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Dissertation

ANTHROPOGENIC PLANT NUTRIENTS AS FERTILISER

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Zusammenfassung

Nachhaltige Landbewirtschaftung impliziert ausgeglichene Pflanzennährstoffflüsse ohne die Abhängigkeit von Düngern aus nicht erneuerbaren Quellen. Stickstoff, Phosphor und Kalium aus der menschlichen Nahrung werden in Mitteleuropa im Allgemeinen in Schwemmkanalisationen gesammelt und dabei mit Schadstoffen vermengt. Neuartige stoffstromtrennende Sanitärsysteme ermöglichen die Bereitstellung von Humanurin und Fäkalien zur Verwendung als Düngemittel.

In der vorliegenden Arbeit wurden praxisrelevante Aspekte der Verwendung von Düngemitteln anthropogener Herkunft untersucht. Die in Gefäß- und Feldversuchen in Berlin Dahlem ermittelte Ertragswirkung zeigte, dass Urin in dieser Hinsicht äquivalenten Mineraldüngern grundsätzlich gleichwertig ist. Bei sehr hohen Konzentrationen kam es abhängig von der Pflanzenart zu Depressionseffekten, welche vermutlich auf den Salz- und Ammoniumgehalt von Urin zurückzuführen sind. Unter Freilandbedingungen traten diese Effekte nicht auf.

Bodenbiologische Auswirkungen von Düngerapplikationen sind entscheidend für die Abschätzung ihrer langfristigen Bodenfruchtbarkeitserhaltung. Sowohl in Laborversuchen als auch im Freiland zeigten sich Regenwürmer durch menschlichen Urin aus Trenntoiletten deutlich beeinträchtigt. Die Ursache der Schädigung konnte nicht geklärt werden. Von einer langfristigen bodenfruchtbarkeitsreduzierenden Beeinträchtigung wird jedoch nicht ausgegangen. Mikrobielle Enzymaktivitäten im Boden wurden im Freiland durch Urinapplikation nicht beeinflusst. Für die Praxis wird empfohlen Urin während der Ausbringung einzuarbeiten, da die Tiere dann weniger mit der Flüssigkeit in Kontakt kommen.

Da es ein umweltpolitisches Ziel ist, die Ammoniakemissionen der Landwirtschaft zu minimieren, wurden diese nach der Urinausbringung im Freiland gemessen. Auf Grund der sehr geringen Trockensubstanzgehalte von Humanurin emittierte deutlich weniger NH_3 als üblicherweise nach Ausbringung von Schweine- oder Rindergülle.

Verbraucherumfragen bestätigten eine hohe Bereitschaft pflanzliche Nahrung, welche mit Urin als Dünger erzeugt wurde, zu kaufen und zu verzehren. Praktizierende Landwirte reagierten dagegen deutlich reservierter.

Die Ausbringung von Urin aus Trenntoiletten kann im Sinne einer nachhaltigen Landwirtschaft grundsätzlich empfohlen werden. Es besteht aber weiterer Forschungsbedarf.

Abstract

Sustainable agriculture implies balanced nutrient flows and independence from fertiliser made from non renewable resources. In Europe, plant nutrients excreted by humans are commonly collected in water borne sewage systems and thus mixed with potentially harmful substances. Novel segregating sanitation techniques can collect separated urine and faeces in a form which enables their use as fertiliser.

In the presented thesis selected aspects concerning the use of anthropogenic plant nutrients relevant to farming were investigated. Pot and field experiments indicated that equal yields can be gained if urine instead of mineral fertiliser is applied. Very high concentrations of urine led to reduced growth, presumably caused by the presence of ammonium or salt. However, this was not found under field conditions.

Soil biological effects caused by the application of a fertiliser must be considered when assessing its long term contribution to soil fertility. Laboratory experiments as well as field investigations showed that human urine application severely affects earthworms, however, the harmful components were not identified. The results suggest that the effect is of short term only. Soil microbial enzyme activities were not influenced by urine fertiliser. For farming practice it is recommended to inject or incorporate urine to prevent earthworms from coming into direct contact with the infiltrating fertiliser.

Gaseous ammonia loss was measured after urine application on fields as reducing harmful emissions from agriculture is a goal of European environmental policy. Because of the very low Dry Matter contents of urine, far less ammonia was emitted to the atmosphere than usually occurs after application of cattle or pig slurry.

A consumer acceptance study showed a general high public willingness to accept urine as fertiliser even if used on crops for food production. The reaction of farmers was mainly reserved as a result of the present legal regulations in Germany.

Within the context of sustainable agriculture the use of human urine as fertiliser can be recommended. Further research is necessary, especially concerning any effects resulting from residues of pharmaceutical substances contained in human excreta.

Key words: Alternative Sanitation, Anthropogenic Plant Nutrients, fertiliser, ammonia, earthworms, human urine

Schlagwörter: Alternative Sanitärsysteme, anthropogene Pflanzennährstoffe, Dünger, Ammoniakemissionen, Bodenbiologie, Akzeptanz

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1. Introduction

Our developed societies lack sustainability in a number of ways. Among the general public, sustainable energy use is often considered to be more important than sustainable matter flow. However, both processes greatly depend on each other. As humans tend to think forward, what we (virtually) leave behind us often fails to become part of our worldview. Our natural residues are, however, of significant importance on the path towards a more sustainable way of life. The following PhD-thesis deals with exactly this topic. It was written to point out the importance of dealing with human urine and faeces in a more sustainable way. Furthermore, it refers to a specific sanitation approach and investigates its suitability from an agricultural, environmental as well as social point of view. Source separation of urine and faeces can be technically simple in execution, but its design is different from what is usually found in the so-called ‘Western World’. Since the introduction of the existing water-borne sewers, the requirements that they were build to serve have changed or, at the very least, have been greatly extended. Increased scientific knowledge about the major significance of matter cycles in sustainability has led to a re-evaluation of our existing waste disposal systems.

1.1. Nutrient Cycles

1.1.1. The Cycle of Matter

The main elements that are found in the organic matter composition of all organisms are carbon (C), hydrogen (H), oxygen (O) and nitrogen (N). Water and minerals, such as phosphorus (P), sulphur (S), calcium (Ca), sodium (Na), potassium (K) and magnesium (Mg), are also essential. These elements pass through the non-living compartments - water, air and soil - and enter living organisms, before eventually returning to the non-living compartment after the organisms’ death, describing a cycle known as the **Cycle of Matter.** This process is deeply entwined with the food chains.

Unlike energy transfer, which flows in one direction, matter is continuously cycling: Chemical elements are removed from the environment, used by organisms and again returned to the environment. All organisms on earth consist of materials that are part of various cycles. In a simplified physical sense, ‘life’ means the development of organisms from available matter and the distribution of the components at the end of life. Added to this, most organisms exchange parts of their components during their lifespan. Life is limited by the availability of energy and matter. Over a long period, matter repeatedly is transferred from one organism to another, and between organisms and their physical environment. As with all material systems, the total amount of matter remains constant, even though its form and location change. Substances are taken up and incorporated e.g. for growing processes or converted for energy production (metabolism). Living organisms obtain matter from cycles and are themselves part of these closed or wider loops. All organisms, including the human species, are part of and depend on two main interconnected global food webs. One includes microscopic ocean plants, the animals that feed on them, and finally the animals that feed on those animals. The other web includes land plants, the animals that feed on them, and so forth. The cycles continue indefinitely, because organisms decompose after death to return food material to the environment. Food provides molecules that serve as fuel and building materials for all organisms. Plants use the energy in light to make sugars out of carbon dioxide and water. This food can be used immediately for fuel or material, or it may be stored for later use. Organisms that consume plants break down the plant structures to produce the materials and energy they need to survive. These are then also consumed by other organisms (ASTRO-VENTURE/NASA, 2005).

Two principle types of matter cycles are known: Long cycles including sediments and short cycles including living matter only. Often, they are referred to as internal and external matter cycles. Internal cycles include transformation and direct transportation in and between living matter, and no large pools. External cycles include large pools of matter like oceans, rock sediments or the atmosphere. Certain elements (nitrogen, phosphorus) are only limitedly available from these large pools. Their availability mainly depends on the chemical form as well as the concentration in which they occur. Nitrogen, for instance, is available from the atmosphere only in very small quantities for plants, although it is quite abundant in the atmosphere. Often, external cycles are not considered as cycles, as a result of questions about the availability from the large pools involved. Nevertheless, in the physical sense, they are in fact cycles. Environmentalists sometimes promote the idea of ‘closing the loop’ or ‘closing the cycle’ of certain substances and thereby describe a management system of ‘re’-cycling matter. However, they predominantly only consider the internal cycle of matter, as the character of a cycle is barely recognisable if large pools of matter are involved and availability is limited. A clear distinction is also difficult, as both cycles are closely connected. Most internal cycles also have ‘openings’ to the atmosphere where matter is added to or removed from the described loop.

1.1.2. The Cycle of Anthropogenic Plant Nutrients

With respect to energy, earth is an open system; with respect to chemical elements, earth is an almost closed system. The elements that are essential to life are called **nutrients**. Because different groups of creatures need different forms of nutrients, the composition of a particular nutrient is always defined by the kind of life it serves. This means that the term ‘nutrients’ is often debated among scientists. Biologists in particular state that, considering their actual meaning, nutrients are organic carbon compounds of a biological origin. In our oxygen-rich environment, these structures can provide energy and enable the composition of biomass (FINCK, 1991). Following this definition, minerals are in fact not nutrients (LIBBERT, 1991). However, minerals are essential to plant life and are often described as plant nutrients, as plants build up organic components from airborne carbon dioxide and minerals. Plants can also obtain essential elements from organic matter after conversion into a mineral form. In the presented work, minerals are therefore also referred to as nutrients. “Anthropogenic Plant Nutrients” include elements and substances that are required for plant growth. If essential, they cannot be replaced by the presence of another element. ‘Anthropogenic’ means that these nutrients are of human origin. In the narrower sense it describes plant nutrients that are released from the human body. However, in the wider sense, the term generally denotes plant nutrients disposed by humans, including other wastes. In the following, the focus will be on nitrogen, potassium and phosphorus from human urine and faeces, as these are the most limiting elements for plant growth in terrestrial environments.

The processes that govern the stock and flow of nutrients are called nutrient cycles. Two basic steps in all nutrient cycles are physical transport and chemical transformation. Plant life is dependent on the availability of plant nutrients, mainly nitrogen, potassium and phosphorus, but also of ten other elements. With sunlight and carbon from the air, the (mineral) nutrients are transformed into higher structures that act as nutrients for vertebrates. These rather complex (organic) nutrients are also essential to human life.

1.1.3. The Nitrogen Cycle

In the following, the fate of nitrogen in the nutrient cycle via the human diet is described, because nitrogen (N) is a main element taken up by humans from food in the form of proteins. Humans are entirely dependent on other organisms for the converting of atmospheric nitrogen into forms available to the body. 99 % of all nitrogen is located in the atmosphere; air is largely made up of nitrogen (78 %). However, the availability of atmospheric nitrogen is highly limited. In nature, a process known as nitrogen fixation occurs, whereby some bacterial species, the symbiotic eubacteria *Rhizobium* (in plant root nodules) and the archaea *cyanobacteria* (otherwise known as blue-green algae) contain an enzyme complex for the reduction of molecular nitrogen to ammonia. In its changed forms (NH_4^+, NO_3^-) it can then be used by plants to form amino acids. Bacteria, plants, and animals can synthesise some amino acids, but not all. Vertebrates cannot synthesise all the amino acids that they need for life, and must obtain some through their diet. Fixed nitrogen is returned to the soil after death and excretion. Animal wastes are rich in urea $(NH_2)2CO$. The proteins from dead organisms are broken down into amino acids by bacteria and fungi. The urea and amino acids are converted into NH_3 by other bacteria in ammonification.

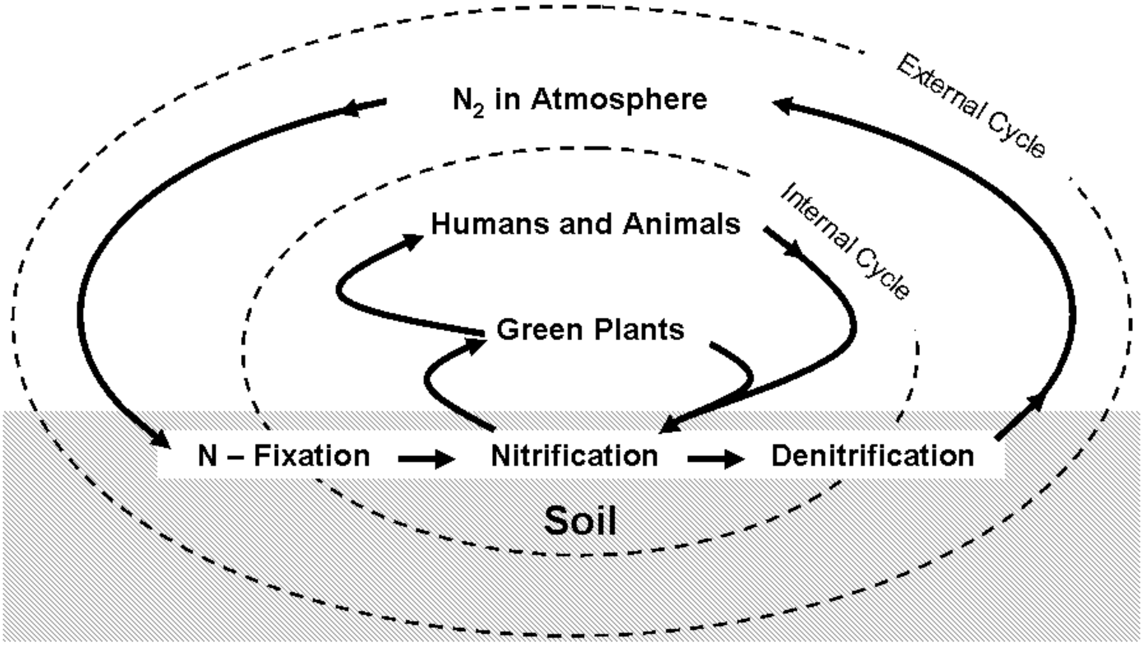


Figure 1: Nitrogen cycle in nature (own illustration)

The global nitrogen cycle has a large internal cycle (uptake → synthesis → excretion → death → decomposition). Actions that influence the internal cycle are likely to be more important than actions influencing external cycles (e.g., N-fixation) (Figure 1).

Almost all the nutrients taken up by humans are excreted as urine and faeces. Urine production and excretion is the body's primary method for removal of urea, a protein metabolic by-product. If disposed of in soil, the contained N is again taken up by plants. Today, in the case of human food, excreted nitrogen is not directly returned to the soil due to the particular kind of sanitation system. During sewage treatment, a large proportion of fixed nitrogen is released into the atmosphere and is therefore lost from the internal cycle. To ensure sufficient food production, mineral N-fertilisers are derived with high energy input from the air. The equivalent of 1.8 l of diesel-oil is required to produce, transport and apply 1 kg of mineral nitrogen (FLUCK, 1992).

In Western Europe, the excreta of a mature human contain 5 kg of plant-available nitrogen per year. Mass balances for plant nutrients can also be calculated for the human body. This means that the same amount of nitrogen, phosphorous and potassium that is consumed in the diet also is excreted, and that this excretion is almost entirely within the urine and faeces. During adolescence, this is not completely true, since some substances accumulate in our growing bodies. However, calculations show that this accumulation is negligible, as it has been calculated to be less than 2 % of the nitrogen consumed between the ages of 3 and 13 (SCHÖNNING, 2001).

1.1.4. The Phosphorus Cycle

Phosphorus (P) is a limiting nutrient for terrestrial biological productivity. Unlike nitrogen, the availability of ‘new’ phosphorus in ecosystems is restricted by the rate of release of this element through soil weathering. Without any link to the atmosphere, the P-cycle is driven only by weathering, uplift, and sedimentation. Because of the limitations of P availability, P is generally recycled in ecosystems to various extents, depending on climate, soil type, and ecosystem level. The weathering of P from the terrestrial system and transport by rivers is the only appreciable source of P for the oceans. On longer time scales, this supply of P also limits the total amount of primary production in the ocean. For plant growth, ten times less phosphorus is required than N, but because of its scarcity in accessible form, it can be the limiting nutrient. This is because P does not form any important gaseous compounds under normal conditions, and P salts are insoluble in water. Most plants are only about 0.2 % P by weight, but this small amount is critically important. Phosphorus is an essential component of adenosine triphosphate (ATP), which is involved in most biochemical processes in plants and enables them to extract nutrients from the soil. Phosphorus also plays a critical role in cell development and DNA formation. Insufficient soil P can result in delayed crop maturity, reduced flower development, low seed quality, and decreased crop yield. Too much P, on the other hand, can be harmful in some situations; when P levels increase in fresh water streams and lakes, algae blooms (eutrophication) can occur. Phosphorus must be in the inorganic form to be available for plants. Organic, adsorbed or primary mineral P cannot be taken up despite the fact that it may be located and accessible in the soil (HYLAND *et al.*, 2005). Processes of weathering, mineralization and desorption increase plant-available P. The application of mineral phosphorus fertiliser is often a precondition for ensuring high yields in crop production. Today, the annual global production of phosphate is around some 40 million tonnes of P_2O_5, derived from roughly 140 million tonnes of rock concentrate. Overall, mineral fertilisers account for approximately 80 % of phosphates used worldwide (BSP, 1998). In 1998, STEEN explained that the “depletion of current economically exploitable reserves can be estimated at somewhere from 60 to 130 years”. A shortage of phosphorus to be used as fertiliser is expected to arise within this period of time.

1.1.5. The Potassium Cycle

Potassium (K, potash) is plentiful in nature. It is the seventh most common element in the Earth’s crust. Certain clay minerals associated with heavy soils are rich sources of K, containing as much as 17 % K. Sea water represents a majority of the element globally, as it typically contains 390 mg l^{-1} of K. Large potash-bearing rock deposits, deriving from minerals in ancient seas that dried up millions of years ago, can be found in many regions of the world. Potash for fertiliser is chiefly derived from this potash rock, requiring only separation from the salt and other minerals and physical grading into a form that is suitable for fertiliser manufacture or farm spreading.

Potassium performs many vital functions in a wide variety of processes in plants, animals and humans. It is typically absorbed in greater quantities than is required and surpluses are naturally excreted. This process occurs in animals and humans via the kidneys and urine, and in plants by the return of potash in senescent tissue at the end of each season - leaves from trees, cereal stubble and roots, etc. K is therefore naturally widely recycled, and in large quantities. Today, soil reserves are an essential requirement for an adequate nutrient supply of K to plants, which commonly contain more potassium than any other nutrient, including nitrogen. Potassium can be lost from the soil through leaching, though amounts are small except on sandy soils. The concentration in water draining from agricultural land in the UK rarely exceeds 3 mg l^{-1} K, and the concentration in rivers rarely approaches 10 mg l^{-1} K. The EC Drinking Water Directive set a maximum admissible limit of 12 mg l^{-1} K, with a guideline of 10 mg l^{-1} K. Losses of potassium to water are not of environmental concern in Europe. Potassium is not lost to the air from soil (PDA, 2006).

It is often argued that the K-cycle is closed despite the fact that mineral K fertiliser is applied. The described cycle includes the transport of K in rivers into the sea and depositions in sediments. Thus, K can theoretically be mined again and be applied on agricultural fields. However, in fact, K fertiliser cannot practically be derived from seawater, except from the Dead Sea. If the concentration and location of K in its original sources is taken into account, it can be referred to as a non-renewable resource. The mining of K from rocks is carried out faster than the deposition in concentrations that are worth being mined.

Total global reserves are not easy to estimate. Current estimates of known, high quality reserves of potassium ore range from 9 to 20 billion tonnes of K_2O. According to the lowest estimate, and at the current rate of consumption, this supply could last up to 350 years. Total resources are estimated to be about 150 billion tonnes of K_2O, which will last many millennia (JOHNSTON, 1997). In 2000, Germany was the fourth largest producer of potash fertiliser. 3.15 million tonnes of K_2O were exploited in the country, of which 95 % was used as fertiliser (FAO, 2000).

1.2. Human Excreta Utilisation Historically

The relationship between humans and their excrement seems to have always been split into two camps. On the one hand, faeces in particular have been seen as a waste that should be disposed of as soon as possible. On the other hand, positive effects such as improved plant growth were observed around places where excrement was deposited. It can reasonably be assumed that these effects were deliberately exploited from very early on. The hygienic aspect only became important where greater numbers of humans were dwelling on a limited area. Contact with others' excreta could be easily avoided as long as sufficient space was available around the living area. Generally, faeces and urine do not seem to have played a significant role in the history of rural life until the 20th century, but were always important in cities and other densely populated places.

The first recorded instruction regarding sanitation/hygiene is thought by many to be the following text from the bible: "Also you shall have a place outside the camp, where you may go out; and you shall have an implement among your equipment, and when you sit down outside, you shall dig with it and turn and cover your refuse" (NELSON IMPERIAL REFERENCE BIBLE, 1983, Deuteronomy 23: 12 + 13). It was obviously not common to cover faeces in that area a few thousand years ago, but in the case of military build-up, it was a necessity due to the high concentration of men over a limited area. This instruction was certainly not made with regard to the fertilising effects of excrement, but one can easily imagine that trees and bushes in particular benefited from significant amounts of nutrients during the presence of larger numbers of soldiers in a specific area during wars in ancient times.

In the 19th century, Justus von Liebig referred to the use of “metropolitan sewage” as one of the key issues for the future. He underlined the importance of nutrient recycling by describing the return of human excreta from urban areas to agricultural land as a precondition for sustaining the wealth and welfare of the states, as well as the progress of culture and civilisation [… so werden sie die Einsicht gewinnen, daß von der Entscheidung der Kloakenfrage der Städte die Erhaltung des Reichtums und der Wohlfahrt der Staaten und die Fortschritte der Cultur und Civilisation abhängig sind.], (ZÖLLER & VON LIEBIG, 1876). Von Liebig was particularly concerned about London's sewage problem. This was following a cry for help from the Lord Mayor of the city. The agricultural-chemist was appalled at what he saw as a complete waste of useful agricultural nutrients being washed into the Thames. GIRADET recounts in 1996 how the German chemist tried to convince the London authorities to build a sewage recycling system for the city in the 1840s. When they instead decided in the 1850s to build a sewage disposal system, von Liebig and others began working on the development of artificial fertilisers, to replenish the fertility of the soil that was feeding the cities by artificial means (now that the human fertiliser was being disposed of into the sea). This political and economic decision contributed to the current unsustainability of both agricultural and urban systems (www.dep.org.uk, 2007).

At the time, the idea of productively exploiting human excreta was also being explored by other scientists: WOLFF (1868) described the use of “latrine-fertiliser” [Latrinendünger] in German agriculture. He saw great potential to increase yields in many areas (especially around cities) and complained about the new water-borne sewerage systems that prevented the night soil (content of latrines) to be used as fertiliser due to a massive dilution with water. Conversely, in 1840, von Liebig still considered the use of sewage water to be the most practical means of returning plant nutrients to agricultural land. In his opinion, the transportation effort of emptying urban latrines prevented this from becoming the system of choice (ZÖLLER & VON LIEBIG, 1876). Particularly, before the introduction of mineral fertiliser, the availability of plant nutrients from human excreta seems to have been of great significance. With the increased availability of nitrogen fertiliser produced by the Haber-Bosch-Technique, the use of anthropogenic nutrients became less important. At the same time, water-borne sewage systems were introduced in towns and the use of nutrients from humans became increasingly limited.

Undoubtedly, usage as a fertiliser was the most common utilisation. MORGAN (2002) described some examples of a traditional African method of recycling human waste, i.e. of planting valuable trees in old abandoned latrine pits - a method that is established in countries as far apart as Rwanda, Kenya, Malawi and India. This is a method that is often hidden from view under an intricate cover, but where this technique has been established, the trees’ growth is known to be spectacular and the fruit produced both large and delicious. Local wisdom has proven that, following given period of time, the excreta do indeed form a suitable medium in which trees can grow. It is an elegant and simple method that allows the nutrients available in human waste to be recycled to form new fruit, which is then eaten before being recycled again.

In 2006, SIJBESMA also described farmers in Drente, a region with sandy soil and low fertility in the Netherlands, bringing the night soil from the city of Groningen to manure their land. She also mentioned the known productive use of urine: In at least six Dutch cities, households collected urine to sell to the textile industry. It was then used to wash and colour wool. During the annual carnival, the inhabitants of one city are still referred to as ‘jarpissers’. The so called ‘fulling’- process in the production of cloth, converting a relatively loosely-woven fabric into a close-knit one, was carried out by soaking it in fresh clean water and fuller’s earth, and then pounding it by foot, much like treading grapes. Stale human urine was often used in this process, as it contains ammonia that breaks down the grease. Once the oils and other impurities were removed, the wool could be dyed. A pre-industrial process for dyeing with indigo, used in Europe, dissolved the indigo in stale urine. Urine reduces the water-insoluble indigo to a soluble substance, which produces a yellow-green solution. Fabric dyed in the solution turns blue after the indigo white oxidizes and returns to indigo. Synthetic urea to replace urine became available in the 1800s (WIKIPEDIA, 2007 ‘indigo’).

In ancient times, human urine was collected and used to make gunpowder. Stale urine was filtered through a barrel full of straw and allowed to continue to sour for a year or more. Water was then used to wash the resulting chemical salts from the straw. This ‘slurry’ was filtered through wood ashes and allowed to dry in the sun. Saltpetre crystals were then collected and added to brimstone and charcoal to create black powder (WIKIPEDIA, 2007 ‘human urine’).

The use of human urine as fungicide on fruit trees is described by RICHARD & CARON (1981). The authors report that it was successfully used in place of synthetic urea to control apple or pear scab *(Venturia inaequalis).*

Today, many drug tests and other clinical chemical analyses use urine to find out whether individuals are pregnant, if they are drug users, or to check hormone levels, alongside aiding testing in a range of other health related questions.

Urine is generally considered to be relatively sterile as long as people are healthy. When it leaves the body, however, the urine can pick up bacteria from the surrounding skin, which would leave it contaminated. However, according to an entry in WIKIPEDIA (2007, ’human urine’), “…it is not generally advisable to use urine to clean open wounds”. In fact, exactly this method is recommended by other sources. HÖRL (1999) not only describes the disinfecting effect of urine for cleaning wounds, or its use as eye drops, ear drops or nose drops. He further states that the oral intake of freshly voided morning urine has been recommended for many diseases such as viral or bacterial infections. Symptoms reported during the first days of oral intake of urine include vomiting, headaches, palpitations, diarrhoea or fever. Several substances in the urine are believed to be beneficial for health, including urea, uric acid, cytokines, hormones or urokinase. Local urine therapies include embrocations, compresses for local tumours, or whole body baths or foot baths in the urine. These ideas are also not new. Hippocrates (460 - 377 B.C.), namesake of the Hippocratic

Oath, was the first person in the Western world to record and teach the practice of uropoty (the drinking of urine) (PESCHEK-BÖHMER & SCHREIBER, 1998).

Recently, a further use of anthropogenic nutrients has come into focus: The production of biogas. In cases where small, decentralised sanitation systems are installed, the faeces are piped into a biogas plant and digested for gas production. This system requires a certain level of Dry Matter in the digester, which can only be realised by very low amounts of flushing water or the addition of household waste. Source-segregating vacuum toilets are suitable in order to gain a minimum content of Dry Matter for digestion. However, it must be considered that these toilets use significant amounts of additional energy for the vacuum (BACKLUND & HOLTZE, 2003). Preferably, thermophile digesters are used to ensure hygienisation. A gas production of 0.020 - 0.028 m^3 biogas per kg of human excreta is reported in the UPDATED GUIDEBOOK ON BIOGAS DEVELOPMENT (1984). The low C/N ratio of eight allows nitrogen-poor materials to be mixed and digested together with Anthropogenic Nutrients. In China, it is customary to load rice straw at the bottom of the digester in latrine waste has been discharged as a means to balance C/N ratio (FAO/CMS, 1996). The advantage of this is that the residues can still be used as fertiliser, as very few nutrients are removed during the process.

1.3. Historical Development of Water-Borne Sewer Systems

It is thought that the word ‘sewer’ is derived from the term ‘seaward’ in Old English. Early sewers in the London area were open ditches that led to the Thames River, and from there on down to the sea (‘seaward’). The use of flush toilets and water to transport wastes is an idea that dates back as far as 2800 B.C. to the Minoans and also the Chalcolithics (REYNOLDS, 1943). Despite being the ‘usual’ system of sanitation in most of Europe and Northern America today, its introduction was heavily debated in many areas. In most cities, no satisfying solution for the removal of human excreta was found for a long time. In higher income regions, faeces were transported to surrounding fields by slaves or paid carriers. In most other areas, human excreta were thrown onto the street together with other wastes. Coming into contact with faeces whilst walking on the street could hardly be avoided. Historians see this as one cause for the epidemics of the time that claimed the lives of great portions of the population (BEDER, 1990). Sanitation only became of interest when high population densities were reached. Even in Europe, it was not an issue in rural regions for a long time. Urban planners often point out that, in fact, water and sanitation represented the first public infrastructure systems and services in urban areas (JUUTI & KATKO, 2005).

But what were the drivers towards a sanitation system that used large amounts of water as a carrier? Often, the removal of rain and storm water from the cities was already necessary, and it was argued that unless the same pipes were used, an additional system would have to be installed, which was hard to justify financially. Additionally, health reasons were addressed. During the 1700s, in many areas, existing dry toilets or cesspits were considered to be unclean and the source of diseases. However, the agriculturalist WOLFF argued in 1886 that the mortality rate in Berlin actually increased after the introduction of water-borne sewers. GASPARI & WOOLF (1985) showed that in 122 cities in the US, sewage systems reduced mortality significantly, while water filtration systems had no impact. BROWN (1988) pointed out that historians credit the sanitation revolution with the decline in mortality, while the spur sanitary reform gave to municipal intervention in local economy through housing regulations and land markets, and the provision of services such as water and sewage, is less well known. In many cases, improperly managed dry sanitation systems were a cause of open questions of responsibility. The existing toilets were used by more than one family rather than being unsuitable in terms of their principle functions. TARR *et al.* (1984) wrote: “Although the actual toilet might remain a private responsibility and therefore be subject to abuse, the automatic nature of the flush toilet removed the need for individual decision making about when and how to remove sewage from the home, and the collection, carriage and disposal was necessarily a centralised, government controlled activity”. As the most modern of conveniences, flushing toilets and water-borne sewers were regarded as a more desirable device. They were relatively simple and automatic to operate and they immediately removed the offensive matter from sight and from the inside of the home. Water-carriage systems offered greater potential for control and were therefore more attractive to the authorities in many cities around the world. The visible signs of dirt and disease would be removed from the city streets once and for all, an important step in cleaning up and ordering the city environment (BEDER, 1990).

However, in 1885 a British survey found that the existence of flushing toilets did not automatically improve the hygienic situation: 90 % of houses inspected had broken or unflushable water closets, and five years later it was found that, of 3000 houses inspected, only 1 % did not have plumbing or draining defects (WOHL, 1983).

The financial aspect was recognised by a writer for the Quarterley Review in England: “Tube-drainage is therefore cheaper than cesspool-drainage, for the same reason, and in the same degree, that steam-woven calico is cheaper than hand-made lace. The filth and the finery are both costly, because they both absorb human toil; the cleanliness and the calico are alike economical, because they are alike products of steam-power” (WARD, 1850).

‘Modern’ water-borne sewer systems are a relatively new technology, which only began to spread in European cities from around the end of the 19th century, when piped water supplies and the use of flush toilets led to increased water consumption, and wastewater production. This led to streams and stagnant pools of wastewater in city streets, causing outbreaks of cholera and other diseases. To tackle this problem, sewer systems were gradually introduced. Later, when this was seen to cause serious water pollution, step–by-step mechanical wastewater treatment plants, biological treatment for the degradation of organic substances, and tertiary treatment for the removal of nutrients were added to reduce the pollution and resulting eutrophication of the receiving water bodies. These now represent the present state-of-the-art in wastewater treatment. Such wastewater treatment plants have improved the hygienic situation in a large number of urban areas, particularly in those where water is in abundant supply. Treated wastewater can be relatively harmlessly disposed of, and the costs of operation and maintenance can be assured. When built and functioning correctly, conventional water-borne sewers and treatment plants allow a relatively well-assured hydraulic transport of excreta, used water and rainwater away from urban areas. They also help to prevent the pollution of surface waters within urban areas (UNESCO/GTZ, 2006).

In Germany or Switzerland, as in many industrialised countries, the technical systems function perfectly, with very few technical failures (PAHL-WOSTL, 2005). Security is of prime importance and is guaranteed by technical means. Zurich’s water supply system has, for example, two additional security systems to provide drinking water in case of the failure of the main system (BLUM, 1995).

For a long time, sanitary reform was virtually synonymous with sewer construction. In the past, water resources management was characterised by clearly defined problems that society wanted solved. Urban water management had its origins in attempts to solve the hygienic problems within cities with new technologies. Today, environmental management needs to adopt a more integrated approach to tackle the pressing and complex problems that society faces. There is a perceived increase in the complexity of decision-making in relation to environmental issues. Science and technology have become increasingly entwined with socio-economic factors. Traditional methods and procedures have quite often proved inadequate to deal satisfactorily with socially sensitive and scientifically complex issues (JOSS & BROWNLEA, 1999).

Initially, people were encouraged to perceive water closets as being clean and sewers as being the mark of progress and civilisation. The question of what to do with the sewage once it had reached its destination and the problem of subsequent pollution at the point of discharge were considered by the authorities and the engineers to be a separate and less important question, and were not allowed to confuse the issue of how best to collect and remove the sewage. It had also been the hope of some of the early sanitary reformers that the sewage collected in sewers could be utilised on sewage farms. Edwin Chadwick, the renowned British sanitary reformer, observed that sewage in Edinburgh was in much demand by farmers and he persistently advocated the utilisation of sewage. At the time, the ‘HERALD’ newspaper warned that ”we shall not always be able to rob the soil, and give it nothing in return” (BEDER, 1990).

Today, there are reasons to question the existing sewer systems; but to some extent from a different perspective than has been applied in the past. The fact that dilution with water prevents the nutrients from being used in agriculture is becoming more important due to rising energy costs in the production of mineral fertiliser. In the case of phosphorus, the element itself is a limited non-renewable resource that needs to be recycled to ensure sustainable land management. The mix of different kinds of wastes in sewage (e.g.: urine, faeces, washing water, diluted wastes from small industries…) prevents the easy installation of waste management solutions. The fact that approx. 30 % of the total water use of households in the Western world is needed for flushing the toilet also raises the general discussion, not only in areas of scarce water supply. As in a centralised water supply system all water has drinking quality, its use as carrier for faeces and urine is questioned.

In many parts of the world, topographical or climate conditions, as well as the existing infrastructure or the cultural background, mean that the installation of water-borne central sewage systems should not be assumed. For example, this might be the case where water is a scarce resource or if the area is frequently flooded.

1.4. The 'Conventional' Use of Anthropogenic Plant Nutrients

The disposal of sewage into the sea or other water bodies was mostly applied where the topography made it possible. For some time, this was done without sufficient treatment of the waste, causing massive environmental pollution. During the 19th century, the river Seine in Paris and the river Thames in London were heavily polluted from sewage. This kind of waste disposal is still practised in many parts of the world. Alternatives needed to be found for areas that lack easy access to the sea or where massive environmental damage has occurred. One alternative is in the implementation of sewage-farms. Thereby, following pre-treatment, the sewage is applied to agricultural fields via an irrigation system. Ideally, the water is cleaned by filtration when passing through the soil, while the nutrients raise the yields in crop and forage production. This only functions properly in light and sandy soils, because a higher content of fine soil particles prevents the water from quickly passing through the soil. When sewage farming was introduced around Berlin in the 19th century, large areas were required to make it work. In 1868, WOLFF described that to clean the sewage of the 1.25 million inhabitants living in Berlin at the time, an area of 50,000 ha would be necessary. He further stated that the soils would irreversibly lose porosity during the process as a result of fine particles entering the sand from the wastewater. The crops from these areas were not attractive due to the surplus of nitrogen over other nutrients, and cattle often refused the resulting feed. An unpleasant flavour in the milk and butter from cows fed with grass from sewage farms was also reported. Today, no sewage farming is practised around Berlin. The formerly utilised fields are contaminated with heavy metals. This means a loss of 17,000 ha of agricultural land around the city, as it can no longer be used for safe crop production (METZ, 2007).

A second way of using anthropogenic nutrients from water-borne sewage systems is to apply sewage sludge on agricultural fields. Sewage sludge is a product of water-cleaning processes in sewage treatment plants. It is rich in organic matter and nutrients, mostly nitrogen and phosphorus. Sludge is lacking in other macronutrients, although lime-stabilised sludge contains significant amounts of calcium and magnesium. About a half of the micronutrients - copper, zinc and manganese - are appropriate for plants (MÄKELÄ-KURTTO, 1994). The fertilising value of sludge is lessened by the fact that its nutrient balance does not correspond to plants' nutrient needs; sludge is poor in nitrogen and rich in phosphorus. The fertilising effect of the nitrogen contained in the sludge is low but long lasting, as it is mainly organically fixed.

Organic matter usually constitutes 50 – 60 % of the Dry Matter of mechanically dried sludge, which is why the use of sludge in agriculture increases the amount of organic substances in cultivated land. Above all, sludge is beneficial in mineral soils. An increase in organic matter in the soil improves the structure and water economy of the soil and stimulates microbe activity. It also effectively binds various harmful substances, such as heavy metals, preventing their action on the soil (MÄKELÄ-KURTTO, 1994).

The heavy metal content of sewage sludge is considered by some to be the most significant restricting factor in the agricultural use of sludge. The problem is that heavy metals remain in the soil and many of them undergo biomagnification in the food chain. Of the heavy metals in sewage sludge, the most hazardous to human health are cadmium, mercury, and lead, while copper, zinc, chromium, and nickel in high concentrations are particularly poisonous to plants (LEVINEN, 1991).

Industry is the main source of heavy metals in sewage sludge. They can also pass into surface waters with rainwater and from corroded piping. Because sewage from households contains relatively low levels of heavy metals, it is sometimes considered to be a safer fertiliser. However, sludge treatment cannot decrease the amount of metals in sludge. If the amount of organic matter decreases during treatment, the metal concentration can even increase.

Today, the application of sewage sludge is not permitted in the Netherlands, Switzerland, and parts of Austria. Its use in agriculture is also not allowed in some German federal states.

Alternatively, sewage sludge can be burned in waste incineration plants or coal power stations. This is a more cost intensive means of disposal. In 2004, 52 % of the German sewage sludge was applied on agricultural fields, or was used for composting or renaturating former surface mining areas (STATISTISCHES BUNDESAMT, 2006). This number is expected to (further) decrease, as contamination limits, which must be fulfilled for this type of use, are likely to become stricter. Between 30 to 48 % of sludge is used in agriculture in the Nordic countries.

Here, the heavy metal content of sludge has notably decreased during the past 10 to 15 years. As a result of stricter discharge standards, the quality of wastewater has improved. Industry also monitors the quality of wastewater more thoroughly than before (LEVINEN, 1990).

The organic compounds that end up in wastewater treatment plants come from industry, households, and storm water; some compounds come from landfill sites and agriculture. These substances can be divided into those indicating general pollution of the environment (PAH, PCB, dioxines, organic stannic compounds, and biocides) and those indicating impurities in domestic sewage (e.g. LAS and NPE). Most organic matters bind with sludge, a process enhanced by the fat content and non-polarity of the compounds (ROGERS, 1996). During the treatment of sludge, the amount and quality of compounds can change considerably. The organic compounds in sewage sludge have not been researched to the same extent as heavy metals, and research has mainly focused on compounds that occur in high concentrations or are persistent, bioaccumulative, or poisonous. According to current knowledge, organic impurities have not been proven to cause permanent damage to microbe activity in the soil. Furthermore, no negative impact on growth has been observed, as long as the quantity of sludge applied has corresponded to the plants' nutrient needs (SMITH, 1996).

Wastewater contains several kinds of pathogens, including microbes, fungi, viruses, protozoa, and parasites. Not all pathogens are destroyed in traditional wastewater treatment; some are spread with sludge into surface waters and fields, thus causing a contamination risk for people, animals, and cultivated plants (LEHMANN & WALLIS, 1983). The contamination risk can be reduced by efficient sludge treatment methods, and rules and restrictions concerning sludge use. Composting is the best method of treatment with regard to the hygienisation of sludge, since lime-stabilisation does not act on parasite eggs, and decaying and digestion are not very efficient in destroying pathogenic organisms.

According to SMITH (1996), the health risks posed by pathogens possibly contained in sewage sludge is relatively low. The infectious dose is usually quite high and requires ingestion of the pathogens. However, the eggs of some parasitic worms can survive in the soil for years. It is possible for pasturing cattle to become infected if sludge has been spread on the field before pasturing, despite the fact that treated sludge usually contains very few viable parasite eggs (SEKLA *et al.*, 1983).

If composted sewage sludge is used, maturity must be ensured. Immature compost can have harmful effects on plants and soil ecosystems, particularly if the compost is applied before sowing, or if it is used as a growth substrate (INBAR *et al.,* 1990).

HARTMANN *et al*. (2004) observed the germination and development of tomato plants on plots where sludge was applied. He concluded that hygienising the sewage sludge with respect to weed seeds and possible potential pathogens was not successful. Sewage sludge hygiene must be carefully considered before application on agricultural fields.

1.5. Alternative Sanitation

The terms 'Alternative Sanitation', 'Ecological Sanitation' (*ECOSAN*) or 'Sustainable Sanitation' are often used interchangeably. This, however, implies that 'Alternative Sanitation' might be the only sustainable way of dealing with human excreta, which might not be true in detail as other sanitation approaches may also fulfil the principles of sustainability. The terms do not describe a specific technique but a strategic sanitation approach of dealing with "what has in the past been regarded as waste and wastewater" (SANDEC, 2002). Generally, this means an alternative way of using human excreta rather than disposing of it via water-borne sewer systems. It is the aim of this approach to integrate all aspects of sanitation, such as human waste, solid waste, Greywater and drainage, with special attention paid to sustainability. This is why a link between sanitation and agriculture does play a great role in the approach. In most cases, close loops of anthropogenic nutrients from the toilet to agricultural fields are promoted, as it is the aim of Alternative Sanitation to move away from a linear to a circular flow of nutrients. Other principles specified are: Simplicity, affordability, disease prevention and acceptability. These aspects allow the assumption that the approach is chiefly originated in development work. Also, water-consumption is often addressed in ecological sanitation, despite not being in scarce supply in most parts of in Central Europe. However, Alternative Sanitation has also been discussed in Europe lasting recent years, mainly in the Nordic countries.

One principle of the relatively new approach is to view urine, faeces and Greywater as separate components, different in terms of nutrient content, pathogens and benefits to soil and plants. This essentially means a differentiation of what is elsewhere summarised as 'waste', and it also requires the introduction of different sanitation techniques.

1.5.1. Source Separation

Different techniques have been developed to realise the mentioned principles of Alternative Sanitation in accordance to the local requirements. A rather drastic break with modern systems is that of water separation at the household level. All Alternative Sanitation systems feature a source separation, at least, of Greywater: Water from taps, showers, dishwashers and clothes-washers drain to a separate on-site filtration device. The filtered water is then typically used for outdoor irrigation. This may be especially advantageous in arid areas, where on-site storm water detention for outdoor use does not meet the evapotranspiration needs on an average annual basis. A further advantage might be seen in the relatively simple treatment of the largest proportion of household liquid waste.

Greywater does not contain significant amounts of nitrogen, allowing constructed wetlands to be used for simple water treatment. There is also very little eutrophication potential from Greywater due to its low nitrogen content. On the other hand, Greywater contains many artificial substances like washing powder, cleansing liquids, soaps and other household chemicals, which should not be spread on agricultural fields without treatment. If urine and faeces are collected separately from Greywater, this so-called ‘Blackwater’ does not contain substances other than those excreted from the human body, toilet paper and flushing water. Many see this as a vital preposition for its sustainable use on agricultural sites. Nevertheless, at the very least, basic hygienisation must be carried out if any faecal matter is used on fields. This can include storage over a long period of time, composting processes or thermal treatment to prevent pathogens entering the food chain via agricultural land. Hygienisation can also be ensured if Blackwater is treated in a biogas plant (BACKLUND & HOLTZE, 2003), or if worm composting is applied (YADAV & TARE, 2006).

Urine separation is perhaps the most radical departure, where urine is tanked on site and used as fertiliser (HANAEUS *et al.,* 1997). A precondition for this approach is the availability of a separation toilet, also known as a ‘diverting’, ‘segregating’ or ‘No-Mix®’ toilet. Initially, in the 1980’s, when Scandinavian pioneers first began promoting the advantages of urine separation and nutrient recovery, the focus was on dry sanitation systems for rural areas only. Since then, however, a number of different technical options have been developed, ranging from low cost systems, such as composting toilets, urine diverting dehydration latrines and constructed wetlands, to high-tech waterborne applications, such as vacuum sewers, anaerobic treatment, chemical processing or membrane technology, most suitable for use in densely populated urban areas all over the world (WERNER, 2004). Separation toilets do not necessarily have to be dry toilets, with which they are often associated. Several models using vacuum technology or gravity separation are commercially available in Europe. They use a small amount of water for flushing but prevent urine from being diluted. In particular, vacuum separation units enable water savings of 90 % compared to conventional flushing toilets. In fact, vacuum technology has been used for a long time on ships and aeroplanes, where the amount of water carried for flushing is an issue. In non-residential spaces like office buildings or public toilets, the installation of waterless urinals is often carried out without the aim of nutrient separation, but with the sole purpose of saving water. A selection of separation toilets can be found in Figure 2.

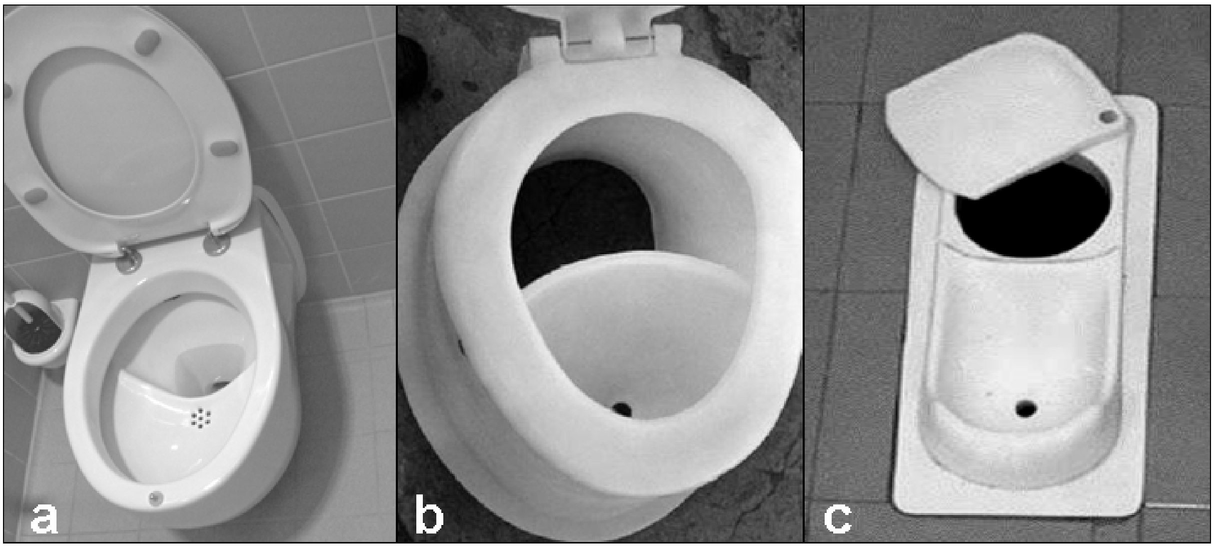


Figure 2: Separation toilets: a – water closet with porcelain bowl (ROEDIGER, Germany); b – dry toilet made of plastic (CSIR, South Africa); c – porcelain squatting pan (China, picture: GTZ)

The separate capture of faeces and urine brings considerable advantages, despite the greater technical demands. The different sanitation flows are easier to treat and recycle safely, if kept separately.

1.5.2. Source-Separated Anthropogenic Nutrients as Fertiliser

Fertilisers are compounds containing nutrients that are given to plants to promote growth. They are usually applied either via the soil, for uptake through plant roots, or by foliar feeding, for uptake through leaves. Fertilisers can be organic (composed of organic matter, e.g. carbon-based), or inorganic (containing simple, inorganic chemicals), but always contain plant nutrients. They can be naturally occurring compounds such as peat or mineral deposits, or manufactured through natural processes (such as composting), or chemical processes (such as the Haber process). Fertilisers typically provide major plant nutrients (e.g.: N, P, K,), secondary plant nutrients, and sometimes micronutrients or trace elements. Fertilisation increases crop yields only if the plant nutrient supplied is one of the most limiting growth factors. No yield increase can be expected when fertilising crops that are primarily limited by factors other than nutrient supply, e.g. lack of water, too low or high pH, etc. For maximum effect, it is important that the excreta are used in the most efficient way. This can differ according to the amount of available nutrients in relation to the available space and the fertiliser requirement per area unit (JÖNSSON *et al.*, 2004).

The fertilising effects of human excreta are reported in many older and recent publications. However, the crops, climate or soil conditions differ across the reports. Additionally, the base of comparison differs widely. In some cases, mineral fertiliser was applied simultaneously or additionally; in other cases, the yield of a certain crop is reported only after fertilising with urine or faeces. As eating habits differ among countries and regions, the ingredients of excreta vary, resulting in limited comparability. The chemical composition of human urine depends on time of day, diet, climate, physical activity, and body size. Other influencing factors are the amount of water drunk as well as whether the individual does strenuous work, which would lead to increased sweating (SULLIVAN &GRANTHAM, 1982). Some findings from the literature regarding the fertilising effects of human excreta are summarised in the following:

In 1840, Justus von Liebig described the recycling system used by soldiers living permanently in barracks in Rastatt (Germany). In a simplified calculation, assuming that bread was the only diet, he stated that, from the present 8,000 soldiers, enough plant nutrients could be collected to produce 43,760 centners (1 centner = 50 kg) of cereals – the amount needed to feed the exact same number of soldiers. He further wrote that after human excreta from the soldiers had been applied around Rastatt and Karlsruhe, the previously existing ‘sand deserts’ [Sandwüsten] were turned into ‘fields of great fertility’ (ZÖLLER & VON LIEBIG, 1876).

According to WOLGAST (1993), the annual quantity of human excreta from one person corresponds to the amount of fertiliser needed to produce 250 kg of cereals, which is also the amount of cereals that one person needs to consume per year.

HEINONEN-TANSKI *et al.* (2006) fertilised cucumber with urine from a kindergarten, a café, and from private households, collected in separation toilets in Finland. The nitrogen content of the stored urine varied from between 2.4 and 3.1 g per litre. The experiment included a mineral fertiliser treatment. However, it is not reported which kind of mineral fertiliser was used. The authors found the same or a slightly better fertilising effect if urine was used instead of 'standard' mineral fertiliser. They further stated: "The results show clearly that recently formed urine could serve as a valuable fertiliser for cucumbers, and these vegetables could be eaten without cooking or used for fermentation."

MNKENI *et al.* (2005) used diluted fresh male urine from students of the Ford Hare University in South Africa to fertilise spinach and cabbage grown in 10-litre pots. Increased dosages of urine resulted in increased yields. The experiment did not include a comparison of yields from other (e.g. mineral) fertilisers.

Urine was tested as a fertiliser on barley in Swedish field experiments from 1997 to 1999 (JOHANSSON *et al.,* 2001; RICHERT-STINTZING *et al*., 2001; RODHE *et al*., 2004). If the amount of nitrogen remaining after ammonia losses is taken into account when applying the urine, yields were about 80 – 90 % of those that resulted from the application of mineral fertiliser. Between 20 and 200 kg of N from human urine were applied in field experiments. A further finding was made: Human urine and mineral fertiliser differ in terms of nitrogen utilisation. In 1997, crops fertilised with human urine containing 98 kg of nitrogen per ha absorbed 44 % of the nitrogen input. The corresponding figure for mineral nitrogen in the same year was 61 %. The figures for 1999 were 70 % and 83 %, respectively. This indicates that crops absorb less of the nitrogen in human urine than they absorb from artificial fertiliser, and the rest remains in the soil or is emitted into the atmosphere. This nitrogen surplus is either released into the air or water by denitrification or leaching, or it is stored in the organic material of the soil.

SIMONS & CLEMENS (2004) applied acidified urine with pH 4, untreated urine with pH 8, as well as mineral fertiliser to *Lolium multiflorum* and *Trifolium pratense* in a greenhouse experiment. The plots treated with urine showed higher N removals compared to the mineral fertiliser plots. The authors suggested that urine N may substitute N from conventional mineral fertiliser. It was furthermore recommended to apply urine with slurry to increase the N content of the fertiliser. The urine used in the experiment contained relatively low contents of nitrogen (1.6 kg m^{-3} total N). Barley and ley were also treated with urine 'as mineral fertiliser' in field trials. Again, the urine in some treatments was acidified in order to reduce ammonia emissions and microbial contamination. The results from field trials showed that the fertilising effect of urine was higher than that of mineral fertiliser in the production of barley. There was no difference in yields between plots fertilised with acidified urine and untreated urine.

VON WOLFFERSDORFF (2004) reported reduced germination of grass, barley and maize after urine application, but higher yields than after mineral fertiliser addition. However, the set-up of the experiments did not ensure equal conditions in all treatments, as more space per plant was available in urine variants after the number of plants was cut following reduced germination. In the case of maize and barley, the plants did not reach maturity but were harvested early.

ARAGUNDY (2005) investigated the use of urine on a household level in Ecuador. She reported a "good growth" of fast-growing vegetables after treatment with stored urine. The experimental set-up did not allow comparisons between mineral fertiliser and urine. The "good taste" of urine-fertilised spinaches is also mentioned in the report. However, no empirical investigation was carried out concerning this.

Also PRADHAN *et al.* (2007) reported that a crop can taste different when grown with urine as fertiliser. In Finland, he spread urine (180 kg ha^{-1} N) from separation toilets on cabbage *(Brassica oleracea)* and established a better growth than after mineral fertilisation, as well as low insect infestations.

Characteristics of Source-Separated Urine

Source-separated urine contains most of the Anthropogenic Plant Nutrients in sewage but makes up less than 1 % of the total volume (Table 1).

Apart from the definition already given, fertilisers must not provide any hazard to humans or the environment. For the application of plant nutrients of an anthropogenic origin, this means that the spread of diseases must be prevented.

Tab. 1: Characteristics of the different components of liquid human waste

	Total	Greywater	Urine	Faeces
Volume [l cap^{-1} a]	25,000 - 100,000	25,000 - 100,000	500	50
Nutrients Nitrogen	4.5 kg cap^{-1} a^{-1}	3 %	87 %	10 %
Phosphorous	0.75 kg cap^{-1} a^{-1}	10 %	50 %	40 %
Potassium	1.8 kg cap^{-1} a^{-1}	34 %	54 %	12 %
CSB	30 kg cap^{-1} a^{-1}	41 %	12 %	47 %
Faecal coliforms [100 ml^{-1}]	-	10^4 - 10^6	0*	10^7 - 10^9

Source: SANDEC, 2002; * Contamination can occur after excretion or if persons are sick

However, faeces can also be used as a fertiliser but the focus is mainly on urine, as storage for at least six months is considered to be sufficient to ensure the safe use of source-separated urine (SCHÖNNING *et al.,* 2002, HÖGLUND *et al.,* 2002). In contrast, faecal matter contains high levels of naturally occurring enteric bacteria and, occasionally, disease-causing pathogens such as *Salmonella*, *Campylobacter*, *Shigella*, enteric viruses, and parasites. Studies have shown that temperatures high enough to ensure adequate hygienisation are normally not reached during faecal storage in single-household compost toilets (CARLANDER & WESTRELL, 1999).

KIRCHMANN & PETTERSSON (1995) stated that the plant availability of the nutrients in source-separated urine is high. The concentrations of different heavy metals in human urine are very low (JÖNSSON *et al.,* 1997). However, as Anthropogenic Plant Nutrients are 'natural' products, their ingredients vary as a result of eating habits, health conditions and terms of collection and storage. Besides the mentioned nutrients, the composition of fresh urine is very complex, usually containing salt, carbolic acid, tannin, pisphenol A, resorcinol, ortho-cresol, guanide, indole, myo-inositole, polyamine, benzoate, uric acid, insulin, glucagons, various hormones, and other substances. Large quantities of pharmaceutical agents or their metabolites are also found in human excreta. ESCHER *et al.* (2002) showed that the toxic effect of a mix of pharmaceuticals, each without any specific mode of toxicity (baseline toxicity), can be estimated by adding up the toxic effects of the individual substances. As mentioned, during storage, compositions may change but are difficult to predict as pH, temperature or light can all influence decomposition processes. A selection of the major components of stored urine collected in different locations is listed in Table 2. There is an obvious difference between the nitrogen content of fresh urine and of urine stored for at least six months. While fresh matter (pH 7) contains approximately 9 g l^{-1} of N (LARSEN &GUJER, 1996; CIBA-GEIGY, 1977), less than half of the concentration is found in stored source-separated urine (pH 9). It is not quite clear whether dilution occurs as a result of mixing with flushing water during collection or if chemical processes during storage change the total nitrogen content. This would mean a gaseous loss of nitrogen into the atmosphere or the fixation of nitrogen due to precipitation in pipes or tanks. However, the observation has also been made for urine collected in waterless urinals or dry toilets (MNKENI *et al.* 2005). In opposition, JÖNSSON *et al.* (2000) stated that the NH_3 loss is below 1 % in human urine collection systems with closed tanks.

Tab. 2: Composition of urine as given in different sources

Parameter	Unit	Concentration						
Source		Household S [1]	School S [1]	Workplace CH [2]	Workplace CH [3]	Household S [4]	Workplace CH [5]	Fresh urine [6], [c]
Dilution[a]	(–)	0.33	0.33	0.26	—	0.75	1	1
pH	(–)	9.0	8.9	9.0	9.0	9.1	9.1	6.2
N_{tot}	$(g_N\ m^{-3})$	1795	2610	1793	—	3631	9200	8830
$NH_4^+ + NH^3$	$(g_N\ m^{-3})$	1691	2499	1720	4347	3576	8100	463
$NO_3^- + NO_2^-$	$(g_N\ m^{-3})$	0.06	0.07	—	—	> 0.1	0	—
P_{tot}	$(g_P\ m^{-3})$	210	200	76	154	313	540	800 –2000
COD	$(g_{O2}\ m^{-3})$	—	—	1650	6000	—	10000	—
K	$(g_K\ m^{-3})$	875	1150	770	3284	1000	2200	2737
S	$(g_S\ m^{-3})$	225	175	98	273[b]	331	505[b]	1315
Na	$(g_{Na}\ m^{-3})$	982	938	837	1495	1210	2600	3450
Cl	$(g_{Cl}\ m^{-3})$	2500	2235	1400	2112	1768	3800	4970
Ca	$(g_{Ca}\ m^{-3})$	15.75	13.34	28	—	18	0	233
Mg	$(g_{Mg}\ m^{-3})$	1.63	1.50	1.0	—	11.1	0	119
Mn	$(g_{Mn}\ m^{-3})$	0	0	—	—	0.037	—	0.019
B	$(g_B\ m^{-3})$	0.435	0.440	—	—	—	—	0.97

The dilution [a] by the flushing water of the collection systems is extracted from the information given by the publications. For comparison, the urine composition of fresh urine (non hydrolysed) is listed in column [6]. Legend: [a]: defined as $V_{urine}/(V_{urine}+V_{water})$, [b]: only sulphate-S ($SO_4^{2-}$ -S), [c]: value measured in undiluted, fresh urine, without precipitation, [1]: KIRCHMANN & PETTERSON (1995); [2]: UDERT *et al.* (2003), [3]: RONDELTAP *et al.* (2003), [4]: JÖNSSON *et al.* (1997), [5]: Udert et al. (2005), [6]: CIBA-GEIGY (1977).

Source: MAURER *et al.,* 2006

During storage, the urea contained in urine is converted to ammonium (or ammonia) and carbon dioxide. As a result, stored urine contains approximately 95 % of its N in the form of NH_4^+, while nitrogen in fresh urine is bound in the form of urea ($(NH_2)_2CO$). Stored human urine is therefore closely related to mineral ammonium fertilisers (e.g. ammonium sulphate) in its basic chemical characteristics. Mineral ammonium fertilisers are rarely used in agriculture as they lead to acidification. Ammonium provides a slower N source than nitrate which, in contrast, raises the pH-value. In commercial agriculture in Europe, N fertilisers containing both ammonium and nitrate (e.g.: Calcium Ammonium Nitrate, CAN) are predominant, as their influence on the pH-value is negligible. Furthermore, the mixture of fast available nitrogen (nitrate) and a slower releasing source (ammonia) is positive as it provides N for plants at sufficient amounts over longer periods of time. Added to this is the fact that urine is a liquid and can infiltrate into the soil quickly, which gives it an advantage over granulated mineral fertilisers, which require additional water to dissolve.

1.5.3. Ammonia Emissions following Application of Urine on Fields

In recent years, environmental considerations have gained in importance, both among the public and politically. Agriculture is considered to be a significant atmospheric polluter. When air from the atmosphere passes over a manure surface, NH_3 from the surface is transported away horizontally by advection and vertically by turbulent diffusion (GÉNERMONT & CELLIER, 1997). This is called ammonia emission and is defined as the function of transfer of NH_3 to the free air phase from the air-phase in immediate contact to the ammoniacal solution. The concentration of NH_3 in air close to the manure surface is in equilibrium with the dissolved NH_3.

Ammonia emissions mean a loss of plant available nitrogen from the internal nitrogen cycle. As this should be minimised, the rate of emission plays a significant role in the context of Anthropogenic Plant Nutrient recycling. Additionally, the presence of ammonia in the environment can be hazardous.

Deposition of ammonia (and ammonium) contributes to soil and water acidification and may cause forest damage (BOUWMAN *et al.,* 1997; LEE & DOLLARD, 1994). The addition of available nitrogen (N) to low-nutrient ecosystems disturbs the competitive balance between plant species, and this can cause unwanted changes in the plant communities present. The N input can also be nitrified to nitric acid (HNO_3) leading to acidification of the soil (VAN BREMEN *et al.,* 1982; SCHULTZE *et al.,* 1989).

Eutrophication can be caused by increased nitrogen supply (in form of ammonia) to terrestrial and aquatic ecosystems (WALKER *et al.,* 2000).

Ammonia is a chemically active gas and readily combines with nitrate (NO_3^-) and sulphate (SO_4^-) in acid cloud droplets to form particulates (ASMAN *et al.,* 1998). The formation of particulates prolongs their existence in the atmosphere and therefore influences the geographic distribution of acidic depositions. The emitted NH_3 is subsequently deposited to land and water, either by dry deposition of NH_3 or by dry and wet deposition of ammonium (NH_4^+) (ASMAN & VAN JAARSVELD, 1991). The lifetime of ammonia gas in the atmosphere is relatively short - between a few hours and a few days (DENTENER & CRUTZEN, 1994; WARNECK, 1988). In contrast, the ammonium ion, as an aerosol, may have a lifetime on the order of 1 – 15 days (ANEJA *et al.,* 2000). Gaseous ammonia typically reacts with oxides of nitrogen and sulphur to form ammonium sulphate and ammonium nitrate particles.

In 1999, the UN-Convention on 'Long-range Transboundary Air Pollution' to abate acidification, eutrophication, and ground-level ozone was extended to include ammonia by the Gothenburg-Protocol. This formed the starting point for the European Union (EU) National Emission Ceilings Directive (NECD), which proposes to make the limitations on the national emissions of NH_3 legally binding.

The NECD has also proposed demanding significant reductions in NH_3 emissions from a number of European countries. On top of this, the implementation of the EU Habitat Directive (Directive 92/43/EEC) may demand additional reductions in ammonia emissions, particularly from farms that are near to low-nutrient ecosystems. It has been estimated that field-applied manure contributes about 10 % of the total emission of NH_3 in Europe (ECETOC, 1994). Economic analyses suggest that reductions in NH_3 losses from field-applied manure would be the most economically effective first step in the reduction of national NH_3 emissions (KLAASEN, 1994).

Farming is generally recognised as a major source of atmospheric ammonia, contributing 50 % of the global NH_3 emissions (SCHLESINGER & HARTLEY, 1992) and over 70 % in areas with intensive livestock farming, such as Europe (BUIJSMAN *et al.,* 1987). Furthermore, the efficiency of NH_4^+ in surface-applied animal slurry as a source of nitrogen (N) to crops can be variable, due to volatilisation of ammonia (JARVIS & PAIN, 1990).

Gaseous ammonia emissions following application of animal slurry were measured by LEICK (2003) in Germany. The author found emission rates between 11 % and 40 % of the applied N_t. Emissions were significantly reduced in cases where rainwater washed the soluble parts of the applied pig or cattle slurry into the soil during or shortly after application.

The high pH of stored urine (~ 9) promotes NH_3 volatilisation. The N loss in the form of NH_3 from animal urine during storage in uncovered tanks can be about 40 % of the total N content (KARLSSON, 1996) or even more (IVERSEN, 1947). With covered storage, the loss can be reduced by 90 % (KARLSSON, 1996). In human urine collection systems with closed tanks, the NH_3 loss is below 1 % (JÖNSSON *et al.*, 2000). However, ammonia emissions cannot totally be prevented when applying urine on fields.

RODHE *et al.* (2004) measured gaseous emissions of ammonia after application of urine on clay soil in Sweden. They found that following a spring application with trailing hoses and harrowing after four hours, the nitrogen loss as ammonia, averaged over three years, was 5 % of the applied N, irrespective of the application rate. The largest loss (10 % of the applied N) was measured after application of 60 tonnes of urine per hectare in spring. Hardly any NH_3 loss occurred after incorporation with a harrow, with the exception of the highest application rate. Loss of NH_3 was very low, close to 1 % of the applied N, when the urine was incorporated directly into the soil in spring by band application with trailing shoes. Virtually no emissions were detected when the urine was applied to the growing crop, neither by trailing hoses nor by trailing shoes.

1.5.4. Effects of Urine Application on Soil Biota

The spreading of manure or fertiliser might influence chemical as well as biological soil properties. Adding plant nutrients to an agricultural ecosystem has an effect both on crops and on the organic soil shares. The soil is considered to be the farmer productive base (DIEPENBROCK *et al.,* 2005). Soil fertility is defined as the contribution of soil to the potential yield at a specific location in an agro-ecosystem (KUNDLER, 1989). It further describes the natural and sustainable ability of a soil to enable plant growth and secure high crop yields on a long-term basis (SCHEFFER & SCHACHTSCHABEL, 1992). Over longer periods, management practices can influence and change soil fertility (BAEUMER, 1992). The chemical, physical and biological properties of a soil are defined by site-specific conditions and management practices. PANKHURST *et al.*, (2005) pointed out that addition of ‘organic waste’, as well as agricultural management practices, can affect soil biota. Changes in microbial activities and the composition of soil microbial communities can in turn influence soil fertility and plant growth by increasing nutrient availability and turnover, disease incidence or disease suppression.

Before applying organic residual materials to soil, it is essential to ensure that these materials do not pose any danger to humans, animals, or to the environment. Organic amendments to soil are of little value if these are injurious to the crop, to whatever nourishes from the crop, to the soil microbial populations, or if these amendments are not transformed to humus materials in the soil environment. Thus, it is essential to ensure the absence of undesired organic and inorganic substances (CLAPP *et al.*, 2007). However, despite being of organic origin, the carbon content of stored human urine is low. Unlike most of the other ‘organic wastes’ (plant or animal residues, manure, sewage sludge or municipal solid waste), its nitrogen fraction is largely not organically bound. This means a significant rise of the soil humus content as a direct result of the addition of organic carbon is not to be expected. Nevertheless, the humus content of soils might be influenced by decreased plant growth and decomposition after spreading of urine, as it contains plant nutrients.

The abundance of earthworms is considered to be a suitable indicator for soil fertility (GISI *et al.*, 1997). Earthworms play an important role in the turnover of organic matter in soil and in building and maintaining a good soil structure (LAVELLE, 1988). They are therefore essential for improved utilisation of added organic matter and, thus, for plant growth, especially in an extensive agricultural system that is based on nutrient release from turnover of organic matter (HANSEN & ENGELSTAD, 1999). However, earthworm populations differ widely with respect to climate, soil and management practice. It is generally accepted that the addition of organic matter raises population densities (ANDERSEN, 1979; LOFS-HOLMIN, 1983; MARSHALL, 1977; HANSEN, 1996). In opposition to this, both cattle slurry and animal urine have been found to be transiently toxic to earthworms as a result of ammonia, benzoic acid and sodium sulphide content (CURRY, 1976).

Earthworms are used as bio-indicators. The abundance of earthworms in soils represents the health of soil ecosystems and the level of environmental safety (PANKHURST *et al.*, 1997). In 1983, Edwards (OECD, 1984) introduced a standardised ecotoxicological test. It was designed to be included in the risk assessment framework for newly registered chemicals and pesticides. In effect, this turned the earthworm *Eisenia fetida* into a model organism for assessing the effects of chemicals on terrestrial saprotrophic invertebrates. With respect to a single soil organism and toxicology, in recent years, by far the highest number of publications has been written about earthworms and their reaction to certain (toxic) substances. This makes the earthworm to one of the worldwide “leading biomarkers” in soil ecotoxicology (SPURGEON *et al.,* 2003).

A further indicator for soil life is Dehydrogenase activity. Active Dehydrogenases are considered to exist in soils as integral parts of intact cells. They do not accumulate extracellulary in the soil. Dehydrogenase activity in soils provides correlative information on the biological activity and microbiological population in the soil. Therefore, measurements of the Dehydrogenase activity represent immediate metabolic activities of the soil microorganisms at the time of test. Dehydrogenases are enzymes that conduct a broad range of oxidative activities that are responsible for degradation, i.e. dehydrogenation of organic matter by transferring hydrogen and electrons from substances to acceptors (WŁODARCZYK *et al.*, 2005). Organic amendments are generally considered to raise Dehydrogenase activity (MADER *et al.*, 1999, KAUTZ *et al.,* 2004, PARHAM *et al.,* 2002).

1.6. The Acceptance of Urine as Fertiliser

The acceptance of urine as fertiliser is a precondition for the successful implementation of the Alternative Sanitation concept. Attitudes and perceptions about health hazards, and revulsion to urine, vary between cultures and generations. TANNER (1995) described that every social group has a social policy for excreting; codes of conduct that will vary with age, marital status, gender, education, class, religion, locality, employment and physical capacity. According to CROSS (1985), the human dimension is a severely neglected concern in environmental health, and yet it is 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 were widely used as fertiliser before modern sanitation systems were introduced. In East Germany, sewage from rural communities was applied to agricultural fields until the 1980’s. This may lead to the assumption that the public acceptance of this ‘natural’ fertiliser may be relatively high. In opposition to this, people may have provisos against the spreading of untreated urine on fields as a result of hygienic or merely emotional concerns. Potential aversion to the idea may result from news information about pharmaceutical residues in urine and their negative influence on fish populations.

At the present time, urine is not registered as a marketable fertiliser in Germany. By law, farmers are not allowed to spread urine on their fields. However, information about the fertilising value of urine, as well as environmental and social investigations (as given in this thesis) can provide a basis for further considerations regarding the legal status. Local farmers are seen as key stakeholders when it comes to implementing Alternative Sanitation (LIENERT *et al.*, 2003). They are directly influenced by the usefulness and hazards involved with the 'new fertiliser'. To support the farmers' decisions, information was required concerning the fertilising value of urine. No other known acceptance studies investigating the attitude of farmers towards urine-fertiliser have been carried out in Germany.

Most acceptance studies concerning Alternative Sanitation in Europe deal with the use of the toilet itself. However, for the introduction of the system, more than just the acceptance of the toilet-users would be required. A broad-based agreement from consumers is necessary, as the system would affect many people via the food cycle. However, some questionnaires included general question on how the participants find 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 fertilised with urine" (PAHL-WOSTL *at al.,* 2003).

2. Aims of this Thesis

This thesis was written to clarify specific related agricultural, environmental and social aspects concerning the use of source-separated Anthropogenic Plant Nutrients (human urine and faeces) as fertiliser. The following questions will be answered:

1. What fertilising effects do human urine and faeces have if collected in an Alternative Sanitation system?
2. Does urine spreading have an impact on soil biota?
3. To what extend is gaseous ammonia lost to the atmosphere after urine application?
4. Would the application of human urine on agricultural fields gain acceptance among farmers and consumers?

3. Materials and Methods

3.1. General

The fieldwork presented within this thesis was carried out within the scope of an EU-Life demonstration project entitled ‘Sanitation Concept for Separate Treatment’ (‘SCST’, LIFE03 ENV/D/000025). In Berlin-Stahnsdorf (13°15’24’’ E, 52°22’10’’ N) the project included the complete setting-up of a source-separating sanitation system in ten private households and in two office buildings. It was carried out from 1 January 2003 to 31 December 2006. Around 5000 litres of urine per year were collected in both gravity separation toilets in the private households and vacuum toilets at the office buildings. Waterless urinals were also installed in the offices. Tanks in the basement of a central administrative building ensured urine storage for at least six months without the addition of any fresh material. The faecal matter was composted with worms. In a late stage of the project, a biogas-plant was connected and the faeces (Brownwater) were digested with additional kitchen waste. All Greywater was treated in a constructed wetland.

3.2. Fertilising Effect

To investigate the fertilising effect of urine, it was compared with a type of mineral fertiliser that is commonly applied in Germany. The granulated mineral fertilisers used in the experiment were Calcium Ammonium Nitrate (CAN, 27 % N), Triple Superphosphate (47 % P) and Potash (40 % K). All three mineral fertilisers were mixed as found in the urine. The mixtures required slight adjustment as the contents in the urine varied. The urine was delivered from the storage tank in Stahnsdorf using a 1000-litre container. Urine from each container was analysed to find out the actual nutrient content and other characteristics. Mean results are shown in Table 3. Due to analytical reasons, the amount of ammonia and organic nitrogen is not given for the faeces compost. The amount of Kjeldahl nitrogen is given for compost only. This value contains all organically bound N and ammonia N.

Tab. 3: Characteristics of stored urine, faeces compost and Brownwater

Parameter	Stored urine	Faeces compost	Brownwater
Total N	0.40 %	0.98 - 2.73 %	0.025 %
Ammonia N	3,690 mg l^{-1}	-	160 mg l^{-1}
N org.	260 mg l^{-1}	-	91 mg l^{-1}
Kjeldahl N	-	13,600 mg kg^{-1}	-
Total P	380 mg l^{-1}	3,400 mg kg^{-1}	48 mg l^{-1}
Total K	2,000 mg l^{-1}	2,800 mg kg^{-1}	100 mg l^{-1}
Total organ. C	3,300 mg l^{-1}	21.5 % (of DM)	
Ignition loss	-	-	94.6 % (of DM)
El. conductivity	37 dS m^{-1}		

Human urine was tested on a range of crops ranging from those 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 *(Zea mays L., variety 'LUKAS')*, spring wheat *(Triticum aestivum L., variety 'TRISO')*, hemp (*Cannabis sativa L., variety 'USO 31'*) and oats *(Avena sativa L., variety 'ATEGO')*. For the field experiments, winter rye (*Secale cereale L., variety 'RASANT'*), winter oilseed rape *(Brassica napus* ssp. *oleifera, variety 'TRABANT'),* spring wheat *(Triticum aestivum L. variety, 'TRISO')* and maize *(Zea mays L., variety 'LUKAS')* were selected.

Initially, pot experiments were set up in 2004 to investigate the fertilising value of urine. Pot experiments allow controlled conditions in terms of water supply and other external influences such as 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. However, if the aim is to apply urine on agricultural fields, it must ultimately be tested under field conditions. Field experiments were carried out in 2005 and 2006.

Soil

All pot and field experiments were carried out in Berlin-Dahlem at the geographical position: 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 % sand, 25 % silt and 3 % clay. In the German soil classification scheme, the location is evaluated at around 35 points. The FAO soil classification is Albic Luvisol.

Because of its relatively high silt content, the soil tends to siltate, and forms a hard surface crust if dry periods follow after heavy rains.

Climate

Weather conditions strongly influence field experiments. Comparisons over longer periods mean that it is possible to detect the characteristics and peculiarities of a specific year. Figures 3 and 4 display monthly temperature and precipitation values as recorded in 2005 and 2006.

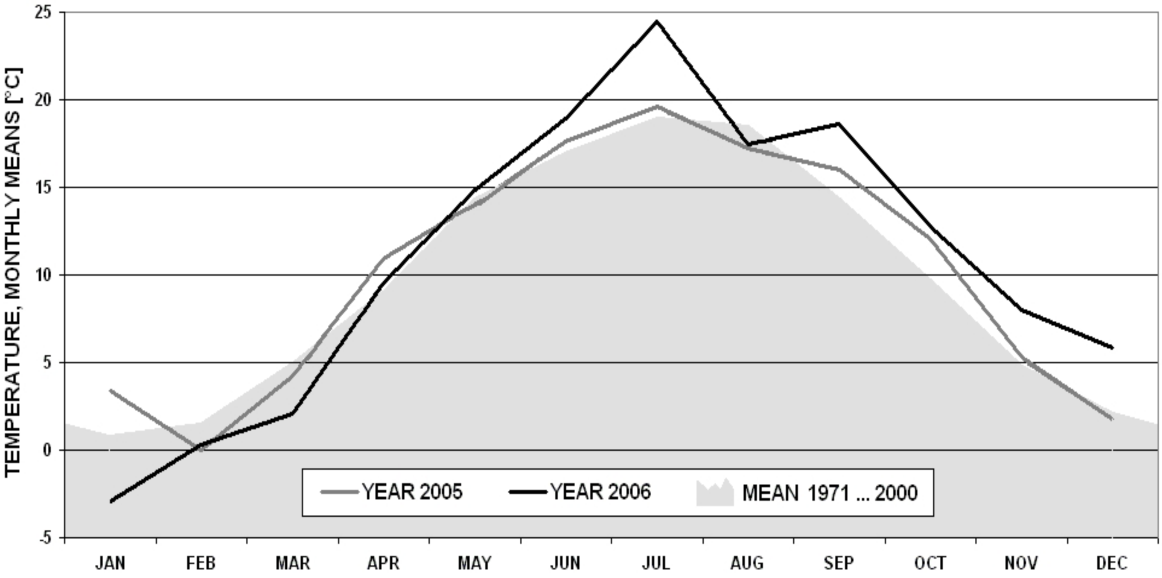


Figure 3: Monthly average temperature in 2005, 2006 and long time means

The average annual precipitation and the average annual temperature were recorded from 1971 to 2000 at 545 mm and 9.6 °C respectively.

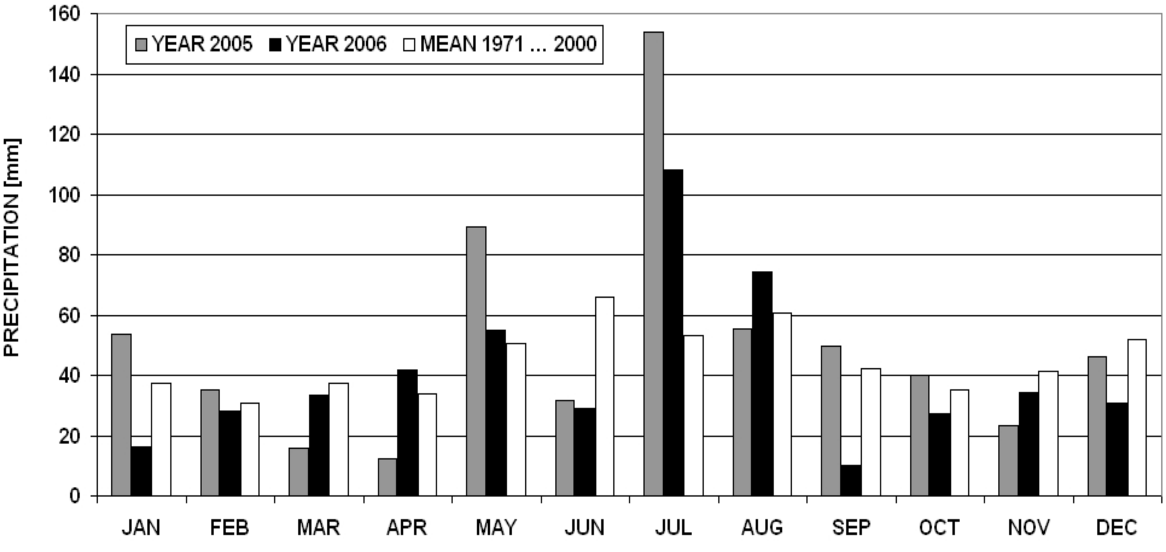


Figure 4: Monthly precipitation in 2005, 2006 and mean over 30 years

In 2005, the mean annual temperature was 10.2 °C; in 2006 it was 10.8 °C. The annual precipitation was 606 mm in 2005 and 487 mm in 2006, respectively.
Figure 5 shows the soil moisture as measured via TDR-sensor at a meteorological measuring field, which was kept free of vegetation (at 20 cm depth).

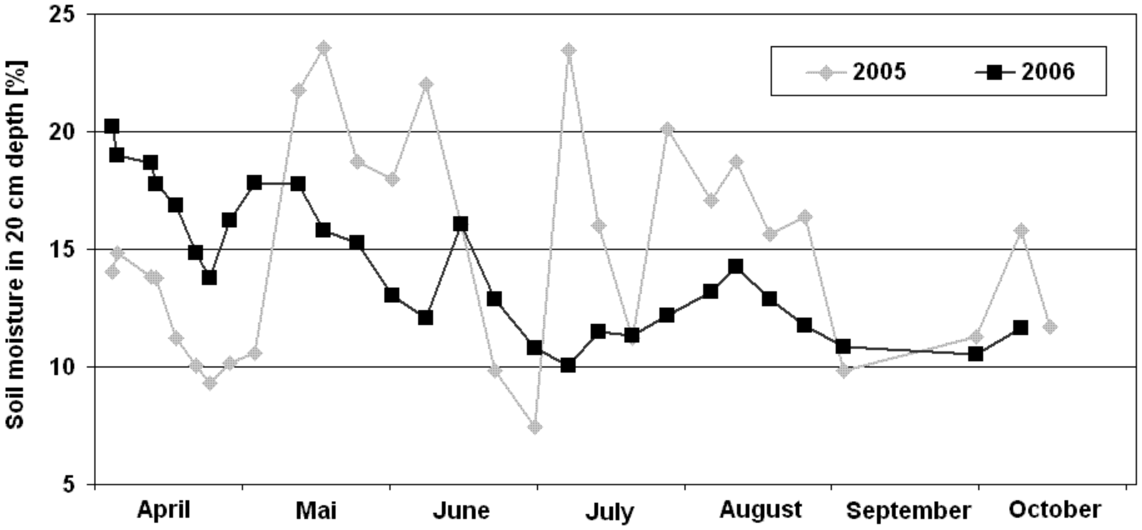


Figure 5: Soil moisture contents in 2005 and 2006 at Berlin-Dahlem (vegetation-free field)

The soil moisture in a vegetation-free field may be different than in a field where crops are grown. When referring to soil moisture contents, it must be taken into account that plant growth usually decreases soil moisture contents in the layers below the first centimetres.

Pot Experiments in 2004

Standardised ‘Mitscherlich’ experimental pots (Figure 6) were used for the experiment. They allow a filling height of 18 cm, are 20 cm in diameter, and are made from metal with an enamel coating.

Figure 6: Standardised experimental 'Mitscherlich'-type pots, planted with hemp

All pots were equal in size and shape and contained the same amount of homogenised soil (6500 g), locally extracted at Berlin-Dahlem. The pots had small openings at the bottom to allow water to run through the soil. This prevented the water content from rising above saturation. They were exposed to the weather but protected from birds. The crops were cultivated in a light and sandy soil as is typically found in Brandenburg and were provided with an optimum amount of water. Special water was used which contained almost no minerals to prevent uncontrolled nutrient intake. 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. 50 % of the urine and mineral fertiliser was incorporated into the soil while filling the pots, and the application of the remaining dosage followed the main period of growth. After the stand had been established, a decollation was carried out to give a number of ten individual plants (spring wheat, oats) or three plants, respectively (maize, hemp).

The yield per pot was established, as well as growing parameters such as plant height or leaf colour index (using an optic N-tester). These are only mentioned in the following when appropriate. Furthermore, the nutrient content in the soil before and after the experiment, as well the nutrient content of the plant matter, were analysed. However, not all of these figures will be presented in the following as not all were considered to be important. The yield was judged to be the central factor for a comparison of the fertilising effect. Further data is given for cases were the results need additional explanation.

The first series of pot experiments was carried out in 2004. It dealt with the fertilising effect of urine and included the crops spring wheat, oats, hemp and maize. Table 4 gives the amounts of nutrients applied in the treatments.

Tab. 4: Nutrients applied in pot experiment 1, carried out in 2004

Treatment	Nitrogen [mg N per pot]	Potassium [mg K per pot]	Phosphorus [mg per pot]	Amount of urine [l]
Control	0	0	0	0
1 g	1000	467.3	88.8	0.234
2 g	2000	934.6	177.6	0.467
3 g	3000	1004.9	266.4	0.701

The experiment comprised eight fertiliser treatments; four of urine and four of mineral fertiliser, in steps of 0, 1, 2, 3 g total N per pot. Including three replications, the total number of pots was 96. Randomisation was ensured by changing the arrangement of the pots once a week.

Pot Experiments in 2005

In 2005, the pot experiments dealt with the fertilising effects of faeces as well as faeces compost. Again, both substances were compared with mineral fertiliser containing ammonia and nitrate. Spring wheat and maize were used as experimental crops.

After collection of faeces in separation toilets, two kinds of use were investigated: Composting and the application of faeces, including Brownwater without any intensive pre-treatment. 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. When testing faeces with flushing water, no separation between solid and liquid matter was carried out for technical reasons. That meant the water content depended strongly on the amount of water used when flushing the toilet. A particular problem was homogenisation before analysing and fertilising. An effort was made to mixing larger contents to secure the most representative results.

Fertilising Effect of Untreated Faeces

Faeces with flushing water (Brownwater) contained only a small amount of nitrogen and more than 99 % water. To add 1 g total N to a pot, 4 l Brownwater was needed. Not all of this faeces-water mixture could be added during the setting up 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. Maize and spring wheat were used. Three plants per pot of maize and ten plants of spring wheat were established. All treatments were carried out in three replications.

Fertilising Effect of Composted Faeces

Faeces compost 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 setting up of the pots. The second share was added during the main growing stage. Compost was incorporated into the soil during the setting up of the pots. A later incorporation of a share was not thought to be possible without damaging the roots of the already developed plants.

Field Experiments

To enable easy comparability, it was decided to directly compare Anthropogenic Nutrients with the fertiliser commonly used locally. Furthermore, crops were chosen that were typical of the region of Brandenburg. In 2005, an experiment to establish the fertilising effect of urine was carried out with a hybrid variety of winter oilseed rape and winter rye, as well as with spring wheat. Maize was used for the experiment on the fertilising effect of faeces (Brownwater).

In 2006, the experiments were repeated with the same types of crops and in the same location as in 2005. However, the location of the crops was changed without changing the parcels' actual locations and distribution. In 2005, winter rye was grown on the field where oilseed rape was planted in 2005. Spring wheat followed winter rye, and the field where spring wheat had been grown was planted with oilseed rape. Table 5 presents an overview of all field experiments carried out in both years.

Tab. 5: Short summary of field experiments and their characteristics

Year	Crop	Amount of N [kg ha^{-1} N]	Type of fertiliser	Number of parcels
2005	Oilseed rape	0, 50, 100, 150	Mineral fertiliser, urine	32
2005	Winter rye	0, 50, 100, 150	Mineral fertiliser, urine	32
2005	Spring wheat	0, 50, 100, 150	Mineral fertiliser, urine	32
2005	Maize	0, 50	Mineral fertiliser, urine, Brownwater	16
2006	Oilseed rape	0, 50, 100, 150	Mineral fertiliser, urine	32
2006	Winter rye	0, 50, 100, 150	Mineral fertiliser, urine	32
2006	Spring wheat	0, 50, 100, 150	Mineral fertiliser, urine	32
2006	Maize	0, 50	Mineral fertiliser, compost of faeces	12

Brownwater (faeces and flushing water) was used on maize in 2005 and compared with CAN and urine. Due to its low nutrient and high water content, only one treatment with Brownwater could be tested. Alongside an unfertilised control, the amount of nitrogen applied in all treatments was 50 kg ha^{-1} N.

The faeces compost used in the experiment with maize was produced by vermiculture. At the Alternative Sanitation system in Berlin-Stahnsdorf, faeces were collected in special containers, thereby ensuring de-watering. Following this, pre-treatment breeded compost worms (*Eisenia fetida*) were added. The worms turned the faeces into compost within three months. Unlike the applied mineral fertiliser, the compost was incorporated into the soil shortly before the maize was planted in 2006.

In Figure 7, a photograph of the field experiment with spring wheat is shown. The parcels are recognisable by their differing plant growth after different fertiliser application rates.

Figure 7: Photograph of field experiment with spring wheat in June 2005; fertilised parcels appear darker

Soil nutrient contents were analysed before initial fertilisation was carried out at the field experiments. The results are displayed in Table 6.

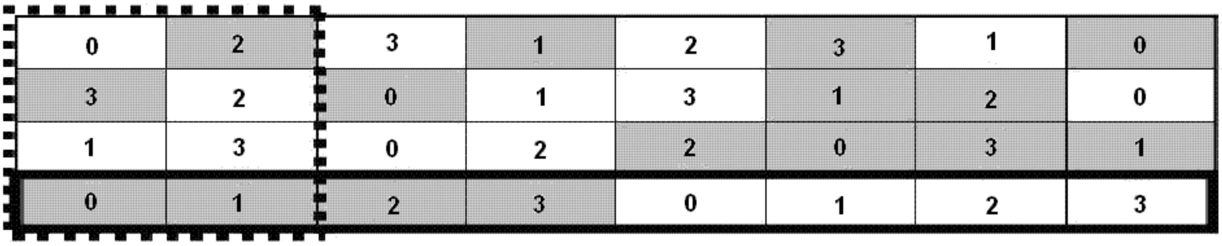
Tab. 6: Nutrient contents, carbon and pH-value of the soil before initial fertiliser application

Element	N_t	KDL	PDL	C_t	pH
Value [unit]	0.097 [%]	16.57 [mg 100 g^{-1} soil]	29.0 [mg 100 g^{-1} soil]	1.22 [%]	6.52

These soil characteristics can be used as guidelines for the soil condition before the start of the field experiments.

Experimental Design of Field Experiments

Excepting maize, each crop was cultivated over an area of approximately 600 m². The crops were divided into 32 parcels (eight treatments and four replications), arranged in a semi-Latin square or ‘modified Latin square’. Among German agronomists, this design is often referred to as ‘Lateinisches Rechteck’. However, this does not meet the international description of a Latin rectangle (PREECE, 1983). The semi-Latin square design used consisted of 4 x 8 (= 32) parcels. The eight treatments with four replications were arranged in four rows and four columns, the columns being grouped into sets, each containing two consecutive columns. Each treatment took place exactly once for each row and exactly once for each set of columns (Figure 8). The number of parcels with unfertilised controls totalled eight for each experiment, as 0 kg ha^{-1} N was included in the experimental factor 'fertiliser amount', which applied to both kinds of fertiliser. This was taken into account during statistical evaluation.



0	2	3	1	2	3	1	0
3	2	0	1	3	1	2	0
1	3	0	2	2	0	3	1
0	1	2	3	0	1	2	3

Figure 8: Randomisation of a semi-Latin square in four rows (solid line) and four blocks (dotted line); grey parcels = urine, white parcels = CAN; 0 = control; 1, 2, 3 = 50, 100, 150 kg ha^{-1} N

Every parcel extended to 6 m in length and 2 m in width. To prevent edge –effects, only a core of 5 m in length and 1.5 m in width was harvested. Each field was also surrounded by an edge of at least 2 m in width.

Plant and Soil Analyses

All plant and soil moisture contents were measured gravimetrically, if not specified otherwise (e.g. TDR). Total nitrogen content of plant matter, compost or soil material was determined using an elemental analysis (Elementar Analysensysteme GmbH, Hanau, Germany). Total phosphorus (P_{tot}) was quantified with a continuous flow analyser (LUFA A 6.2.1.2) and potassium (K_{tot}) with atomic absorption spectroscopy. Mineralised nitrogen contents (N_{min}) were measured in soil depths of 0 – 30 cm and 30 – 60 cm after VDLUFA (1991). The total N contents of the whole grain of spring wheat and winter rye were analysed using near infrared spectroscopy (NIRS).

Fertilisers Used

Beside a control, the urine and granulated mineral fertiliser were applied in steps of 50 kg, 100 kg and 150 kg of total nitrogen per hectare. The granulated 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 urine nutrient content. In each treatment, the total amount of urine or mineral fertiliser was divided in two equal halves. The first was applied when spring temperatures first allowed plant growth. The second share was spread at the main growing season, when nutrient uptake was at its peak.

From spring to harvest, the leaf colour as well as the Leaf Area Index (LAI) was measured weekly for each parcel. The nitrate, potassium and phosphorus contents 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 % DM for oilseed rape and cereals, respectively, to enable comparability. The Dry Matter (DM) yield was determined separately for the maize cobs, stems and leaves. Also, the yield structure was established by counting the plants per square meter as well as the number of pods per plant (oilseed rape only) and through measurement of the thousand seeds weight (TSW). Protein contents and falling numbers were established for the cereals as a measure of quality.

Pesticides were applied on all crops to prevent weeds, insects or fungal pathogens influencing the results. In autumn 2004, a herbicide treatment was carried out on 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, excluding maize and an insecticide was spread on the oilseed rape during a rape beetle infestation at early flowering. Please refer to appendix I for more detailed information regarding the pesticide applications. No irrigation was carried out. The oilseed rape fields, as well as the spring wheat fields, required protection from birds by a net.

Statistical Evaluation

Differences between treatments for each experiment were analysed using the SAS 8.1 statistical package (SAS Institute Inc. 1994) for two-factor designs. The pot and field experiments with composted or liquid faeces were of a single-factor design. Their evaluation was carried out using the SAS-based program “Feld-VA 2” (developed by BBA Kleinmachnow, Germany). Differences at the 5 % level of probability were considered to be statistically significant. As previously mentioned, the experiments in semi-Latin design consisted of double the number of unfertilised control parcels (eight instead of four). Despite being actually treated in exactly the same manner, during ANOVA, the parcels need to be handled as two separate variants. When results are shown, e.g. in figures, this may cause confusion. Consequently, the orthogonal core was first analysed separately and each treatment was then compared with the combined results from the controls. It was assumed that all parameters were normally distributed. The Tukey-test was applied for all statistical evaluations in pot and field experiments.

3.3. Soil-Biological Effects

Earthworm Abundance Field Investigations 2005 and 2006

In 2005 and 2006, field investigations were carried out concerning the abundance of earthworms after urine application. The experiments were meant to show whether or not urine has an effect on earthworm populations on agricultural fields. Furthermore, the enumeration in spring, and additionally in autumn after harvest, enables an assessment of the duration of an effect. Because of their function as a 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 is associated with a number of undesirable and negative effects.

The studies were carried out at the experimental field station in Berlin-Dahlem, in parallel to the fertilising field experiments described earlier. In both years, the experiments consisted of two investigations. The first took place in May, 14 days after the application of the second share of fertiliser, on a field sowed with winter rye. The second was carried out on the same parcels after harvest in October. Investigations included the following treatments: Control, 150 kg ha-1 N from mineral fertiliser (CAN) and 150 kg ha-1 N from urine. In total eight replications were placed at the four parcels of each treatment, covering a total area of 1 m² per treatment. On these 24 locations, the soil was excavated up to a depth of 20 cm. Worms and their cocoons were searched for at each replication. Four to six people carried out this highly labour-intensive work over 4 days. Excavation activities were completed within eight hours. All worms and cocoons found were identified according to their species. Furthermore, the soil moisture content at 5 - 10 cm depths and the soil temperature at 5 cm were recorded for each excavation.

First Avoidance Response Test

The first Avoidance Response Test was carried out to assess whether earthworms exhibit general reaction towards human urine. The effect of a changing impact with extended residence time of urine in soil was investigated in the experiment by confronting the animals with substrates of different age after incorporation of the urine. The standardised test (STEPHENSON *et al.*, 1998) established their behaviour, but not the harmfulness to the worms of the urine. This makes use of the fact that earthworms can respond to different substrates because of their chemical receptors (EDWARDS & BOHLEN, 1996).

Beside an unfertilised control, one treatment included soil and urine incorporated 24 hours previously. The other two treatments contained soil and urine incorporated 14 days and 28 days previously. In Table 7, an overview of all four treatments is given.

Tab. 7: Composition of the test substrates, pH-values and residence time at the first Avoidance Response Test

Treatment	Air-dry soil [g]	Urine	Water [ml]	Residence time	pH-value
1	2000	-	269	-	6.5
2	2000	103.0	166	24 hours	7.7
3	2000	103.1	166	14 days	6.3
4	2000	103.6	165	24 days	5.7

In all treatments, the locally sourced sandy soil was used and the water content was adjusted to an equal level. The wooden boxes used for the experiment are shown in Figure 9.

Figure 9: Wooden boxes used for Avoidance Response Tests, worms placed in the middle

For all treatments, the pH-values of the substrates were measured before insertion of the worms. In this test, the compost worm (*Eisenia fetida)* was used. The earthworms were placed into the box in a way that allowed them a free choice between the four substrates. The whole experiment contained four replications. 20 individuals were used in each, giving a total number of 80 earthworms. None of the animals had been in contact with urine before. The same amount of urine was used in all boxes, corresponding 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. The four replications enabled a statistical evaluation.

Second Avoidance Response Test

The second Avoidance Response Test was carried out with respect to the results of the first test, in which it was observed that human urine affects worms. This test was to investigate if single components of human urine cause the avoidance. It was assumed that either ammonia or pharmaceutical residues are responsible for the worms' avoidance. This was to be verified. The experiment included four variants: A control, a urine treatment, a treatment with ammonia, and one with pharmaceutical substances.

Again, the soil was from the same local field. 2 kg of soil per box was prepared by homogenisation, and its water content was adjusted so that it contained equal levels in all treatments before worm insertion.

In the urine treatment, 128 ml of urine were mixed into the box contents of 2 kg of soil. This amount corresponded to the highest fertiliser treatment in the field experiments. In the ammonia treatment, 2 g of 25 % ammonium hydroxide (SUPRAPUR®, MERCK) was used and diluted according to the content of ammonia in urine. In the hours that followed, it was found that the mixture did not give off the characteristic odour. This led to the assumption that a significant share of the highly concentrated ammonia had been lost as a result of NH_3-votalisation. To correct this, an additional dose of 2 g SUPRAPUR® was added to the corresponding boxes shortly before introducing the worms, whilst taking into account that a quantitative comparison was no longer possible. The scientific institute IWW in Mühlheim/Ruhr (Germany) supplied the pharmaceutical agents Ibuprofen and Bezafibrate bound with inert sea sand. They were applied according to their appearance in the used urine. Inert sea sand without pharmaceuticals was added to the other variants in the same quantities. Refer to Table 8 for an overview of the treatments. As with the first Avoidance Response Test, wooden boxes were used, but this time only 16 animals per box were inserted. With four replications, a total number of 64 individuals of the species *Aporrectodea caliginosa* were used. These were collected at local agricultural sites. All worms were weighed and selected in a way that all boxes contained an equal distribution of weight.

Tab. 8: Composition of the test substrates of the second avoidance response test

Treatment	Air-dry soil + sand [g]	Substance	Water [ml]
1	2100	-	293.4
2	2100	IBUPROFEN & BEZAFIBRAT, 60 µg of each	290.7
3	2100	2 + 2 g NH_3	292.5
4	2100	129.8 ml urine	166.3

There was a residence time of 24 hours between the mixing of the substrates and the insertion of the animals. The enumeration was carried out 48 hours after the worms had been placed into the boxes.

Dehydrogenase Activity

The Dehydrogenase activity is a measure of the soil's biological status. As such, it is also considered to be an indicator for soil fertility and quality (SCHLOTER *et al.,* 2003; MADER *et al.*, 1999; NANNIPIERI, 1994). In the experiment, which is described in the following, it was aimed to investigate the influence of human urine on soil micro biota. The investigation was carried out in spring 2006, in parallel to the earthworm field experiments with winter rye. All three mineral and urine treatments, as well as the unfertilised control, were included in the experiment. Soil samples were taken at five sampling points per parcel using a drill/corer (0 – 15 cm depth). Samples from all treatments were mixed, sieved (2 mm), homogenised and finally frozen awaiting analysis.

Dehydrogenase activity was finally established in the laboratory, applying the method described by THALMANN (1967). Soil samples of 5 g each were incubated in triplicate for 24 hours, with 2, 3, 5-triphenyltetrazolium chloride (TTC, 3 mg ml^{-1}) at pH 7.8 and 27 °C. The gained triphenylformazan (TPF) was extracted with acetone and measured photometrically at 546 nm. Dehydrogenase activity was expressed as µg TPF g^{-1} soil 24 h^{-1}.

3.4. Ammonia Emissions

Ammonia emission measurements were carried out in parallel to the field experiments in 2005 and 2006. Due to the limitations in space (parcel size) and the presence of different treatments close to each other in the same field, an open-chamber method was used. This mainly consisted of a cover chamber, which was placed on the field immediately after application, a gas concentration meter and a vacuum pump to create a flow of air (wind) inside the chamber. The emissions were calculated as the difference between the concentrations in the inlet and the outlet air, as well as the flow of air created by the electric vacuum pump. This method enables simulation of controlled conditions close to reality. However, each chamber covers only a small area and spatial variations have to be compensated for using a number of replications.

Gas Concentration Measurement

A 'Multi-Gas Monitor 1302' from INNOVA AIRTECH in Denmark was used to measure ammonia gas concentrations. This uses the photoacoustic effect, which is based on the conversion of light energy into sound energy by a gas, liquid or solid. The measurement system in Innova's photoacoustic Multi-Gas Monitor 1302 is presented in Figure 10 and is described in the following.

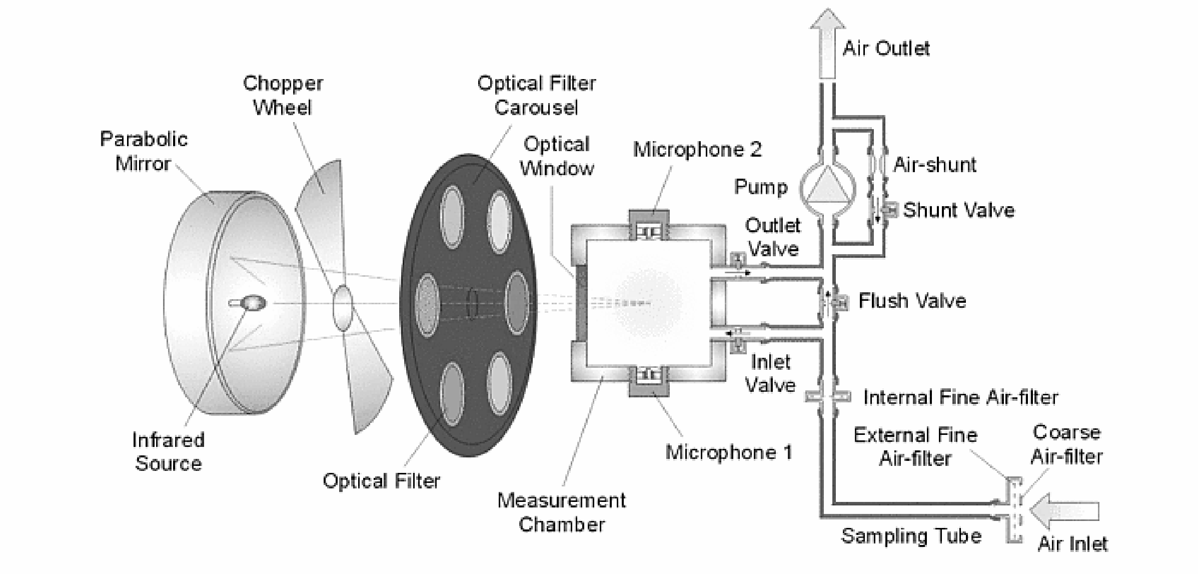


Figure 10: Photoacoustic measurement system used in field Multi-Gas Monitor 1302 (Source: Innova Air Tech, Denmark)

When a gas is irradiated with light of a frequency that corresponds to a resonant vibration frequency of the gas, some of the light will be absorbed. This will cause some of the molecules in the gas to be excited to a higher vibration energy state. These molecules will subsequently relax back to the initial vibration state through a combination of radiation and non-radiation processes. For vibration excitation, the primary relaxation process is non-radiation vibration to translation energy transfer. This results in increased heat energy of the gas molecules and, therefore, a temperature and pressure increase in the gas. If the irradiating light is modulated, then the temperature and pressure will also be modulated. The modulated pressure will result in an acoustic wave, which can be detected with a sound-measuring device, such as a microphone. The amplitude of the acoustic wave will depend upon such factors as the geometry of the gas cell, incident light intensity, absorbing gas concentration, absorption coefficient, and the background gas.

In the instrument, a heated nichrome wire is used as an infrared radiation source. The light from the source is focused using an ellipsoidal mirror, modulated with a mechanical chopper, and passed through an optical filter before entering the photoacoustic gas cell. The acoustic signal is detected with a pair of specially designed condenser microphones. The electrical signals from the microphones are amplified by pre-amplifiers mounted directly on the backside of the microphone and added together in a summation amplifier before being sent to an analogue-to-digital converter for further processing. The digitised signal is then converted to a concentration reading using the calibration factor stored in the instrument, or using a data logger.

Experimental Design

Each gas chamber, sealed at the bottom, had the air inlet at 100 cm above surface. Air was pumped constantly from the chambers via vacuum pumps during the measurements; each chamber was equipped with its own pump. Air was extracted and piped to the analyser at a location between the chamber and the pump. The ammonia concentration of incoming air was also established. At each measurement point, the concentration was reported every 10 to 15 minutes, providing a high frequency set of data. In Figure 11, the experimental design is presented. The system principally consists of four gas chambers, each connected to a flow meter and a separate vacuum pump. At the air inlet and air outlet of each chamber, a measuring point was installed, which was connected to the Multipoint Sampler and further to the Multi-Gas Analyser for establishment of gas concentration. A computer was used as a data logger.

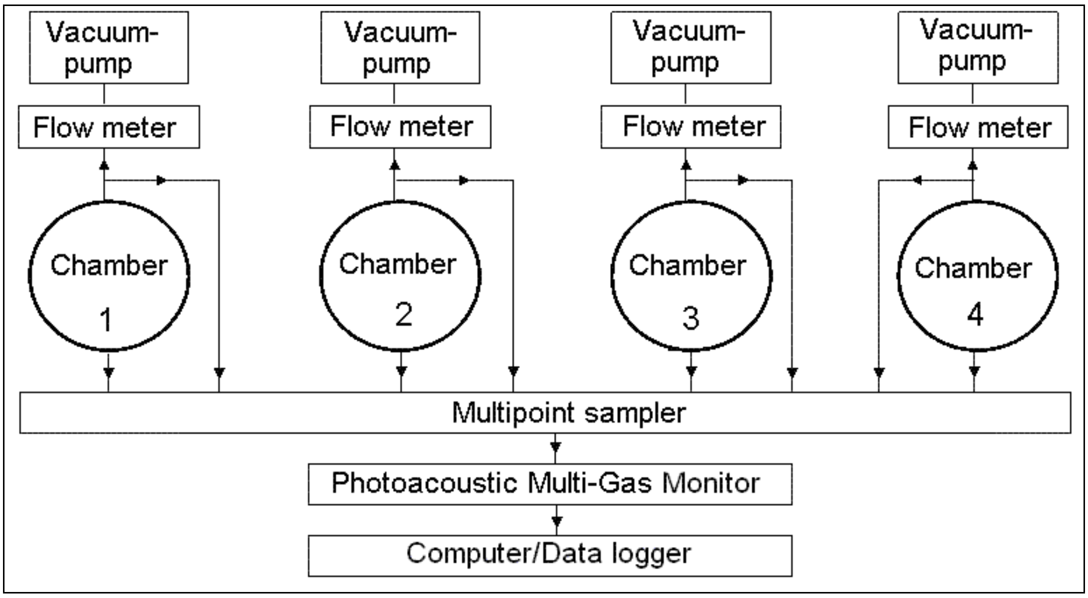


Figure 11: Ammonia emission measurement system scheme with four gas chambers

All devices used in the experiment are listed in the following:

- Multi-Gas Monitor: INNOVA 1302 (Innova Airtech Instuments A/S, Denmark), Photoacoustic infrared detection method. Accurate – compensates for temperature fluctuations, water-vapour interference and interference from other known gases
- Multipoint sampler: INNOVA 1303 (Innova Airtech Instuments A/S, Denmark), Full remote-control from a personal computer over an interface, 12 sample-input channels
- Flow meter: AALBORG ‘GFM37’, (AALBORG INSTRUMENTS & CONTROLS, INC., The Netherlands), metering range: 0 - 50 l min^{-1}
- Vacuum pumps: HARTMANN & BRAUN AG, Membran-Pump ‘2-Wisa’, 2 - 10 l min^{-1}, 230 V
- Gas chamber: Self constructed from polyethylene (PE), area covered: 0,075 m², height of the fresh air inlet over ground: 100 cm, (Figure 12)
- Flexible PTFE tubes: All of the same length (10 m) and made from PTFE; used to connect the Multipoint-Sampler and the measuring points.

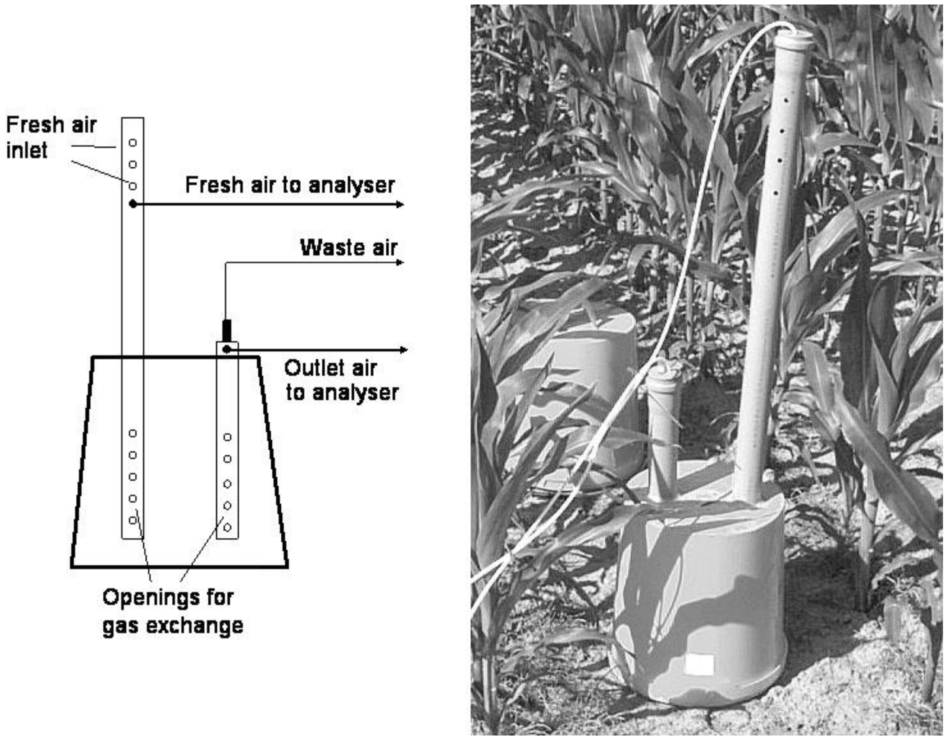


Figure 12: Gas measurement chamber: Scheme and its application between maize rows

The measurements were principally carried out in 2005 and 2006 at the fields of the aforementioned fertiliser experiments on spring wheat and maize. Grassland was also tested. Urine spreading was carried out using a standard garden watering can. This method simulates a band spreader application without incorporation of the liquid. If used on grassland, an area of 1 m² was spread for each gas chamber and the hood was placed at the centre.

3.5. Acceptance

Sustainable development implies people's opinions and perceptions have been regarded. Thus, it was part of the presented study to assess the acceptance of the use of urine as fertiliser. Two main stakeholders were identified: Farmers and consumers. Acceptance among farmers was seen as an essential precondition as they would make the direct decision whether to choose this type of fertiliser. However, their decision may also be influenced by the public acceptance. In consequence, consumer attitudes were also investigated.

The financial scope of the described project did not allow the studies to be carried out to an extent that would represent more general conditions. This means the results have to be seen in respect to the specific scope of the studies. Nevertheless, the studies were, as far as possible, kept free of distorting influences.

Acceptance among Farmers

The acceptance of urine as a fertiliser among farmers is a precondition 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 can be supplied. The system can only be introduced on a broad basis if they agree to apply urine on their fields. On the one hand, urine could be the source of an alternative fertiliser, and is likely to become even more attractive with rising energy costs and prices for mineral fertiliser. On the other hand, farmers might be concerned about their reputations if the application of urine is not supported by the general public. At present, urine is not registered as a marketable fertiliser in Germany. By law, farmers are not allowed to spread urine on their fields. This renders this study rather theoretical in character, despite it being unknown to which extent the farmers were familiar with the legal details.

When planning the study, it became clear that, with the given resources, statistical representativeness could hardly be achieved. Considering this limitation, the investigation was instead aimed to indicate motivations for the farmers' decisions. The distributions of responses will be given nevertheless; their limitations only require consideration when forming a general conclusion.

At the beginning of the study, six expert interviews with selected farmers or farm managers were carried out to identify factors that could potentially influence the farmer's decision whether or not to use urine as fertiliser. 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 buyers of urine from the city. Local governments from these areas supplied the postal addresses of 400 farmers. The possibility to answer by fax was given; however, some returns were made by post. Information regarding the gender and age of the participant, as well as farm size, management type and distance from Berlin was also requested for statistical evaluation.

The complete farmers' questionnaire (in German) is presented in appendix II.

Acceptance among Consumers

Consumer attitudes towards urine spreading on farmland are also of fundamental importance. As was the case with the farmers' acceptance study, the available resources (finance, working hours) did not allow to an investigation that could produce results representative of more general conditions to be carried out. In a pre-study, a widespread lack of information regarding the existence of Alternative Sanitation systems and source-separating toilets became obvious. People just did not take the questions seriously, because they did not consider it to be possible to separate urine and faeces in a toilet. To overcome that problem during the final study, people were interviewed in front of a life-size model of a separation toilet. Firstly, they were given an introduction to the working principles of the toilet and were then asked to answer a questionnaire regarding the use of urine on farmland. Despite being carried out in an unbiased a manner as possible, the information itself may have influenced the answers of participants. Especially when no or very little knowledge exists regarding a certain aspect, the first information they are given about it may disproportionately influence the listeners' opinion, as it is the only information they have to go on.

The investigations took place at three different exhibitions with considerably diverse types of visitors. Firstly, 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 in Berlin-Dahlem ("Lange Nacht der Wissenschaften") in May 2006. 40 more returned questionnaires were collected at a local farmers exhibition in the Brandenburg countryside ("Brandenburgische Landwirtschaftsausstellung 2006", short: "BraLa") giving a total of 175.

For the interviews, a questionnaire was developed, which was to be completed within three minutes and contained the following questions:

- What do you think of 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, or over-fertilisation?
- Would you accept food produced with urine?
- Would you prefer to buy such products in the context of sustainable agriculture?

All interviews were carried out face-to-face, but using the pre-determined questionnaire. A copy of this form is shown in appendix III.

4. Results

4.1. Fertilising Effect

In the following, the results of fertilising experiments will be presented. Special attention will be paid to yields and the fate of nitrogen, as it was considered to be the most yield-determining nutrient under the given conditions. The first pot experiments to explore the fertilising value of urine collected in separation toilets were carried out in 2004.

Pot Experiment with Urine in 2004 – Hemp

After planting directly into the tail pots (as with the other crops), hemp showed reduced germination in the urine treatments, resulting in less than the minimum number of three plants per pot. Consequently, the experiment was repeated with pre-cultivated hemp plants (height of 5 cm), which were used instead of inserting the seed into the trail pots. The development of the plants during the first week did not show any considerable differences. Figure 13 shows the DM yields of hemp as harvested in a pot experiment in 2004. The application of both kinds of fertilisers lead to increased yields. However, in the 2 g and 3 g treatments, higher amounts were harvested after mineral fertilisation (ammonium nitrate). In both cases the differences were significant.

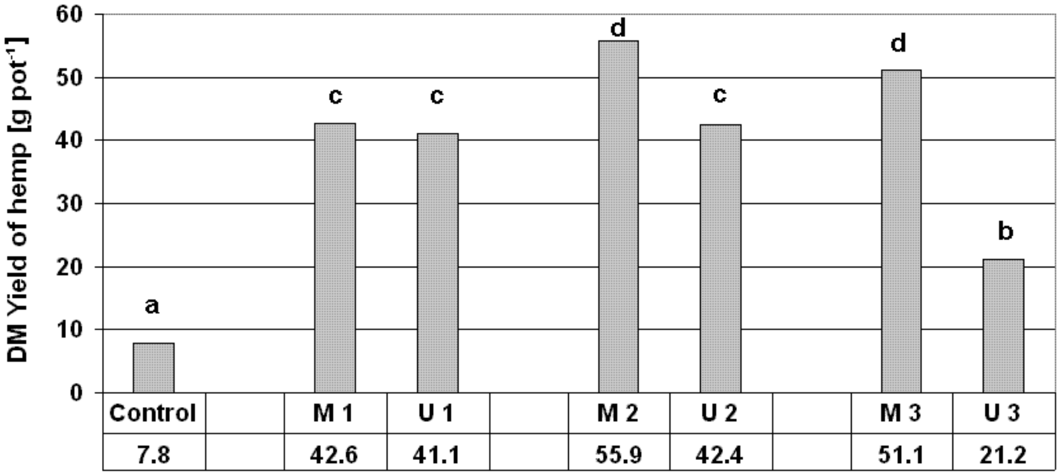


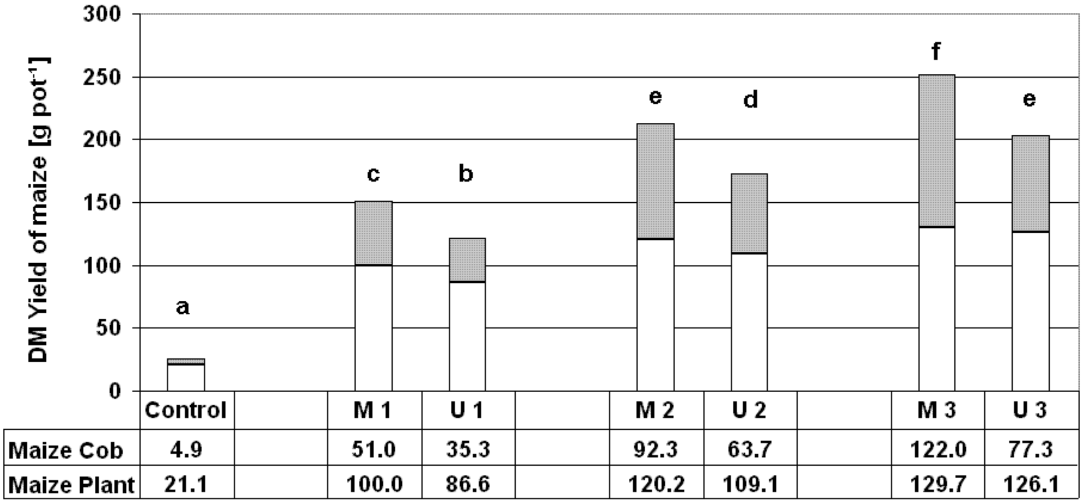
Figure 13: Dry Matter yield of hemp (plant matter above surface) after urine application, compared to ammonium nitrate in a pot experiment; different letters indicate significant difference (Tukey, $p \leq 0.05$)

No statistically different contents of total nitrogen were measured in the plant matter of hemp (not shown). Compared to all other treatments, a surplus of 1 g per pot

(6.5 kg soil) total nitrogen was found in the soil of the pots in the U 3 variants after harvest (not shown). The difference was significant.

Pot Experiment with Urine in 2004 – Maize

Significantly lower Dry Matter yields of maize were achieved after urine use in place of mineral fertilisation in the first pot experiment in 2004 (Figure 14).

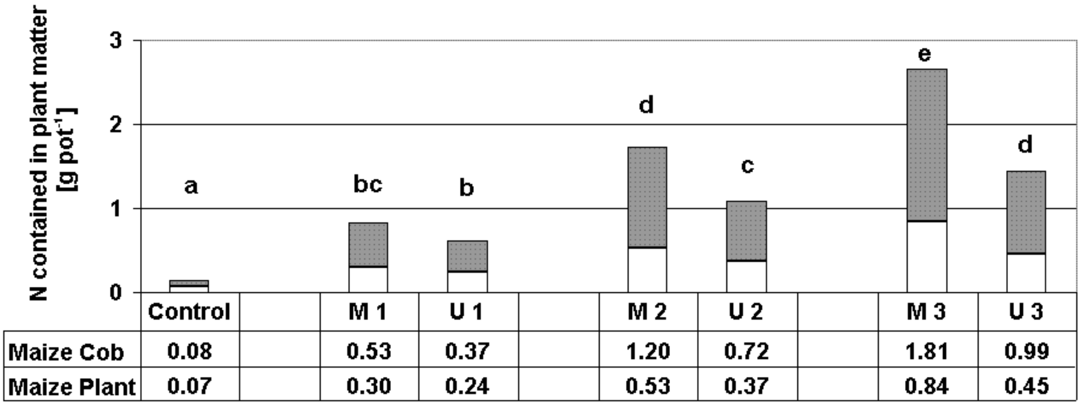


	Control		M 1	U 1		M 2	U 2		M 3	U 3
Maize Cob	4.9		51.0	35.3		92.3	63.7		122.0	77.3
Maize Plant	21.1		100.0	86.6		120.2	109.1		129.7	126.1

Figure 14: Dry Matter yield of maize after urine application, compared to ammonium nitrate in a pot experiment; different letters indicate significant difference of the quantities of cob and plant matter (Tukey, $p \leq 0.05$)

The differences were mainly caused by smaller amounts of cob matter harvested, while the DM of stems and leaves was not significantly reduced.

In Figure 15, the amounts of nitrogen that were taken up by the plants (excluding the roots), are presented. As the concentration of N in maize cobs is higher than in stems or leaves (KTBL, 2002), the differences were extended where the development of cobs was reduced.



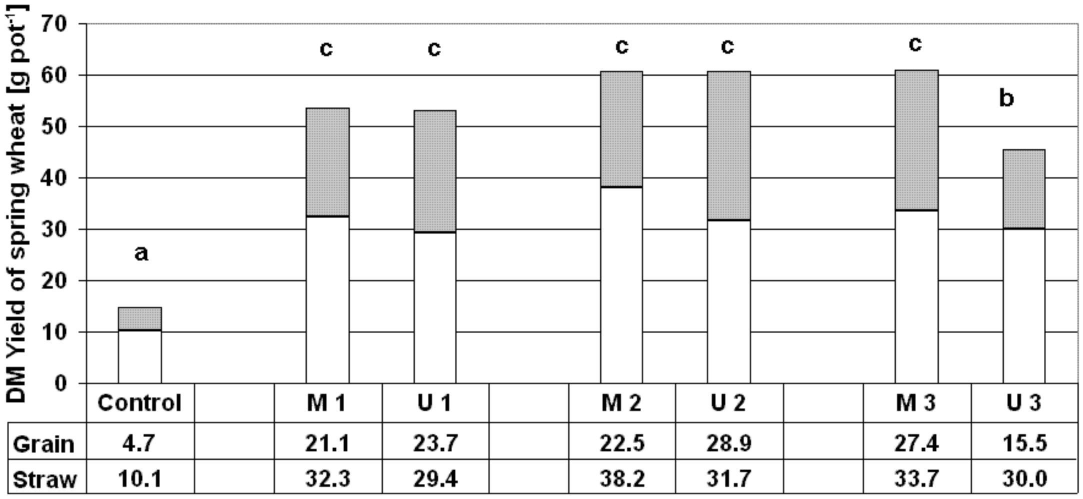
	Control		M 1	U 1		M 2	U 2		M 3	U 3
Maize Cob	0.08		0.53	0.37		1.20	0.72		1.81	0.99
Maize Plant	0.07		0.30	0.24		0.53	0.37		0.84	0.45

Figure 15: Nitrogen contained in surface plant matter after application of urine and ammonium nitrate in pot experiment with maize; different letters indicate significant difference of the quantities of cob and plant matter (Tukey, $p \leq 0.05$)

Total nitrogen contents in the soil after harvest were not significantly different within the fertilised treatments and only approximately 0.2 g N_t per pot higher than in the control. The largest difference was 0.3 g N_t per pot (not shown).

Pot Experiment with Urine in 2004 – Spring Wheat

In Figure 16, the yields of spring wheat are displayed after fertilisation with urine and mineral ammonium nitrate in a pot experiment.



	Control		M 1	U 1		M 2	U 2		M 3	U 3
Grain	4.7		21.1	23.7		22.5	28.9		27.4	15.5
Straw	10.1		32.3	29.4		38.2	31.7		33.7	30.0

Figure 16: Grain and straw yields of spring wheat after urine application compared to ammonium nitrate; different letters indicate significant difference of the total amount of Dry Matter per pot (Tukey, $p \leq 0.05$)

Generally, fertilisation caused an increase of yield. The same amount of plant matter (DM) was harvested if urine was used instead of ammonium nitrate in the 1 g and 2 g treatments. In the highest urine treatment, a significant decrease of grain yield was observed compared to all other fertilisation variants.

In Figure 17, the total amount of nitrogen as removed by wheat plants in the pot experiment is given. However, these numbers do not include the nitrogen contained in roots.

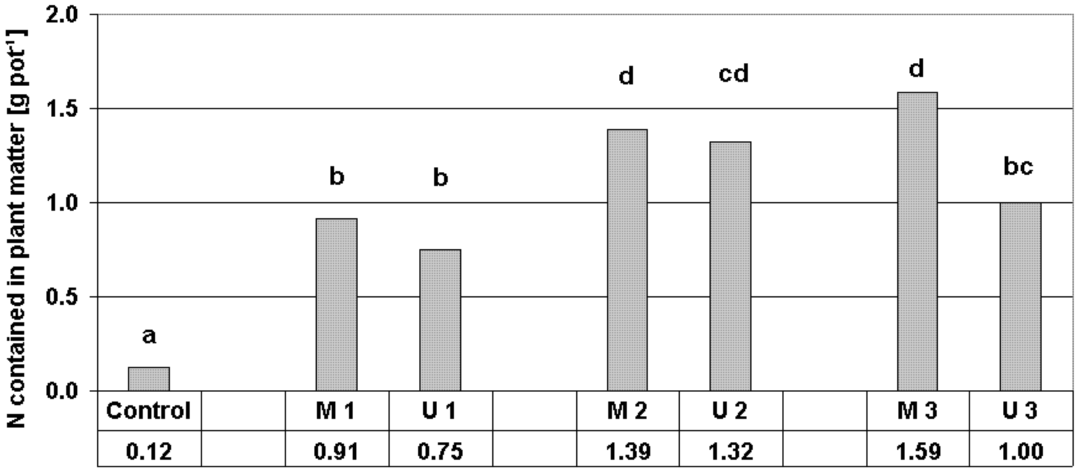
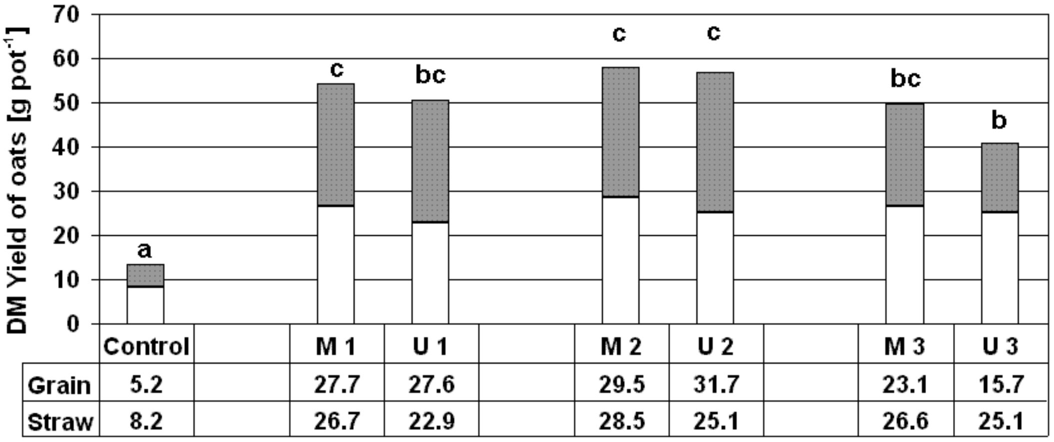


Figure 17: Total nitrogen (N_t) as contained in spring wheat after fertilising with mineral nitrogen and urine; different letters indicate significant difference (Tukey, $p \leq 0.05$)

The root matter was not separated from the soil as a consequence of the great effort this would have entailed. The plants did not take up statistically different amounts of nitrogen per pot if 1 g or 2 g nitrogen of each of the two fertilisers was applied. However, a difference occurred in the highest fertiliser application (3 g) as less total nitrogen was found in the urine treatment. The difference was mainly a result of the lower amounts of harvested matter because the N_t concentrations differed only little (not shown). Also not significant were the differences in N_t found in the soil after harvest. Compared to the control, up to 1 g per pot additional nitrogen was found in the fertilised treatments.

Pot Experiment with Urine 2004 – Oats

Figure 18 gives the DM yields of oats as achieved in a pot experiment in 2004. The figures refer to the total plant matter above surface. Fertilising generally raised both, straw and grain yields. A further yield increase did not occur between the 2 g and 3 g treatments; instead, the yield decreased.



	Control	M 1	U 1	M 2	U 2	M 3	U 3
Grain	5.2	27.7	27.6	29.5	31.7	23.1	15.7
Straw	8.2	26.7	22.9	28.5	25.1	26.6	25.1

Figure 18: Dry Matter yield of oats (whole plant above surface) after urine application, compared to ammonium nitrate; different letters indicate significant difference of the total yield (Tukey, $p \leq 0.05$)

No statistical difference was found between the yield effects of the two kinds of fertilisers. However, generally, less plant material was harvested, especially in the highest dosage urine treatment. The difference was mainly a consequence of lower grain development at the 3 g urine treatment. The straw yields of both treatments did not differ.

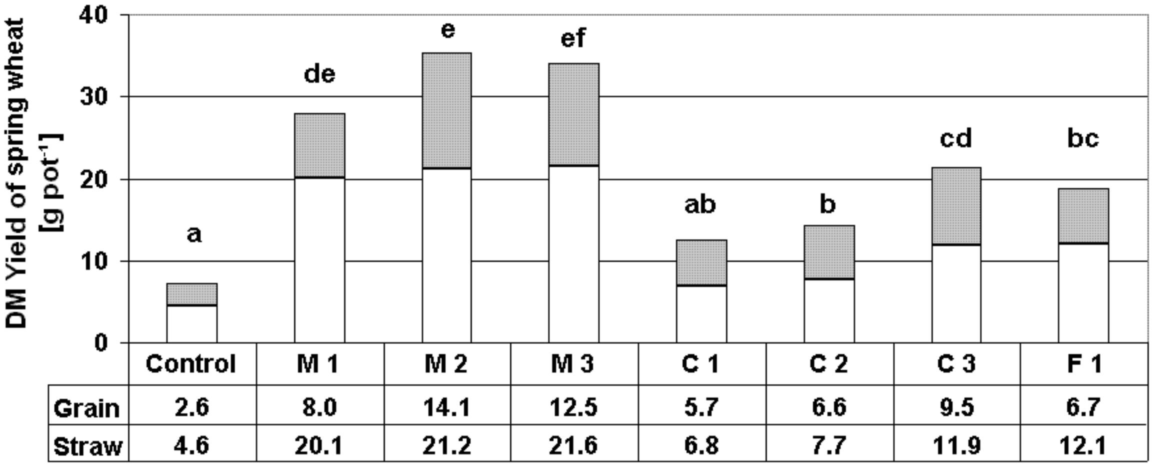
Total nitrogen contents could only be measured in oats straw because the amounts gained from grain did not suffice for analysis. No significant differences were found in the straw.

N_t in the soil after harvest did differ significantly to some extent (not shown). The highest total nitrogen contents were measured in the 3 g mineral variant, significantly more than in the 3 g urine treatment.

Pot Experiments with Faeces Compost and Faeces in 2005 – Spring Wheat

In the following, the results of the pot experiments with faeces compost and faeces (incl. flushing water) are presented. These experiments were intended to enable evaluation of the fertilising effects of the tested substances in comparison to conventional mineral fertiliser. They were carried out with spring wheat and maize in 2005.

Figure 19 shows the Dry Matter yields of spring wheat. The highest yields were attained after mineral fertilisation. In comparison, significantly lower amounts of grain and straw were harvested after the application of composted faeces.



	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 19: Grain and straw yields of spring wheat after application of mineral fertiliser (M), faeces compost (C), and faeces (F); different letters indicate significant difference of the total yield (Tukey, $p \leq 0.05$)

However, the addition of compost also led to increased yields, but to a smaller extent. The DM weights of the plants were only statistically different from the control in the 2 g (C 2) and 3 g (3 C) total nitrogen treatments. Digested faeces with 1 g total nitrogen per pot did result in yields greater that these after application of compost with the same nitrogen content, but smaller than after mineral fertilisation.

Nitrogen was extracted from the soil as a result of plant growth in relation to yields and nitrogen concentrations in the plants. The amounts of extracted nitrogen are shown in Figure 20. Differences are a result of both, higher or lower amounts harvested, as well as of different concentrations of N_t (not shown). Mineral fertilised treatments contained more nitrogen than all others. The concentration in plants from the M 3 variants was more than three times higher than after application of compost, or than in the control.

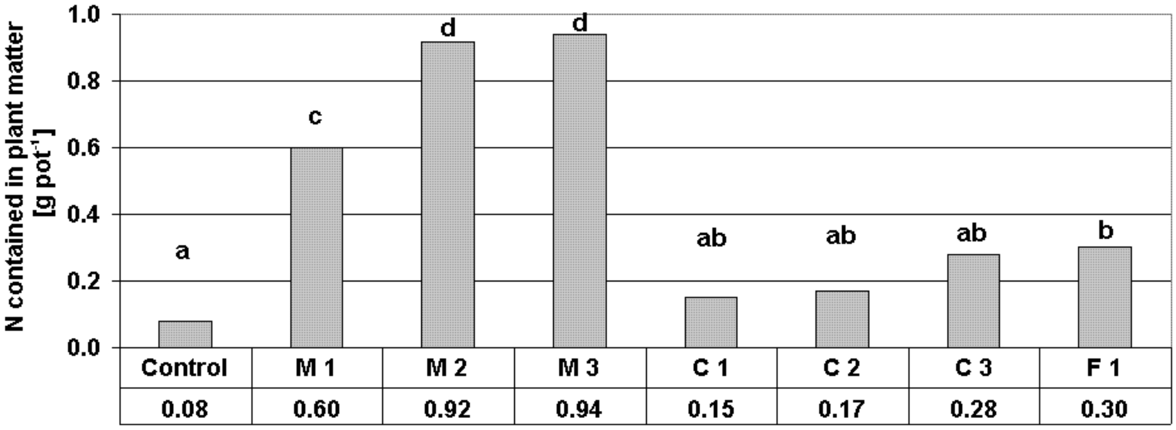


Figure 20: Nitrogen contained in spring wheat (above surface) at harvest time after application of 1 to 3 g N of mineral fertiliser (M), compost (C), and faeces (F); different letters indicate significant difference of total amounts (Tukey, $p \leq 0.05$)

Compared to the control, compost application did not result in increased nitrogen uptake. A slight increase was measured after the addition of faeces. Mineral nitrogen fertiliser resulted in a great increase of nitrogen uptake by the plants. Contrary to that, more nitrogen was found in the soil after harvest in the three compost treatments (Figure 21). In the case of compost, approximately the same amounts of nitrogen were found in the soil as had been applied before. No statistically different amounts of N were found in all other variants.

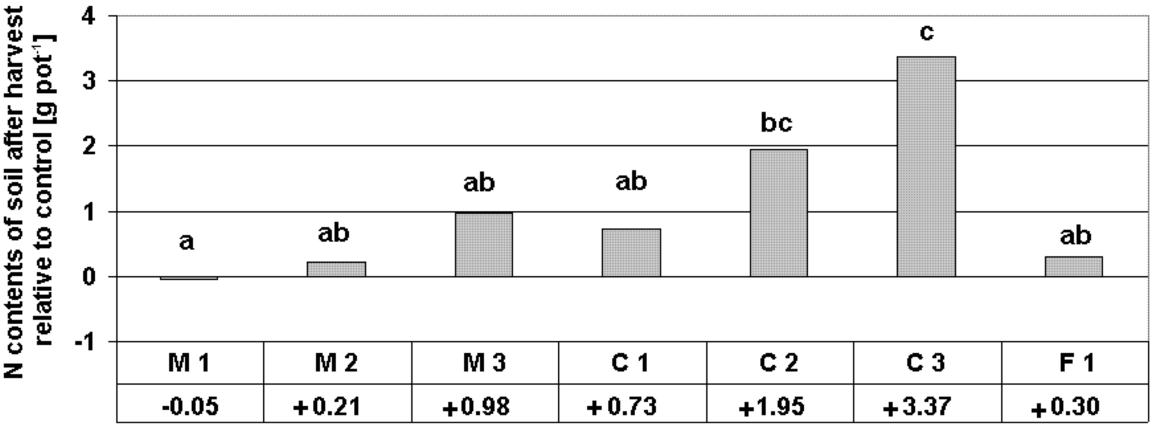
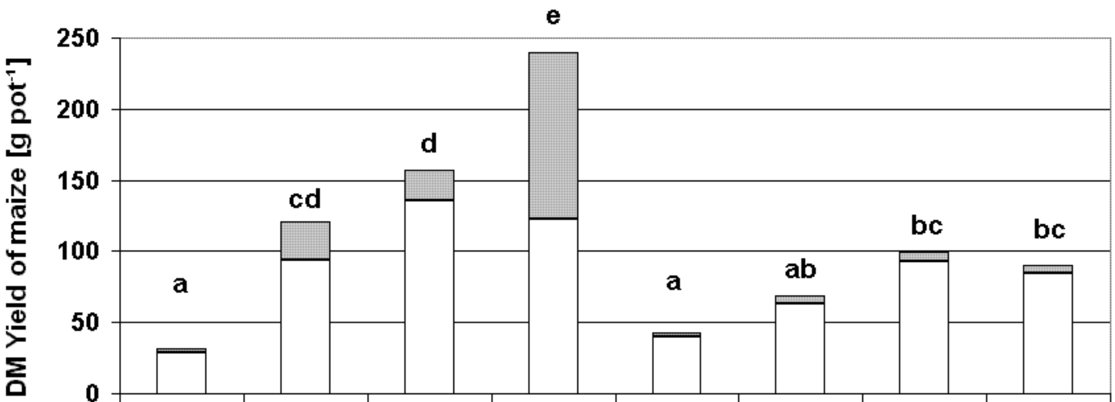


Figure 21: Nitrogen in soil per pot after harvest of spring wheat, relative to the control; different letters indicate significant difference, mineral fertiliser (M), compost (C), and faeces (F), control = a (Tukey, $p \leq 0.05$)

Pot Experiments with Faeces Compost and Faeces in 2005 – Maize

In parallel with the pot experiment with spring wheat, maize was used as an experimental plant. The results obtained are presented in the following.

In Figure 22, the Dry Matter yields of maize (cob and stem/leaves) are shown. Mineral fertilisation led to a strong increase in yield that was significantly different to the control in any of the three applications.

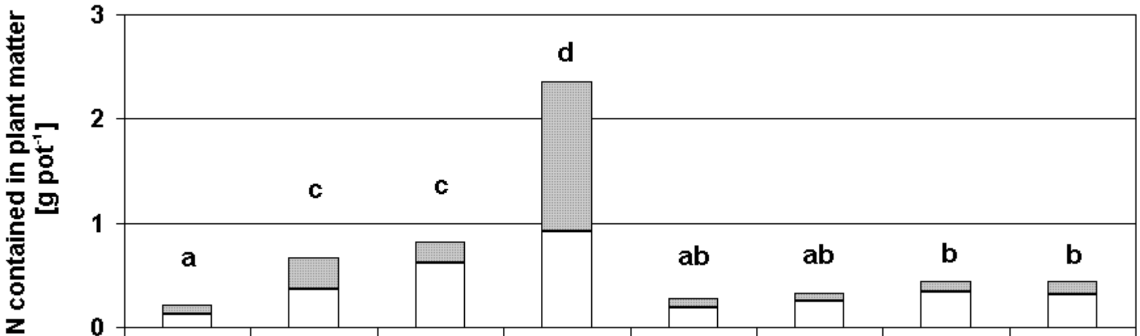


	Control	M 1	M 2	M 3	C 1	C 2	C 3	F 1
Maize Cob	3.5	26.9	21.1	116.4	3.6	6.0	6.4	5.6
Maize Plant	28.4	93.9	135.9	122.9	39.6	62.8	93.1	84.4

Figure 22: Maize yields (DM) after application of mineral fertiliser (M), faeces compost (C) and faeces (F); different letters indicate significant difference of the total yield (Tukey, $p \leq 0.05$)

Compost application did also increase yields but to a smaller extent. Only the highest dosage resulted in significantly greater yields than no fertilisation at all. Very little maize cob development was found for all variants, except for the M 3 treatment.

Figure 23 shows the nitrogen as taken up by the maize plants. In particular, the greater cob weight in the M 3 treatments led to increased N_t contents in the plants and therefore increased total uptake.



	Control	M 1	M 2	M 3	C 1	C 2	C 3	F 1
Maize Cob	0.09	0.31	0.21	1.44	0.09	0.08	0.11	0.12
Maize Plant	0.12	0.37	0.62	0.92	0.19	0.25	0.34	0.32

Figure 23: Total nitrogen contained in maize (above surface) at harvest time after application of 1, 2 and 3 g N of mineral fertiliser (M), compost (C), and faeces (F); different letters indicate significant difference of total amounts (Tukey, $p \leq 0.05$)

The addition of compost led to a slightly (overall) increased nitrogen uptake. A significantly greater amount was only taken up in the highest dosage (C 3). In contrast, when the experiment was finished, high concentrations of nitrogen were found in the soil after compost application (Figure 24).

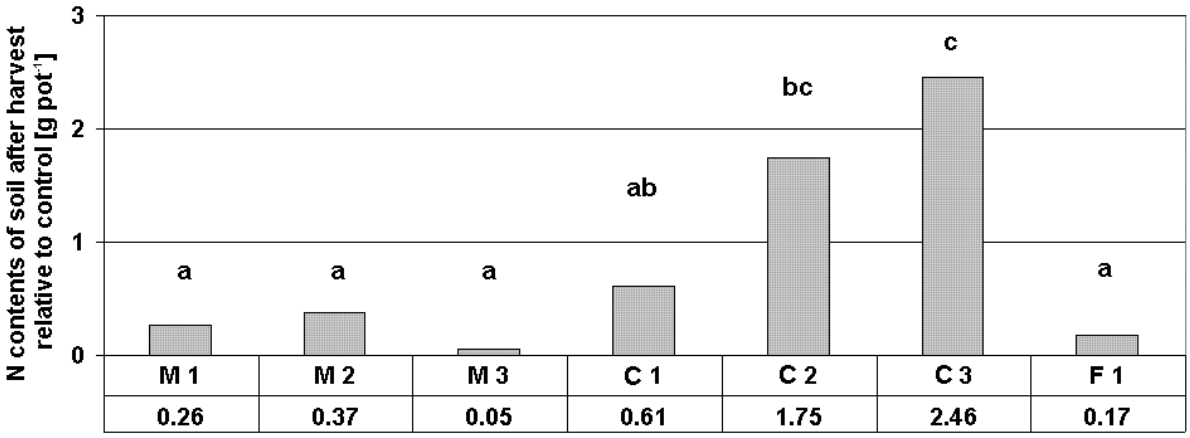


Figure 24: Total nitrogen in the soil per pot after harvest of maize relative to the control, mineral fertiliser (M), compost (C), and faeces (F); control = a; different letters indicate significant difference (Tukey, p ≤ 0.05)

In these variants, the only amounts found were a little smaller than applied. Almost no difference in N_t concentration was measured in all other treatments.

Results - Field Experiments

Field experiments were carried out in 2005 to investigate the fertilising effects of human urine. The tests with winter crops began in autumn 2004. In the following, the grain or seed yields achieved are displayed, as well as nitrogen uptake by plants and N contents in the soil after harvest.

Field Experiment with Winter Rye 2005

Figure 25 shows the grain yields (DM 86 %) harvested in the parcel experiment in 2005. The addition of both kinds of fertiliser led to a significant increase in yield.

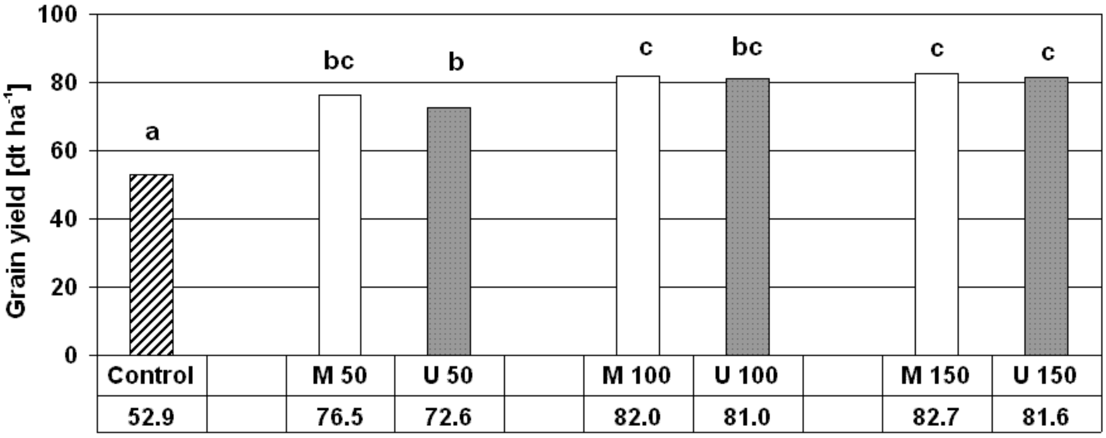


Figure 25: Grain yield of winter rye after application of CAN (M) and urine (U) in 2005, DM content: 86 %; different letters indicate significant difference (Tukey, p ≤ 0.05)

Very little difference was found between CAN and urine within the same fertiliser dosages. In no cases were the yields statistically different.

Figure 26 shows the amount of nitrogen that was taken up and incorporated into the plants. In parcels where no additional fertiliser was applied, more than 80 kg ha^{-1} N was reached. Fertilisation further increased total N amounts contained in plants per area.

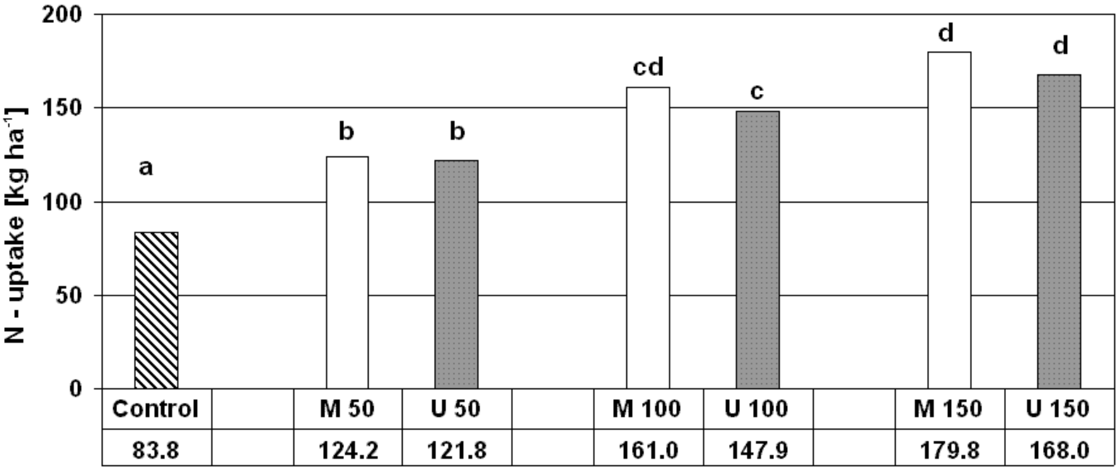


Figure 26: Nitrogen uptake of winter rye after fertilisation with CAN (M) and urine (U) in dosages of 50, 100 and 150 kg ha^{-1} N; different letters indicate significant difference (Tukey, $p \leq 0.05$)

Despite generally less nitrogen being found in the crops after urine spreading, the difference between the two fertilisers within one dosage was not statistical in any case. Mineralised nitrogen (N_{min}) was measured in the soil before fertiliser application and after harvest. At the beginning of April 2005, a mean of 8 kg ha^{-1} N_{min} was found in the topsoil layer (0 – 30 cm depth), and 10 kg ha^{-1} N_{min} at 30 – 60 cm. N_{min}-values after harvest are shown in Figure 27.

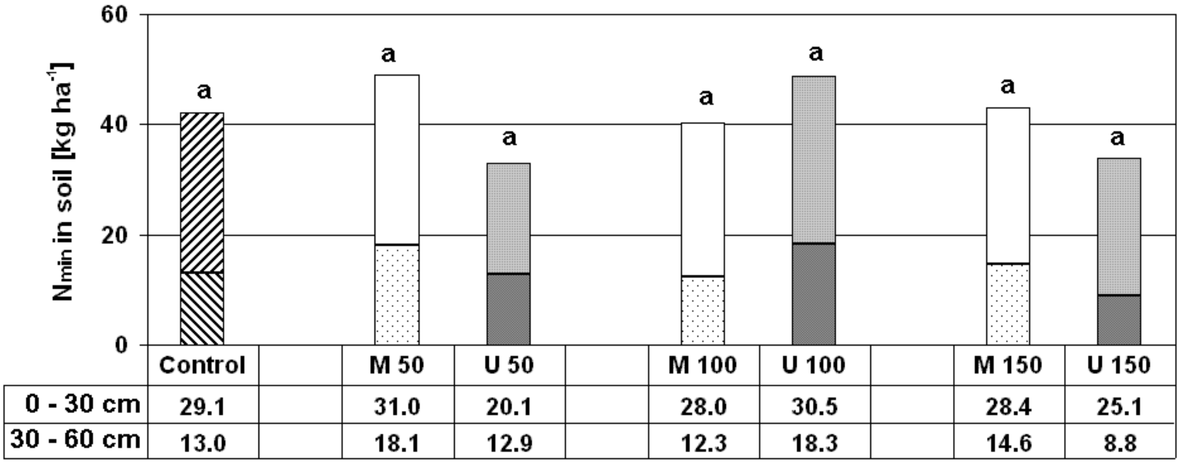


Figure 27: Mineral nitrogen contents in soil after harvest of winter rye fertilised with CAN (M) and urine (U), applications of 50, 100, and 150 kg ha^{-1} N; different letters indicate significant difference over both depths (Tukey, $p \leq 0.05$)

The numbers (at both depths) varied from 33 kg ha^{-1} to 49.1 kg ha^{-1} N_{min}, but no trend or significant difference was found between any of the treatments (Figure 27).

The total nitrogen content (N_t) was also analysed. In September, no obvious differences were found in the soil layer 0 – 30 cm. The values varied between 0.8 % and 1 % (contents of N_t in air-dried soil) without showing any trend (not shown).

Field Experiment with Winter Oilseed Rape 2005

The field experiment in 2005 also included winter oilseed rape. Its yield is displayed in Figure 28. No significant difference was found between the treatments within the same fertiliser amount, despite the control being statistically different from the fertilised variants. The greatest difference was found between the highest applications. Around 12 % less was harvested when 150 kg ha^{-1} of urine was applied instead of CAN.

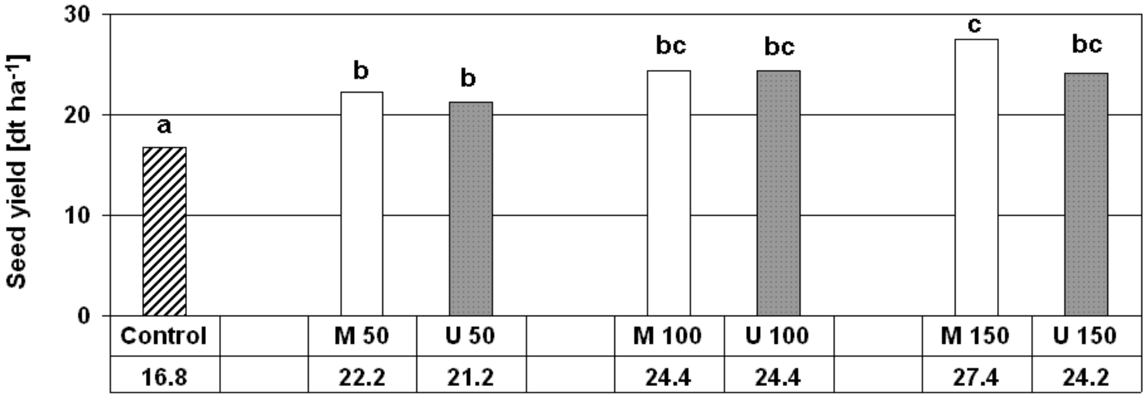
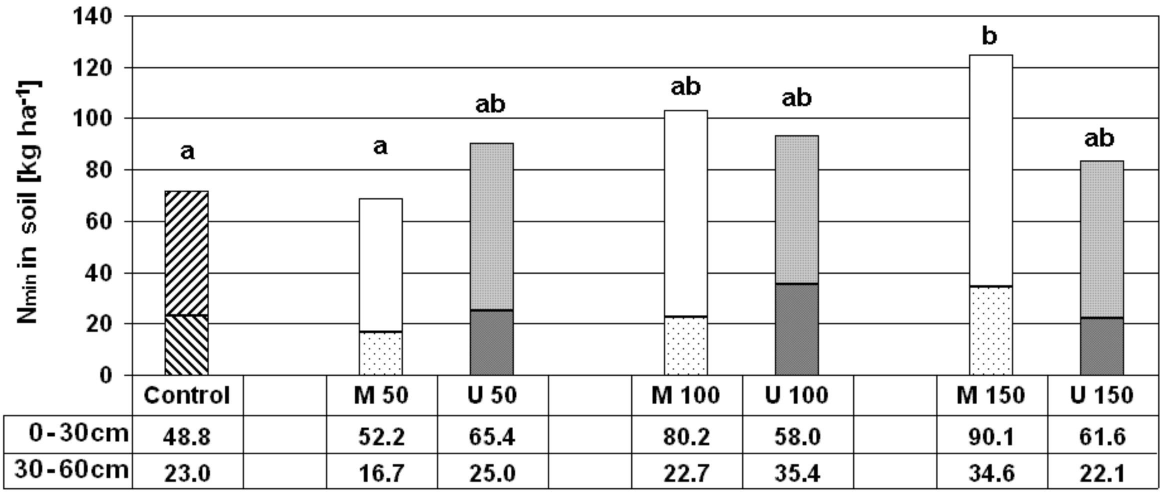


Figure 28: Seed yield of oilseed rape after application of CAN (M) and urine (U) in 2005, DM content: 91%; different letters indicate significant difference (Tukey, p ≤ 0.05)

Straw yields and plant nitrogen contents were not measured.

Very low contents of mineralised nitrogen in the soil were measured in spring. The soil contained 9 kg ha^{-1} at 0 – 30 cm and additionally 7 kg ha^{-1} at 30 – 60 cm (not shown).

N_{min} contents in September after harvest are displayed in Figure 29. Between 49 kg ha^{-1} (control) and 90 kg ha^{-1} of mineral nitrogen were found in the upper soil layer (0 – 30 cm). The variant with the highest amount (M 150) is statistically different to the control and to the M 50 treatment in both the 0 – 30 cm layer as well as in the sums of the two, but not in the 30 – 60 cm layer alone. A tendency of rising N_{min} contents with rising application rates can be assumed with CAN, but not in the case of urine.



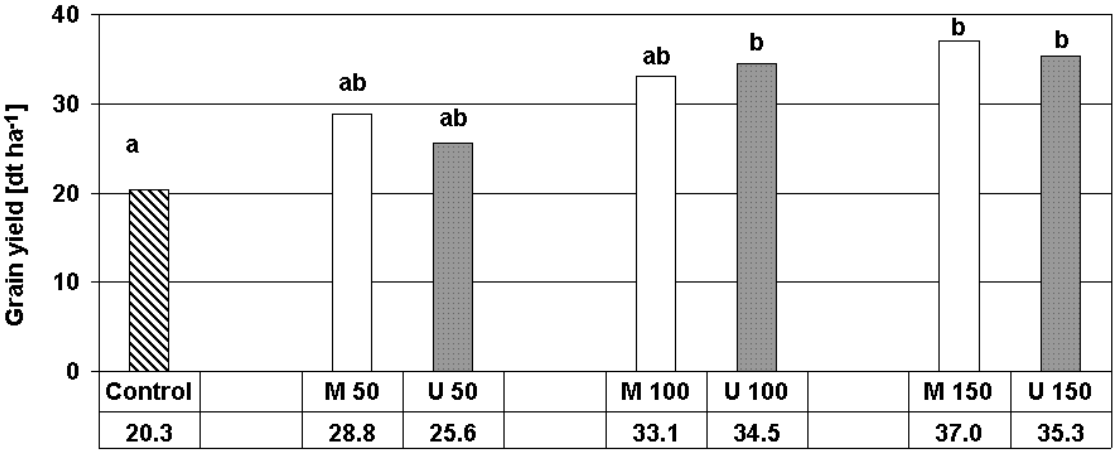
	Control		M 50	U 50		M 100	U 100		M 150	U 150
0-30cm	48.8		52.2	65.4		80.2	58.0		90.1	61.6
30-60cm	23.0		16.7	25.0		22.7	35.4		34.6	22.1

Figure 29: Mineral nitrogen contents in soil after harvest of winter oilseed rape fertilised with CAN (M) and urine (U), applications of 50, 100, and 150 kg ha^{-1} N; different letters indicate significant difference over both depths (Tukey, $p \leq 0.05$)

Total nitrogen contents (N_t) in the soil after harvest varied from 0.69 % to 0.81 % but did not show any trend or significance (not shown).

Field Experiment with Spring Wheat 2005

Beside winter rye and winter oilseed rape, spring wheat was included in the experiment to investigate the yield effect caused by urine compared to conventional mineral fertiliser (CAN). The grain yield of spring wheat is presented in Figure 30.



Control		M 50	U 50		M 100	U 100		M 150	U 150
20.3		28.8	25.6		33.1	34.5		37.0	35.3

Figure 30: Grain yield of spring wheat after application of CAN (M) and urine (U) in 2005, DM content: 86 %; different letters indicate significant difference (Tukey, $p \leq 0.05$)

Difficulties occurred close to harvest, when nets to prevent wild birds eating the grain usually cover the fields. This was a particular problem at the field experimental station Dahlem because of its location close to the centre of Berlin. On one occasion, heavy winds removed the net and partly exposed the field with spring wheat. This was not discovered for a whole day as it happened during a weekend. By the time the problem was detected, birds had drastically diminished the yields at a part of the experiment. The affected parcels needed to be excluded from the yield calculations. Fortunately, this was for single parcels per treatment only and the calculation could be carried out with three instead of four replications in these cases. However, this incident caused increased variance in the statistical evaluation of the yield. The addition of fertiliser led to an increase in spring wheat grain yield. This was at least partly significant, but no statistical difference was found between the two fertilisers within the same amount of N applied.

Figure 31 gives the amounts of N taken up by spring wheat in straw and grain. No statistical difference was found between CAN and urine, despite 9 kg ha^{-1} more nitrogen being reached after CAN application in the 50 kg ha^{-1} treatments.

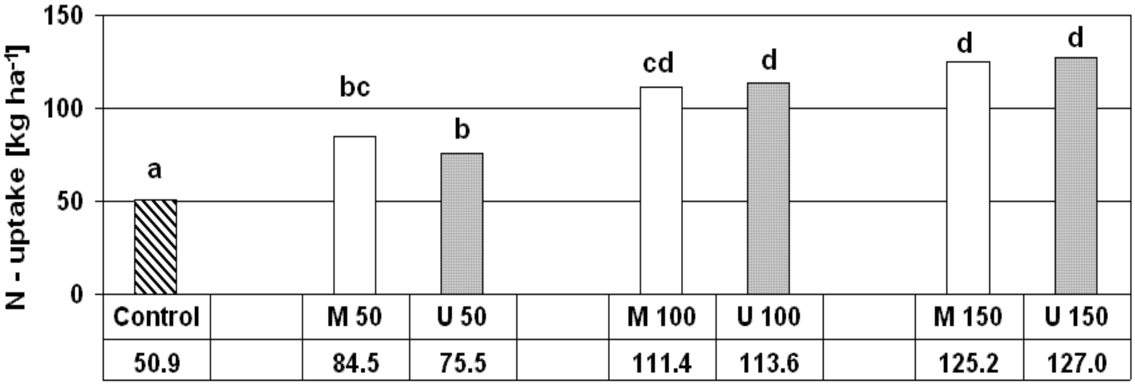


Figure 31: Nitrogen uptake of spring wheat after fertilisation with CAN (M) and urine (U) in dosages of 50, 100, and 150 kg ha^{-1} N; different letters indicate significant difference (Tukey, $p \leq 0.05$)

The mineralised nitrogen contents (N_{min}) at 0 – 60 cm depth are shown in Figure 32.

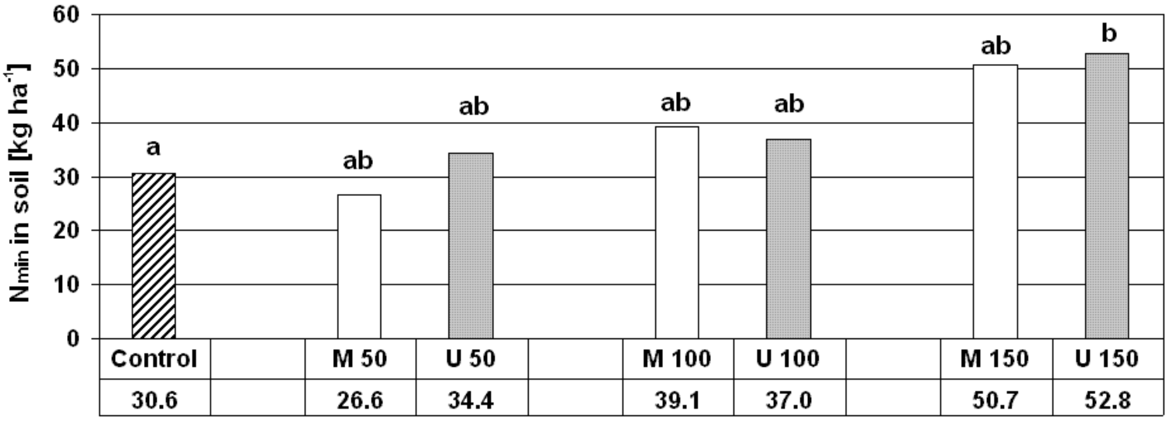


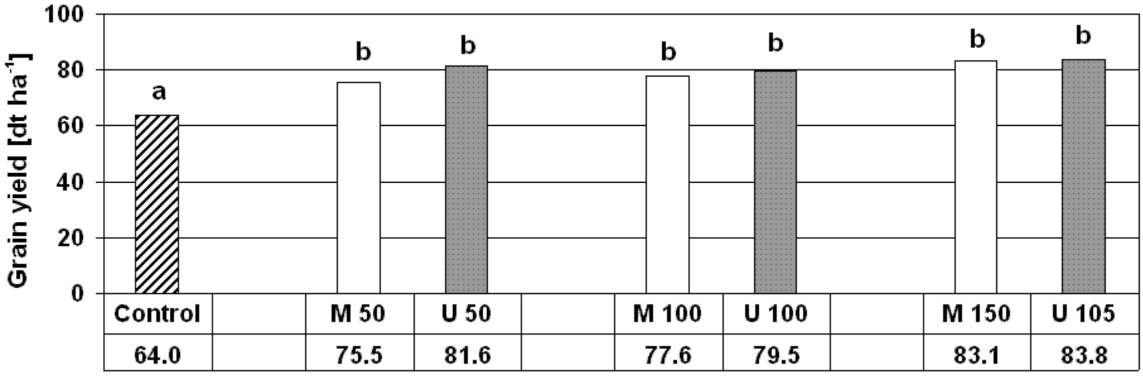
Figure 32: Mineral nitrogen contents (0 - 60 cm) in soil after harvest of spring wheat fertilised with CAN (M) and urine (U), applications of 50, 100, and 150 kg ha^{-1} N; different letters indicate significant difference (Tukey, $p \leq 0.05$)

There is an obvious tendency of rising N_{min} contents with growing application rates. However, the only significant difference was between the control and the U 150 treatment.

Field Experiment with Winter Rye 2006

In 2006, the field experiments with winter rye, winter oilseed rape and spring wheat were repeated. The results are presented in the following.

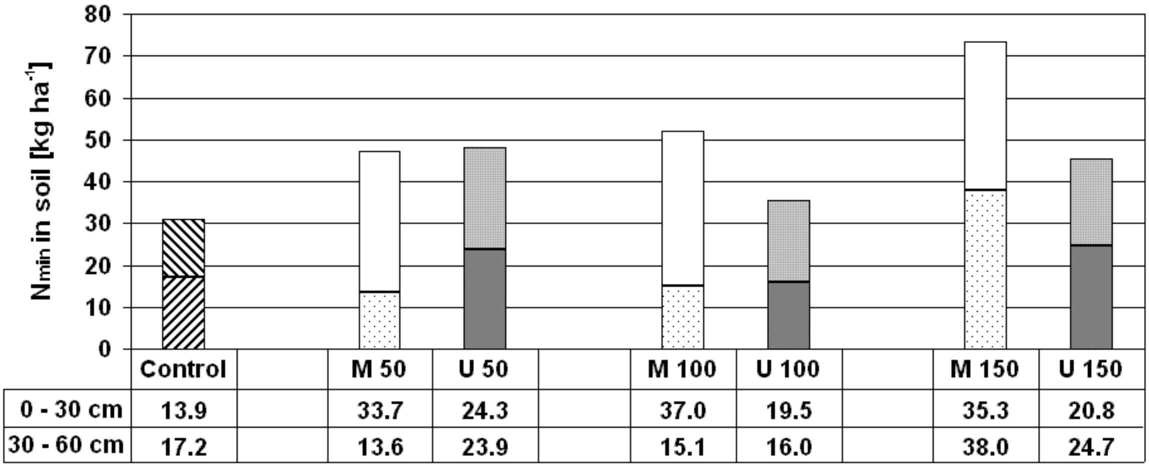
In the case of winter rye, fertilisation generally led to significantly increased yields. No difference was found between the different rates or the two types of fertilisers (Figure 33).



Control		M 50	U 50		M 100	U 100		M 150	U 105
64.0		75.5	81.6		77.6	79.5		83.1	83.8

Figure 33: Grain yield of winter rye after application of CAN (M) and urine (U) in 2006, DM content: 86 %; different letters indicate significant difference (Tukey, $p \leq 0.05$)

The relatively high yields also caused high total nitrogen uptakes by the plants. 90 kg ha^{-1} N was contained in the grain of the control. All fertilised treatments differed significantly from this, with even higher total amounts of up to 160 kg ha^{-1} in the M 150 variant (not shown). However, no clear trend or significance could be seen between the two fertilisers. Before fertiliser application, the soil N_{min} contents were measured (samples taken March 31, 2006). At a depth of up to 30 cm below surface, values between 13.9 kg ha^{-1} (control) and 37 kg ha^{-1} (M 100) were found (Figure 34).

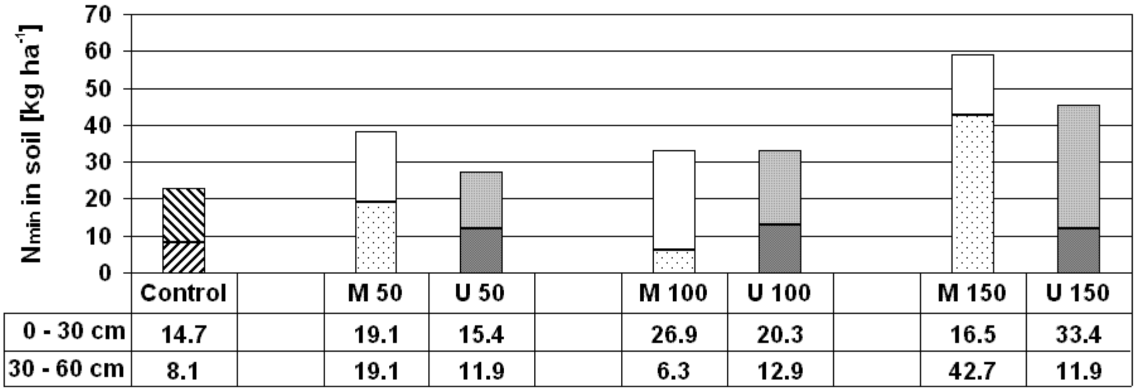


	Control		M 50	U 50		M 100	U 100		M 150	U 150
0 - 30 cm	13.9		33.7	24.3		37.0	19.5		35.3	20.8
30 - 60 cm	17.2		13.6	23.9		15.1	16.0		38.0	24.7

Figure 34: Mineral nitrogen contents in soil before fertilisation of winter rye in 2006, CAN (M), urine (U), applications of 50, 100, and 150 kg ha^{-1} N; no statistics due to mixed sampling

The soil in CAN treatments generally contained 10 – 15 kg ha^{-1} more mineralised nitrogen than with urine treatments. A statistical evaluation was not carried out due to mixed sampling. Oilseed rape was the pre-crop in 2005 at this location. After harvest of the pre-crop, the same tendency arose (refer to Figure 28). The treatments were placed at the same locations in both years and only the crops were changed. At 30 – 60 cm, no clear tendency was obvious. Approximately 17 kg ha^{-1} N$_{min}$ was measured in the control and 38 kg ha^{-1} in the M 150 treatment, which was the highest.

N$_{min}$ contents after harvest of the crop are shown in Figure 35.



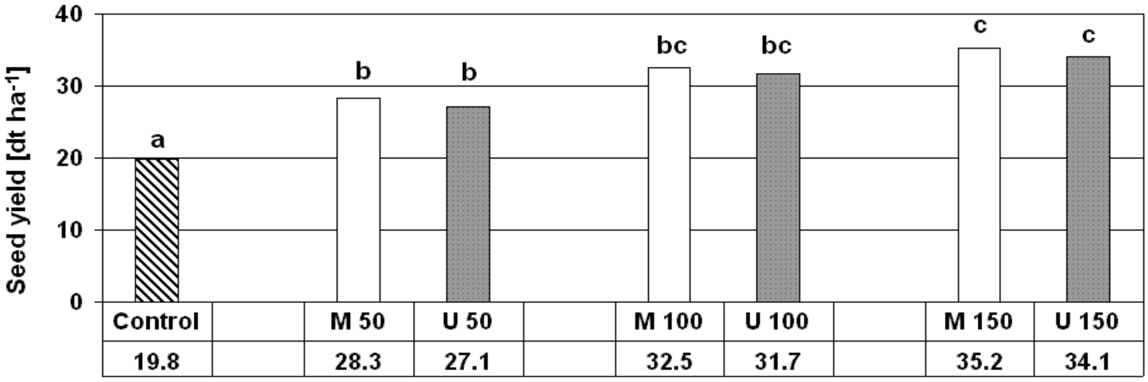
	Control		M 50	U 50		M 100	U 100		M 150	U 150
0 - 30 cm	14.7		19.1	15.4		26.9	20.3		16.5	33.4
30 - 60 cm	8.1		19.1	11.9		6.3	12.9		42.7	11.9

Figure 35: Mineral nitrogen contents in soil after harvest of winter rye in 2006, CAN (M), urine (U), applications of 50, 100, and 150 kg ha^{-1} N; no statistics due to mixed sampling

Considering the total amount up to 60 cm depth, slightly higher amounts were contained in the soil after mineral fertiliser application. This was not true for the 100 kg ha^{-1} treatments, which did not differ from each other.

Field Experiment with Winter Oilseed Rape 2006

In 2006, winter oilseed rape was grown on a field where spring wheat was the pre-crop. The locations of the parcels were not changed. Regardless, fertilisation led to a significant increase in yield (Figure 36).



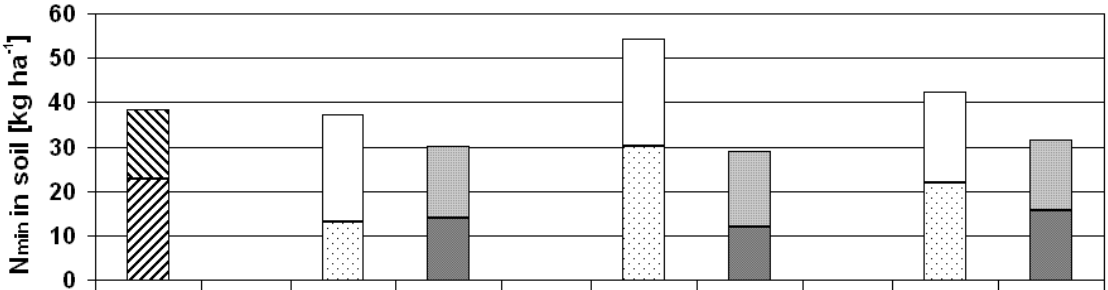
Control		M 50	U 50		M 100	U 100		M 150	U 150
19.8		28.3	27.1		32.5	31.7		35.2	34.1

Figure 36: Seed yield of oilseed rape after application of CAN (M) and urine (U) in 2006, DM content: 91 %; different letters indicate significant difference (Tukey, $p \leq 0.05$)

The effect of the two fertilisers differed very little and was in no case significant; nor was an obvious trend visible.

Values of nitrogen uptake could not be calculated as (like the previous year) straw was not collected separately and the seed was not analysed for nitrogen concentrations.

N_{min} contents of the soil before fertiliser application and after harvest are displayed in the following two figures. Firstly, the mineralised nitrogen before fertiliser spreading is shown (Figure 37).

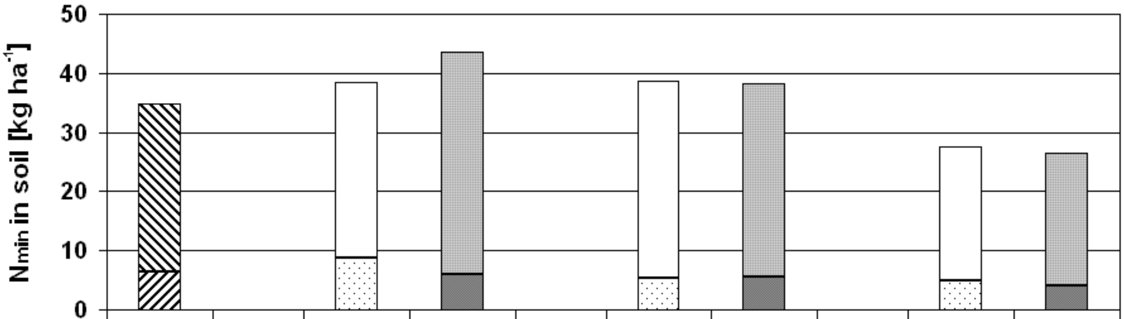


	Control		M 50	U 50		M 100	U 100		M 150	U 150
0 - 30 cm	15.4		24.2	16.3		24.1	17.0		20.6	15.8
30 - 60 cm	22.9		12.9	13.8		30.1	11.9		21.9	15.7

Figure 37: Mineral nitrogen contents in soil before fertilisation of winter oilseed rape in 2006, CAN (M), urine (U), applications of 50, 100, and 150 kg ha^{-1} N; no statistics due to mixed sampling

In particular at a depth up to 30 cm, in the urine treatments, N_{min} contents were at the level of the control. Slightly higher amounts were found in the mineral fertiliser treatments. It cannot be stated whether these differences are significant. Also in the deeper layer, more mineralised nitrogen was available in the CAN variants, except for the 50 kg ha^{-1} N rate.

The following figure presents the N_{min} contents after harvest (Figure 38).



	Control		M 50	U 50		M 100	U 100		M 150	U 150
0 - 30 cm	28.4		29.8	37.6		33.3	32.8		22.8	22.4
30 - 60 cm	6.4		8.7	6.0		5.4	5.5		4.8	4.1

Figure 38: Mineral nitrogen contents in soil after harvest of winter oilseed rape in 2006, CAN (M), urine (U), applications of 50, 100, and 150 kg ha^{-1} N; no statistics due to mixed sampling

The autumn values appeared to be much more balanced (Figure 38). In the soil of the lower two application rates (50 + 100 kg ha^{-1} N), approximately the same amounts of mineralised nitrogen were found as in the control. In the M 150 and

U 150 parcels, slightly lower values were measured. No difference was obvious between CAN and human urine.

Field Experiment with Spring Wheat in 2006

In 2006, spring wheat was grown after winter rye. The yield results are displayed in Figure 39.

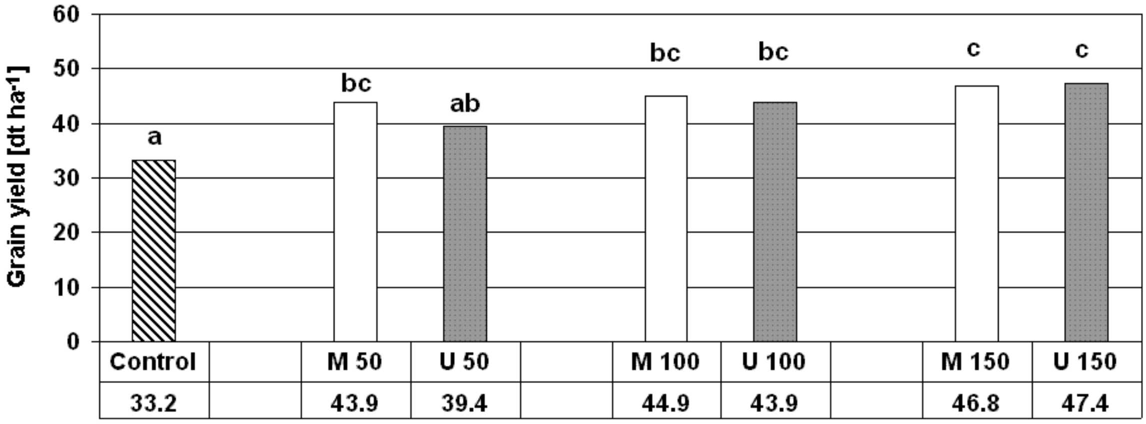
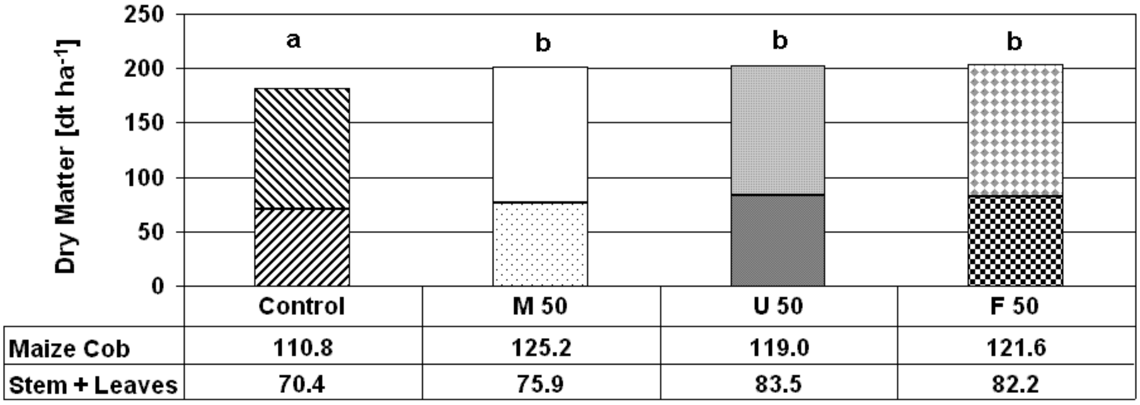


Figure 39: Grain yields of spring wheat after application of CAN (M) and urine (U) in 2006, DM content: 86 %; different letters indicate significant difference (Tukey, $p \leq 0.05$)

Except for the U 50 treatment, the addition of fertiliser led to a significant surplus in grain yield. Generally, it can be stated that CAN and urine did result in the same yield effects, despite the fact that, in the U 50 treatment, the amount harvested was 11 % lower than in the M 50 variant. At the 100 and 150 kg ha^{-1} N rates, the yields were equivalent.

Field Experiment with Brownwater in 2005

In 2005, the fertilising effect of Brownwater (faeces and flushing water) was investigated. Maize was grown and fertilised with Brownwater and urine and compared with conventionally applied mineral fertiliser (CAN). The corresponding Dry Matter yields are displayed in Figure 40. If total yields (cob + stem and leaves) are considered, the fertilised treatments were significantly different to the control but a statistical differentiation between them was not possible.

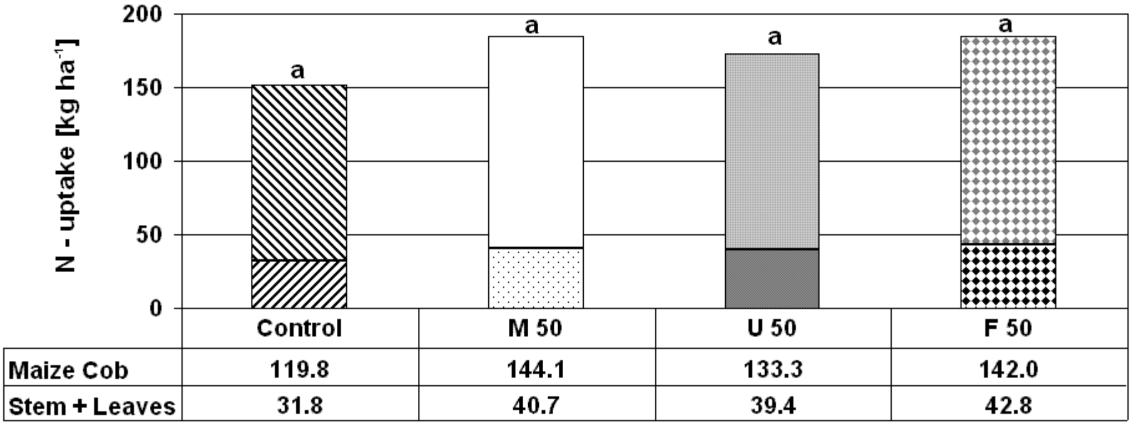


	Control	M 50	U 50	F 50
Maize Cob	**110.8**	**125.2**	**119.0**	**121.6**
Stem + Leaves	**70.4**	**75.9**	**83.5**	**82.2**

Figure 40: Dry Matter yields of maize after application of CAN (M 50), urine (U 50), and faeces (F 50) in 2005; application rate: 50 kg ha^{-1} N; different letters indicate significant total difference (Tukey, $p \leq 0.05$)

Also, no appreciable difference between the three fertilised variants was discovered in growth parameters such as the height of the plants or number of cobs developed. The plants' development during growing season measured in LAI and leaf colour index did also not differ noticeably (not shown).

Unlike in the yield, no statistically different values were found concerning the N uptake by plants despite, again, the control showing the lowest value (Figure 41).



	Control	M 50	U 50	F 50
Maize Cob	**119.8**	**144.1**	**133.3**	**142.0**
Stem + Leaves	**31.8**	**40.7**	**39.4**	**42.8**

Figure 41: Nitrogen uptake by spring wheat after fertilisation with CAN (M) urine (U) and faeces in dosages of 50, 100, and 150 kg ha^{-1} N; different letters indicate significant total difference (Tukey, $p \leq 0.05$)

Most of the nitrogen was incorporated into the cobs as they contain the major part of protein.

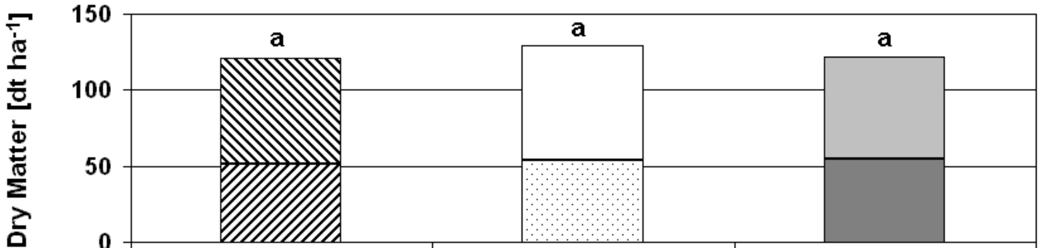
No differences were found in the pH, N_t, Ct, K_{DL} and P_{DL} values in soil before or after harvest (not shown).

The highest amount of plant-available nitrogen (N_{min}) in the soil after harvest was found in the mineral fertiliser treatments (35 kg ha^{-1} in 0 – 30 cm). Noticeably less was found after urine application (22 kg ha^{-1}) and after spreading of faeces (11.8 kg ha^{-1} N_{min} in 0 – 30 cm depth). Mixed sampling prevented statistical evaluation.

Field Experiments with Composted Faeces in 2006

In the following, the results of the fertilising field experiment with composted faeces, carried out in 2006, will be presented. The figures are restricted to yields only as the informational value of further figures was limited by various factors. In particular, this means a good nutrient supply in the soil before the experiment was set up and relatively low amounts of nutrients applied, resulting in poor differentiation of fertilising effects. Furthermore, the local weather conditions in 2006 only allowed relatively low maize yields when compared to 2005.

In Figure 42, the achieved yields are shown. The spreading of CAN led to a slightly increased amount of Dry Matter harvested, which was not significant, however. The application and incorporation of compost into the soil before seeding did not increase yields.



	Control	CAN	Compost
Maize Cob	69.7	75.1	67.8
Stem + Leaves	51.3	54.0	54.4

Figure 42: Dry Matter yields of maize after application of CAN and composted faeces in 2006; no significant difference in total yields (Tukey, $p \leq 0.05$)

Compared to the control, the soil C_t-contents (total carbon) in the compost treatment were slightly increased after harvest but not statistically different. (Mean control: 1.18 %; CAN: 1.25 %; compost: 1.24 %.)

4.2. Soil-Biological Effects

First Avoidance Response Test

Avoidance Response Tests are carried out to investigate the reaction of a certain bio-indicator towards test substances. In the first experiment, the reaction of *Eisenia fetida* if given the choice of a soil-urine mixture as habitat or soil only was to be observed. Furthermore, three different soil-urine mixtures were prepared with different resistance times before the worms were inserted into the pots.

The numbers of earthworms found in the substrates are presented in Table 9. The highest number (35) was counted in the controls, but total avoidance was observed for the substrate consisting of soil and urine mixed 24 hours previously. In total, 18 worms were counted in the treatments with urine incorporated 14 days previously and 27 animals were found in the treatments with urine incorporated 28 days previously.

Tab. 9: Distribution of *Eisenia fetida* in Avoidance Response Test with different resistance times of urine in soil

	Treatments			
Replication	Control	Urine incorp. 24 hours prev.	Urine incorp. 14 days prev.	Urine incorp. 28 days prev.
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 indicate significant differences, (ANOVA), $p \leq 0.05$)

Freshly incorporated stored urine obviously affected the earthworms, although the effect decreased with time. A statistical difference could only be established between the control and the treatment with a 24-hour holding time.

The incorporation of alkaline urine (pH 8.8) into slightly acidic soil (pH 6.5) led to an increased pH-value (Figure 43).

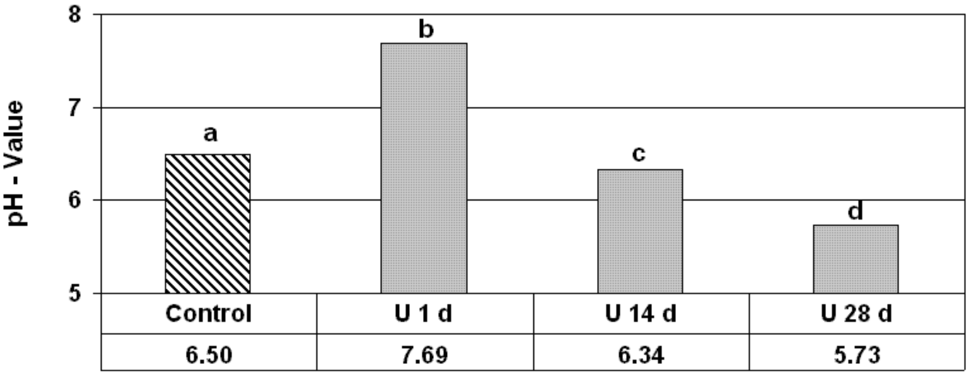


Figure 43: pH-values after incorporation of urine into soil; control = no urine, U 1 d = urine added 1 day ago, U 14 d and U 28 d = 14 and 28 days between urine application and pH measurement respectively; different letters indicate significant difference (Tukey, $p \leq 0.05$)

After 14 days, the soil became slightly acidic and with further time the reverse effect was observed.

Second Avoidance Response Test - Urine, Pharmaceuticals and Ammonia

The second response test was carried out with *Aporrectodea caliginosa.* Soil with urine, ammonia and pharmaceutical residues were tested in the experiment.

In Table 10, the distribution of worms after 48 hours is shown. Total avoidance was found at the urine treatment only. Neither pharmaceuticals nor ammonia caused a negative response. An even distribution was counted between these and the control.

Tab. 10: Distribution of *Aporrectodea caliginosa* in avoidance response test with urine, pharmaceutical residues and ammonia; substances consisted of: soil only, urine + soil, IBUPROFEN + BEZAFIBRAT + Soil, ammonia and soil

	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

64 worms were used for the experiment but only 63 animals were found during counting. The fate of the missing earthworm could not be clarified.

The addition of urine as well as ammonia changed the pH-values after 24 hours (Figure 44).

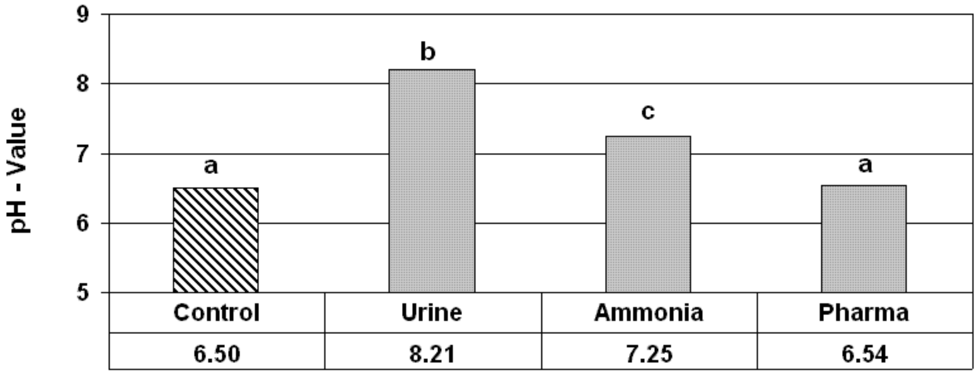


Figure 44: pH-values 24 hours after incorporation of urine, ammonia and pharmaceutical residues (Pharma) into soil; different letters indicate significant difference (Tukey, $p \leq 0.05$)

As expected, pharmaceutical substances did not affect the pH-value.

Earthworm Abundance in Field Experiment 2005

The increased presence of earthworms at the surface was observed by the author in parcels of different crops after urine spreading. However, no quantitative analysis of the phenomena was carried out. Nevertheless, the observation indicates that the normal behaviour of earthworms may be disturbed as a result of to urine application.

A quantitative analysis of earthworm abundance was investigated in a field experiment with winter rye in 2005. Enumerations were carried out in May after fertilisation and in October after harvest. In Table 11, the corresponding numbers are presented according to the species and in individuals per m². A statistical difference was established between the control and the urine treatment (Dunnett-test, one way) in May only. After urine spreading, the number of worms declined. In October, the differences in the treatments were small and no significance could be established.

Tab. 11: Earthworm abundance after urine fertilisation in 2005; numbers in individuals per m², different letters indicate significant difference (Dunnett-Test p ≤ 0.05)

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^{a}	19^{ab}	11^{b}	53	42	45

The largest increase was counted in the populations of *Aporrectodea caliginosa* and *Aporrectodea chlorotica.* The abundance of other species was not significantly changed.

Soil water contents were measured gravimetrically and simultaneously. The averages of the soil moistures in spring were 13.7 % in the control, and 12.1 % and 12.0 % in the urine treatments and the mineral fertiliser treatment respectively. In autumn, the water content was above 15 % in all cases.

Earthworm Abundance in Field Experiment 2006

The abundance of earthworms was also established in 2006. Again, earthworm quantities were counted two weeks after fertilisation (May) and after harvest in October. In spring, reduced numbers of worms were found in both fertiliser treatments compared to the control (Table 12).

Tab. 12: Earthworm abundance after urine fertilisation in 2006; numbers in individuals per m², different letters indicate significant difference (ANOVA p ≤ 0.05)

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^{a}	23^{ab}	10^{b}	41^{a}	21^{ab}	14^{b}

Despite the fact that less than half of the worms were counted after urine spreading compared to CAN application, this was not significantly different. Statistical difference was established between the unfertilised control and the urine variant.

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 rates approximately correspond to the numbers of earthworms found in May. In 2006, weather conditions at the experimental area were generally dry. In spring, soil moisture contents measured at the time of soil excavation for earthworm enumeration were 9.9 %, 7.5 % and 7.1 % in the control, CAN, and the urine treatments, respectively. At the time of the investigation in October, the soil moisture was still low. The value of 7.8 % soil moisture was measured in the control, and 7.4 % in both fertiliser treatments.

In 2006, deceased earthworms were observed at the soil surface one day after urine spreading. This was particularly clear after the fertilisation of the oilseed rape and maize and thus a low number of plants per area, enabling good visibility. The observation cannot be evaluated numerically as an enumeration was not carried out.

Dehydrogenase Activity

Microbial activity was investigated in May 2006 alongside the spring earthworm investigations in all treatments of the fertilising experiment. Soil samples were taken two weeks after fertilisation. During analysis in the laboratory, the following figures were established. In Figure 45, values for Dehydrogenase activity are presented as measured after application of 50, 100, and 150 kg ha^{-1} N from mineral fertiliser and urine.

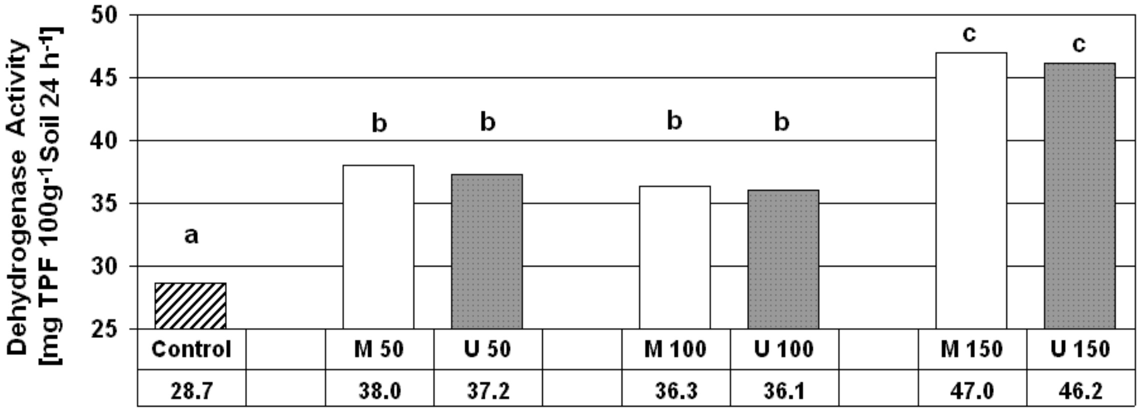


Figure 45: Dehydrogenase activity at a field experiment after mineral fertilisation and application of urine; different letters indicate significant difference (Tukey, $p \leq 0.05$)

Fertilisation generally raised microbiological activity, but no difference was evident between the two fertilisers. Also, no difference was established between the 50 kg ha^{-1} N and the 100 kg ha^{-1} N treatments. Compared to the two lower application rates, Dehydrogenase activity was significantly higher in the highest dosage variant.

4.3. Ammonia Emissions

Six measurements were carried out to establish ammonia emissions after surface application of urine. The emission rates generally exhibited the characteristics of the graph in Figure 46. A steep rise shortly after application was followed by a more gentle decrease within six hours. By that time, the major part of the emissions had taken place. When urine was applied in the evening or late afternoon, a smaller peak was measured the next day. After 48 hours, the emission rate dropped below measuring precision.

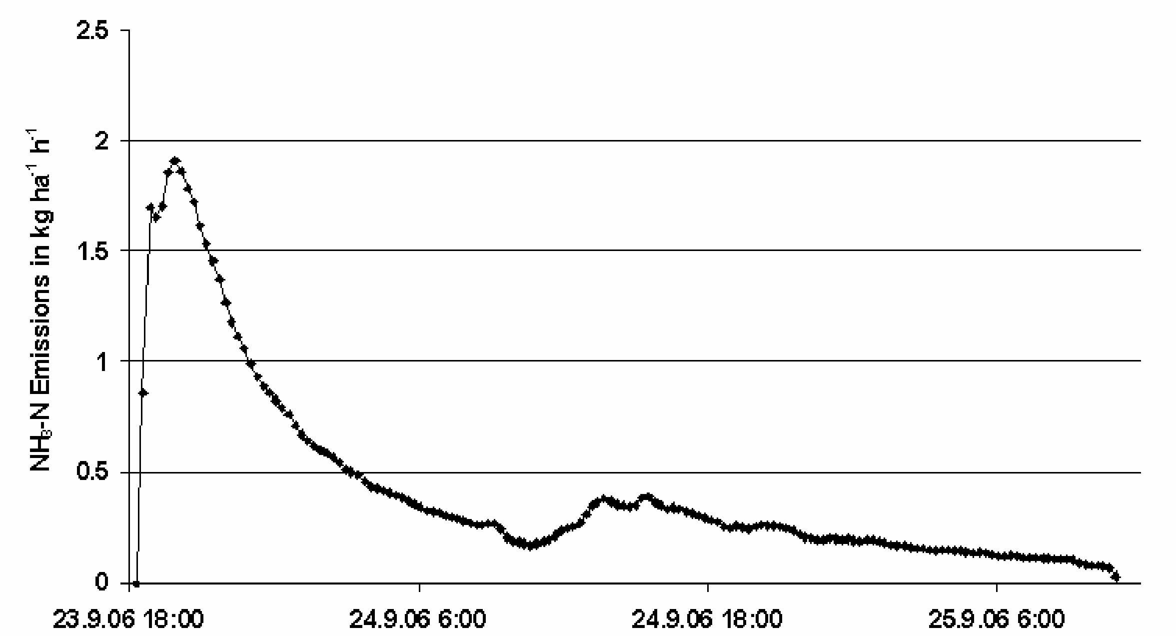


Figure 46: Ammonia-N emissions after application of urine with 100 kg ha^{-1} N on grassland; total emissions: 5.2 kg NH_4-N

In Table 13, the total ammonia emissions per measurement are listed, together with information regarding the type of plant cover and the corresponding amounts applied. The application dosage varied between 50 and 150 kg ha^{-1} N, and the corresponding emission rates between 2.7 % (50 kg ha^{-1} N on grassland) and 9.9 % (9.9 kg ha^{-1} on maize).

Tab. 13: Dates of measurement N-amounts applied, type of plant cover and ammonia emissions rates in % of total N applied in one dosage

Date	Amount of N applied [kg ha^{-1}]	Type of plant cover	Ammonia emission [%]
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

As weather conditions may influence emission rates, the corresponding air and soil temperatures, as well as relative humidity (moisture content respectively), are given in Table 14. The data was obtained electronically at a nearby field, which was free of vegetation. During evaluation, it must be taken into consideration that the vegetation at the actual measurement locations was likely to have caused further reduction in soil moisture contents.

Tab. 14: Temperature and humidity of air and soil on the dates of measurement

Date	Air temperature [°C]	Soil temperature in 5cm [°C]	Rel. air humidity [%]	Soil moisture in 15cm [%]
July 06, 2005	13.2	16.3	94	21
June 09, 2006	18.0	18.8	64	15
July 12, 2006	25.3	25.7	59	8
July 15, 2006	21.2	23.2	53	9
September 23, 2006	18.7	18.0	58	8

The actual dates for the emission measurements were unusual in terms of the fertilisation of the plants, especially for maize and wheat. Originally, it was planned to carry out the experiment alongside the fertilising experiments. Due to technical difficulties, this could not be realised and measurement dates needed to be shifted towards summer and early autumn.

4.4. Acceptance

Farmers Acceptance

In April 2006, 400 questionnaires were sent to farmers located in districts around Berlin to assess their attitudes towards the use of separated urine in agriculture. 68 of them replied via fax, giving a return rate of 17 %. The results of this study cannot be considered to be representative for all farmers around Berlin due to its quantitative limitations. Furthermore, it was intended to point out the motivations for various attitudes. A statistical evaluation for representativeness, including farm size and management practice, was also not carried out despite the figures suggesting a distribution close to real life (not shown). In the following, only selected results are presented.

When asked whether they would apply urine on their fields, the majority of the responders were uncertain. As shown in Figure 47, only one quarter gave a clear 'Yes' response.

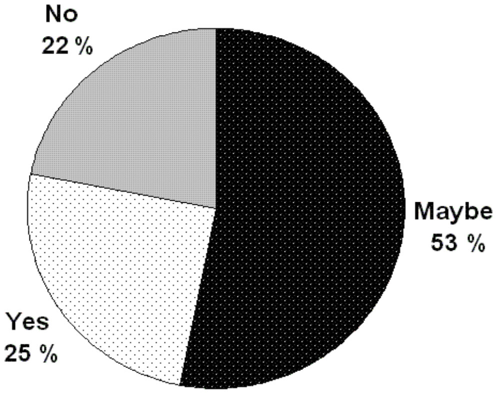


Figure 47: Farmers' answers to the question "Would you apply human urine on your fields?"

Some reasons for this clear hesitation may be uncovered with the help of the answers to further questions. Asked for the reason behind their decisions, 72 % answered that present legal regulations would prevent them from implementing the alternative fertiliser.

If they were permitted to apply urine, only 10 % of the farmers would spread it on food crops, but half of the participants would use it on energy crops. 63 % were worried about the saleability of their products if vegetables (including potatoes) were fertilised with urine. The closer the farmland to Berlin, the greater the concern about odour pollution. In total, half of the farmers considered the odour worse than the odour associated with cattle or pig slurry applications, and this was given as a reason not to apply urine.

The participants did not express ecological concerns or consider logistical aspects that might potentially prevent 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 the most important factors (Table 15).

Tab. 15: Distribution of answers when farmers were asked "Please rank the following aspects in order of their importance"; values in %, numbers bold if greater than 20 %

Aspects	Ranking: 1 = very important; 8 = not important at all							
	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
Odour 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 were still more important than logistical issues or the potential impact to the ecosystem.

Consumer Acceptance

Consumer attitudes were assessed in face-to-face interviews at agricultural-related exhibitions. In total, 175 participants completed the one page questionnaire. Besides the actual questions, all responders were asked to indicate their gender and age.

A statistical evaluation including this data was generally possible but not carried out due to the limited extent of the investigation. The general design of the study did not aim to provide statistically representative figures, but was intended to give a general overview of consumers' attitudes when confronted with the idea of urine as a fertiliser.

The answers of the question "What do you think of the idea of applying urine on agricultural fields?" are given in Figure 48.

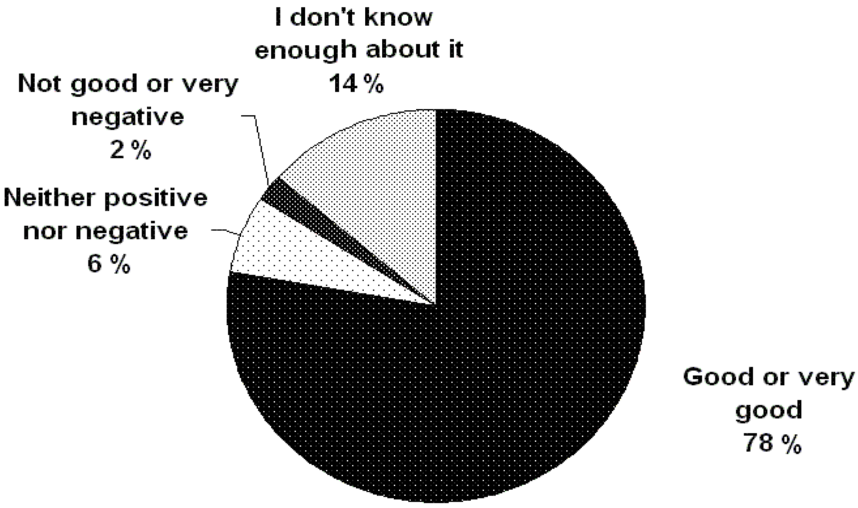


Figure 48: Answers of consumers to the question "What do you think of the idea of applying urine on agricultural fields?"

Clearly, a broad majority liked the idea of urine recycling in principle. However, some concern was expressed in the answers to further questions: More than 61 % were worried about pharmaceutical residues in urine. About a quarter expressed concern regarding the potential transmission of diseases but only 12 % considered hygiene to be a potential problem. Odour pollution during and after application was expected to be very unpleasant, and was mentioned by 15 % of the participants as being a potential problem. 11 % considered urine recycling to be unnecessary because of "already existing over-fertilisation".

In Figure 49, the answers concerning the acceptance of food produced with urine as fertiliser are presented. Three quarter of the participants agreed to the idea, 8 % would not accept such products

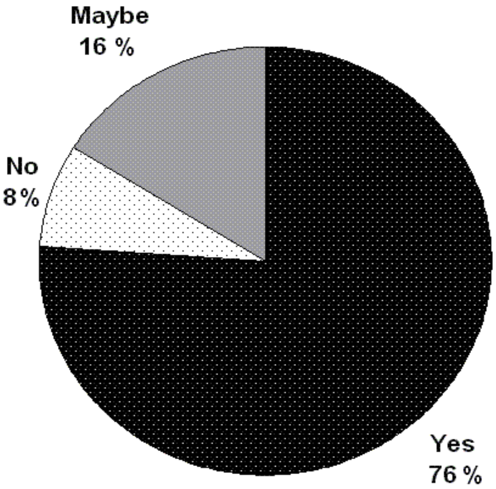


Figure 49: Answers of Consumers to the question: "Would you accept food produced with urine as fertiliser?"

The last question focused on the purchasing behaviour of the consumers. They were asked “Would you prefer to buy such products in the context of sustainable agriculture?”, 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 % gave the condition that the products would have to be “not more expensive than others”. Slightly varying answers were recorded at the different locations. At the open door day in Berlin-Dahlem (presumably largely made up of urban residents), only 7 % restricted the purchase to an equal or lower price, with 20 % giving this condition at the exhibition in a rural area (Brandenburgische Landwirtschaftsausstellung).

5. Discussion

5.1. Effects on Crops

The maintenance of anthropogenic nutrients (especially N) in plant-available form as practiced in sanitary source separation is considered a precondition for more sustainable matter flows. The performance of urine as a fertiliser plays a critical role in the whole nutrient recycling system. When it comes to an evaluation of the applied Alternative Sanitation system, the question just how efficiently urinary plant nutrients can be used essentially determines the overall value of source separation. Therefore, an understanding of the effectiveness of urine and faeces fertilisation, as well as of its limitations, is crucial.

When the results gained from fertiliser experiments are discussed in the following section, pot experiments and field experiments require separate examination. Pot experiments enable an evaluation of the limiting factors of a specific fertiliser, especially when applied in high dosages, rather than giving a realistic picture of what effects can be expected at field conditions. In that respect, the pot experiments carried out within this work revealed some possible limitations of urine as fertiliser. A further differentiation has to be made between the fertilising effects of urine, Brownwater and composted faeces. Due to their different characteristics, the substrates act completely differently.

Crop Growth after Urine Fertilisation

Usual farming practice was applied when field experiments were carried out. A significant yield difference could not be established in any of the experiments if fertilised with urine instead of CAN. There was also no indication of a clear tendency. Both fertilisers generally raised yields significantly, but this was not true in every case for spring wheat. The findings mainly confirm what SIMONS and CLEMENS (2004) found. In contrast, reduced yields were found in Sweden. JOHANSSON *et al.* (2001) reported that after urine spreading, yields reduced by 10 to 20 %, compared to mineral fertilisation, and a reduced nitrogen uptake was also observed. These differences cannot be explained from the available data.

In sandy soils around Berlin, the most limiting yield factor is usually water, not nitrogen (ELLMER et al, 2007). As these soils are known for their low water-retaining capacity, precipitation at the time of crop development is essential. CHMIELEWSKI &

KÖHN (1999) found that weather conditions from May to July have the greatest influence on cereal yields (barley, oats). In 2005, rainfall in May was above the long-time mean. In June, the precipitation accounted for only half of the usual amount. This, together with very high rainfall and temperatures not higher than average in July 2005, is most likely responsible for the relatively good yields of winter rye and spring wheat. Oilseed rape may not have benefited from the water in July. In 2006, the situation was different: Precipitation in May was within the usual range, but in June it was far below the long-time mean. High amounts of rainfall were measured during the following month, but also high temperatures. Overall, 2006 was dry with high temperatures and consequently high radiation. In a field experiment, precipitation is highly likely to influence yields more than fertilisation under the mentioned conditions, especially with high soil nutrient contents. This theory is supported by high yields in the control variants. The generally high nutrient supply of the soil at the outset of the experiments may have prevented plant nutrition effects from becoming more differentiated.

A main difference between granulated CAN and urine is the state of aggregation. In terms of plant availability, this can set the fertilisers apart. Urine as a liquid with very little Dry Matter infiltrates into the soil quickly and reaches the soil solution with very little delay. This process also occurs at dry conditions. In particular, when the fertiliser application is split into two dosages, the state of aggregation can mean an advantage for urine because the second share is often applied later in the year when the conditions are much more dry. In contrast, granulated ammonium nitrate must be dissolved in additional water before entering the soil solution. Morning dew can be beneficial if precipitation water is not available. However, especially under dry conditions, it is not quite clear if granulated fertiliser can reach the root zone without rainfall. Scientific studies concerning this problem are not available, despite its relatively simple nature. Nevertheless, it can be assumed that under dry conditions especially, the liquid form gives urine an advantageous position. Furthermore, the distribution of nutrients within the soil may be quicker because urine infiltrates directly instead of remaining at the surface, as is the case for granulated fertilisers.

The application of both urine and CAN can lead to gaseous ammonia emissions. This means not only a potential hazard to the environment but also a loss of nutrients. The loss of ammonia from CAN is generally considered to be low (DU PREEZ & DU BURGER, 1988). In CAN, half of the N is in the NH_4^+ form and half in the NO_3^- form.

Therefore, only half of the applied N is susceptible to NH_3 volatilisation, which gives it a distinct advantage over urine. On the other hand, drying conditions (high temperature, high wind speed and low humidity) favour losses from mineral N fertilisers in particular, as the grains can remain at the surface for a considerable time (BUIJSMAN *et al.,* 1987). The precise ammonia losses after CAN application were not measured during the presented project and are therefore subject to estimation. Ammonia emissions from urine application ranged from 2.7 % to 9.9 % of the total applied nitrogen. It can generally be assumed that in the case of the mentioned field experiments with urine, the ammonia losses were higher than those after mineral fertilisation. However, this had very little influence on the yields or nutrient contents of the plant matter.

The results from field experiments allow the conclusion that human urine is a suitable fertiliser for cereals and oilseed rape. In calculations, its nitrogen content can be considered to be just as effective as that of mineral fertiliser. Because its nutrient content is balanced, urine could be applied for many crops without the addition of other fertiliser.

Potential Limitations of Urine Fertiliser - Pot Experiments

In the pot experiments, it can be summarised that the yields after application of urine were equal or lower than after combined (mineral) ammonium nitrate fertilisation. The findings only partly confirm what SIMONS & CLEMENS (2004) found in a pot experiment with *Lolium multiflorum* and *Trifolium pratense.* They reported equal or higher yields after urine application compared to CAN. However, the general tendency observed in the pot experiments was such: The higher the application rate, the more likely a lower yield was harvested after urine spreading. This difference is mainly exhibited by a reduced development of generative plant parts (grain, maize cob), while the DM yield of stem and leaves (straw) remained almost unchanged. The gradient of the effect did vary with the type of crop (wheat and oats less sensitive, maize and hemp more sensitive). These results suggest that a more differentiated answer to the question regarding the fertilising effect of urine has yet to be found. In pot experiments, calcium ammonium nitrate (CAN) and stored human urine both increased yields, but not to the same extent in all cases.

Stored human urine contains almost no urea, but does contain ammonium, which is (despite its organic origin) an inorganic form of nitrogen. Unlike fresh urine (e.g. as in urine patches caused by grazing animals), the nitrogen characteristics of the urine used in the presented studies are similar to those of conventional mineral ammonium fertiliser, but not to CAN, which contains both ammonium and nitrate.

Clearly, the yield effect of urine in the pot experiment studies strongly depended on the factors ‘type of crop’ and ‘application rate’. ISMUNADJI & DIJKSHOORN, (1971) mentioned the plant species as being important for the general reaction towards ammonium nutrition. They considered plants adapted to acid soils and plants adapted to soil with low soil redox-potential as having a preference for ammonium. In contrast, plants with preference to high pH soils utilise nitrate preferably (KIRKBY, 1967). Whether this is due to direct or indirect effects is not quite clear, as the application of ammonium also leads to acidification. However, as a rule, the highest growth rates and plant yields are obtained by the combined supply of both ammonium and nitrate (MARSCHNER, 1986). In this respect, urine is at a disadvantage to CAN.

The effects of exclusive ammonium nutrition in hydroponically-grown plants when compared to sole nitrate or combined ammonium-nitrate supply have been studied by many authors (CRAMER & LEWIS, 1993). Field studies comparing yield responses of crops treated with ammonium, nitrate or a mixture of both have led to highly contradictory results. This can be explained by the fact that the application of different forms of nitrogen may affect plant growth via numerous processes in the soil and within the plant (WIESLER, 1997).

Ammonium is generally considered a slower acting fertiliser than nitrate. Despite that plants can rapidly take it up in hydro culture, it often has a slower fertilising effect in soil. After application, ammonium is first adsorbed in soil particles and is then only gradually released and nitrified (IFA, 1992). This is a result of its reactivity. The build-up of plant matter from the three maize plants per pot was up to five times greater than from hemp, spring wheat or oats. This correlates with the total nutrient demand, but the experiments were carried out with the same rates of nitrogen in all three crops. Consequently, the relative nutrient supply in maize was lower, and a nutrient deficiency was far more likely to occur. This assumption is also supported by the observation that Dry Matter yield in maize still increased between the 2 g and 3 g N treatments, both for the artificial and urinary fertilisers, whereas this was not the case with wheat and oats. Maize converted the additional nitrogen into additional plant matter. The higher total nitrogen demand made by maize, together with the fact that ammonium is adsorbed by soil particles, could explain the significantly lower yields after urine application. The fact that soil temperatures in pots are less likely to be influenced by air temperature than soil temperatures in a field may have provided better conditions for mineralization. On the other hand, the high water content may have counteracted this.

An exclusive supply of ammonium causes growth depression effects, in literature summarised as "ammonium toxicity". The cause of this phenomenon is multiple and far from being understood (BRITTO & KRONZUCKER, 2002). The authors further displayed a NH_4^+ sensitivity classification with respect to plant families. Maize, spring wheat and oats belong to the same family (*Poaceae*), which cannot be generally classified as ammonium sensitive or tolerant, due to its large diversity. Hemp (*Cannabaceae*) is considered to be very adaptable to soil and climatic conditions, but prefers neutral to slightly alkaline conditions (KLAPP, 1954). Unlike spring wheat, oats and maize, germination decreased significantly when hemp was planted into pots where urine had been added to the soil. Hemp was the only plant at which, because of this phenomenon, required that all plants be pre-grown in a glasshouse. They were planted into the actual trail pots at a height of 5 cm. The fact that germination was reduced, together with its preference for neutral or alkaline soils, suggests that the species hemp is highly sensitive to ammonia or other stress from urine, particularly at an early growing stage. Nevertheless, not only germination was affected. The fact that a higher rate of urine led to reduced yield suggests that urine in high dosages has a toxic effect specifically to hemp, not only during germination but also at later growing stages. As field experiments with hemp were not carried out, the transferability of this observation to natural conditions is not known.

The roots of maize are not considered particularly sensitive to ammonia. CRAMER & LEWIS (1993) explained that, unlike wheat, the biomass accumulation in maize is not reduced when supplied exclusively with NH_4^+ instead of NO_3^-. The cited authors further related the differences in the responses of wheat and maize to nitrogen nutrition to differences in the assimilation capacity of the C_3 and C_4 photosynthetic mechanisms of wheat and maize, respectively, and to differences in the availability of carbohydrates within the roots of these plants (LEWIS, *et al.*, 1990). In hydroculture, ammonium-nutrition affected the root development of wheat especially, but not that of maize. These results suggest that maize is less prone to ammonia toxicity. In addition to this, SMICIKLAS & BELOW (1992) reported an enhanced reproductive development of maize if supplied with both forms of nitrogen (NH_4^+ and NO_3^-). This is considered to be an effect of cytokinin, a growth-regulating substance. BELOW & GENTRY (1987) noted that maize plants supplied with ammonium and nitrate at the same time partitioned a larger amount of Dry Matter to the grain. Identical observations were made in the pot experiment with maize. Notable differences in total Dry Matter yields resulted only from reduced maize cob yield.

Human urine contains approx. 150 mM of NaCl (GANROT et al, 2007; ALTMAN & DITTMER, 1974). In water (which urine consists primarily of), this corresponds to a concentration of 8.8 g l^{-1}. (Because the sodium content of urine used in the experiment was not measured, literature values are referred to.) Salt stress from sodium chloride can be a major constraint in plant production, especially in arid conditions (LEVITT, 1980). Salt sensitivity varies with factors such as plant species and temperature. BERNAL *et al.* (1974) reported growth depression of 10 to 50 % grain yield of wheat when treated with a solution of 50 mM NaCl. In a simplified calculation, assuming that the pots did not contain salt other than the salt from the urine, at 80 % water capacity, the concentration in the soil solution at the time of planting was 35 mM NaCl in the U 3 treatments. (80 % water capacity corresponds to 1495 ml total water per pot). After addition of the second fertiliser share, the concentration was further raised by 100 % during plant growth. A negative influence on the growth of the crops is likely to have occurred in this environment. The electrical conductivity (EC) of urine used in the pot experiments was 37 dS m^{-1}. During the setting up of the pots, this was diluted with 4.25 units of water per unit urine in the U 3 treatments. Again, following the assumption that soil particles do not influence salinity, an EC value of 8.7 dS m^{-1} was theoretically found in the soil extract immediately after the setting up of the pots (at 80 % water capacity). Threshold values of salt sensitivity for different crops are given by MAAS (1985). For wheat, he states that an EC of 6.0 dS m^{-1} is the maximum soil salinity that does not reduce yield. The value for maize is 1.7 dS m^{-1}. The source also provides information regarding the expected yield reduction effects, as slopes are given assuming a linear curve of yield reduction. Following this data, a yield reduction of 19 % would be expected in the U 3 variant for wheat as long as only the first share of fertiliser was applied. This value would have risen significantly after the second fertiliser application. In the case of maize, the cited author expected only 10 % of the yield compared to conditions without salt for the U 3 treatment after application of the first share. However, looking at the highest application rates only, the yields of wheat and maize in the pot experiments were reduced after urine application, but not to such a great extent. Nevertheless, salt from urine applied in the pot experiments may have negatively influenced the yields. Reduced seed germination (as in the case of hemp) is less likely to have been a source of sodium, as plants are usually less prone to salinity at this development stage (UNGAR, 1974). These observations leave the question of whether the salt content of urine may be of importance when applied on farmland. The answer strongly depends on the local climatic and soil conditions. As a rule of thumb, urine contains equal amounts of sodium chloride and nitrogen. The application of 100 kg ha^{-1} salt per year can be negligible, but at certain locations (especially arid) quite significant at the same time.

It is reasonable to assume that the change in soil pH after urine application in pot experiments also stresses the plants. At first, after spreading the alkaline urine (pH 8.8) on the slightly acidic soil (pH 6.5), the pH- value rises. During the process of ammonium conversion into nitrite and finally into nitrate, cations are released. Consequently, the pH drops before finally falling below the initial values of the soil. In addition to this, the uptake of ammonia by plants releases additional protons, which are exchanged against cations. MARSCHNER (1986) demonstrated that ammonium assimilation in roots produces about one proton per molecule of ammonium taken up. The strong change of soil pH can cause stress to the plants, leading to a toxicity effect and reduced yields (LEVITT, 1980). However, these considerations cannot automatically be transferred to field conditions. The extremely limited amount of soil in pots may have exaggerated the impact.

The Fate of Nitrogen after Urine Application

As nitrogen is considered to be the most yield-limiting nutrient (under the given conditions), its dynamics are of special interest. However, the calculation of nitrogen balances from field experiments is associated with many uncertainties (MARSCHNER 1986). Factors such as hectare amounts of nitrogen emitted into the atmosphere, and mineralised, fixed or leached vary and can hardly be correctly estimated for the specific situation. Besides the defined nutrient supply by fertilisation, the only reliable measures in the calculation are the amount of nitrogen removed by plant matter due to harvest and the amount of mineralised nitrogen in the soil before and after plant growth. This, however, does not take into account other forms of soil nitrogen.

After fertilisation in field experiments, approximately the same amounts of N were contained in above-surface plant matter as were applied. This does not allow the specific origin of nitrogen in plants to be stated. Compared to the input, the uptake was slightly higher at low dosages. However, in the controls, considerable amounts of N were removed without any addition of nitrogen fertiliser, even in the two years that followed. The only explanation for this phenomenon is that nitrogen contained in the soil was mineralised before the experiment began. Nitrogen deposition from the atmosphere is also possible, but unlikely to such an extent.

Increased fertiliser application rates did not generally lead to higher amounts of N_{min} in the soils after harvest. After the harvest of spring wheat in 2005, however, the values suggest increased amounts of N_{min} as a result of fertiliser application. A reverse trend was found after harvest of oilseed rape in 2006. In both cases, the (not statistical) difference between the highest and lowest values was approximately 20 kg ha^{-1}, which is negligible.

In the pot experiments, the situation was different. When the amounts of N taken up by maize plants are considered together with the fact that virtually no different N_t contents were found in the soil, a question arises regarding the fate of the applied ammonium from urine. In the case of fertiliser application with ammonium nitrate, the N recovered in plants approximately matches the amounts applied, although large quantities are missing in the balance after addition of urine. In the case of urine fertilisation, only roughly half of the nitrogen was incorporated into plants. The missing quantities were not contained in the soil after harvest. This assumes a loss of gaseous nitrogen into the atmosphere. In the case of hemp, a significantly larger total amount of nitrogen was measured after harvest in the soil containing the highest quantity of urine rate. In the case of oats, more total nitrogen was measured in the soil containing the highest quantity of mineral treatment. These results are contradictory and cannot be explained. Even in the cases where N supply was far greater than uptake (wheat, oats), the corresponding difference in N could not be found in the soil. Compared to field conditions, the N dynamics in a pot experiment under the given conditions are far greater. The relatively small amount of soil means that soil temperature changes during the day are greater. In addition to this, the nutrient concentrations were higher than under field conditions, and the constant watering may have encouraged greater biological activity.

In summary, urine is a fast-acting nitrogen source but is therefore prone to emissions and leaching, as with any other ammonium fertiliser. This needs to be considered before application. Unlike most other fertilisers with organic origins, it should be applied at the time of plant nutrient uptake and not far in advance. Its characteristics enable foliar application, and incorporation is not a perquisite (although this would bring advantages).

Crop Growth after Application of Faeces (Brownwater)

As with urine, the application of Brownwater led to contrary results when its fertilising effect was tested in pot experiments instead of field experiments.

In the field experiment with maize, neither the yield nor the N-uptake was significantly different in any of the treatments, but rose above the control in tendency. The low amount applied in total (50 kg ha^{-1} N) prevented further differentiation between the variants. In the more controlled environment of the pot experiments, the Dry Matter yields were significantly lower after addition of faeces than after mineral fertilisation.

In a field ecosystem, the amount of soil per plant is less limited than in a pot experiment. This means that the plants are likely to derive a greater quantity of nutrients through their root systems. Thereby, nutrient deficiency is less likely to occur. This theory is also supported by the fact that the amounts of N taken up by plants at the field were more than three times greater than the applied amounts. The high amount of nitrogen taken up by plants in the control demonstrates the high nitrogen demand of maize and the high soil fertility at the specific site. Also, the weather conditions in 2005 were suitable for maize.

As the nitrogen concentration of faeces was very low, and presuming that no relevant amounts of salt or other toxic substances were contained in the faeces, the fertilising effect in pot experiments may have been largely influenced by the plant availability of the nutrients. While N in ammonium nitrate is readily plant-available, N from faeces is partly organically bound. The process of mineralization requires time, and the fertilising effect will be noticeable not only in the first year after application but also in the following year (JACOB, 1960). The set-up of the experiments did not allow an investigation of this effect. However, the total nitrogen content remaining in the pots after harvest could provide a clue. Neither in the case of wheat nor in the case of maize was there clear evidence for the presence of significantly different amounts of N remaining in the pots after harvest.

Field studies regarding the fertilising effect of Brownwater (without urine) under comparable conditions have not been published. This may be because this is of rather theoretical interest, as the low nutrient content of Brownwater from gravity separation toilets limits its practical use. The very high water content makes transport and spreading cost-intensive.

Unlike urine, Brownwater contains considerable amounts of carbon. The addition of organic matter to sandy soils is generally considered to maintain soil fertility (EREKUL, 2000). The benefit of Brownwater as fertiliser is therefore assumed to be far greater, suggested alone by its nitrogen-fertilising effect.

The investigations did show that, from an agricultural point of view, the use of human faeces from separation toilets would be welcomed. The practical implementation of this particular type of fertiliser must, however, be doubted. Overly high water content seems to prevent this from becoming reality. The substrate characteristics may change if Brownwater is digested in a biogas plant, where it is likely to be mixed with kitchen wastes. This could result in not only a rise in total nitrogen content (making the fertiliser more attractive to farmers), but also a drop in carbon content. A thermophile digestion can ensure sufficient hygienisation, which is a precondition for any application of faeces on agricultural land.

The aspect of hygiene requires further investigation. The use of human faeces for food crops is yet to be critically evaluated from a hygienic point of view. To prevent human pathogens from entering the food chain, it should generally be recommended to apply faeces on non-food crops only, if hygienisation is not monitored.

Solid/liquid separation using a cyclone-type separator can be useful to reduce water content of Brownwater. However, this would mean additional effort, as the separated liquid phase, containing nutrients and pathogens, must also be treated.

The actual technical design of the sanitation concept determines whether Brownwater emerges as fertiliser, or is to be further treated and converted. If it is to be applied at fields, no general limitations from the agricultural side are anticipated.

Crop Growth after Application of Composted Faeces

A more likely use for faeces is composting. This can be carried out without any expensive equipment. Compost has low water contents, enabling efficient transport and application. However, it is also a different type of fertiliser, with different applications. Therefore, the comparison with CAN is not appropriate. CAN is used to supply nitrogen close to the time when it is needed. In agriculture, it is mainly spread in large-scale farming. Compost as a natural product contains a number of nutrients and also considerable amounts of organic carbon. It is mainly used in horticulture but would be useful in agriculture if larger amounts were available. Because of the high lime content - especially for organic matter - composts should primarily be considered as soil conditioners. In addition, they contain substantial quantities of nutrients, so that a targeted application as fertiliser (multinutrient fertiliser) becomes necessary. On average, less than 5 % of the compost N consists of immediately plant-available ammonium (NH_4^+) and nitrate (NO_3^-). Generally, following compost application, up to 90 % of the nitrogen remains in the soil, thereby increasing the soil N content (EBERTSEDER & GUTSER, 2001). The general beneficial effects of compost in soil include an improvement in the water-retaining capacity, the soil structure and the supply of nutrients other than nitrogen (DLG, 2006).

The difference between CAN and composted faeces was also reflected in the experiments. Significantly lower yields in all cases were found after compost application. Similar results were found by SVENSSON *et al.* (2004). The authors studied the fertilising effects of compost and biogas residues of source-separated household waste in field experiments in Sweden. Many more experiments have been carried out concerning the fertilising effects of compost (BRINTON, 1985; CHEN *et al.,* 1996; EGHBALL & POWER, 1999). However, the origins and compositions of compost vary and not much research has been done in the specific field of vermi-composted faeces. Compost is generally considered to have a small nitrogen-fertilising effect, as the contained nitrogen is largely not readily plant-available during the first year of cultivation. The same was found in the pot experiments carried out for this thesis. The composted faeces proved to have an even lower fertilising effect than untreated faeces. However, the comparison can only be made for a low application rate.

Compost application in pot experiments led to low nitrogen recovery rates in the plants (15 – 25 %). This confirms what CHEN *et al.* (1996) found in field experiments. Again, a differentiation between the origins of nitrogen (whether it came from the soil or from compost) cannot be made. Considerable amounts of N_t were left in the soil after harvest. Mineralization may have made the organically fixed N plant-available in the period that followed, but the experiment was ended after harvest of the first crop.

Composted faeces can be used as fertiliser. However, to test its specific quality, further (different) methods need to be applied.

5.2. Environmental Effects of Urine Application

Any fertiliser applied in significant amounts will directly or indirectly influence its environment. As agricultural sites are complex ecosystems, fertiliser application may shift population balances at many levels. The environmental impacts of a fertiliser can furthermore hardly be limited to a specific location. Leaching of nutrients or gaseous emissions may lead to effects arising far from the actual place of application. Environmental effects must be assessed in the evaluation of a specific type of fertiliser. As this can never be carried out exhaustively to the complexity of an ecosystem, important single aspects need to be highlighted. In the following, the effects of urine application on soil biota, as well as ammonia emissions, will be discussed.

Toxicity of Urine to Earthworms

In both avoidance response tests and field investigations, earthworms totally avoided urine. The effect decreased with time and is obviously not species-related. In an avoidance response test, a substrate is considered toxic if a difference to the control of more than 80 % can be established (HUND-RINKE *et al.,* 2002). Following this definition, urine was toxic to earthworms at a time close to application. This, however, did not provide information about whether urine application would actually harm earthworm populations on a long-term basis.

The results of the first avoidance response test (different residual times of urine in soil) suggest that a process of change, or reduction, begins in the urine after it is 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 first increased (due to the addition of alkaline urine), but ultimately dropped below the initial soil value. The change in pH suggests, that in this case, mineralization occurs, whereby the ammonium is transferred into nitrate, which is less harmful to earthworms.

The field experiments in both years also revealed a reduction in earthworm umbers at places where urine was applied. In tendency, earthworm numbers were also lower after mineral fertilisation. However, this was seen as an effect of soil moisture reduction caused by increased water uptake by plants. Earthworms are usually fully active in spring and autumn, as long as soil moisture is above 14 mass-percent (EDWARDS & BOHLEN, 1996). At dry conditions, they remain in an inactive state at deeper soil layers. To a broad extent, this was the case during field investigations in 2005. The soil was too dry to allow a larger number of animals to be counted.

The observed effect was of a short-term nature in the first year. In October 2005, equal numbers of worms were found in all treatments. The numbers were also generally higher. Obviously, a period of approximately six months was enough to compensate for the initial reduction. In 2005, soil moisture conditions between the two field investigations enabled the development of the worms, as the values were at least partly over 14 mass-percent. It is ultimately not clear if the rise in abundance in urine parcels was a result of reproduction or simply a movement of animals from neighbouring areas. However, apart from specific terrestrial species, a movement of significant numbers of worms is unlikely in such a short space of time (EDWARDS & BOHLEN, 1996).

In 2006, the population did not rise to initial extend between fertiliser application and harvest. During the vegetating period in 2006, the soil moisture was considerably lower than in 2005. It can reasonably be assumed that this was the limiting factor for earthworm reproduction in 2006.

In 2006, the presence of perished earthworms on the surface one day after urine application was observed in particular at fields with maize and oilseed rape. The number of earthworms that appear at the surface after application of a ‘‘normal’ amount of slurry is thought to be less than 1 %. However, this proportion decreases non-linearly as larger amounts are spread. More than 10 % of the worms were found at the soil surface after slurry application of 75 m^3 per hectare. In the longer term, slurry application does not generally decrease earthworm numbers. (GALLER, 1989)

The exact cause and mechanism leading to avoidance and population decrease could not be established in any of the tests. In the second avoidance response test, it was assumed that either ammonia or pharmaceutical residues generate the response, but both substances did not. Comparable studies in literature with human urine are not known to exist. Avoidance effects in earthworms towards organic fertiliser containing animal urine are reported in literature (CURRY, 1976). In the cited article, ammonia gas that develops during the decomposition of animal urine is thought to cause the avoidance response. A concentration of 0.5 mg g^{-1} ammonia is reported to be toxic for earthworms. However, in this experiment, the corresponding reaction was not observed, as the ammonia variant was also accepted. Ammonia-votalisation occurring during the setting up of the experiment and resulting in an actually lower content of ammonia in the substrate might have been the cause. A loss of gaseous ammonia was observed during preparation of the solution, but this cannot be exactly attested to be the reason. Both urine and ammonium application raised pH-values. The fact that urine contributed to a higher alkalinity than ammonium can be interpreted as evidence for an actually lower amount of NH_4^+ in the ammonium solution than in urine. This assumption would suggest that both substances have the same buffer capacity, which is not known.

Earthworms' reaction towards human urine and cattle slurry may be of the same origin. In comparison to slurry, urine contains very little Dry Matter. If spread at the soil surface without any tillage or incorporation, it quickly infiltrates. Thereby, it is likely to run into earthworm burrowing holes and come into direct contact with the animals. The mobility of urine as a quickly infiltrating liquid can intensify its toxicity. Any tillage operation shortly before or at the time of urine spreading may prevent the liquid from reaching earthworms at their natural habitats and will therefore diminish the reduction effect. However, precise investigations concerning this matter are yet to be carried out.

Agricultural activities often affect earthworm populations (KRÜCK, 1998). CUEDENT (1983) estimated that the direct mortality arising from injury caused by ploughing in a range of soils in Switzerland was about 25 %. The effects of more intensive forms of cultivation can be considerably greater. For example, BONSTRÖM (1988) reported that rotary cultivation killed 60 – 70 % of the earthworms in grass and lucerne leys in Sweden. Population reductions in the order of 50 % have been indicated in a number of studies following ploughing and conventional cultivation for cereal crops (CURRY *et al.*, 1995) and potatoes (BUCKERFIELD & WISEMAN, 1997). However, it is debated whether these effects of cultivation appear to be transitory or more long-lasting. While the mentioned authors found that populations to generally recovered within 6 – 12 months in the presence of an adequate food supply, CURRY *et al.*, (2002) observed a lack of population recovery over two succeeding years under cereal crops after intensive production of potatoes. He postulated that the capacity of the population to recover from perturbation may have been fatally compromised. This leads to the recommendation that in agricultural ecosystems where human urine is used as a standard fertiliser, its earthworm population should be monitored.

In summary, stored human urine is toxic to several earthworm species and, if applied at fields, it can significantly reduce their abundance. Despite that the effect is generally short term only, it can last for more than six months if the application is carried out at a critical moment, for example before a seasonal drought.

Microbial Activity

The Dehydrogenase activity, which is considered to be a measure of microbiological activity, was analysed only ones, two weeks after application of the second fertiliser share, which was six weeks after the first. Any conclusion drawn from this data is limited by this fact. A direct toxic effect from urine should have been indicated by the experiment. This was either generally not the case or the effect was of such a short term that it was no longer noticeable.

The measured values range from 28.7 mg TPF 100 g^{-1} soil 24 h^{-1} (control) to 47 mg TPF 100 g^{-1} soil 24 h^{-1} (150 kg ha^{-1} N). KAUTZ *et al.,* (2004) measured Dehydrogenase activity at a long-time field experiment near the actual location in Berlin Dahlem. They reported 10 to 20 mg TPF $100g^{-1}$ soil 24 h^{-1} for the control, measured from 2001 to 2003. This corresponds to the value of 28.7 mg TPF $100g^{-1}$ soil 24 h^{-1} that was measured at the control used in this thesis. The authors further stated that the application of mineral fertiliser (160 kg ha^{-1} N) did not significantly increase Dehydrogenase activity. This could not be confirmed. The application of 150 kg ha^{-1} N from CAN did raise the value to 47 mg TPF $100g^{-1}$ soil 24 h^{-1}. Over their three years of investigations, KAUTZ *et al.* (2004) did not measure values this high. They assumed that carbon is the main influencing factor, as Dehydrogenase activity was raised by annual straw and sugar beet leaf manure application. An explanation for the obvious difference between the reactions of microbiological activity to mineral fertilisation in the mentioned source and the experiments from this thesis could not be found.

PARHAM *et al.* (2002) reported that the application of cattle manure every four years compared to an annual fertilisation with mineral NPK-fertiliser significantly increased Dehydrogenase activity. Investigations in Holland revealed a higher activity of the soil micro life at farms applying organic amendments (VAN DIEPENINGEN *et al.*, 2006). The long-term encouraging effect is often thought to be the result of the addition of organic carbon. KAUTZ & RAUBER (2007) found that fertilisation with residues from biogas plants significantly raised soil microbial activity. They further assumed that in this case it was not an effect of carbon but of other nutrients. After application of human urine, nitrogen in particular may promote microbial activity as it contains very little organic carbon.

However, all these investigations were carried out not only ones but had a rather long-term character. Reports concerning the influence of human urine on soil micro-biological life are not available.

The issue of why, in the longer term, the addition of organic fertiliser or organic amendments raises the general biological activity of a soil (ANDERSEN, 1979; LOFS-HOLMIN, 1983; MARSHALL, 1977; HANSEN, 1996; MADER *et al.*, 1999) has often been addressed. Obviously, this is not the case for stored human urine. This may be a result of the lack of organic compounds that organisms can use directly as food. Nevertheless, the addition of nutrients from urine can lead to increased plant growth and therefore also to increased availability of digestible material e.g. for worms. This suggests that, apart from the short-term toxicity of urine, it should be referred to as a mineral fertiliser rather than organic manure.

General concern may arise about pharmaceutical residues in urine potentially influencing soil microbial activity. The availability of such studies is limited. THIELE-BRUHN & BECK (2005) observed no effect of sulfonamide and tetracycline antibiotics on soil Dehydrogenase activity, even at concentrations of up to 1000 µg g^{-1}. Contrary to this, antibiotics are known to inhibit glucose-6-phosphate Dehydrogenase of *Bacillus subtillis* (MOHAN DAS & KURUP, 1963). An influence from antibiotics can therefore not be completely excluded, despite reasonable doubts existing as to whether field-applied urine actually contains significant quantities.

Ammonia Gas Emissions

Ammonia gas emissions were analysed after urine application using an open-chamber technique. The technique was developed especially for this purpose and had not been previously applied elsewhere. On the whole, the system worked satisfactorily. However, limitations may exist because the simulated wind in the chambers does not entirely correspond to conditions found outside of the chambers. At (real life) field conditions, the wind direction follows mainly a horizontal movement, but the wind exchange rate at a particular location is far higher than under a chamber. This may lead to under-estimation, as the equilibrium concentration between soil surface (urine) and air may be reached sooner. On the other hand, the actual wind speed at ground level may be rather slow. The design of the chambers enabled air of greater height with lower ammonia concentration to enter. This may lead to an over-estimation of the emission rates. An advantage of this method is the high density of data produced, enabling exact chronological traceability of emissions.

Emission rates between 2.7 % and 9.9 % (of the amount applied) were measured. This corresponds to what was found by RODHE *et al.* (2004) on clay soil. In the source, a mean value over three years of 4.7 % after surface urine spreading was reported. Also, the reported maximum of 10 % after application of 60 t ha^{-1} urine (approx. 180 kg ha^{-1} N) confirm the maximum values presented in this thesis.

Similar findings were reported by CLEMENS (2007). He measured mean ammonia emissions of 6 % after urine application.

Ammonia emissions from urine spreading seem to be generally lower than those from cattle slurry: LEICK (2003) found 11 % to 40 %, THOMPSON & MEISINGER (2004) between 17 % and 71 % and SOMMER & HUTCHINGS (2001) reported emission rates of 38 % to 45 %. The application of residues from biogas plants led to gaseous ammonia losses of between 13 % and 21 % (GERICKE *et al.,* 2007).

Increased infiltration of the substrate into soil due to low Dry Matter content decreases NH_3-emissions (GERICKE *et al*., 2007). This can explain the relatively low emissions after urine spreading. Urine contains very little Dry Matter that could potentially remain at the soil surface after spreading. The presented experiments demonstrated that the main part of NH_3 is emitted within the first 24 hours after urine surface application. Normally, no solid organic matter from urine that can act as an additional ammonia votalisation source remains above the soil surface.. The kinetics of ammonia emissions can be related to the Dry Matter content of the substrate applied. PACHOLSKI *et al.* (2007) detected longer-lasting emissions with rising DM content. In contrast, slurry with low Dry Matter content generated lower emissions.

The incorporation of urine into soil may further reduce ammonia emissions. This is reported for slurry (SOMMER & HUTCHINGS, 2001) and may also apply to human urine. However, the overall low total emissions may suggest surface spreading without tillage at the time of nutrient demand, when the already established crops prevent tillage operations from being carried out

Pharmaceutical Residues

The presence of pharmaceutical residues in urine raises public concern. This is true for water-borne sewage treatment systems, but would not be less important for

Alternative Sanitation. Very few studies are available that clearly demonstrate the impact of these substances on the environment. New analysing techniques enable the fate of pharmaceuticals to be traced in detail. These recently uncovered the presence of pharmaceuticals in many water bodies that were at some point connected to a sewer. However, this does not allow for an assessment of the hazards involved, as the concentrations detected are actually very low. When source separation is applied, including urine spreading on fields, the means by which pharmaceutical residues enter the environment are different to those of 'conventional' water borne sewage treatment. In urine, these substances are of a far higher concentration than in the system, as there is no dilution with water. The low volume could enable sufficient treatment before application, but as a result of the different decomposing behaviours of the large variety of pharmaceutical agents applied in human medicine, this appears to be a complicated process, or at least highly energy consuming. Consequently, the high concentration of pharmaceuticals in urine could be disadvantageous. On the other hand, urine application transfers residues from medicines into a terrestrial as opposed to aquatic environment, which offers different means of decomposition. At this point, a number of questions arise that are yet to be answered:

What is the chemical fate of pharmaceutical residues in a terrestrial agro-ecosystem?
Does leaching into ground water occur?
Do crops take up these substances?
Are there any long-term effects on soil biota of pharmaceutical residues in urine?

The spatial proximity of pharmaceutical-rich urine to crops after fertilisation, together with the accumulating behaviour of, for example, some cereal crops in the harvested parts, strongly suggest a scientific investigation of the relevant processes involved.

5.3. Acceptance

Sustainable development is impossible without taking into account the feelings and perceptions of people involved. An idea or new technique cannot be implemented successfully without public acceptance. The acceptance is often formed by the information people are exposed to and may not reflect the actual ecological or economical suitability of the idea. Human excreta are generally perceived as dirty, unhygienic, and unhealthy, which makes it difficult to address specific related issues. In addition, the existing water-borne sanitation systems have taken responsibility away from the public. The fact that most people have never been confronted with any questions regarding the fate of our excreta implies (to them) that no problem exists regarding the issue. In this respect, the reply-rate of the farmers' acceptance study (17 %) is an acceptable value, taking into account that no reminder was send (BABBIE, 2001). The limited scope of both studies limits the resulting generalisation and conclusions. For statistically representative studies, the data presented here could be better applied as a pre-study.

When asked a general question, only one quarter of participating farmers expressed a positive attitude towards urine as fertiliser. More than 50 % were unsure and almost one quarter totally refused the idea. Equivalent investigations around Berlin have not been made. However, LIENERT *et al.* (2003) found that a high percentage (57 %) of farmers in Switzerland would accept urine as fertiliser. They also expressed a number of relevant concerns, including the fate of pharmaceuticals in the environment.

Clearly, farmers around Berlin tend to react conservatively when confronted with new ideas. This may be due to bad experiences with sewage sludge. Early advisors recommended its use as fertiliser (CANDINAS, 1989) but today the application is strongly limited and often involves negative publicity. This may have caused farmers to be more cautious as regards new ideas. Furthermore, farmers find themselves being made responsible for a broad variety of environmental concerns (PONGRATZ, 1992).

When asked to give a ranking, the farmers considered legal regulations as well as cost to be the most important factors. In doing so, farmers showed at least some basic knowledge of the present legal status of urine. This, however, also reflects the tense economic situation of many farmers in Germany (BMELV, 2007). The saleability of their products as well as potential hazards resulting from micro-pollutants were ranked lower, but were still more important than logistical issues or the predicted impact to the ecosystem. More than half of the participants considered potential risks resulting from pharmaceutical residues to be one of their three main concerns. This number is higher among farmers in Switzerland than the one found in the quoted study. LIENERT *et al.* (2003) reported that 30 % of the farmers mentioned micro-pollution from pharmaceuticals as a potential problem. The spatial proximity to Berlin may have influenced the answers in this respect. Despite their relative distance from natural issues, urban citizens often feel more general environmental concern.

It may come as a surprise that consumers would widely accept urine fertilisation. This, however, is confirmed by the 80 % acceptance that PAHL-WOSTL *et al.* (2003) found in Switzerland. SCHMIDTBAUER (1996) also reported high acceptance of urine instead of mineral fertiliser in Sweden. It needs to be mentioned that all these investigations were of rather theoretical character, as the implementation of an Alternative Sanitation system was not being put forward as an genuine alternative. Consumers may react more conservatively if they are being asked to make a real choice. Additionally, many consumers are not aware of the complexity of a (conventional) sanitation system and may find it rather difficult to judge the 'details'.

About three quarters of the surveyed consumers expressed concern about the spread of pharmaceuticals "into the environment". This also corresponds with what PAHL-WOSTL *et al.* (2003) found in Switzerland and seems to be one of the major concerns among the public towards the application of urine on fields. The high share may come as a surprise as, presently, no investigations that indicate that traces of pharmaceutical agents (e.g. in drinking water) can pose a risk to human life are known to exist. Actually, very few studies are known that report influences of these trace elements on the aquatic environment. One of the best-known examples may be the gender imbalance of fish living in a waste-water treatment effluent resulting from synthetic estrogens (STUMPF *et al.,* 1996; DESBROW *et al.,* 1998). People obviously feel a general concern about the presence of human-pharmaceuticals in water or soil. This is not related to a personally experienced danger. Also, despite being applied in comparable total amounts, the presence of residues from animal pharmaceutical products does not seem to bother consumers in the same way (FENT *et al.,* 2006).

Beside the expressed concerns, the study also revealed a high willingness among the public to contribute to actions focusing on greater sustainability. This is underlined by the high percentage of participants who would be willing to pay for products deriving from urine fertilisation. Only 11 % limited the theoretical purchase to the case of price equivalence with conventional products. In addition to this, a high number of participants expressed a willingness to eat food produced with urine fertiliser. This corresponds with the low share of people that expressed concern about hygienic issues (12 %). More details and all the results of the study were presented by KRAUSE (2006).

In summary, consumers expressed a broad acceptance of urine recycling with very few practical constraints, but are concerned about the (at the moment rather theoretical) hazards posed by pharmaceuticals.

6. Conclusions

The application of human excreta on agricultural land enables the redirection back to their origins of plant nutrients from the human food chain, therefore closing the matter cycle. The design of sanitary collection systems determines any utilisation of Anthropogenic Plant Nutrients. Not only do the nutrients need to be available in a plant useful form, the presence of artificial and unnecessary substances can represent an additional limitation. Pure human urine to be used as fertiliser can be collected in source separation sanitation systems.

Stored human urine has a fertilising effect that is not different to mineral fertiliser under field conditions. It can be surface-applied at the time when crops are in need of nutrients, as its nitrogen is in plant-available from. It can also be toxic to plants if very high concentrations of urine occur at root surfaces.

When compared to urine, the agricultural importance of faeces is rather low. If composted, it can be used just like comparable products. If hygienisation is ensured prior to land application, other forms of processed faeces (thermo-digested Brownwater) may also be suitable and will promote plant growth.

Due to its physical and chemical characteristics, urine field application can lead to transient environmental damage. In particular, the abundance of earthworms decreases, but rises again as soon as general soil conditions allow reproduction. In management systems using urine as a main fertiliser, their population should be monitored. More intense research is needed concerning the exact mechanism leading to the toxicity effect.

Ammonia emissions resulting from the field application of urine are low.

Many open questions remain regarding the presence of pharmaceutical residues in anthropogenic plant nutrients. These potentially restrict the application. In particular, long-term research is needed regarding the fate and impact of pharmaceuticals in the environment.

In Germany, a re-evaluation of the legal status of human excreta is necessary to adopt present regulations according to new technological developments and the accompanying research findings. The registration of urine as marketable fertiliser would find public acceptance and give farmers the required legal safety.

Fertilising with Anthropogenic Plant Nutrients should be considered as a serious option in developed as well as developing countries.

List of Terms and Abbreviations

ANOVA	Analysis of variance
ATP	Adenosine triphosphate
B	Boron
BBA	Biologische Bundesanstalt
B.C.	Before Christ
Blackwater	Human faeces including flushing water and urine
BraLa	Brandenburgische Landwirtschaftsausstellung
Brownwater	Human faeces including flushing water
BSP	British Sulphur Publishing
C	Carbon
Ca	Calcium
CAN	Calcium Ammonium Nitrate
Cl	Chloride
COD	Chemical oxygen demand
CSIR	Council for Scientific and Industrial Research (South Africa)
DLG	Deutsche Landwirtschafts-Gesellschaft
C_t	Total carbon
DM	Dry matter
DNA	Desoxy-ribonucleic acid
Ds	Deci Siemens
EC	European Commission
EC	Electrical conductivity
ECETOC	European Centre for Ecotoxicology and Toxicology of Chemicals
ECOSAN	Ecological Sanitation
e.g.	Latin: ‘exempli gratia' – for example
FAO	Food and Agriculture Organisation of the United Nations
FAX	Facsimile
G	Grams
GTZ	Gesellschaft für Technische Zusammenarbeit
Greywater	Domestic household waste water originating not from the toilet
H	Hydrogen
Ha	Hectare
IFA	International Fertiliser Association
IWW	Rheinisch-Westfälisches Institut für Wasserforschung
K	Potassium, potash
K_2O	Potassium dioxide
Kg	Kilogram
KTBL	Kuratorium für Technik und Bauwesen in der Landwirtschaft
L	Litre
LAI	Leaf Area Index
LAS	Linear alkylbenzene sulphonates
LUFA	Landwirtschaftliche Untersuchungs- und Forschungsanstalt
m^3	Cubic metre
Mg	Magnesium
Mg	Milligram
Ml	Millilitre
Mm	Millimetre
Mn	Manganese

List of Terms and Abbreviations - continued

N	Nitrogen
Na	Sodium
NaCl	Sodium chloride
NECD	National Emission Ceilings Directive
NIRS	Near infrared spectroscopy
Nm	Nanometre
(NH2)2CO	Urea
NH_3	Ammonia
NH_4^+	Ammonium
N_{min}	Mineral nitrogen
NO_3^-	Nitrate
NO_2^-	Nitrite
NPE	Nonylphenol ethoxylates
NPK	Nitrogen Phosphorus Potassium (Fertiliser)
N_{tot}, N_t	Total nitrogen
O	Oxygen
OECD	Organisation for Economic Co-operation and Development
P	Phosphorus
P_2O_5	Phosphorus pentoxide
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PDA	Potash Development Association
PE	Polyethylene
pH	Potential of hydrogen
P_{tot}	Total phosphorus
S	Sulphur
SAS	Statistical Analysis System
SCST	Sanitation Concept for Separate Treatment
SO_4^-	Sulphate
T	Tonnes
TDR	Time Domain Reflectometer
TPF	Triphenylformazan
TSW	Thousand seeds weight
TTC	Triphenyltetrazolium chloride
UK	United Kingdom
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
US	United States (of America)
VDLUFA	Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten
Mg	Micrograms
%	Percent
°C	Degree Celsius

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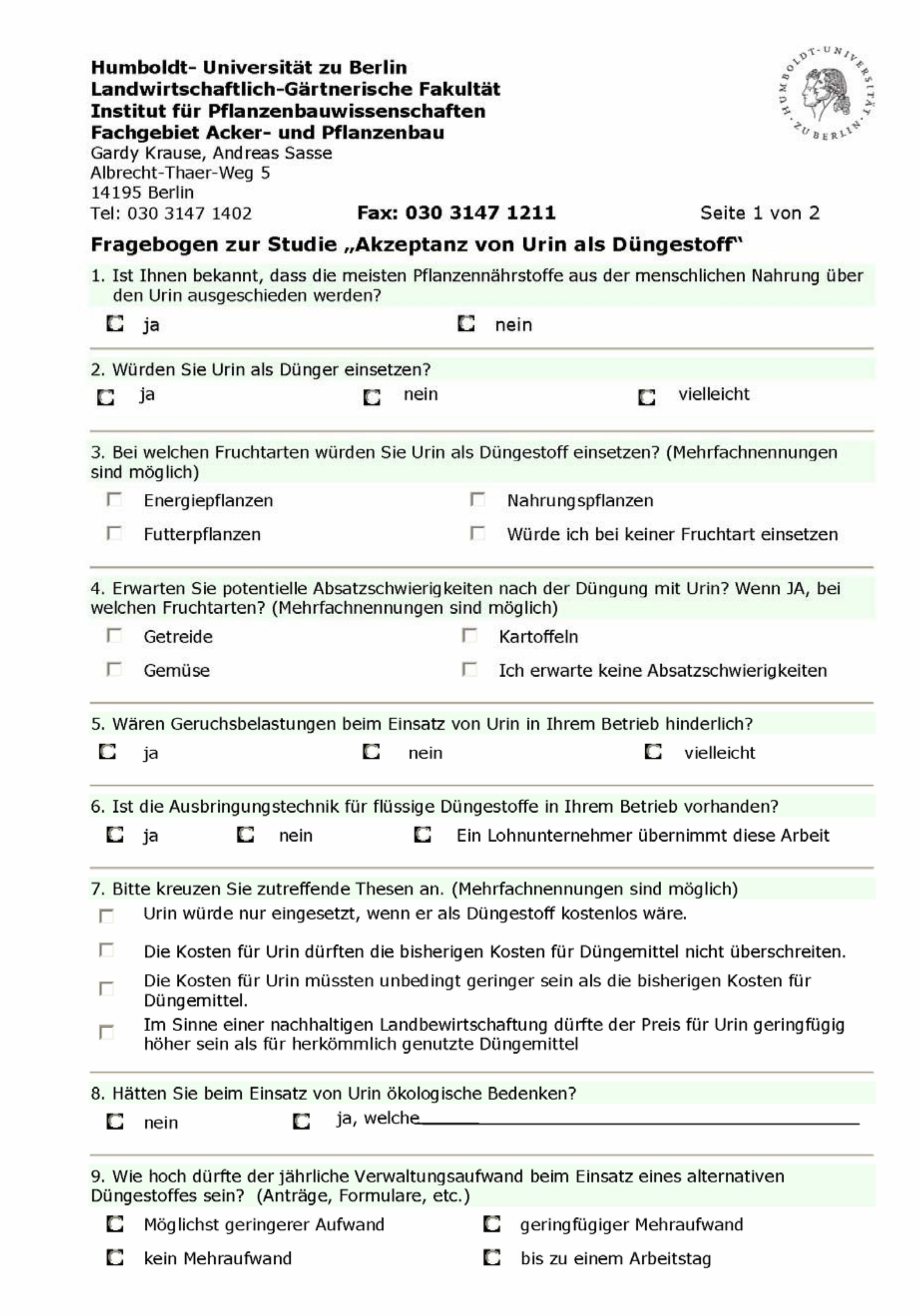
Appendix I

Sowing, pesticide applications and harvest as carried out in the field experiments

Crop	**Date** [mm/dd/yyyy]	**Action, (chemicals used and application rates)**
Winter oilseed rape 2005	08/23/2004	Seedbed preparation and sowing
	09/03/2004	Herbicide application, (BUTISAN TOP: 2.0 l ha^{-1})
	10/05/2004	Fungicide + insecticide application, (FOCUS ULTRA: 2.5 l ha^{-1} + FASTAC SC: 0.1 l ha^{-1} + CARAMBA: 1.5 l ha^{-1})
	04/13/2005	Insecticide application, (ULTRACID 40: 0.6 kg ha^{-1})
	07/29/2005	Harvest
Winter rye 2005	09/20/2004	Sowing
	10/26/2004	Herbicide application, (FENIKAN: 1.0 l ha^{-1})
	05/19/2005	Fungucide application, (AGENT: 1.0 l ha^{-1})
	08/02/2005	Harvest
Spring wheat 2005	04/04/2005	Seedbed preparation and sowing
	04/26/2005	Herbicide application, (ORKAN: 1.0 l ha^{-1})
	08/09/2005	Harvest
Winter oilseed rape 2006	08/24/2005	Sowing
	09/02/2005	Herbicide application (BUTISAN TOP: 2.0 l ha^{-1})
	10/12/2005	Fungicide application (FOLICUR: 1.0 l ha^{-1})
	04/21/2006	Fungicide + insecticide application (CARAMBA: 1.5 l ha^{-1}, KARATE ZEON: 0.075 l ha^{-1})
	04/25/2006	Insecticide application (TRAFO WG: 0.15 kg ha^{-1})
	05/11/2006	Fungicide + insecticide application (CANTUS: 0.1 l ha^{-1}, FASTAC SC: 0.1 l ha^{-1})
	07/13/2006	Harvest
Winter rye 2006	09/22/2005	Sowing
	10/10/2005	Herbicide application (STOMP SC: 1.5 l ha^{-1} + LEXUS: 15 g ha^{-1})
	05/22/2006	Fungicide application (PRONTO PLUS: 1.0 l ha^{-1} + AMISTAR: 0.75 l ha^{-1})
	07/19/2006	Harvest
Spring wheat 2006	04/12/2006	Sowing
	05/11/2006	Herbicide application (U 46 M: 0.75 l ha^{-1} + BASAGRAN: 0.75 l ha^{-1})
	06/06/2006	Fungicide application (AGENT: 1.0 l ha^{-1})
	06/27/2006	Fungicide application (FANDANGO: 1.5 l ha^{-1})
	07/27/2006	Harvest

Appendix II – Questionnaire as used for farmers acceptance study



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Fragebogen zur Studie „Akzeptanz von Urin als Düngestoff"

1. Ist Ihnen bekannt, dass die meisten Pflanzennährstoffe aus der menschlichen Nahrung über den Urin ausgeschieden werden?

☐ ja ☐ nein

2. Würden Sie Urin als Dünger einsetzen?

☐ ja ☐ nein ☐ vielleicht

3. Bei welchen Fruchtarten würden Sie Urin als Düngestoff einsetzen? (Mehrfachnennungen sind möglich)

☐ Energiepflanzen ☐ Nahrungspflanzen
☐ Futterpflanzen ☐ Würde ich bei keiner Fruchtart einsetzen

4. Erwarten Sie potentielle Absatzschwierigkeiten nach der Düngung mit Urin? Wenn JA, bei welchen Fruchtarten? (Mehrfachnennungen sind möglich)

☐ Getreide ☐ Kartoffeln
☐ Gemüse ☐ Ich erwarte keine Absatzschwierigkeiten

5. Wären Geruchsbelastungen beim Einsatz von Urin in Ihrem Betrieb hinderlich?

☐ ja ☐ nein ☐ vielleicht

6. Ist die Ausbringungstechnik für flüssige Düngestoffe in Ihrem Betrieb vorhanden?

☐ ja ☐ nein ☐ Ein Lohnunternehmer übernimmt diese Arbeit

7. Bitte kreuzen Sie zutreffende Thesen an. (Mehrfachnennungen sind möglich)

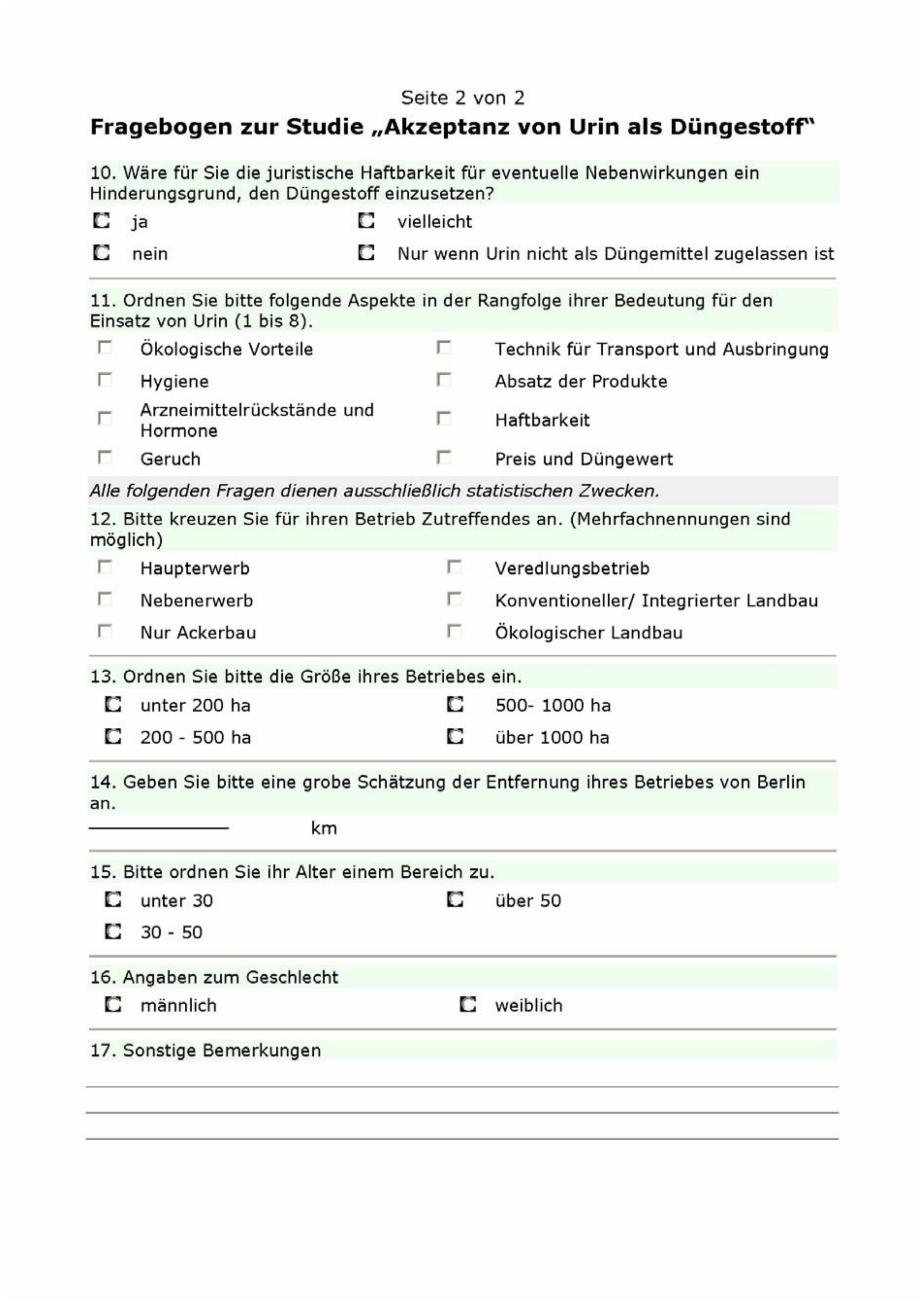
☐ Urin würde nur eingesetzt, wenn er als Düngestoff kostenlos wäre.
☐ Die Kosten für Urin dürften die bisherigen Kosten für Düngemittel nicht überschreiten.
☐ Die Kosten für Urin müssten unbedingt geringer sein als die bisherigen Kosten für Düngemittel.
☐ Im Sinne einer nachhaltigen Landbewirtschaftung dürfte der Preis für Urin geringfügig höher sein als für herkömmlich genutzte Düngemittel

8. Hätten Sie beim Einsatz von Urin ökologische Bedenken?

☐ nein ☐ ja, welche____

9. Wie hoch dürfte der jährliche Verwaltungsaufwand beim Einsatz eines alternativen Düngestoffes sein? (Anträge, Formulare, etc.)

☐ Möglichst geringerer Aufwand ☐ geringfügiger Mehraufwand
☐ kein Mehraufwand ☐ bis zu einem Arbeitstag



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Fragebogen zur Studie „Akzeptanz von Urin als Düngestoff"

10. Wäre für Sie die juristische Haftbarkeit für eventuelle Nebenwirkungen ein Hinderungsgrund, den Düngestoff einzusetzen?

○ ja
○ nein
○ vielleicht
○ Nur wenn Urin nicht als Düngemittel zugelassen ist

11. Ordnen Sie bitte folgende Aspekte in der Rangfolge ihrer Bedeutung für den Einsatz von Urin (1 bis 8).

☐ Ökologische Vorteile
☐ Hygiene
☐ Arzneimittelrückstände und Hormone
☐ Geruch
☐ Technik für Transport und Ausbringung
☐ Absatz der Produkte
☐ Haftbarkeit
☐ Preis und Düngewert

Alle folgenden Fragen dienen ausschließlich statistischen Zwecken.

12. Bitte kreuzen Sie für ihren Betrieb Zutreffendes an. (Mehrfachnennungen sind möglich)

☐ Haupterwerb
☐ Nebenerwerb
☐ Nur Ackerbau
☐ Veredlungsbetrieb
☐ Konventioneller/ Integrierter Landbau
☐ Ökologischer Landbau

13. Ordnen Sie bitte die Größe ihres Betriebes ein.

○ unter 200 ha
○ 200 - 500 ha
○ 500- 1000 ha
○ über 1000 ha

14. Geben Sie bitte eine grobe Schätzung der Entfernung ihres Betriebes von Berlin an.

_______________ km

15. Bitte ordnen Sie ihr Alter einem Bereich zu.

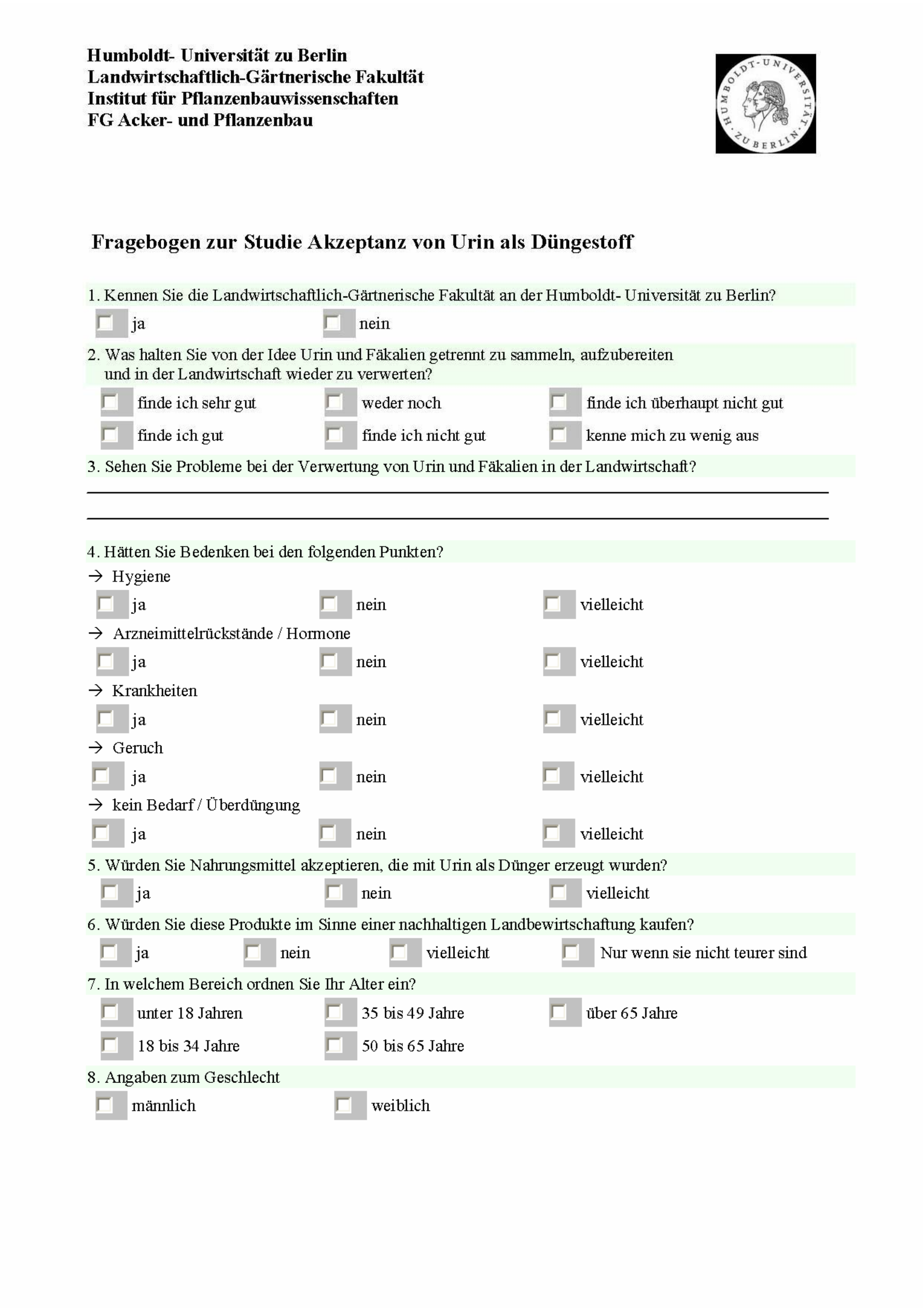
○ unter 30
○ 30 - 50
○ über 50

16. Angaben zum Geschlecht

○ männlich
○ weiblich

17. Sonstige Bemerkungen

Appendix III - Questionnaire as used for consumers acceptance study



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Institut für Pflanzenbauwissenschaften
FG Acker- und Pflanzenbau

Fragebogen zur Studie Akzeptanz von Urin als Düngestoff

1. Kennen Sie die Landwirtschaftlich-Gärtnerische Fakultät an der Humboldt- Universität zu Berlin?

☐ ja ☐ nein

2. Was halten Sie von der Idee Urin und Fäkalien getrennt zu sammeln, aufzubereiten und in der Landwirtschaft wieder zu verwerten?

☐ finde ich sehr gut
☐ finde ich gut
☐ weder noch
☐ finde ich nicht gut
☐ finde ich überhaupt nicht gut
☐ kenne mich zu wenig aus

3. Sehen Sie Probleme bei der Verwertung von Urin und Fäkalien in der Landwirtschaft?

____

____

4. Hätten Sie Bedenken bei den folgenden Punkten?

→ Hygiene
☐ ja ☐ nein ☐ vielleicht

→ Arzneimittelrückstände / Hormone
☐ ja ☐ nein ☐ vielleicht

→ Krankheiten
☐ ja ☐ nein ☐ vielleicht

→ Geruch
☐ ja ☐ nein ☐ vielleicht

→ kein Bedarf / Überdüngung
☐ ja ☐ nein ☐ vielleicht

5. Würden Sie Nahrungsmittel akzeptieren, die mit Urin als Dünger erzeugt wurden?

☐ ja ☐ nein ☐ vielleicht

6. Würden Sie diese Produkte im Sinne einer nachhaltigen Landbewirtschaftung kaufen?

☐ ja ☐ nein ☐ vielleicht ☐ Nur wenn sie nicht teurer sind

7. In welchem Bereich ordnen Sie Ihr Alter ein?

☐ unter 18 Jahren
☐ 18 bis 34 Jahre
☐ 35 bis 49 Jahre
☐ 50 bis 65 Jahre
☐ über 65 Jahre

8. Angaben zum Geschlecht

☐ männlich ☐ weiblich

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