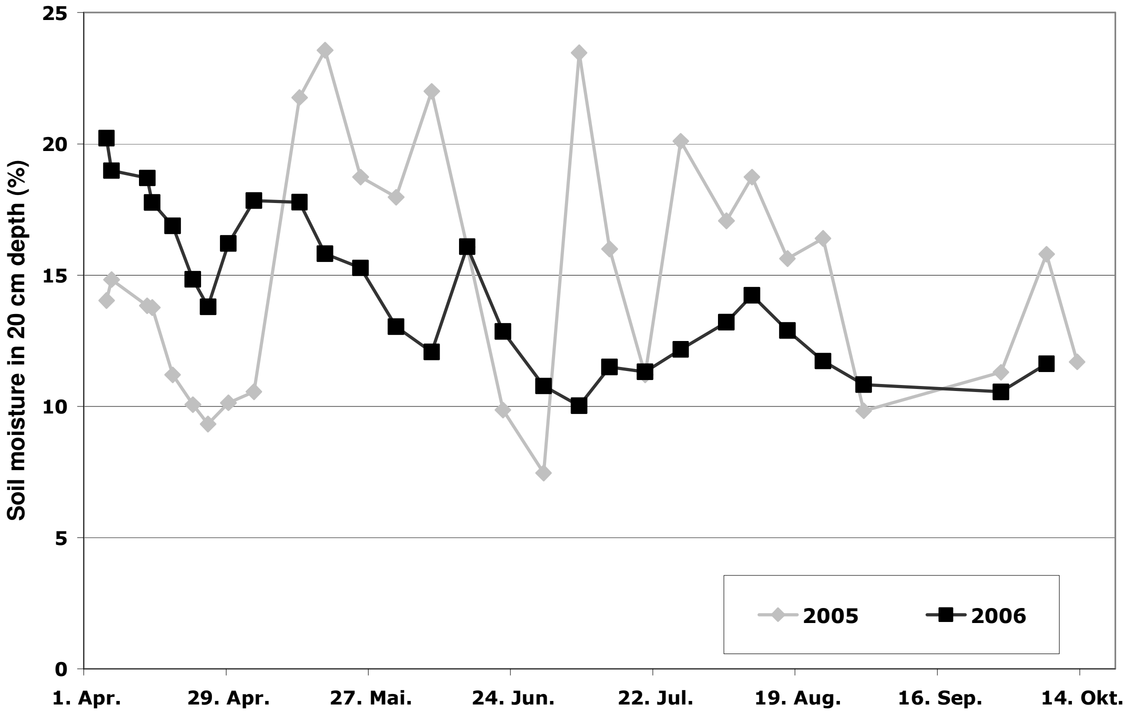


Appendix 3: Nitrogen removal maize pot experiment 2004



Appendix 10:
Wooden boxes earthworm Avoidance Response test

Appendix 11: Soils Moisture in 2006



Appendix 20: Picture gas chamber

Appendix 30: Questionnaire and answers of the consumers' acceptance study

1. Do you know the faculty of agriculture and horticulture at the Humboldt-University of Berlin?

60 % Yes 40 % Now

2. How do you like the idea to collect urine separately and use it in agriculture?

42 % Very good 6 % Neither nor 1 % Not good at all

36 % Good 1 % Not good 14 % I do not know enough about it

3. What problems do you expect if urine was used as fertiliser?

---

4. Do you feel concern about the following aspects?

→ Hygiene

12 % Yes 68 % No 20 % Maybe

→ Pharmaceutical residues/ Hormones

61 % Yes 14 % No 25 % Maybe

→ Diseases

24 % Yes 46 % No 30 % Maybe

→ Smell

15 % Yes 68 % No 17 % Maybe

→ No need for such fertiliser because of over-fertilisation

11 % Yes 69 % No 20 % Maybe

5. Would you accept food produced with urine as fertiliser?

76 % Yes 8 % No 16 % Maybe

6. Would you prefer to buy such products in the meaning of sustainable agriculture?

63 % Yes 5 % No 21 % Maybe 11 % Only if not more expensive

7. What is you age?

2 % Under 8 28 % 35 to 49 years 6 % over 65 years

40 % 18 to 34 years 24 % 50 to 65 years

8. Sex

54 % Male 46 % Female

Appendix 31: Questionnaire and answers of the farmers' acceptance study

Page 1 of 2

1. Did you know that most nutrients are excreted from the human body via urine?

64 % Yes   36 % No

---

2. Would you apply urine as fertiliser on your fields?

25 % Yes   22 % No   53 % Maybe

---

3. At which crops would you apply urine? (More than one answer possible)

47 % Energy crops   10 % Food crops
32 % Fodder crops   11 % At no crops

---

4. Do you expect a reduced saleability of crops fertilised with urine? If YES at which crops? (More than one answer possible)

23 % Cereals   29 % Potatoes
34 % Vegetables   14 % I do not expect reduced saleability

---

5. Would an unpleasant smell after application be a main negative factor?

50 % Yes   21 % No   29 % Maybe

---

6. Is the application technique for liquid manure available at your property?

57 % Yes   27 % No   16 % Is carried out by a contractor

---

7. Please mark! (More than one answer possible)

48 % Urine would only be applied if supplied for free
14 % The cost of urine must not succeed the costs of conventional fertiliser
38 % The costs of urine have to be lower than conventional fertiliser
0 % In the meaning of sustainable agriculture the price for urine may be slightly higher then the one for conventional mineral fertiliser

---

8. Do you feel ecological concern if urine is spread on fields?

63 % No   37 % Yes

---

9. What annual administrative effort regarding the introduction of a new fertiliser would you accept?

36 % As little as possible   12 % Slightly more effort
47 % No additional effort   5 % Up to one day more effort

Page 2 of 2

10. Would the legal liability for potential spill overeffects prevent you from implementing the new fertiliser?

72 % Yes
3 % No
6 % Maybe
19 % Only if not registered as fertiliser

11. Please rank the following aspects in order of importance for the application of urine on agricultural fields (1 to 8).

8	Ecological advantages	7	Logistics and transportation
6	Hygiene	5	Saleability of products
3	Pharmaceutical residues and Hormones	1	Legal liability
4	Smell	2	Price and value

All following questions are for statistical evaluation only

12. Please mark as appropriate. (More than one answer possible)

43 % Full time farmer
3 % Sideline base farm
9 % Crops only
21 % Crops and livestock
18 % Conventional / Integrated
6 % Organic farming

13. Please mark as appropriate

15 % Less than 200 ha
19 % 200 - 500 ha
13 % 500- 1000 ha
53 % More than 1000 ha

14. What is the distance from your fields to Berlin?

5 to 120 Km

15. Your age?

2 % below 30
58 % 30 - 50
40 % over 50

16. Sex

96 % Male
4 % Female