TAMPERE POLYTECHNIC UNIVERSITY OF APPLIED SCIENCES
Environmental Engineering

Final Thesis

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HEAVY METAL TRACES IN GROWING MEDIUM OF BARLEY AND CARROT FERTILISED WITH SEPTIC TANK SLUDGE, URINE AND COMPOSTED FAECES

Supervisor Senior Lecturer Eeva-Liisa Viskari
Commissioned by Tampere Polytechnic University of Applied Sciences
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TAMPEREEN AMMATTIKORKEAKOULU
Environmental Engineering

Ari Laukkanen

Ohran ja porkkanan raskasmetallipitoisuudet saostuskaivolietteellä, virtsalla ja käymäläkompostilla lannoitetuissa kasvualustoissa

Tutkintotyö 68 sivua + 24 liitesivua
Työn valvoja Yliopettaja Eeva-Liisa Viskari
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Hakusanat Raskasmetallit, kadmium, kupari, lyijy, nikkeli, sinkki, ohra, porkkana, sakokaivoliete, saostuskaivoliete, virtsa, ulosteet, kompostoidut ulosteet

TIIVISTELMÄ

Tutkimuksen tarkoituksena oli selvittää lannoitteina käytettyjen saostuskaivokaivolietteen, kompostoitujen ulosteiden sekä virtsan vaikutuksia ohraan ja porkkanaan, joita verrattiin teollisiin lannoitteisiin. Saostuskaivolietteen käsittelyä koskevat uudet määräykset antoivat aiheen tutkia vaihtoehtoisia ja luonnonmukaisempia keinoja käsitellä lietettä joista lietteen käyttäminen sellaisenaan käsittelemättömänä lannoitukseen on yksi. Tärkeimpinä kohdealueina oli tutkia taudinaiheuttajien, ravinteiden ja raskasmetallien kertymistä ja vaikutusta kasveihin. Tämä osio tutkimuksesta keskittyy raskasmetalleihin, kadmiumiin, kupariin, lyijyyn, nikkeliin ja sinkkiin, sekä niiden pitoisuuksiin lannoitteissa, kasvatusalustoissa ja lopullisissa tuotteissa. Analyysimenetelminä käytettiin märkäpolttoa näytteen hajotukseen ja liekki-AAS menetelmää. Lannoitteissa raja-arvo ylittyi vain kadmiumin osalta lietteessä noin 25 %. Kasvatusalustoissa kaikkien muiden raskasmetallien pitoisuudet, paitsi Cd, pysyivät hyvin annettujen raja-arvojen alapuolella. Ohran kasvatusalustan kadmiumpitoisuudet pysyivät raja-arvojen alapuolella, mutta lietteellä lannoitetussa porkkanan kasvatusalustassa raja-arvo ylittyi noin 16 %. Ohrassa kaikki tutkitut raskasmetallit pysyivät annetuissa raja-arvoissa. Lietteellä lannoitetun porkkana Pb pitoisuus ylittyi noin 10 %. Cd raja-arvot ylittyivät kaikissa käsittelyissä. Eräänä syynä tähän voi olla epäilty kasvualustan happamuus, sekä mahdollinen ravinteiden puutos, joka myös hidasti porkkanoiden kasvua. Raskasmetallien haitallisista vaikutuksista tutkittujen kasvien kasvuun ei ole kiistattomia todisteita johtuen muista häiritsevistä tekijöistä. Raja-arvojen perusteella käsittelemätöntä saostuskaivolietettä voidaan käyttää ohran lannoitteena, mutta Cd:n kertymistä olisi tutkittava tarkemmin kenttäkokeilla. Porkkanan osalta lisätutkimukset tarkemmin valvotuissa olosuhteissa olisivat tarpeen, jotta ympäristöstä ja muista tekijöistä johtuvat kasvun ja raskasmetallien kertymisen häiriöt voitaisiin pitää mahdollisimman pieninä.

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ABSTRACT

The aim of this experiment was to study the effects of septic tank sludge, composted faeces and urine used as a fertiliser for barley and carrot. Commercial fertilisers were used as reference. New regulations' concerning septic tank sludge and its handling give a reason to study alternative and more ecological uses for it. Direct application of STS as a fertiliser is one of them. The main study areas were pathogens, nutrients and heavy metals and their transfer and effect to these plants. This part of the study concentrates on heavy metals, cadmium, copper, lead, nickel and zinc, in fertilisers, substrates and final products. Wet digestion and flame AAS was used for determining heavy metals. Limit values for STS as a fertiliser was exceeded only on Cd by 25 %. On growing substrate all other heavy metal concentrations stayed well below limit values except Cd. On substrates for barley limit values of Cd were not exceeded but on substrate for carrot fertilised with STS it was exceeded by 16 %. All studied heavy metals stayed below limit values on barley. On carrot samples fertilised with STS limit value on Pb was exceeding by 10 %. Limit value on Cd was exceeded with all determined fertilisers. One of the reasons for this could be suspected acidity of the substrates and possible lack of nutrients, which also slowed the growth of carrots. There was no indisputable evidence of adverse effect of the studied heavy metals to the growth of barley and carrot caused by other disturbing factors. Concerning limit values, STS can be used as a fertiliser for barley but accumulation on Cd has to be studied more closely in field studies. For carrots more studies should be done in more stable environment to mitigate the disturbances on growth and uptake of heavy metals.

LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrometry
BDL	Below Detection Limit
HDPE	High Density Polyethylene
HM	Heavy Metals
IC	Inorganic Carbon
ISO	International Organization for Standardization
LECA	Light Expanded Clay Aggregate
MTT	Agrifood Research Finland, Maa- ja elintarviketeollisuuden tutkimuskeskus
ND	Not Determined
NGO	Non-Governmental Organisation
PP	Polypropylene
PRC	The People's Republic of China
RH	Relative Humidity
STS	Septic Tanks Sludge; residual sludge from septic tanks and other similar installations for the treatment of sewage
SYKE	Finnish Environment Institute, Suomen Ympäristökeskus
TC	Total Carbon
TOC	Total Organic Carbon
WWTP	Waste Water Treatment Plant

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Today new and stricter regulations and laws concerning the use and disposal of septic tank sludge (STS) are causing potentially expensive and environmentally sensitive problems. It is a problem worldwide but particularly here in Nordic countries caused by the large number of households that are not connected to the main sewage system and economical questions caused by long distances to the nearest waste water treatment plant (WWTP). The population density can be as low as 1–2 people km^{-2} in northern parts when the average is 17 people km^{-2}. It's estimated that 2.2 million people in Finland are using other than public wastewater system. This number includes summer cottages and permanent dwellings. The annual STS production in Finland is about 11 000 tonnes of dry solids per year. The Finnish Environment Institute (SYKE) is assuming that about 10 % of Finnish STS is mixed with manure and spread on cultivated land and about 5 % is composted and used as fertiliser. About 25 % of the sludge is dumped at landfills. The rest is treated at WWTP's and there is an on-going trend to increase treatment of STS. Consumers or NGO's don't oppose the use of sludge in agriculture as long as it is proved to be safe for human health. Authorities and contractors on waste management are concerned about obstacles of recycling sludge and companies are worried about costs and availability of techniques and unclear situation on requirements. Still the major limiting factor and biggest concern when making regulations for using sewage sludge is the potential release of heavy metals (HM) and heavy metal accumulation to toxic levels in top soils. Sewage sludge has good buffering properties but still using sludge as fertiliser may have significant adverse effects upon crop quality and biological soil fertility. The composition of sludge may change due to decomposition of organic matter causing HM previously bound by organic matter release to soil. It is also suggested that with high Cd content on sludge and soil, plants are more likely to have bigger uptake than with lower concentrations because at higher Cd concentrations more Cd occupies weaker cation exchange sites. /18, 29/

All heavy metals in this study are natural components in nature but cause concern when they are added to the soil in large amounts. Some of them are essential to the plants, micronutrients, like copper and zinc, but can still be harmful in excessive

concentrations. The uptake of heavy metals by plants depends greatly on their concentration in soil and also from pH of the soil. Uptake of plants of nutrients and heavy metals take place in ion-form. Usually if soil pH is above 6.5, heavy metal cations are hold strongly adsorbed by negatively charge soil and can't be uptake by plants. At the same time when HM uptake increases caused by decreasing pH, uptake of phosphorus decreases caused by formation of iron and aluminium phosphates. Accumulation of HM is greatest in roots and straws and smallest, 7 % on average of the total uptake of the plant, in grains on cereal plants. This is the case especially with Cd and Zn. Pb is not normally uptake by plants but still most of it is retained in roots. Uptake of HM can be reduced by liming to raise pH above 6.5 or adding organic matter that have the same effect as liming. /12, 19/

The value of human excreta as fertilisers is under valued. One person consumes about 250 kg of cereals per year but at the same time produces amount excreta that can be used as a fertiliser to produce the same amount of cereals. Human urine contains some human pathogens and can be used as such making it more valuable as a fertiliser. Human faeces contains high amount of pathogens and therefore must be treated before use for example by composting it. /28/

The use of STS in agriculture is regulated by European and Finnish directives and regulations. While the Council Directives give framework for national regulations, the national regulations can be stricter and in this case in Finland they are.

European Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, regulates the use of sewage sludge in EU. It states that sewage sludge can have valuable agronomic properties and its use should be encouraged when used correctly and without harming either the quality of agricultural products or soil. It has to be used so that it prevents harmful effect on environment and can be used when it not contradicts Council Directives 75/442/EEC on Wastes and 78/319/EEC on Toxic and dangerous wastes and also takes in consideration Council Directive 75/440/EEC on The quality required of surface water intended for the abstraction of drinking water and Council Directive 80/68/EEC of the protection of groundwater against pollution caused by certain dangerous substances. It limits the concentrations of some HM in soil and sludge

and set time limits when the application of sludge can be take place. Usually treated sludge is used but also untreated sludge can be used when it is worked in to the soil as soon as it is spread or injected. The limit value concentrations of HM in soil are in Table 1 and sludge in Table 2. /23/

At the moment there are proposals for the revision of the Sewage Sludge Directive 86/278/EEC and for a Directive on the biological treatment of biodegradable waste. Here are some of the major points proposed for revising the Directive 86/278/EEC, which are linked to the use of the sludge in agriculture and HM.

- *Whenever possible, the use of sludge on land should be close to the production site to avoid the environmental impacts caused by transport and favour a better control of sludge quality.*

- *The scope should also be extended to non-agricultural land. Use restrictions should be set accordingly, thereby improving the existing situation where only agricultural land is covered.*

- *In order to make effective, in sludge management, the principle contained in Article 174 of the EC Treaty that environmental damage should be rectified at source, Member States could be required to take appropriate measures designed to reduce the amount of pollutants (heavy metals and organic compounds) that end up in the sewer, and therefore in sewage sludge. This measure would constitute an innovation as compared to Directive 86/278/EEC, which had an end-of-pipe approach.*

- *The aforementioned measures could be designed in such a way as to reach the long-term goal of making 75% of urban sludge in principle suitable for land spreading in the whole of the enlarged EU within 20 years. In this context, soil protection is deemed to imply a steady state condition for heavy metal inputs to soils that would guarantee that total background concentrations are not dramatically increased in the long term.*

- *The maximum allowable concentrations for heavy metals in sludge could be lowered. This would allow a reduction of the overall input of heavy metals to the environment in general and the soil in particular. The threshold limits*

should allow the use on land of the majority of sludge produced in the EU with the exception of the most polluted ones.

- *The threshold for heavy metal concentrations in soil could be reduced to better reflect existing soil maximum background concentrations in "natural" agricultural soils. Soils, in particular agricultural soils, are a finite and precious resource and should be protected to the extent possible. The proposed heavy metals threshold in soils would be inherently precautionary and aim at preserving agricultural soil quality, and thus farming opportunities, for future generations.*

- *An important aspect where Directive 86/278/EEC has been found particularly deficient with time is the aspect relative to the sampling and analytical standard methods to be used to measure the parameters (e.g. pH and heavy metal concentrations) mentioned in the Directive. The adoption and the development of European horizontal standards should be promoted for enhancing the comparability of data within and among Member States. In this context, the Commission has actively participated in the setting up of a research consortium called "Horizontal" to which many Member States are also contributing. Main task of this consortium is the elaboration of horizontal standards in the fields of sludge, biowaste and soil. It is expected that the first standards should be available in 2006.* /38/

Ministry of Environment's Government Decision 282/1994 of 14 April 1994 on the use of sewage sludge in agriculture, regulates the use of sewage sludge in Finland. It is based on the EU Directive and promotes the same values and targets for using sludge. It takes in consideration the Water Act (264/1961) and the Public Health Act (469/1965). This decision does not approve the use of untreated sludge and it must be treated with digestion or lime stabilisation or some other method that reduces its pathogens, although there are no limit values attached to this requirement, odours and other negative impact to environment and health. The limit values for heavy metal concentrations in soil and sludge are also stricter than in the EU Directive. The limit value concentrations of HM in soil are in Table 1 and sludge in Table 2. /35/

Table 1. Limit values for concentrations of heavy metals in dry matter in soil.

Trace Element	Limit Values, Dry Matter (mg kg^{-1})	
	EU	Finland
Cadmium	1 to 3	0,5
Copper	50 to 140	100
Lead	50 to 300	60
Nickel	30 to 75	60
Zinc	150 to 300	150

Table 2. Limit values for concentrations of heavy metals in dry matter in sludge.

Trace Element	Limit Values, Dry Matter (mg kg^{-1})	
	EU	Finland
Cadmium	20 to 40	1,5
Copper	1000 to 1750	600
Lead	750 to 1200	100
Nickel	300 to 400	100
Zinc	2500 to 4000	1500

The government Degree on Treating Domestic Wastewater in Areas outside Sewer Networks (542/2003) also limits the use of STS in agriculture quite strictly. Its objective is to reduce domestic wastewater emissions and environmental pollution, giving special consideration to national water protection targets. In Section 9, Use and maintenance of wastewater systems, it states: *The sludge in the wastewater system and the waste accumulated in cesspools (holding tanks) must be transported and treated in accordance with the provisions contained in and issued under the Waste Act (1072/1993).* /34/

Concerning the accumulation of HM in soil long-term field experiment shows that HM have adverse effects to microbial diversity and function of soils. The current upper limit values of Directive 86/278/EEC do not sufficiently protect soil micro-organisms and don't meet criteria for a sustainable development. /37/

Because sewage sludge contains similar quantities of nitrogen, phosphorus and organic matter as farmyard slurry, it is potential and in some amounts also used fertiliser. If the sludge is treated in WWTP's, it increases the price of waste water management. While STS don't contain as much HM as sludge from sewage treatments, which is caused by industrial activities, it clearly limits the usage of the sludge. When examining the sludge use on land, on the waste management hierarchy point of view, it is the best practicable environmental option. It is also the

most affordable and economical method of handling sludge and also one of the most practicable. Still there is the question about the security of the use of sludge on soil, towards the environment and human health. Precautionary measures should also be considered along with how practicable, affordable, sustainable and acceptable the usage is. While heavy metal concentrations in sludge has become lower since Directive 86/278/EEC was implemented they are still not on the level that sludge can be safely applied to soil without regulating it. The agricultural sector needs a secure, long term, supply of nutrients to compensate for losses through uptake by crops. If the limits are set as low as possible and maximum amounts of sludge that can be applied also set low, it will make applying sludge impracticable and not to be worthwhile. The fertiliser and organic value of added sludge becomes too small and cost compared to value inconvenience and associated soil damages too low. The balance between minimising risks to health and inputs to the environment compared to the use of sludge as the most desirable means of managing sludge has to be maintained. Tighter quality standards are essential but they have to be scientifically reasoned. /27/

Recycling and agricultural use is preferred ones for sludge but also health and possible soil contamination caused by pathogens, HM and other contaminants has to be considered. Scientific approach to prove safety of the sludge, resolution about legal questions of using sludge, financial warranties for farmers in case of pollution occurs and social debate is needed. Social debate is important because if the use of the sludge is not accepted by consumers, the farmers have to stop the use of sludge. /33/

Potentially toxic metals in sewage sludge have been studied in the Woburn Market Garden Experiment. Sludge was applied for a period of 20 years followed by almost 25 years with no application. During this experiment they noticed that metals from sludge accumulates in soils and their solubility stays higher for longer periods than native metals; uptake by crops stay high for extended periods, Cd concentrations can exceed EU Regulations in grains even when soils applied with sludge contains just 1 mg kg^{-1} Cd, and metal availability does not decrease with time after sludge application has been stopped. /31/

A field experiment conducted on Alfisols S-W France studied agronomic and environmental impacts of a single application of heat-dried sludge pellets to a maize field. Inorganic fertiliser was used as reference. The sludge was collected from the WWTP of Toulouse. Sludge was dewatered, made as pellets and dried with flash thermal process at 105 ˚C. The heavy metal contents of pellets are in Table 3.

Table 3. Heavy metal contents of the pellets used in the experiment on Alfisol.

Trace Element	Mass Fractions (mg kg^{-1})
Cadmium	1,57
Copper	188
Lead	49,5
Nickel	16,1
Zinc	330

They noticed that average heavy metal contents of the soil remained low and heavy metal input was about 10 % of the maximum cumulative input over 10-year period according French legislation. Finnish regulations are tighter especially concerning cadmium. The greatest amount of metals supplied to the soil by sludge were Cu and Zn. Total biomass was slightly bigger but maize grain yield was about 8 % smaller in crops fertilised with sludge than crop fertilised with inorganic fertiliser. Pb, Ni and Zn content in grains was slightly higher but Cd and Cu content slightly lower than crop fertilised with inorganic fertiliser. They noticed that single application of heat-dried sludge did not have any effect on the heavy metal content of maize. /26/

In a greenhouse experiment using Calciorthid soil (pH 8.77), which is the type most frequently used for agricultural purposes in SE Spain, barley (*Hordeum vulgare*) and three different types of composted sewage sludge mixed with barley straw was made in Spain in 1990's. The Cd contents of the sludge varied from 2–830 mg kg^{-1} so the sludge used can be described as contaminated. They noticed that a high rate of heavy metals, mainly Cd, was reason for decreased grain yields but it did not affect straws. Ni and Cu were not transferring to plants but Zn and Cd were. The study also shows that high pH calcareous mitigated the negative effects of high Cd and other HM containing sludge. /32/

In a 3-year field experiment also carried out in Spain growing barley (*Hordeum vulgare*) fertilised with single application and with 3 cumulative applications of sewage sludge was studied. Total application on both batches was same. They noticed that repeated application of sewage sludge increased grain yield. Using sewage sludge also improved soil chemical, microbiological and biochemical properties, which were increasing barley yield. The results of this study also indicated that low applications of sewage sludge could be used for several years to maintain crop production due to low uptake of HM in that type of soil. But if long-term applications are considered, the significant increase of grain heavy metal concentration should be taken into consideration. /21/

MTT Agrifood Research Finland experimented growing barely with composted sewage sludge in 2000–2002. Results of this experiment were quite similar than in the experiments above. There we no big changes in overall HM contents of soil. Cd content was diminishing towards fall but Zn content was accumulating to the level that could ban the use of sludge as a fertiliser. Biggest changes were caused by weather conditions and not by experiment arrangements, except on Zn. They noticed that when using composted sludge, large amounts of HM are added to the soil, but mostly they are in insoluble form and can't be uptake by plants if the conditions are normal. The grains uptake mostly Zn and Cu, and straws Cd, the uptake of Pb and Ni was not significant and they were left mostly to the soil. /29/

There are also several other studies conducted with treated sewage sludge around the world with similar or comparable results like from Gardiner et al. in USA /25/, Wei and Liu in PRC /36/, Bergkvist et al. in Sweden /20/ and by Frost and Ketchum Jr in USA /24/. All of them concluded that Cd uptake is the biggest problem using sewage sludge as fertiliser but also that other HM are not accumulated to the plants if the pH level is high, like in calcareous soils or if the soil or treated sewage sludge is stabilised with lime treatment to avoid acidification of soil.

The maximum levels of heavy metals in foodstuffs are regulated by Commission Regulation 466/2001 and it sets the limits just to Cd and Pb (mg kg^{-1} wet weight). For other HM studied here there is no determined limit to concentrations. From

those Zn has recommended maximum daily intake value while there are no limitations for Cu and Ni because the limits are high with no normal nutritional way to be achieved. Limit values are in Table 4.

Table 4. Maximum level of heavy metals in cereals and vegetables. /1,22/

Trace Element	Cereals Wet Weight (mg kg^{-1})	Vegetables Wet Weight (mg kg^{-1})
Cadmium	0,1	0,05
Copper	ND	ND
Lead	0,2	0,1
Nickel	ND	ND
Zinc	45*	45*

*Recommended maximum daily intake (mg d^{-1})
ND Not Determined

The object of this greenhouse experiment on cultivating barley and carrot was to study the transfer of heavy metals and nutrients to the plants as well as the adverse effect on soil hygiene and transfer of pathogens to the plants introduced from septic tank sludge, separated urine and composted faeces. This part of the experiment is concentrating on heavy metals.

Use of sewage sludge treated with various methods has been studied quite extensively around the world. The regulations demand it to be treated before using it as a fertiliser. But there is no separation made between sewage sludge from WWTP and from septic tanks. WWTP sludge usually contains larger amounts of heavy metals than STS caused by the industrial load. STS on the other hand is from one or few private households without any industrial load. This makes it potential subject to study if it can be used as a fertiliser without any preconditioning.

This study was conducted in an indoor greenhouse using horticultural peat stabilised with lime to give all subtreatments an equal growing substrate with no previous heavy metal or nutrient loads. This gives more accurate information about the nutrient values of the used fertilisers and uptake of the used plants as well as minimise the effects from previous applications of fertilisers to the results.

2. GROWING EXPERIMENT

2.1. MODEL PLANTS

Barley (*Hordeum vulgare var. Scarlett*) and carrot (*Daucus carota var. Napoli FI*) were used as model plants in this experiment. Carrot seeds were fungicide treated with thiram, iprodiome and metalaxyl.

2.2. TIMETABLE OF THE EXPERIMENT

The preparations for growing experiment were started fall 2005 and preparation of substrates already in the middle of the October. The growing experiment itself was started November 8 2005 when sowing was done and ended February 20 2006 when the carrots were picked up. The timetable of the experiment and all tasks done is in the Table 5.

Figure 1. The Greenhouse inside Tampere Polytechnic University of Applied Sciences.

Table 5. The timetable of the experiment.

Date	Time		Action	End
	Weeks	Days		
12.10.2005	-4	-27	Mixing peat and lime	12.10.2005
04.11.2005	-1	-4	Mixing peat and sand	04.11.2005
07.11.2005	0	-1	Sampling soil samples I	
08.11.2005	0	0	Growing experiment	20.02.2006
08.11.2005	0	0	Sampling of STS	
08.11.2005	0	0	Sowing	
09.11.2005	0	1	Air drying soil samples I	18.11.2005
18.11.2005	1	9	Sieving soil samples I	23.11.2005
25.11.2005	2	17	Singling	28.11.2005
07.12.2005	5	29	TC of soil samples I	
09.12.2005	5	31	Light-dark sequence 19/5	
12.12.2005	6	34	Determination of dry matter soil samples I	13.12.2005
13.12.2005	6	35	Greenhouse door left ajar	08.01.2006
16.12.2005	6	38	Extraction soil samples I, barley	20.12.2005
21.12.2005	7	43	AAS, soil samples I, barley	
28.12.2005	8	50	Extraction soil samples I, carrot	29.12.2005
30.12.2005	8	52	AAS, soil samples I, carrot	
08.01.2006	9	70	Greenhouse door closed	
17.01.2006	11	71	Sampling 30 spikes of barley	
19.01.2006	11	73	Sampling soil samples II, barley	
20.01.2006	11	74	Barley harvested	
02.02.2006	13	87	Sampling 50 carrots	
09.02.2006	14	94	Carrots picked	10.02.2006
16.02.2006	15	101	Sieving soil samples II, barley	
20.02.2006	16	105	Sampling soil samples II, carrot	
22.02.2006	16	107	Sieving soil samples II, carrot	
27.02.2006	17	112	Extraction soil samples II, barley	28.02.2006
01.03.2006	17	115	Extraction soil samples II, carrot	02.03.2006
07.03.2003	18	120	AAS, soil samples II, barley and carrot	
09.03.2006	18	122	Dry mass of barley	
09.03.2006	18	122	Sampling of composted faeces	
09.03.2006	18	122	Dry matter STS	10.03.2006
13.03.2006	19	126	Sieving of composted faeces	
15.03.2006	16	128	TC of STS and composted faeces	
16.03.2006	16	129	Extraction, fertilisers	17.03.2006
30.03.2006	18	149	Mass of 1000 grains	
04.04.2006	19	154	Moisture content of barley	05.04.2006
05.04.2006	19	155	Drying of carrot	07.04.2006
07.04.2006	19	157	Grounding barley and carrot	
10.04.2006	20	160	Extraction barley and carrot	12.04.2006
13.04.2006	20	163	AAS barley and carrot	18.04.2006

2.3. GREENHOUSE

Greenhouse was built indoors to process engineering Hall of Tampere Polytechnic University of Applied Sciences. The size of the greenhouse was (W*L*H) 2.3*5*2.5 m. The temperature was controlled by a fan cooler equipped with a condensation tank. No additional heating was needed because of the indoor location and excess amount of heat supplied by lamps. The experiment was hoped to correspond as much as possible the field conditions of Finnish June. Light periods and temperature maximums were set to match these requirements. The lights were done with six high-pressure 400 W high-pressure sodium lamps. Their luminous intensity was 10000 lx at the level of the substrates. The light–dark sequence was controlled with timer and was 20/4 hours. This was changed after 5 weeks to 19/5 hours to correspond shortening days. The floor was covered with 50 mm thick Styrofoam slabs (expanded polystyrene) under the area where the growth crates were placed to insulate them from below. This was done to avoid the temperature of substrate dropping too low if there would be cold draft below the greenhouse.

2.4. CARE-TAKE OF THE GREENHOUSE AND GROWING CONDITIONS

Greenhouse was taken care of generally in one week shifts. Some exceptions were due to holidays and other personal reasons.

Irrigation was done with a watering can and for carrots later with a bottle. Also underground irrigation was used from time to time. Growth crates were irrigated several times a week with no predetermined amounts or schedules. The amounts and irrigation schedules were adjusted by monitoring moisture of substrates. If excess moisture was noticed irrigation was diminished. If water appeared in under drains irrigation was suspended until substrate was dry enough to continue irrigation.

Fungal growth appeared in several substrates due to excess irrigation. Fungi were eliminated by diminishing or suspending irrigation for these substrates until they dried enough.

Five brandling worms (*Eisenia fetida*) were used per crate to loosen substrates soil composition.

Due to the heat produced by lights plants' length grew fast yet strength didn't. Watered down growth regulator was sprayed to barley twice to add strength. Carrots were mulched to add strength.

When plants had developed more growth they began lodging due to the weakness of stems. For barley supportive netting was set by heaving the seedlings through it. Netting hindered further lodging of barley. Mulching of carrots strengthened stems and prevented lodging only for a while. When carrot stems were noted to lodge again a bottle was used for irrigation and it was concentrated between the seedling rows.

Fan cooler thermostat was set in the beginning of growing experiment to 17 ˚C. Because the thermostat was unable to cool down the greenhouse efficiently enough the thermostats optimum temperature was dropped first to 15 ˚C and then to 13 ˚C. Excess heat was a major problem in the growing experiment. Greenhouse was ventilated in December first so that greenhouse door was left open during measurements. During week 6, greenhouse door was decided to be left open until temperature cools down. 3 weeks later door was decided to be kept shut because it was unclear if ventilation was compounding or amending the temperature levels.

2.5. MEASUREMENTS

Temperature was measured at least once a workday (Mon to Fri) excluding bank holidays. Temperature was measured with three different meters; digital centigrade thermometer; analogous centigrade thermometer and substrate centigrade thermometer. Digital centigrade thermometer showed not only the current temperature but also minimum and maximum temperatures since the last measurement.

Air humidity was measured with two gauges, Vaisala digital RH meter and analogous RH hair meter. All measurements and other notes were written in a greenhouse diary, which included also water amounts used for irrigation.

Information of the highest and lowest measured values of temperature and moisture in the greenhouse during the growing experiment are in Table 6.

Table 6. Highest and lowest measures of temperature and moisture from greenhouse in each category.

	T_{wall} (°C)	$T_{digital}$ (°C)	T_{max} (°C)	T_{min} (°C)	$T_{substrate}$ (°C)	RH (%)	RH_{hair} (%)
Lowest Value	20	19,7	22,2	12,5	16,7	21,8	27
Highest Value	26	29,5	30,3	28,9	29,8	75,2	95

2.5.1. TEMPERATURE

Highest temperature during the growing experiment, 30.3˚C, was measured December 9 2005 at 9 AM. Lowest temperature, 12.5˚C, was measured December 22 at 4 PM.

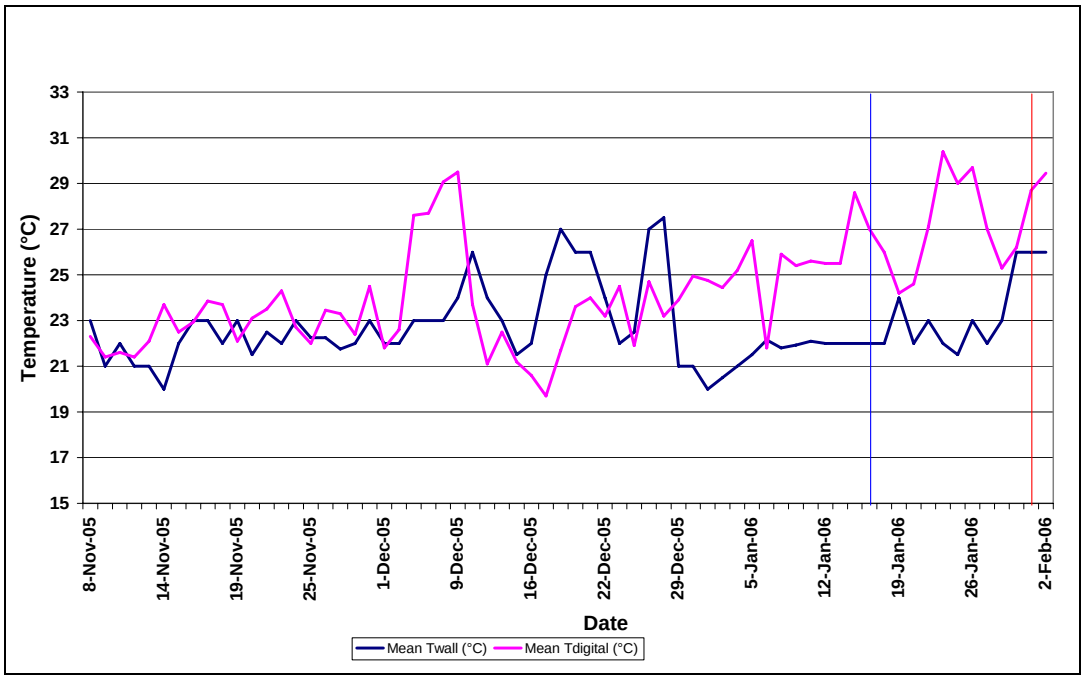

Figure 2. Greenhouse temperature variation during growing experiment.

2.5.2. RELATIVE HUMIDITY

Highest relative humidity during the growing experiment, 75.2 % was measured December 30 2005 at 3:35 PM. Lowest RH, 21.8 % was measured January 20 2006, the day the growing experiment ended.

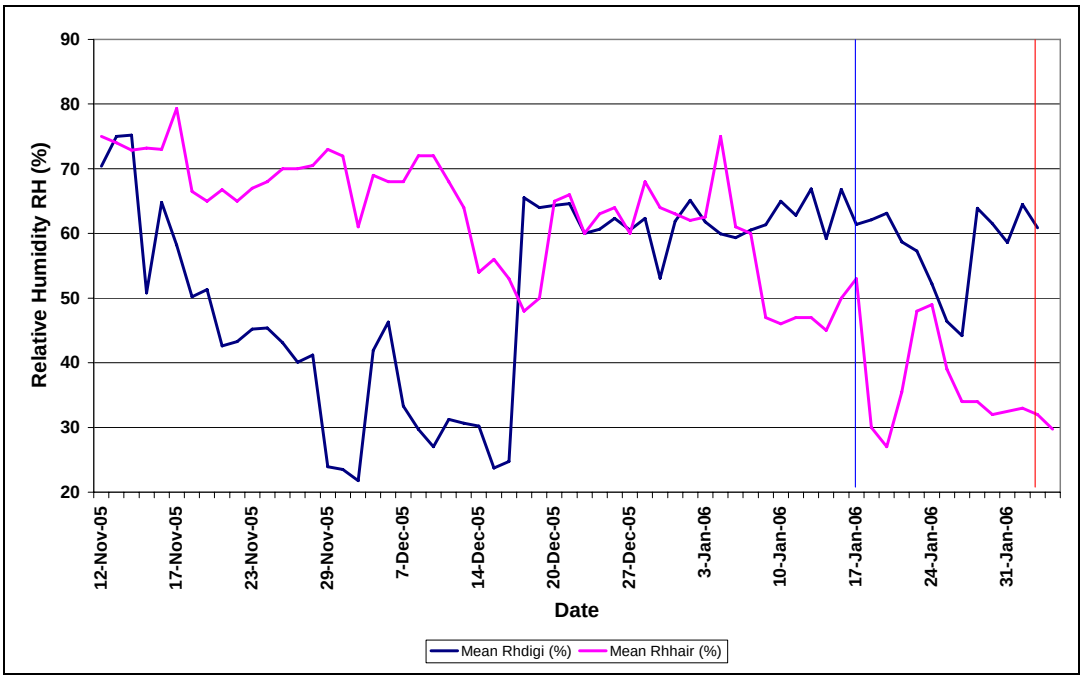

Figure 3. Greenhouse relative humidity (RH) variation during growing experiment.

Greenhouse diary with detailed report of actions can be found in Appendix 1.

2.6. SUBSTRATES

The substrate was made by mixing 2 m^3 of Biolan unfertilised horticultural peat pH 3.5, density 65 g l^{-1}, particle size >35 mm, country of origin Finland, 6 kg of lime was added per m^3 to adjust pH and 0.66 m^3 of sand. particle size 2–6 mm. Lime was added outdoors on a tarpaulin to the peat 4 weeks before starting the growing experiment to stabilise the pH of acidic peat. Mixing was done manually by spreading the lime over the peat and turning it over several times with spades. The mixed peat was left outside under the tarp. Three weeks later 0.66 m^3 of sand was mixed to the peat to improve substrate's aeration properties with the same method mentioned above.

Figure 4. Mixing substrate and lime outside.

Plastic crates, made from HDPE, size (W*L*H) 0.26*0.76*0.25 m were used as growth crates. The volume of one crate was 0.1064 m^3. Plastic drainage pipes, 80 mm diameter PP plastic, were put to two corners of a crate to ensure adequate aeration of the substrate. This was also a preventive act in order to control possible excessive irrigation of substrates. A 50 mm thick layer of LECA gravel was added to the bottom of the crates for aeration and under drain purposes. Different substrates were added on top of the LECA gravel and tightened so that every crate was full to 10 mm below the rim. This was done because the substrate was expected to become tighter caused by watering and its own weight. There were total of 16 crates in the greenhouse, 8 for carrot and 8 for barley. We used 2 parallel treatments of both barley and carrot: commercial fertilisers, Kevätviljan Y3 -fertiliser for barley; Puutarhan kevät -fertiliser for carrot; 2 for separated urine; 2 for composted human faeces, collected from private households and 2 for STS, collected from private households in municipality of Kangasala. The placement of the crates is in Figure 5.

Barley Fertiliser I	Barley Fertiliser II	Barley Faeces I	Barley Faeces II	Barley Urine I	Barley Urine II	Barley STS I	Barley STS II
							Door
Carrot Fertiliser I	Carrot Fertiliser II	Carrot Faeces I	Carrot Faeces II	Carrot Urine I	Carrot Urine II	Carrot STS I	Carrot STS II

Figure 5. Placement of the crates in the greenhouse.

Figure 6. Greenhouse with cooling unit and substrates ready for sowing.

The amounts of fertilisers were determined based on the recommendation for the commercial fertilisers. Recommendation for Kevätviljan Y3 -fertiliser is 500 kg/100,000 m^2 and for Puutarhan kevät -fertiliser 8 kg/100 m^2. The nitrogen content was used as a determining factor in calculations for other fertilisers. The

amount of nitrogen in Kevätviljan Y3 -fertiliser is 20 % and in Puutarhan kevät -fertiliser 8 %. The nutrient concentrations in percentage of weight are presented in Table 7.

Table 7. Nutrient concentrations of the fertilisers on percentage of weight.

Nutrient	Puutarhan kevät	Kevätviljan Y3
Total Nitrogen (N)	8,00	20,00
Ammonium Nitrogen (NH_4N)	5,50	11,40
Nitrate Nitrogen (NO_3N)	N/A	8,60
Phosphorus (P)	2,50	3,00
Phosphorus, water soluble (P)	4,00	2,80
Potassium (K)	3,40	8,00
Magnesium (Mg)	14,00	0,50
Sulphur (S)	2,00	3,00
Boron (B)	8,00	0,02
Copper (Cu)	0,07	N/A
Iron (Fe)	0,05	N/A
Manganese (Mg)	0,35	N/A
Molybdenum (Mo)	0,01	N/A
Selenium (Se)	N/A	0,001
Zinc (Zn)	0,05	N/A

The area of a crate was 0.8 m *0.6 m = 0.48 m^2 and two crates were used for one treatment thus the total area for one treatment was 0.96 m^2. The amount of Kevätviljan Y3 -fertiliser amount was calculated:

$$\frac{500kg}{100000m^2} = \frac{x}{0.96m^2}$$
$$\Leftrightarrow x = \frac{500kg * 0.96m^2}{10000m^2}$$
$$\Leftrightarrow x = 0.048kg \approx \underline{\underline{48g}}$$

The amount of nitrogen was calculated:

$$48g * 20\% = \underline{\underline{9.6g}}$$

The amount of Kevätviljan Y3 -fertiliser was calculated:

$$\frac{8kg}{100m^2} = \frac{x}{0.96m^2}$$
$$\Leftrightarrow x = \frac{8kg * 0.96m^2}{100m^2}$$
$$\Leftrightarrow x = 0.0768kg \approx \underline{\underline{76.8g}}$$

The amount of nitrogen was calculated:

$$76.8g * 8\% = \underline{\underline{6.144g}}$$

Human produce 5.7 kg of nitrogen, 0.6 kg phosphorus and 1.2 kg of potassium yearly. This means approximately 500 kg of urine and 50 kg of faeces. 90 % of the nitrogen is secreted with urine and 10 % with faeces. When faeces are composted they are mixed with equal amount of mixture compound bringing the total up to 100 kg. /28/

The nitrogen content of faeces was calculated:

$$\frac{5700g * 10\%}{100kg} = \underline{\underline{5.7g * kg^{-1}}}$$

The amount of composted faeces for barley was calculated:

$$9.6g = x * 5.7g * kg^{-1}$$
$$\Leftrightarrow x = \frac{9.6g}{5.7g * kg^{-1}}$$
$$\Leftrightarrow x = \underline{\underline{1.684kg}}$$

The amount of composted faeces for carrot was calculated:

$$6.144g = x * 5.7g\ kg^{-1}$$
$$\Leftrightarrow x = \frac{6.144g}{5.7g\ kg^{-1}}$$
$$\Leftrightarrow x = \underline{\underline{1.078kg}}$$

The nitrogen content of separated urine was calculated:

$$\frac{5700g * 90\%}{500kg} = \underline{\underline{10.26g\ kg^{-1}}}$$

The amount of separated urine for barley was calculated:

$$9.6g = x * 10.26g\ kg^{-1}$$
$$\Leftrightarrow x = \frac{9.6g}{10.26g\ kg^{-1}}$$
$$\Leftrightarrow x = \underline{\underline{0.936kg}}$$

The amount of separated urine for carrot was calculated:

$$6.144g = x * 10.26g\ kg^{-1}$$
$$\Leftrightarrow x = \frac{6.144g}{10.26g\ kg^{-1}}$$
$$\Leftrightarrow x = \underline{\underline{0.599kg}}$$

According to Oksjoki (2004), the average amount of nitrogen in STS is 44 g l^{-1}. /13/

The amount of STS for barley was calculated:

$$9.6g = x * 0{,}44g\ l^{-1}$$
$$\Leftrightarrow x = \frac{19{,}2g}{0{,}44g\ l^{-1}}$$
$$\Leftrightarrow x = \underline{\underline{21.8l}}$$

The amount of STS for carrot was calculated:

$$6.144g = x * 0{,}44g\ l^{-1}$$
$$\Leftrightarrow x = \frac{6.144g}{0{,}44g\ l^{-1}}$$
$$\Leftrightarrow x = \underline{\underline{13.964l}}$$

Barley and carrot crates with commercial fertiliser treatment were filled up with arrant substrate without addition of fertilisers. The fertilisers were added later along side with the seeds. For barley and carrot fertilised with composted human faeces and STS the substrates were mixed with calculated amount of fertilisers before filling the crates. The mixing was done on a tarpaulin inside the process hall. For barley and carrot fertilised with separated urine the crates were filled first with the substrate and afterwards the urine, mixed up to 5.5 l with water, was added. All crates were irrigated, except the ones fertilised with STS, to have the same moisture content in all crates. The amounts of fertilisers and water added are in Tables 8 and 9.

Table 8. Fertiliser type and amount and water added to barley crates.

BARLEY *Hordeum vulgare var. Scarlett*			
Crate	**Fertiliser**	**Amount/Crate**	**Water Added/ Crate**
Fertiliser I	Kevätviljan Y3	24 g	11 l
Fertiliser II			
Faeces I	Composted Faces	842 g	11 l
Faeces II			
Urine I	Separated Urine	468 g	up to 11 l
Urine II			
STS I	Septic Tank Sludge	11 l	None
STS II			

Table 9. Fertiliser type and amount and water added to barley crates.

CARROT *Daucus carota var. Napoli F1*			
Crate	**Fertiliser**	**Amount/Crate**	**Water Added/ Crate**
Fertiliser I	Puutarhan kevät	38,4 g	11 l
Fertiliser II			
Faeces I	Composted Faces	539 g	11 l
Faeces II			
Urine I	Separated Urine	300 g	up to 11 l
Urine II			
STS I	Septic Tank Sludge	7 l	4 l
STS II			

2.7. SOWING

The sowing was done on November 8 2005. Barley was planted to 6 rows in depth of approximately 10 mm to all 8 substrates. The seeds were pressed against the substrate to ensure their stay covered. The sowing was done quite dense to ensure sufficient amount of seedlings to germinate. For commercial fertiliser 7 rows were made on sides of the sowing rows and the fertiliser was planted evenly in depth of approximately 20 mm.

Carrots were planted to 5 rows in depth of approximately 5 mm to the rest of the 8 substrates. The sowing was done quite dense to ensure sufficient amount of seedlings to protrude. For commercial fertiliser 6 rows were made on sides of the sowing rows and the fertiliser was planted evenly in depth of approximately 20 mm.

Figure 7. Sowed carrot seeds with fertilisers applied on sides of the planted seeds.

All substrates were tightened evenly with hands to ensure a better contact with seeds to the soil and to avoid possible pooling of irrigation water.

2.8. SINGLING

Singling was done two weeks after sowing. Carrot seedlings were singled out with tweezers so that there was left about 6–7 seedlings per 10 cm. Barley was singled out with hands and tweezers so that there was left about 6 seedlings per 10 cm.

Figure 8. Singling barley.

2.9. CROP YIELD

In general the control substrates fertilised with artificial fertilisers grew fastest and produced highest yield. All eight barley treatments starting from the closest one: STS II, STS I, Urine II, Urine I, Compost II, Compost I, Fertiliser II and Fertiliser I can be seen in Figure 9. The six closest ones are clearly shorter and ripened earlier than two commercial fertiliser treatments in the back. Both of them are also longer and producing longer spikes.

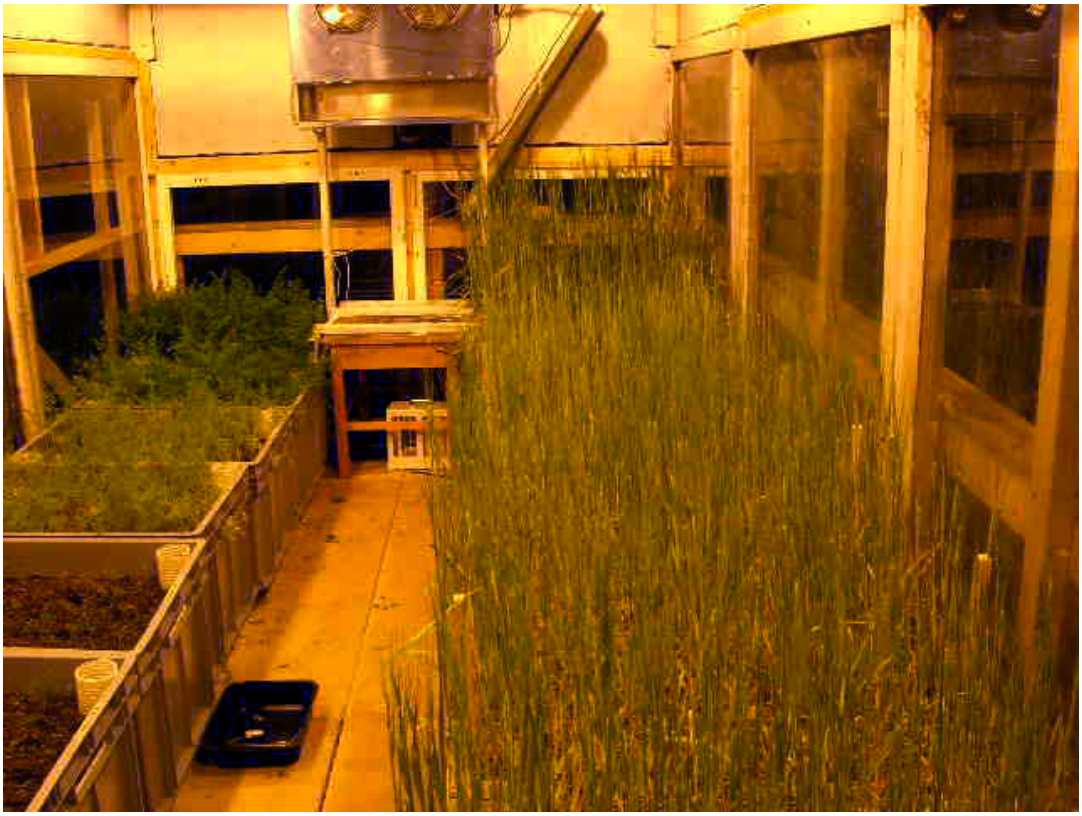

Figure 9. STS, urine and composted faeces treatments of barley in front. Clearly longer and greener commercial fertiliser treatment is farthest back.

All 8 carrot treatments starting from the closest one: STS II, STS I, Urine II, Urine I, Compost II, Compost I, Fertiliser II and Fertiliser I can be seen in Figure 10. The four closest ones, STS and urine treatments, are not crowing lot of tops and are visibly suffering. Next two, fertilised with compost, are growing better and producing healthier looking tops, which are little bit pale. Last two treatments, commercial fertiliser, are doing quite well producing healthy looking green tops.

Figure 10. STS and urine treatments of carrot are in the front. Better grown composted faeces treatment behind them and farthest back the greenest and best grown commercial fertiliser treatment.

Following yield descriptions were reported by laboratory engineer Seija Haapamäki; carrot yield description February 2 2006, barley yield description January 17 2006.

2.9.1. CARROT YIELD

Carrot yield was best in control substrates with artificial fertilisers. Tops were the greenest and largest yet lanky and lodged.

Carrot tops in substrates fertilised with composted human faeces were the second largest but with a clear difference to control substrates. Tops were firmer than with control substrates which necessitated to no lodging. Colour of tops was yellowish green.

Human urine fertilised substrates showed the weakest yield. Tops were stunted and coloured dark, reddish and lilac. Top length was only around a couple of

centimetres. Growth was weak and ceased fully after the first couple of weeks of growing experiment.

Human STS fertilised substrates showed a larger yield than with human urine. Tops were a couple of centimetres longer than with human urine but stunted compared to growth fertilised with composted human faeces. Colour of tops is more yellowish than with composted human faeces fertilised growth but greener than with human urine fertilised growth. Human STS fertilised substrates seemed to get growth going better on the last couple of weeks of growing experiment.

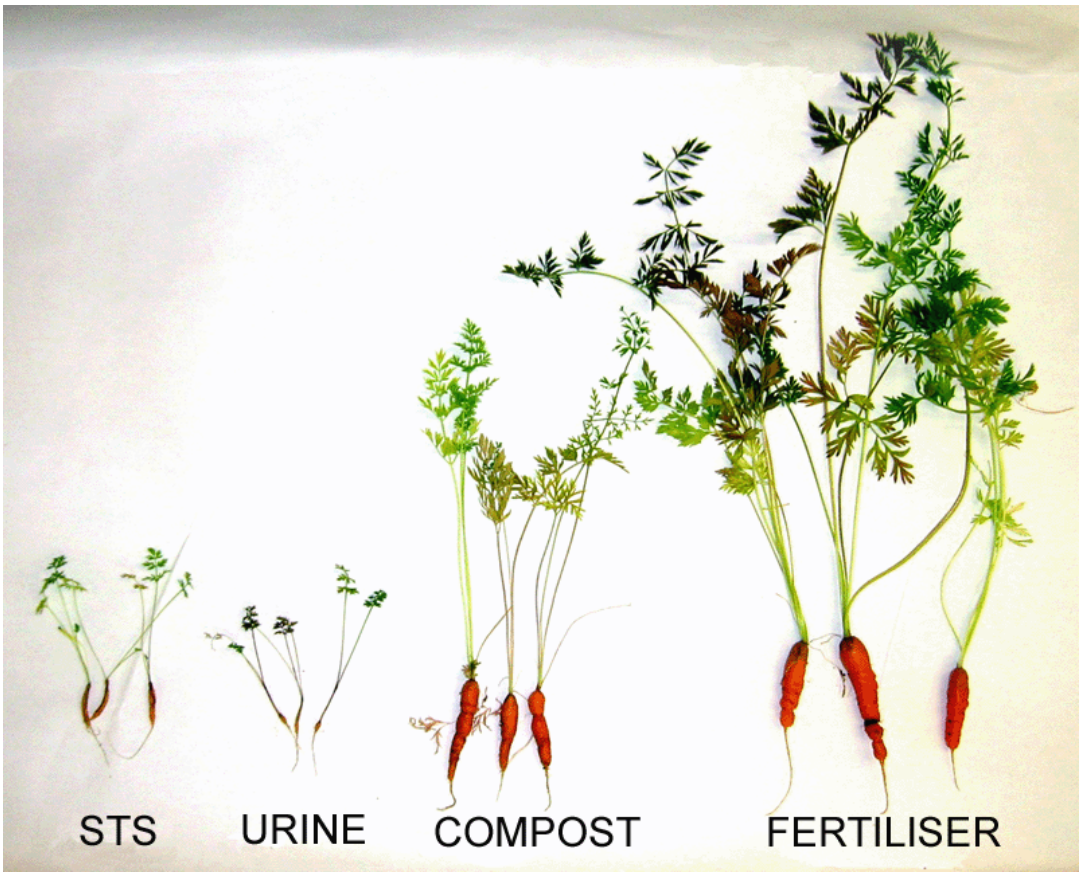

Figure 11. Carrots grown with STS, separated urine, composted faeces and commercial fertiliser.

The colour of oven dried and ground samples from different treatment gives also a clue how carrots were growing. The colour of the samples from fertiliser and compost treatments have healthy orange colour. The colour of samples from urine and STS treatments is not orange but greyer while urine treatment is almost colouring of the substrate.

Figure 12. Oven dried and ground carrot samples. In the middle compost I. Starting clockwise from 12 o'clock: fertiliser I, urine I, compost II, STS I, fertiliser II, STS II and urine II.

2.9.2. BARLEY YIELD

Least ripened spikes were in control substrates. Approximately one fourth of spikes were ripened, overall colour of spikes were green.

Most ripened spikes were in human urine and human STS fertilised substrates. According to colour about four fifth of spikes were ripened.

In composted human faeces fertilised substrates about one half of spikes were ripened.

Ripeness of different barley treatment can be seen from the colour of air dried and ground samples. Fertiliser treatment is visibly green while others have normal colour of wholemeal flour.

Figure 13. Air dried and grinded barley samples: fertiliser I, compost I, urine I and STS I.

3. METHODS FOR SUBSTRATES AND FERTILISERS

3.1. SAMPLING AND PRETREATMENT OF SUBSTRATES

Pretreatment of soil samples from substrates was done according to the international standard ISO 11464. Sampling was done in the beginning and in the end of the experiment. Two samples were taken from every substrate. A-sample was taken from the front of the crate and B-sample from the rear of the crate, Figure 14. When sampling in the beginning took place, commercial fertilisers were not added to the substrates yet. This was done since there would have not been enough time to fertilisers to mix with substrates and it would have given too much variation in the determination of HM. This also gave heavy metal concentrations of the substrate itself. All samples were bagged and tagged accordingly. /8/

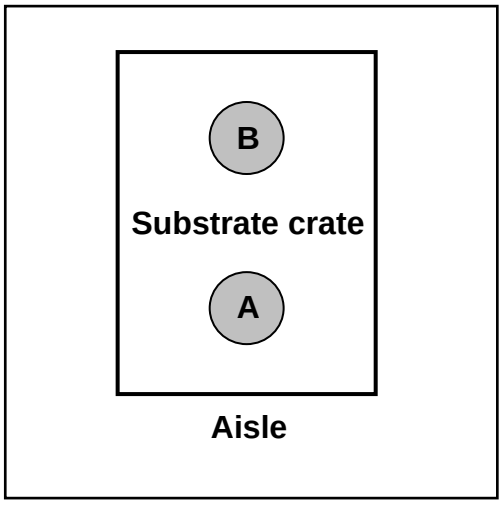

Figure 14. Sampling places in substrate crates.

Samples were placed on plastic trays for air drying. The sample layers thickness was below 15 mm. At this point larger stones and sticks were removed. Both samples, A and B, were placed on same tray with 3 cm gap separating them from each other during first sampling. During second sampling samples were placed in separate trays. Trays were placed on top of the cabinets in environmental technology laboratory away from direct sunlight. Air temperature in the room was +20±2 ˚C. During drying bigger clods that were still on sample trays were broken up and the samples mixed for thorough drying.

Sieving of the samples was done when samples were dried thoroughly. Mesh sieve of 4 mm was used to get bigger clods of organic matter separated. Mesh sieves of 2 mm and 250 µm were used to sieve the samples to required size. Used samples were weighted with a balance before sieving. Samples were sieved in a mechanical shaker for 10 minutes; coarser material removed and sieved sub samples weighted with an analytical balance. Sieved subsamples were united because the amount of finer part was not big enough for analysis. When sieving second samples 250 µm mesh was not used and sieving time was reduced to 5 minutes. Weights of the samples before and after sieving are in Tables 10 and 11.

Figure 15. Sieving with mechanical shaker.

Table 10. Weights of the first substrate samples before and after sieving.

Sample	Weight (g)	
	Total	< 2 mm
Barley, substrate, IA	192,5	138,149
Barley, substrate, IB	147,5	123,487
Barley, substrate, IIA	224,5	187,793
Barley, substrate, IIB	161,5	131,989
Carrot, substrate, IA	141,5	115,627
Carrot, substrate, IB	175,0	142,994
Carrot, substrate, IIA	179,5	147,520
Carrot, substrate, IIB	147,0	119,424
Barley, compost, IA	158,5	131,554
Barley, compost, IB	152,5	124,784
Barley, compost, IIA	151,0	125,405
Barley, compost, IIB	157,0	131,182
Carrot, compost, IA	171,0	134,659
Carrot, compost, IB	133,0	103,209
Carrot, compost, IIA	134,0	106,849
Carrot, compost, IIB	205,0	168,682
Barley, urine, IA	200,0	163,959
Barley, urine, IB	177,5	151,226
Barley, urine, IIA	177,0	149,727
Barley, urine, IIB	153,0	127,561
Carrot, urine, IA	176,0	146,483
Carrot, urine, IB	181,0	151,812
Carrot, urine, IIA	203,0	172,730
Carrot, urine, IIB	176,5	175,961
Barley, STS, IA	133,5	104,917
Barley, STS, IB	117,5	95,235
Barley, STS, IIA	103,0	80,633
Barley, STS, IIB	144,0	116,053
Carrot, STS, IA	153,5	124,260
Carrot, STS, IB	134,5	107,097
Carrot, STS, IIA	129,0	103,156
Carrot, STS, IIB	125,5	101,469

Table 11. Weights of the second substrate samples before and after sieving.

Sample	Weight (g)	
	Total	< 2 mm
Barley, fertiliser, IA	283,0	241,539
Barley, fertiliser, IB	321,0	271,202
Barley, fertiliser, IIA	459,5	384,000
Barley, fertiliser, IIB	374,0	308,851
Carrot, fertiliser, IA	479,5	396,481
Carrot, fertiliser, IB	533,5	415,267
Carrot, fertiliser, IIA	745,0	556,041
Carrot, fertiliser, IIB	476,5	371,079
Barley, compost, IA	440,0	372,499
Barley, compost, IB	568,0	484,041
Barley, compost, IIA	511,5	425,975
Barley, compost, IIB	478,0	400,909
Carrot, compost, IA	590,5	461,603
Carrot, compost, IB	541,0	420,470
Carrot, compost, IIA	562,5	448,690
Carrot, compost, IIB	542,5	422,154
Barley, urine, IA	600,0	512,717
Barley, urine, IB	496,0	423,462
Barley, urine, IIA	594,5	512,012
Barley, urine, IIB	463,5	394,026
Carrot, urine, IA	825,0	647,354
Carrot, urine, IB	663,5	531,500
Carrot, urine, IIA	683,5	563,259
Carrot, urine, IIB	623,5	519,251
Barley, STS, IA	407,0	316,283
Barley, STS, IB	368,5	291,100
Barley, STS, IIA	445,5	350,088
Barley, STS, IIB	357,5	283,199
Carrot, STS, IA	520,0	380,791
Carrot, STS, IB	364,0	256,595
Carrot, STS, IIA	359,0	265,257
Carrot, STS, IIB	237,0	179,616

3.2. SAMPLING AND PRETREATMENT OF FERTILISERS

Sampling and preservation was done according standard SFS 3044. Sampling of STS was done in the beginning of the experiment. 1 l of STS was sampled from the well shaken batch of sludge used. 10 ml of 7 M HNO_3 was added and the sample was preserved in refrigerator for further analysis. /15/

Separated urine was stored in the air tight container it was collected to. No further preservative measurements were done to it.

Two samples from the batch of composted faeces were collected in the end of the experiment and pretreatment according to the international standard ISO 11464. The wet weights of the samples were 660 g for sample 1 and 780 g for sample 2. Samples were dried on plastic trays in a fume cupboard for faster drying and avoidance of odours in laboratory premises in environmental technology laboratory. /8/

Sieving was done after the samples were thoroughly dry with the same method used for soil samples and the weights before and after sieving are in Table 12.

Table 12. Weights of the composted faeces samples before and after sieving.

Sample	Weight (g)	
	Total	< 2 mm
Compost 1	134,5	29,709
Compost 2	164,5	30,149

3.3. DETERMINATION OF DRY MATTER OF SUBSTRATES

The determination of dry matter and water content on a mass basis was done according to the international standard ISO 11465. Determination was done from four selected samples from first sampling of carrot substrates: fertiliser IA, compost IA, urine IA and STS IA. It was expected that substrates are homogenous and fertilisers are not making any significant changes. The temperature used for drying the samples was 50 ˚C because samples were high in organic matter and they could decompose in higher temperatures. /9/ Dry matter and the water contents are shown in Table 13.

Table 13. Dry matter and water content in selected samples.

Sample	Dry Matter Content (%)	Moisture Content (%)
Fertiliser 1A	99,33	0,68
Faeces 1A	99,36	0,64
Urine 1A	99,62	0,39
STS 1A	99,18	0,82
Avg.	**99,37**	**0,63**

The average amounts were used in calculations.

3.4. DETERMINATION OF DRY MATTER OF FERTILISERS

Determination of dry matter of STS was done according SFS Standard SFS-EN 12880. Determination was done from two parallel samples of pretreated STS. About 100 mg of sludge was used for determining the dry matter content. /16/ Masses, dry matter and water contents are shown in Table 14.

Table 14. Dry matter and water content in STS samples.

Sample	Dry Matter Content ($g\ kg^{-1}$)	Moisture Content ($g\ kg^{-1}$)
STS 1	31	969
STS 2	32	968
Avg.	**31**	**969**

According to these results two parallel samples of STS was dried to get enough pretreated STS for *aqua regia* extraction. The weights of STS and estimated dry matter are in Table 15.

Table 15. Wet weights and estimated dry weights of STS samples.

Sample	Wet weight (g)	Estimated dry weight (g)
STS 1	163,9	5,1
STS 2	160,7	5,0

The dry matter content of composted faeces was not determined because after drying it in fume cupboard dry matter content was expected to be close to 100 %.

3.5. DETERMINATION OF TOTAL CARBON OF SUBSTRATES

Determinations of TC were done according the International Standard ISO 10694. TC was measured because in extraction of trace elements soluble in *aqua regia* -method, standard ISO 11466, the amount of HNO_3 used in extraction is sufficient only for oxidation of about 0.5 g of organic carbon /6,10/. Only TC was measured first because TOC cannot be higher than TC and if TC is below 0.5 g compared to 3 g sample no IC measurement is needed. Measurements were done only to selected samples from first sampling of barley substrates: fertiliser IA, composted IA, urine IA and STS IA. It was expected that substrates are homogenous and fertilisers don't have significant effect to TC content. The same results were also used for second samples because significant changes it TC content was not

expected to take place. Determination was done with Shimadzu Solid Sample Module SSM 5000A. The amounts of TC and their comparable amounts in 3 g of soil samples are in Table 16.

Table 16. Total carbon in substrate samples.

Sample	Weight (mg)	TC (mg)	Conc. (%)	Comparable amount in 3 g of soil (g)
Fertiliser 1A	50,3	2,453	4,9	**0,15**
Faeces 1A	50,7	1,172	2,3	**0,07**
Urine 1A	49,6	1,772	3,6	**0,11**
STS 1A	50,1	2,242	4,5	**0,13**
Avg.	**50,2**	**1,910**	**3,8**	**0,11**

The amounts of TC in samples gave no reason to increase the amount of HNO_3 in extraction of trace elements. /10/

3.6. DETERMINATION OF TOTAL CARBON OF FERTILISERS

Determinations of total carbon were done according the International Standard ISO 10694. TC was measured from composted faeces and STS although *aqua regia* extraction was made according the SFS Standard SFS-EN 13346, which do not require determination of TC. The method for extraction is exactly the same as in ISO 11466 so it can be expected that the amount of *aqua regia* used is sufficient only for oxidation of about 0.5 g of organic carbon. Determination was done with Shimadzu Solid Sample Module SSM 5000A. The amounts of TC and their comparable amounts in 3 g of soil samples are in Table 17. /6, 10, 17/

Table 17. Total carbon in STS and composted faeces samples.

Sample	Weight (mg)	Conc. (%)	Comparable amount in 3 g of soil (g)	Avg. amount (g)
Compost 1	87,4	32,17	0,97	**0,97**
Compost 2	77,6	32,49	0,97	
STS 1A	63,3	36,00	1,08	**1,10**
STS 2	60,1	37,03	1,11	

According the standard 1 ml of HNO_3 should be added to every 0.1 g of organic carbon above 0.5 g. The amounts of NHO_3 to be added in extraction of trace elements are in Table 18. /10/

Table 18. Addition of HNO_3 required in Aqua regia extraction of composted faeces and STS.

Sample	Amount of carbon above 0,5 g (g)	Amount of HNO_3 to be added (ml)
Composted faeces	0,47	**5**
STS	0,60	**6**

Total carbon was not determined from separated urine because its amount was expected to be insignificant.

4. ANALYSES FOR SUBSTRATES AND FERTILISERS

4.1. EXTRACTION OF TRACE ELEMENTS OF SUBSTRATES

The extraction of trace elements soluble in aqua regia was done according the international standard ISO 11466. Soil samples were ungrounded with particle size less than 2 mm. Reason for this was that HM bound to the sand used are not likely to be available to the plants when the pH of the substrate is grater than 6.5. /19/ Because mercury was not determined no non-return type absorption vessel was used. The extractions were done by the batch of 16 samples along with 1 blank for samplings done in the beginning and in the end of growing experiment. Samples were left for preliminary digestion for overnight. The samples are identified in Tables 10 and 11. /10/

During the filtration of the extracted samples of the samples taken in the beginning of the experiment sample barley compost IIB formed water seal in the neck of the volumetric flask causing it to over flow. All results concerning this sample were not used in calculations concerning average levels of trace metals in substrates.

Timetable for extractions is in Table 5.

4.2. EXTRACTION OF TRACE ELEMENTS OF FERTILISERS

The extraction of trace elements soluble in *aqua regia* for composted faeces was done according the international standard ISO 11466 from ungrounded samples because the sample was expected to dissolve almost completely to *aqua regia* when sieved to <2 mm; STS pretreated according SFS-EN 12880 according the SFS

standard SFS-EN 13346 for extraction under reflux conditions (method A); and separated urine according the international standard ISO 15587-1 for digestion in an open system using electrical heating. For extraction for separated urine 250 ml digestion vessel was used instead of 100 ml mentioned in the standard. No non-return type absorption vessel was used. All extractions were run simultaneously with two parallel samples and one blank. Samples were left for preliminary digestion for overnight. The composted faeces samples are identified in Table 12 and the STS samples in Table 15. The amounts of HNO3 added are in Table 18. /10, 11, 17/

Timetable for extractions is in Table 5.

Figure 16. Extraction of trace element of fertilisers with reflux condenser and heat mantle.

4.3. DETERMINATION OF THE TRACE ELEMENTS WITH FLAME AAS OF SUBSTRATES

Determinations of cadmium (Cd), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn) were done according the international standard ISO 11047. The samples are identified in Tables 10 and 11.

Standard solutions without lanthanum were done from stock solutions containing 1000 mg l^{-1} of corresponding metal. Calibration solutions for determining trace elements from the substrate samples taken in the beginning of the experiment were done according the standard.

As the amounts of trace elements in the samples taken in the beginning of the experiment were small the calibration curves were decided to be weighted more to the lower part. Five calibration solutions were made for all trace elements. The amounts of standard solutions pipette and corresponding concentrations can be seen in Table 19.

Table 19. Amounts of standard solution pipette to 100 ml volumetric flasks and their corresponding concentrations.

	Cu		Pb		Ni	
	Amount (ml)	Conc. (mg l^{-1})	Amount (ml)	Conc. (mg l^{-1})	Amount (ml)	Conc. (mg l^{-1})
1	1,25	0,25	1,25	0,25	1,25	0,25
2	2,50	0,50	2,50	0,50	2,50	0,50
3	5,00	1,00	5,00	1,00	5,00	1,00
4	10,00	2,00	10,00	2,00	10,00	2,00
5	20,00	4,00	20,00	4,00	20,00	4,00
	Cd		Zn			
	Amount (ml)	Conc. (mg l^{-1})	Amount (ml)	Conc. (mg l^{-1})		
1	0,25	0,05	0,25	0,05		
2	0,50	0,10	0,50	0,10		
3	1,00	0,20	1,00	0,20		
4	2,00	0,40	2,00	0,40		
5	4,00	0,80	4,00	0,80		

Determination of trace elements was done with SOLAAR AA Series Spectrometer using air-acetylene gas mixture. When determining the trace elements in the samples every element was run separately from all the samples. Also sample barley compost IIB was ran but the results of it were not used in the calculations. Sample from substrate for carrot taken in the beginning of the experiment Substrate IB was clearly out of the normal deviation and was also excluded from the calculations.

Equation 1. Determination of the trace elements corresponding to the absorbance of the test portion.

$$w_{(M)} = \frac{(\rho_1 * f - \rho_0)}{m} * V$$

where

$w_{(M)}$ is the fraction of the element M in the sample (mg kg^{-1});

ρ_1 is the concentration of the element (mg kg^{-1}) corresponding to the absorbance of the test portion;

ρ_0 is the concentration of the element (mg kg^{-1}), corresponding to the absorbance of the blank test solution;

f is the corresponding dilution factor of the diluted test portion;

V is the volume (l) of the test portion for analysis;

m is the mass of the sample (kg) corrected for the water.

All corresponding figures are presented in Appendix 2, 3, 4 and 5. Mass fractions were calculated for all samples and from them averages for all eight corresponding substrates were calculated. The amounts of trace elements were calculated with Equation 1. The results are in the Tables 26, 27, 28 and 29. /7/

4.4. DETERMINATION OF THE TRACE ELEMENTS WITH FLAME AAS OF FERTILISERS

Determination of cadmium (Cd), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn) was done according the international standard ISO 11047. Determination of trace elements was done with SOLAAR AA Series Spectrometer using air-acetylene gas mixture. The samples are identified in Tables 12 and 15.

Standard solutions without lanthanum were done from stock solutions containing 1000 mg l^{-1} of corresponding metal. Calibration solutions for determining trace elements were done according the standard.

All corresponding figures are presented in Appendix 6 and 7. Mass fractions were calculated for all samples and from them averages for all fertilisers. The amounts of trace elements were calculated with Equation 1. The results are in Table 25. /5, 7/

Figure 17. Determination of trace elements with AAS.

5. METHODS FOR BARLEY AND CARROT SAMPLES

5.1. SAMPLING AND PRETREATMENT

Sampling and pretreatment was done by adapting the principles by Radojevic (1999). The sampling of barley was done after most of them had ripened. Barley fertilised with composted faeces, separated urine and STS were ripened very well but barley fertilised with commercial fertiliser was still not totally ripened. This was caused probably by the low nutrient levels in the first three treatments because the later one was still growing. The faster than normal growth rate caused by higher than normal temperatures made the straws of barleys to grow weak making it to be flattened and thou forcing us to harvest them earlier than we wanted to.

Barley was sampled to two batches. 30 spikes and straws were separated from the rest of the harvest to be used for analysing weight, length and number of grains. Rest of the grains was used for trace element and nutrient analysis. /14/

The spikes were air dried in plastic trays and straws packed loosely in paper bags protected from direct sunlight. Both batches of grains were separated from husks and awns manually.

From the batch of 30 spikes the length of straw, the length of spike, the weight of the fresh spike, the weight of the dried spike, number of grains and weight of the grains was recorded. From rest of the spikes the number of grains was also recorded. About 10 g of grains from rest of the samples was ground with ceramic mortar for further analysis.

Determination of the mass of 1000 grains was done according the international standard ISO 520. /2/

Carrots were harvested and sampled 2 weeks later. Carrots were sampled to two batches. 50 carrots were separated for analysing length of the root, carrot and tops and the weight of the carrot and tops. Rest of the carrots was used for trace element and nutrient analysis. Soil was removed from carrots by wiping. /14/

The carrots and tops were air dried in plastic trays protected from direct sunlight. Later about 10 g of carrots fertilised with commercial fertiliser and composted faeces and rest of the carrots fertilised with separated urine and STS were diced smaller with knife and dried in an oven at temperature >60 ˚C to avoid thermal decomposition. Weights of the carrots before and after drying are in Table 20. The samples were ground for further analysis with ceramic mortar. /14/

Table 20. Weights of the carrots separated for further analysis before and after drying.

Sample	Weight (g)	
	Before drying	After drying
Fertiliser I	10,0	9,2
Fertiliser II	9,8	9,1
Compost I	9,8	9,0
Compost II	9,8	9,3
Urine I	0,8	0,8
Urine II	0,8	0,7
STS I	7,7	7,5
STS II	6,5	6,2

5.2. DETERMINATION OF MOISTURE CONTENT

Determination of moisture content for barley was done according the international standard ISO 712. Determination was done from four selected barley samples: fertiliser II, compost II, urine II and STS II. The dry matter content was expected to be same between different crates of the same treatment. /3/ Dry matter and the water contents are shown in Table 21.

Table 21. Dry matter and water content in barley.

Sample	Dry Matter Content (%)	Moisture Content (%)
Fertiliser II	92,65	7,94
Faeces II	93,65	6,78
Urine II	92,45	8,17
STS II	92,52	8,09

Moisture content for carrots was determined in two stages. The weight of the carrots was recorded when sampled. Dry weight of the air dried carrots was recorded. The moisture content of the air dried carrots was determined from the carrots separated for further analysis. Weights are in Table 20. Obtained figures were used to correct weights of the air dried carrots and moisture contents and dry matter contents were calculated. Equations from ISO 712 were used for calculations. /3/ Dry matter and moisture content from the carrots fertilised with urine was not determined because there were not enough plant material for analyses. The dry matter and the water contents are shown in Table 22.

Table 22. Dry matter and water content in carrot.

Treatment	Dry Matter Content (%)	Moisture Content (%)
Fertiliser	14,99	85,01
Faeces	14,72	85,28
STS	22,05	77,95

6. ANALYSES FOR BARLEY AND CARROT

6.1. DIGESTION OF ORGANIC MATTER

Digestion of organic matter was done according the international standard ISO 5515. Procedure was done without the use of perchloric acid and without adding water in the first stage. Samples were left for preliminary digestion for overnight. Decomposition of all samples was run simultaneously along with 1 blank. Procedure was done with BÜCHI Digestion System K-437. Solutions were made up to 50 ml. /4/ Samples are identified in Table 23.

Table 23. Barley and carrot samples used in extraction of trace elements.

Sample	Weight
Barley fertiliser I	5,010
Barley fertiliser II	5,015
Barley compost I	5,008
Barley compost II	5,008
Barley urine I	5,013
Barley urine II	5,008
Barley STS I	5,009
Barley STS II	5,006
Carrot fertiliser I	5,002
Carrot fertiliser II	5,009
Carrot compost I	5,008
Carrot compost II	5,009
Carrot STS I	5,002
Carrot STS II	5,006

Figure 18. Digestion of organic matter of barley and carrot with Büchi Digestion System.

6.2. DETERMINATION OF THE TRACE ELEMENTS WITH FLAME AAS

Determination of cadmium (Cd), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn) was done according the international standard ISO 11047. Determination of trace elements was done with SOLAAR AA Series Spectrometer using air-acetylene gas mixture. /7/ Samples are identified in Table 23.

Standard solutions without lanthanum were done from stock solutions containing 1000 mg l^{-1} of corresponding metal. Five calibration solutions were made for all trace elements. The amounts of standard solutions pipette and corresponding concentrations can be seen in Table 24.

Table 24. Amounts of standard solution pipette to 100 ml volumetric flasks and their corresponding concentrations.

	Cu		Pb		Ni	
	Amount (ml)	Conc. (mg l^{-1})	Amount (ml)	Conc. (mg l^{-1})	Amount (ml)	Conc. (mg l^{-1})
1	1,00	0,20	1,00	0,20	1,00	0,20
2	2,00	0,40	2,00	0,40	2,00	0,40
3	3,00	0,60	3,00	0,60	3,00	0,60
4	4,00	0,80	4,00	0,80	4,00	0,80
5	5,00	1,00	5,00	1,00	5,00	1,00
	Cd		Zn			
	Amount (ml)	Conc. (mg l^{-1})	Amount (ml)	Conc. (mg l^{-1})		
1	1,00	0,20	1,00	0,20		
2	2,00	0,40	2,00	0,40		
3	3,00	0,60	4,00	0,80		
4	4,00	0,80	6,00	1,20		
5	5,00	1,00	8,00	1,60		

All corresponding figures are presented in Appendix 8 and 9. Mass fractions were calculated for all samples and from them averages for all treatments. The amounts of trace elements were calculated with Equation 1. The results are in Table 30 and 32. /7/ The results were fitted as concentrations in wet weight. Results are in Table 31 and 33.

7. RESULTS

The amount of heavy metals was low, as expected, in composted faeces and urine. In STS all, except Cd, were below limit values of the sludge used as fertiliser. The weight of the urine was expected to be 1 kg l^{-1}.

Table 25. Mass fractions of the trace elements in composted faeces, separated urine and STS.

Trace Element	Mass Fractions			
	Faeces (mg kg^{-1})	Urine (mg l^{-1})	STS (mg kg^{-1})	Limit Value (mg kg^{-1})
w(Cd)	0,67	BDL	2,1	1,5
w(Cu)	75	0,19	380	600
w(Pb)	0,79	BDL	75	100
w(Ni)	7,9	0,15	57	100
w(Zn)	540	0,15	910	1500

BDL Below Detection Limit

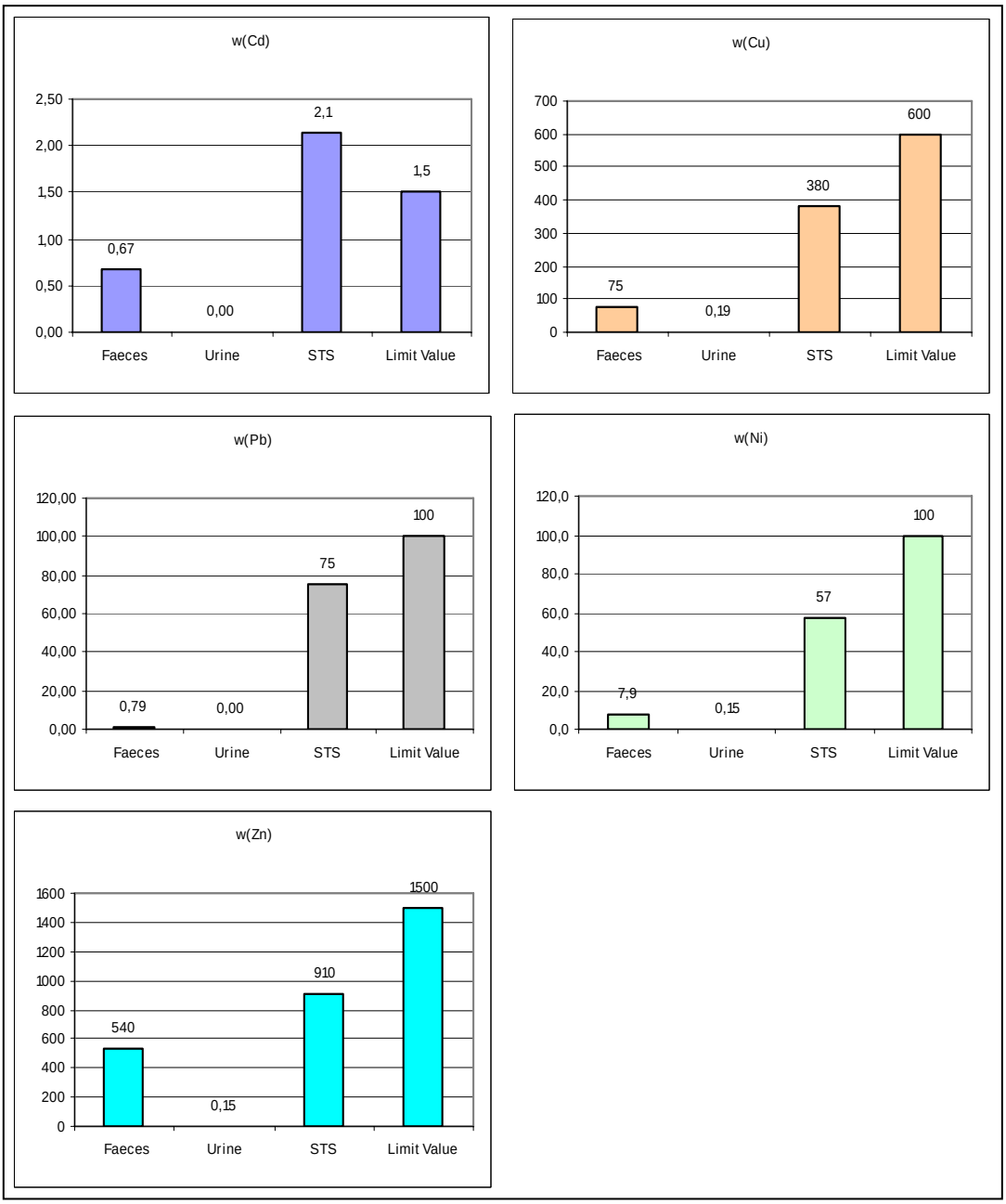

Figure 19. Comparison between the obtained results from analysis of fertilisers and limit values set by the Council of the State. /35/

Heavy metal traces in differently fertilised substrates didn't vary much from the results got from substrate with no added fertiliser. All the results from samples taken in the beginning of the experiment stayed well below the set limit values. Two of the samples were excluded from the calculations, Barley Compost IIB for inappropriate handling of the extracted sample and Carrot Substrate IB for AAS result deviating from the others so much it can only be explained as a random deviation. All negative results and samples where absorption was same or clearly

less than the absorption of the blank were interpret to be below detection limit (BDL).

Table 26. Mass fractions of the trace elements in different treatments for growing barley from samples taken in the beginning of the experiment and limit values set by the Council of the State. /35/

Trace Element	Mass Fraction (mg kg^{-1})				
	Substrate	Faeces	Urine	STS	Limit Value
w(Cd)	BDL	BDL	BDL	BDL	0,5
w(Cu)	3,2	2,1	3,3	2,7	100
w(Pb)	BDL	BDL	BDL	BDL	60
w(Ni)	2,6	3,1	3,3	3,8	60
w(Zn)	13	12	12	12	150

BDL Below Detection Limit

Table 27. Mass fractions of the trace elements in different treatments for growing carrot from samples taken in the beginning of the experiment and limit values set by the Council of the State. /35/

Trace Element	Mass Fraction (mg kg^{-1})				
	Substrate	Faeces	Urine	STS	Limit Value
w(Cd)	BDL	BDL	BDL	BDL	0,5
w(Cu)	0,62	0,28	0,67	0,74	100
w(Pb)	BDL	BDL	BDL	BDL	60
w(Ni)	2,2	2,1	2,2	2,0	60
w(Zn)	8,5	8,6	7,5	7,1	150

BDL Below Detection Limit

Heavy metal traces from the samples taken in the end of the experiment don't show any big changes in the heavy metal concentrations. The most significant changes had happened in Cd concentrations, which are probably closer to the reality than the results from the previous sampling. The only one that is not below the limit values is Cd concentration in soil sample for growing carrot fertilised with STS, which exceeds the limit by 0.08 mg kg^{-1} or 16 %.

Table 28. Mass fractions of the trace elements in different treatments for growing barley from samples taken in the end of the experiment and limit values set by the Council of the State. /35/

Trace Element	Mass Fraction (mg kg^{-1})				
	Fertiliser	Faeces	Urine	STS	Limit Value
w(Cd)	0,094	0,36	0,24	0,26	0,5
w(Cu)	3,7	3,3	2,6	2,8	100
w(Pb)	2,8	3,0	1,3	2,6	60
w(Ni)	2,1	2,1	2,2	1,9	60
w(Zn)	15	13	14	14	150

Table 29. Mass fractions of the trace elements in different treatments for growing carrot from samples taken in the end of the experiment and limit values set by the Council of the State. /35/

Trace Element	Mass Fraction (mg kg^{-1})				
	Fertiliser	Faeces	Urine	STS	Limit Value
w(Cd)	0,38	0,41	0,44	0,58	0,5
w(Cu)	3,0	2,3	2,2	2,5	100
w(Pb)	4,0	4,1	2,5	2,3	60
w(Ni)	2,5	1,7	1,8	1,9	60
w(Zn)	14	14	14	14	150

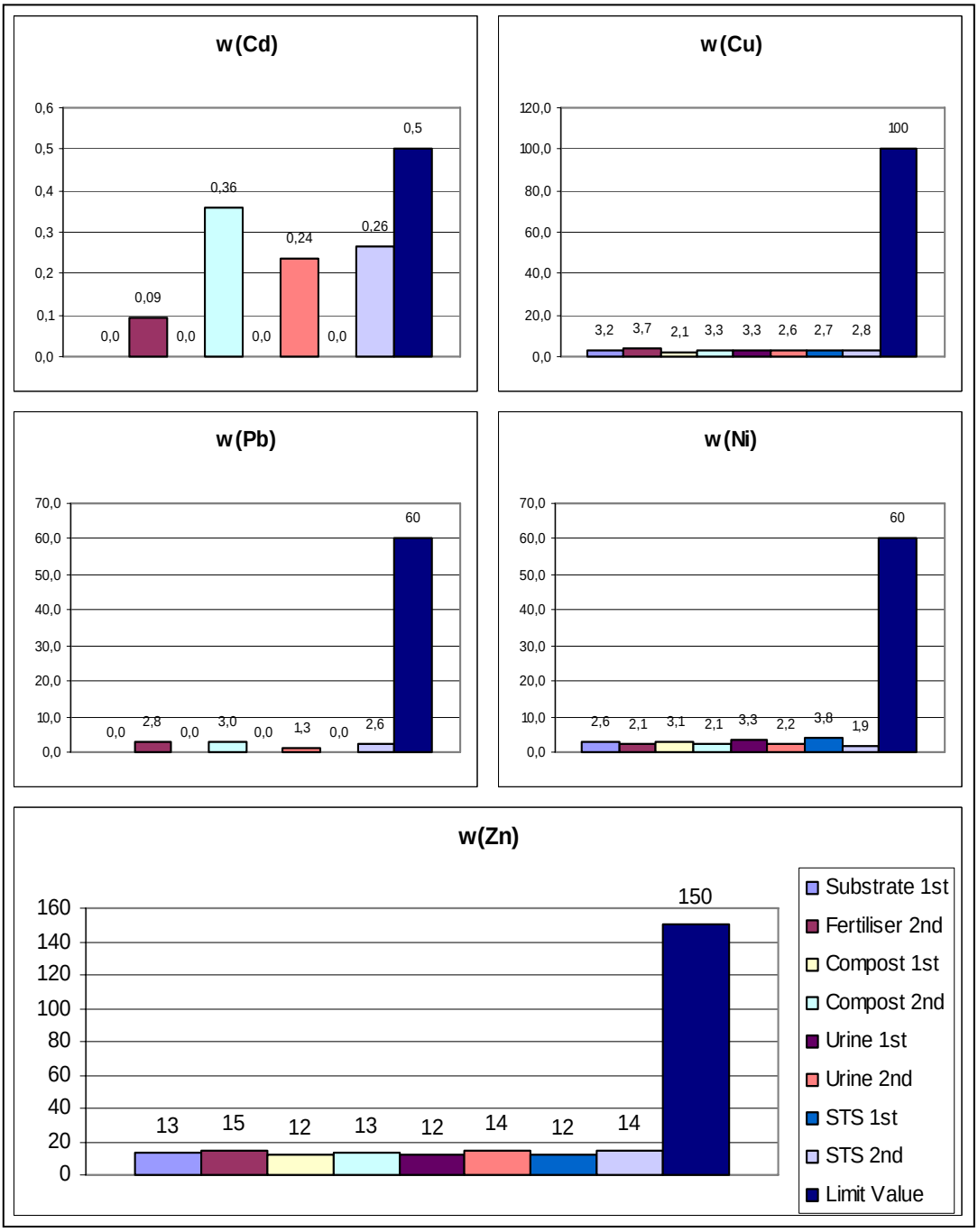

Figure 20. Comparison between the obtained results from first and second analysis of substrates for growing barley and limit values set by the Council of the State. /35/

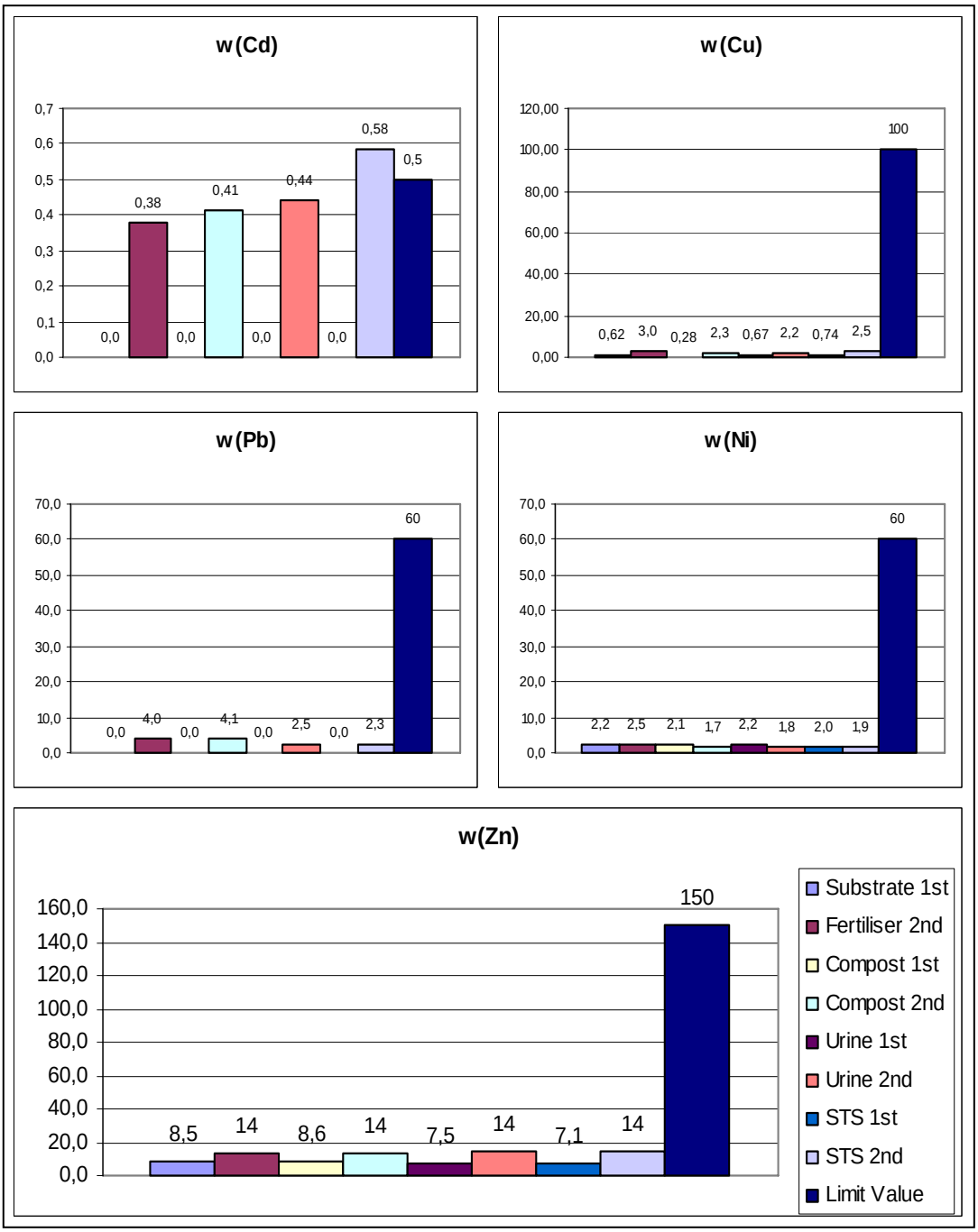

Figure 21. Comparison between the obtained results from first and second analysis of substrates for growing carrot and limit values set by the Council of the State. /35/

The heavy metal concentration in plants by uptake was one of the main concerns in this experiment. Only the concentration of Cd and Pb is limited by regulations and from the rest of the heavy metals only Zn has recommended maximum daily intake value. Cadmium, which is the one we were more worried about, stayed below limit values by approximately 50 % in barley and only Pb value that was above detection limit on barley was also 50 % below the limit value. The concentrations are fitted to the wet weight of barley.

Table 30. Mass fractions of the trace elements in barley, dry weight.

Trace Element	Mass Fraction Dry Weight (mg kg^{-1})			
	Fertiliser	Faeces	Urine	STS
w(Cd)	0,018	0,050	0,068	0,048
w(Cu)	2,4	1,4	2,4	3,0
w(Pb)	BDL	0,11	BDL	BDL
w(Ni)	0,40	0,17	0,16	0,21
w(Zn)	29	25	24	32

BDL Below Detection Limit

Table 31. Mass fractions of the trace elements in barley, wet weight and limit values set by the European Commission. /22/

Trace Element	Mass Fraction Wet Weight (mg kg^{-1})				
	Fertiliser	Faeces	Urine	STS	Limit Value
w(Cd)	0,017	0,047	0,063	0,044	0,1
w(Pb)	BDL	0,098	BDL	BDL	0,2

BDL Below Detection Limit

Cd concentrations on carrot exceeded the limit value 3 fold. On carrots fertilised with STS the exceeding was even larger, 10 fold. Also Pb concentrations were exceeded in carrots fertilised with STS. Both, carrot fertilised with urine and STS, probably suffered from nutrient deficiency, preventing the growth totally and/or slowing it considerably. For analyses of carrot fertilised with urine there was not enough plant material and for carrots fertilised for STS just barely enough to get results. That fact is one factor that made concentrations of Cd and Pb higher in carrots fertilised with STS. The concentrations are fitted to the wet weight of carrot.

Table 32. Mass fractions of the trace elements in carrot, dry weight.

Trace Element	Mass Fraction Dry Weight (mg kg^{-1})			
	Fertiliser	Faeces	Urine	STS
w(Cd)	1,0	1,1	ND	3,3
w(Cu)	0,64	0,72	ND	0,82
w(Pb)	0,10	0,12	ND	0,76
w(Ni)	0,37	0,50	ND	0,42
w(Zn)	8,4	9,5	ND	14

ND Not Determined

Table 33. Mass fractions of the trace elements in carrot, wet weight and limit values set by the European Commission. /22/

Trace Element	Mass Fraction Wet Weight (mg kg^{-1})				
	Fertiliser	Faeces	Urine	STS	Limit Value
w(Cd)	0,16	0,17	ND	0,49	0,05
w(Pb)	0,015	0,017	ND	0,11	0,1

ND Not Determined

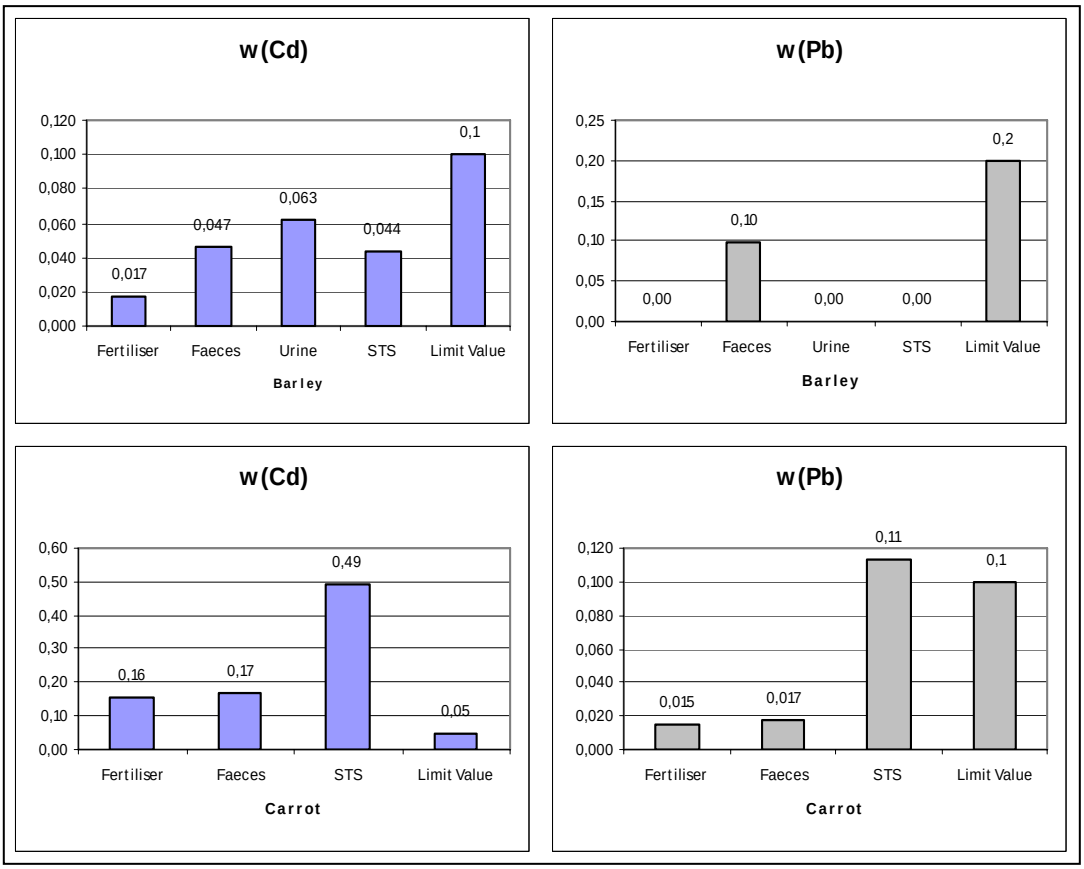

Figure 22. Comparison between obtained results from analysis of plants fitted to mass fractions of trace element to wet weight and limit values set by the European Commission. /22/

The growth of the barley was varying from treatment to treatment. Commercial fertiliser gave best value in length of straw and in number of the grains. Mass of the grains compared to their number was smallest caused by harvesting when they were not ripened yet leaving grains with big moisture content. Urine treatment gave best comparison between mass of the grains to number of the grains. Compost treatment gave the smallest amount of grains.

Table 34. Comparison of different parameters of 30 spikes of barley from different treatments.

Substrate	Avg. Length of Straw (cm)	Number of the Grains	Mass of The Grains (g)	Mass of 1000 Grains (g)
Fertiliser	75	467	14	30
Compost	53	201	7	33
Urine	59	310	11	34
STS	57	243	8	35

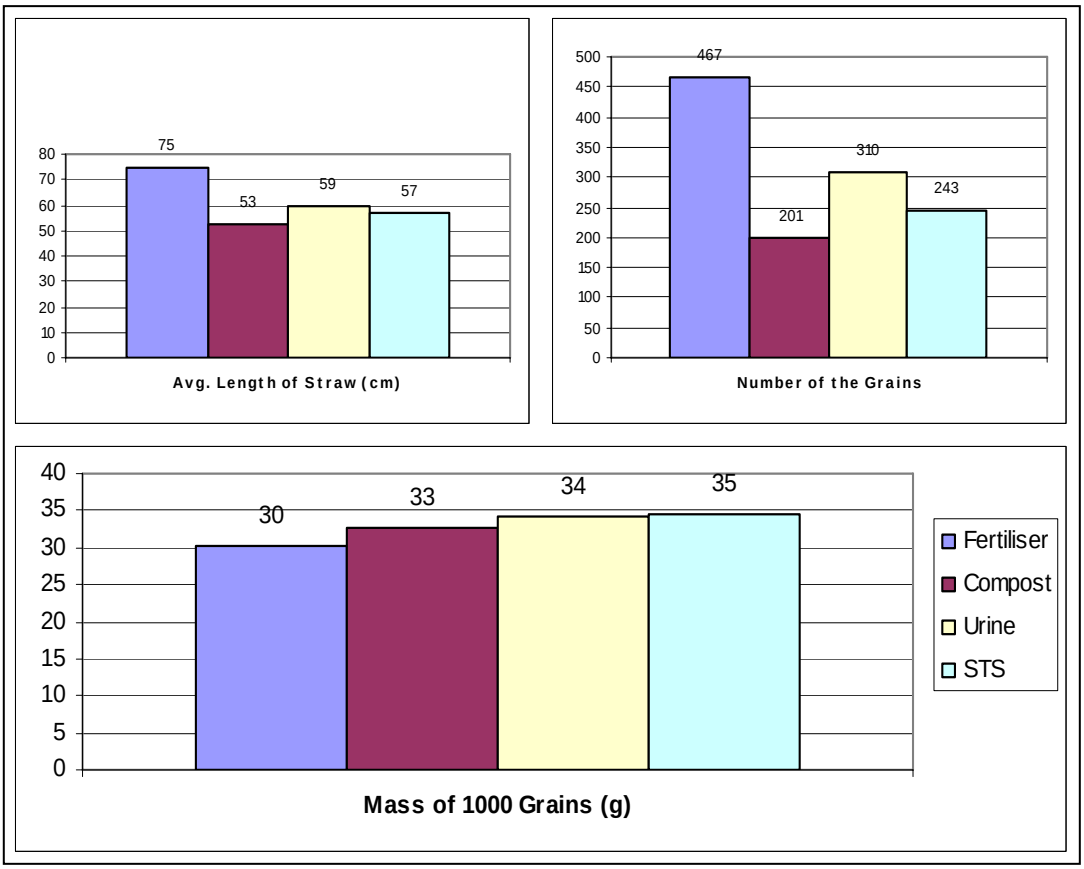

Figure 23. Average length of straw, number of the grains and mass of 1000 grains of 30 spikes of barley from different treatments.

Commercial fertiliser treated carrots were clearly growing best. That could be seen above the ground as well as from the carrots them selves. Both length and the produced biomass were above the others. Compost treatment did also quite good. Urine treatment was not growing at all after initial germination and growing root. Treatment was visibly suffering because the colour of the seedlings was brownish red when all the others were green. The carrots from this treatment were merely root with no grown biomass. STS treatment was not doing much better but the carrots grew bit thicker giving slightly higher biomass.

Table 35. Average length and mass of 50 carrots from different treatments.

Substrate	Avg. Length of Carrot (mm)	Total mass of fresh Carrots (g)
Fertiliser	48	203
Compost	42	96
Urine	15	1
STS	17	4

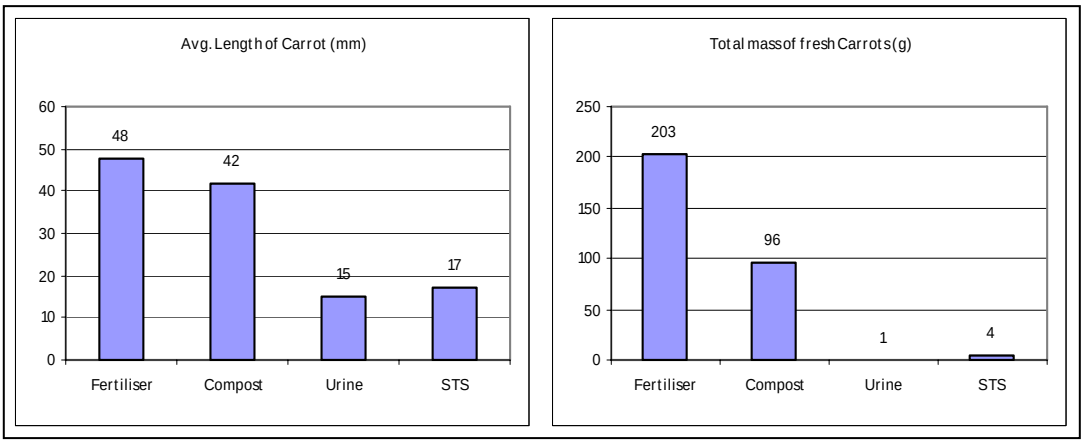

Figure 24. Average length and mass of 50 carrots from different treatments.

8. CONCLUSIONS

8.1. HEAVY METALS

The heavy metal concentrations in STS and other fertilisers used were not alarming and all stayed below limit values except Cd, which exceeded the limit value roughly by 25 %.

On substrates limit value of Cd was exceeded only on substrate for carrot fertilised with STS from second sampling by 16 %. On some treatments of barley and carrot Cd concentrations were high but stayed below limit value. All other HM stayed well below limit values.

On barley samples all heavy metal concentrations stayed below limit values. On carrot fertilised with commercial fertiliser and composted faeces Cd limit value was exceeded 3 fold and on samples fertilised with STS 10 fold. Limit values on Pb was exceeded by 10 % only on samples fertilised with STS. Higher concentrations on carrot were expected because HM accumulates mainly to the roots but the magnitude wasn't.

We found no indisputable evidence of adverse effect of the studied heavy metals to the growth of barley and carrot caused by other disturbing factors. This experiment does not rule out the use of untreated STS as fertiliser.

According to these results STS can be used for barley because heavy metal contents stayed below given limits. Cd accumulation gives some concern an it should be monitored if STS is used and further field studies could give a better understanding how much and how often STS can be used. Urine and composted faeces treatments would have better results as long as nutrient contents and soil pH is determined in the beginning of the experiment and monitored during the growth.

For carrots the results were not so promising. Other growing environment disturbances, like excess heat and suspected acidity of substrates, made impossible to get comparable results from carrots. For them more studies should be done in more stable environment to mitigate the disturbances on growth and uptake of heavy metals, first indoors and later outdoors during the summer.

8.2. OBSERVATIONS FROM THE EXPERIMENT

The experiment didn't succeed all of its goals. One of the main failures was exceeding the optimum temperature values for the time period this experiment supposed to represent. This made barley to grow too rapidly which caused them to flatten. This was one of the reasons which caused harvesting of barley to be early. Other treatments than barley treated with commercial fertiliser were already ripened but that treatment was still green. This can noticed from the fact that number of the seeds was much larger than on other treatments but the weight of 1000 grains was smaller.

The pH of the substrates was not monitored. The acidic influence of peat was stabilised by liming in the beginning of the experiment but the effect of the fertilisers was not taken in consideration. This could have been a factor for slow growth of the carrots fertilised with urine and STS as well as early ripening of barley in other treatments than fertilised with commercial fertiliser.

Because nutrient contents of the fertilisers were assumed to be what they are on average, we were not able to tell accurately what the nutrient values of applied amounts of fertilisers were. This combined with suspected low pH would also cause low growth on carrots are early ripening on barley.

The heavy metal concentrations in substrates, and especially in carrots, were quite high. Just the Pb concentration in carrots fertilised with STS would prohibit its use as foodstuff. More concerning was the fact that Cd concentrations were high in all analysed treatments. They were high also in barley although they didn't exceed the limit value. One of the reasons for this could be that carrots were harvested before they were fully grown. The other factor probably causing higher heavy metal concentration was supposed low pH of the substrates. That would have caused metals to be easier to uptake by plants lowering the availability of phosphorus at the same time. The extraction with BÜCHI could also caused contamination between different samples and making results unreliable.

8.3. IMPROVEMENTS FOR FUTURE STUDIES

This experiment could give more accurate results by couple of improvements:

- The greenhouse or the cooling unit should be located outdoors to give sufficient temperature control
- The substrates and fertilisers should be analysed before beginning the experiment for their pH and nutrient contents to have more accurate application of fertiliser and also heavy metal concentrations should be available
- pH of the substrates and fertilisers should be monitored and raised if necessary to avoid adverse effects of low pH to plants and to avoid leaching of HM
- When sowing, the number of barley grains per row should be defined more accurately to avoid the need for singling. Carrots, which are harder to plant, could be planted with seeds in sowing band for the same reason. These actions could improve the germination of the seeds as well as mitigate the need for singling, which visibly caused stress to the plants
- Determination of Cd and Pb should be carried out using larger amounts of samples. In this experiment it was not possible caused by low growth and lack of plant material and most probably caused unwanted variations in results
- Using Graphite Furnace AAS to get more accurate results on small concentrations

- Decompositioning of organic matter should be run in separate vessels, not inter connected like in BÜCHI to avoid contamination between different samples.

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APPENDIXES

APPENDIX 1. Greenhouse Diary

The growing experiment began in early November. 10 November 2005 lights and fan cooler arrived and were installed to the greenhouse. Fan cooler had a condensation tank, first one that had to be manually emptied daily; later the condensation waters were lead to a 1000 l plastic tank with no need for emptying in the middle of experiment. Fan cooler was set on. On the same day five brandling worms (Eisenia fetida) per crate were added to loosen substrate soil composition. Watering of 1 l per crate was done on top of the crates. Fan cooler thermostat was set to 17 ˚C.

A disinfection lotion VirkonS 1% was brought for shoe sole disinfection, for salmonellae and other bacteria were suspected to occur in some crates due to use of human faeces as a fertiliser. Seed rows were covered lightly after sowing was finished with and crates were tightened by hands. Lights were set off manually from greenhouse for the night. It was noted that barley had begun germinating.

11 November 2005 RH hair hygrometer, temperature graphic plotter and temperature min-max-meter were ordered. The anniversary clock was set to have a light period 20 hours and a dark period 4 hours. Thermostat of cooling fan was set to the optimum 15 ˚C. Four Dyno boxes were set on the greenhouse floor full of water for air moisturising. For watering one litre was used per crate. It was noted that barley shoots were up to 1 cm long in artificial fertiliser control substrates.

12 November 2005 barley germinated in all crates. Strongest growth was noted again in artificial fertiliser control substrates. Dew drops had appeared in the ends of barley shoots.

13 November 2005 carrot substrates still had not begun germinating.

14 November 2005 for watering 2.5 l was used per crate for carrot substrates fertilised with STS, composted human faeces and urine.

15 November 2005 all carrot substrates had begun germinating. Barley was watered 3 l per crate; carrots 4.5 l per crate for substrates fertilised with urine and composted human faeces, 2 l per crate for artificial fertiliser control and STS substrate. Thermostat was set to 13 ˚C because despite earlier thermostat adjustments the greenhouse temperatures were over 20 ˚C and even minimum temperature measured was over 16 ˚C.

17 November 2005 barley was noted to lodge. Barley substrates were watered 2.5 l per crate. Singling was done and carrot crates fertilised with urine and STS were watered. All barley substrates except for the artificial fertiliser control substrate were watered again 2.5 l per crate. Temperature minimum had risen over 20 ˚C.

18 November 2005 carrots were watered 2 l per crate. One spray bottle of watered down growth regulation was sprayed to barley. Later on the same day all substrates were watered 2 l per crate.

19 November 2005 barley was noted to be recovering from lodging.

21 November 2005 fungi or mould growth was noted in substrates Carrot STS II, Barley Y3 II, Barley Y3 I, Barley Compost I, Barley Compost II and Barley Urine I.

22 November 2005 carrot substrates were watered. Carrot stems were noticed to be very weak and barley stems were not that firm either.

23 November 2005 fungi growth was noted also in substrate Carrot STS II.

24, 26 and 28 November 2005 all crates were watered. 26 November 2005 watering to carrots was done with a bottle in between of the seedling rows due to the weakness of seedlings. Barley substrates fertilised with composted human faeces seemed most stout for they did not lodge when watering with a watering can.

Singling of carrots was done 24–25 November 2005, of barley 28 November 2005.

29 November 2005 barley was lodged in all its crates for the supportive element is missing. Carrot Compost seemed quite stout, Carrot Kevät lodged a bit. Urine and STS fertilised substrates were nearing others' growth rate. Growth regulation spray was sprayed to barley.

30 November 2005 all crates were watered 5 l per crate. Barley rows were assorted preliminary for their supporting element. Netting is set to support barley by heaving the seedlings through it.

1 December 2005 carrots were again singled and also mulched, except for substrates fertilised with STS.

2 December 2005 carrot crates were watered 1.5 l per crate except for crates with STS fertilised substrates. Watering was done between the sapling rows with a bottle. After Carrot STS crates were mulched on the same day they were watered with the same amount.

3 December 2005 the mulching was noted to have a clear effect. Carrot saplings looked stronger. All crates were watered with a watering can 3 l per crate. Barley crates were quite dry which could be expected. Netting had hindered barley from lodging anymore. Carrot substrates were noted to be quite moist and barley substrates were noted to be pressed quite stiff.

7 December 2005 all crates were watered 3 l per crate with a watering can. Carrot lodged again which showed it was still too weak for watering with a watering can. Barley substrates fertilised with composted human faeces looked yellow which might be a sign of a deficiency.

8 December 2005 all crates were watered 3 l per crate. Barley substrates showed a significant difference in top soil hardness compared to carrot substrates.

9 December 2005 temperature was noted to be on a sharp rise as e.g. 2 December 2005 the temperature was measured to be 21.8˚C (T_{digi}) yet 9 December 2005 it was 28.8˚C (T_{digi}). Light period was switched to 19 h light period and 5 h without lights period. Compressor's cooling pipe was insulated. All crates were watered 3 l per crate.

12 December 2005 the condense container had an overflow due to blockage in the drain pipe. The greenhouse was aired for a couple of hours by leaving the greenhouse door open. This was done due to the temperature rise. Additional watering was given to substrates Carrot STS 1 & 2 and Carrot Urine 1 & 2 because they seemed dry. Process hall ventilation outcome was set shut and expulsion on to get the process hall temperature in control. Greenhouse temperature was still 24 ˚C which was considered too high.

13 December 2005 process hall seemed a lot cooler yet this didn't have a notable effect on greenhouse temperature. Greenhouse door was decided to be left open except for the time of measurements until there's a change on temperature.

14 December 2005 all crates were watered 2.5 l per crate, 16 December 2005 5 l per crate as underground irrigation. 17 December 2005 again 5 l per crate watering.

19 December 2005 crates Barley Y3 1 & 2, Barley Urine 1 & 2, Barley STS 1 & 2, Carrot Compost 2, Carrot Kevät 1 & 2 were dry from below. Door was closed as temperature had dropped a bit. Barley STS and Barley Urine were noted to be in the ear. Condense container was emptied for the Christmas holidays. 23 December 2005 all crates were watered 5 l per crate as underground irrigation. Additional watering was given to barley 2 l per crate, for carrot Kevät and carrot Compost 1.5 l per crate. Carrot Urine and Carrot STS were moist and thus left without watering.

27 December 2005 all barley crates were watered 2.5 l per crate. All substrates were noted to be in the ear. Carrot Urine 1, Carrot STS 1 and STS 2 were noted to have fungi growth. Barley Compost was seen as the palest and the shortest of substrates. Carrot STS and Urine were on the date growing little or no roots and looked stunted. Carrot urine was so moist that water could be seen in under drains. Battery was changed for digital Vaisala RH meter. $T_{substrate}$ and Vaisala RH meters were decided to be kept outside the greenhouse so that high level of air humidity wouldn't cause damage.

28 December 2005 all substrates looked moist. In both Carrot Urine substrates under drains showed water. Singling of Carrot Compost and Carrot Kevät was begun.

30 December 2005 Barley Urine was watered 3 l per crate. Carrots were still moist and thus their moisture should be monitored for a while.

2 January 2006 all barley crates were watered 3 l per crate. Carrot Urine 2 was left without watering for the crate showed water in under drains. To other carrot substrates watering was 1.5 l per crate.

4 January 2006 all barley crates were watered 3 l per crate and carrot crates 1.5 l per crate.

8 January 2006 the greenhouse door was shut for the temperatures had been rising again. Opened door was thought to be a possible reason for this.

9 January 2006 all crates were watered 5 l per crate.

12 January 2006 barley crates Y3 1 & 2 were noted to be clearly more lodged.

13 January 2006 all crates were watered 2 l per crate.

17 January 2006 majority of barley was harvested. In all substrates some barley was left to grow because Launokorpi would take samples for microbial analysis later.

18 January 2006 the air humidity was noted to have dropped severely due to barley harvest. 19 January 2006 rest of the barley was harvested and all carrot crates were watered 3 l per crate.

20 January 2006 carrots were harvested except for the ones left for Launokorpi for later sampling. The growing experiment had come to its end.

APPENDIX 2. Mass Fraction Calculations for Substrates for Growing Barley Sampled in the Beginning of the Experiment

Barley, Cd							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0096	0,1	0,00		
BIA	3,053	1	-0,0333	0,1	99,37	-0,7812	
BIB	3,051	1	-0,0302	0,1	99,37	-0,6795	
BIIA	2,974	1	-0,0328	0,1	99,37	-0,7850	
BIIB	3,039	1	-0,0365	0,1	99,37	-0,8909	-0,7841
KIA	3,070	1	-0,0335	0,1	99,37	-0,7835	
KIB	3,001	1	-0,0333	0,1	99,37	-0,7946	
KIIA	3,035	1	-0,0319	0,1	99,37	-0,7393	
KIIB	3,062	1	-0,0390	0,1	99,37	-0,9661	-0,7725
VIA	3,066	1	-0,0344	0,1	99,37	-0,8141	
VIB	3,035	1	-0,0310	0,1	99,37	-0,7095	
VIIA	3,060	1	-0,0327	0,1	99,37	-0,7596	
VIIB	3,009	1	-0,0361	0,1	99,37	-0,8862	-0,7611
LIA	2,956	1	-0,0313	0,1	99,37	-0,7389	
LIB	3,075	1	-0,0327	0,1	99,37	-0,7559	
LIIA	3,017	1	-0,0334	0,1	99,37	-0,7938	
LIIB	2,977	1	-0,0327	0,1	99,37	-0,7809	-0,7674
Barley, Cu							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0716	0,1	0,00		
BIA	3,053	1	0,0449	0,1	99,37	3,8399	
BIB	3,051	1	0,0119	0,1	99,37	2,7544	
BIIA	2,974	1	0,0502	0,1	99,37	4,1212	
BIIB	3,039	1	-0,0107	0,1	99,37	2,0169	3,1831
KIA	3,070	1	-0,0125	0,1	99,37	1,9375	
KIB	3,001	1	-0,0123	0,1	99,37	1,9882	
KIIA	3,035	1	-0,0007	0,1	99,37	2,3506	
KIIB	3,062	1	-0,0958	0,1	99,37	-0,7952	2,0921
VIA	3,066	1	0,0479	0,1	99,37	3,9228	
VIB	3,035	1	0,0254	0,1	99,37	3,2160	
VIIA	3,060	1	0,0081	0,1	99,37	2,6207	
VIIB	3,009	1	0,0033	0,1	99,37	2,5047	3,2532
LIA	2,956	1	-0,0008	0,1	99,37	2,4106	
LIB	3,075	1	0,0363	0,1	99,37	3,5307	
LIIA	3,017	1	-0,0005	0,1	99,37	2,3714	
LIIB	2,977	1	0,0048	0,1	99,37	2,5829	2,7239

Barley, Pb							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	0,0109	0,1	0,00		
BIA	3,053	1	0,0235	0,1	99,37	0,4153	
BIB	3,051	1	0,0542	0,1	99,37	1,4283	
BIIA	2,974	1	0,0262	0,1	99,37	0,5177	
BIIB	3,039	1	-0,0124	0,1	99,37	-0,7717	0,3974
KIA	3,070	1	0,0011	0,1	99,37	-0,3213	
KIB	3,001	1	0,0095	0,1	99,37	-0,0469	
KIIA	3,035	1	0,0375	0,1	99,37	0,8819	
KIIB	3,062	1	-0,0038	0,1	99,37	-0,4831	0,1712
VIA	3,066	1	0,0155	0,1	99,37	0,1510	
VIB	3,035	1	0,0416	0,1	99,37	1,0178	
VIIA	3,060	1	0,0097	0,1	99,37	-0,0395	
VIIB	3,009	1	0,0261	0,1	99,37	0,5083	0,4094
LIA	2,956	1	0,0146	0,1	99,37	0,1260	
LIB	3,075	1	0,0511	0,1	99,37	1,3154	
LIIA	3,017	1	0,0434	0,1	99,37	1,0840	
LIIB	2,977	1	0,0032	0,1	99,37	-0,2603	0,5663
Barley, Ni							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	0,0489	0,1	0,00		
BIA	3,053	1	0,1230	0,1	99,37	2,4423	
BIB	3,051	1	0,1284	0,1	99,37	2,6225	
BIIA	2,974	1	0,1335	0,1	99,37	2,8625	
BIIB	3,039	1	0,1291	0,1	99,37	2,6561	2,6459
KIA	3,070	1	0,1495	0,1	99,37	3,2981	
KIB	3,001	1	0,1539	0,1	99,37	3,5204	
KIIA	3,035	1	0,1270	0,1	99,37	2,5893	
KIIB	3,062	1	0,1120	0,1	99,37	2,0735	3,1359
VIA	3,066	1	0,1501	0,1	99,37	3,3221	
VIB	3,035	1	0,1533	0,1	99,37	3,4613	
VIIA	3,060	1	0,1547	0,1	99,37	3,4789	
VIIB	3,009	1	0,1326	0,1	99,37	2,7990	3,2653
LIA	2,956	1	0,1860	0,1	99,37	4,6681	
LIB	3,075	1	0,1659	0,1	99,37	3,8285	
LIIA	3,017	1	0,1284	0,1	99,37	2,6515	
LIIB	2,977	1	0,1692	0,1	99,37	4,0670	3,8038

Barley, Zn							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	0,2257	0,1	0,00		
BIA	3,053	1	0,6760	0,1	99,37	14,8420	
BIB	3,051	1	0,6184	0,1	99,37	12,9541	
BIIA	2,974	1	0,6123	0,1	99,37	13,0809	
BIIB	3,039	1	0,5724	0,1	99,37	11,4822	13,0898
KIA	3,070	1	0,5703	0,1	99,37	11,2974	
KIB	3,001	1	0,5586	0,1	99,37	11,1614	
KIIA	3,035	1	0,5945	0,1	99,37	12,2270	
KIIB	3,062	1	0,2823	0,1	99,37	1,8599	11,5619
VIA	3,066	1	0,5996	0,1	99,37	12,2740	
VIB	3,035	1	0,5623	0,1	99,37	11,1598	
VIIA	3,060	1	0,6202	0,1	99,37	12,9718	
VIIB	3,009	1	0,5896	0,1	99,37	12,1692	12,1437
LIA	2,956	1	0,5589	0,1	99,37	11,3450	
LIB	3,075	1	0,6659	0,1	99,37	14,4043	
LIIA	3,017	1	0,5402	0,1	99,37	10,4893	
LIIB	2,977	1	0,6067	0,1	99,37	12,8806	12,2798

APPENDIX 3. Mass Fraction Calculations for Substrates for Growing Carrot Sampled in the Beginning of the Experiment

Carrot, Cd							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0096	0,1	0,00		
BIA	3,057	1	0,0423	0,1	99,37	1,7084	
BIB	3,034	1	0,0500	0,1	99,37	1,9767	
BIIA	3,017	1	0,0547	0,1	99,37	2,1444	
BIIB	3,025	1	0,0549	0,1	99,37	2,1459	1,9939
KIA	2,981	1	0,0535	0,1	99,37	2,1303	
KIB	3,095	1	0,0577	0,1	99,37	2,1884	
KIIA	3,056	1	0,0594	0,1	99,37	2,2721	
KIIB	3,035	1	0,0660	0,1	99,37	2,5064	2,2743
VIA	3,098	1	0,0624	0,1	99,37	2,3388	
VIB	3,076	1	0,0668	0,1	99,37	2,4995	
VIIA	3,133	1	0,0708	0,1	99,37	2,5823	
VIIB	3,063	1	0,0707	0,1	99,37	2,6383	2,5147
LIA	3,124	1	0,0708	0,1	99,37	2,5897	
LIB	3,090	1	0,0732	0,1	99,37	2,6967	
LIIA	3,025	1	0,0713	0,1	99,37	2,6917	
LIIB	3,146	1	0,0736	0,1	99,37	2,6611	2,6598
Carrot, Cu							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0716	0,1	0,00		
BIA	3,057	1	-0,0377	0,1	99,37	1,1159	
BIB	3,034	1	-0,0475	0,1	99,37	0,7993	
BIIA	3,017	1	-0,0572	0,1	99,37	0,4802	
BIIB	3,025	1	-0,0685	0,1	99,37	0,1031	0,6246
KIA	2,981	1	-0,0479	0,1	99,37	0,8001	
KIB	3,095	1	-0,0736	0,1	99,37	-0,0650	
KIIA	3,056	1	-0,0688	0,1	99,37	0,0922	
KIIB	3,035	1	-0,0624	0,1	99,37	0,3050	0,2831
VIA	3,098	1	-0,0462	0,1	99,37	0,8251	
VIB	3,076	1	-0,0429	0,1	99,37	0,9389	
VIIA	3,133	1	-0,0446	0,1	99,37	0,8672	
VIIB	3,063	1	-0,0699	0,1	99,37	0,0559	0,6718
LIA	3,124	1	-0,0414	0,1	99,37	0,9727	
LIB	3,090	1	-0,0523	0,1	99,37	0,6286	
LIIA	3,025	1	-0,0521	0,1	99,37	0,6488	
LIIB	3,146	1	-0,0492	0,1	99,37	0,7165	0,7416

Carrot, Pb							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	0,0109	0,1	0,00		
BIA	3,057	1	0,0491	0,1	99,37	1,2574	
BIB	3,034	1	0,4566	0,1	99,37	14,7823	
BIIA	3,017	1	0,0069	0,1	99,37	-0,1334	
BIIB	3,025	1	0,0298	0,1	99,37	0,6288	4,1338
KIA	2,981	1	0,0320	0,1	99,37	0,7124	
KIB	3,095	1	0,0317	0,1	99,37	0,6764	
KIIA	3,056	1	-0,0014	0,1	99,37	-0,4050	
KIIB	3,035	1	0,0160	0,1	99,37	0,1691	0,2882
VIA	3,098	1	0,0585	0,1	99,37	1,5462	
VIB	3,076	1	-0,0017	0,1	99,37	-0,4122	
VIIA	3,133	1	-0,0153	0,1	99,37	-0,8415	
VIIB	3,063	1	0,0243	0,1	99,37	0,4403	0,1832
LIA	3,124	1	0,0012	0,1	99,37	-0,3124	
LIB	3,090	1	0,0231	0,1	99,37	0,3973	
LIIA	3,025	1	-0,1007	0,1	99,37	-3,7131	
LIIB	3,146	1	-0,0173	0,1	99,37	-0,9020	-1,1326
Carrot, Ni							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	0,0489	0,1	0,00		
BIA	3,057	1	0,1162	0,1	99,37	2,2153	
BIB	3,034	1	0,1336	0,1	99,37	2,8092	
BIIA	3,017	1	0,0966	0,1	99,37	1,5908	
BIIB	3,025	1	0,1100	0,1	99,37	2,0328	2,1620
KIA	2,981	1	0,1141	0,1	99,37	2,2012	
KIB	3,095	1	0,1180	0,1	99,37	2,2469	
KIIA	3,056	1	0,1022	0,1	99,37	1,7551	
KIIB	3,035	1	0,1175	0,1	99,37	2,2743	2,1194
VIA	3,098	1	0,1089	0,1	99,37	1,9490	
VIB	3,076	1	0,1304	0,1	99,37	2,6663	
VIIA	3,133	1	0,1043	0,1	99,37	1,7793	
VIIB	3,063	1	0,1193	0,1	99,37	2,3130	2,1769
LIA	3,124	1	0,0990	0,1	99,37	1,6137	
LIB	3,090	1	0,1137	0,1	99,37	2,1105	
LIIA	3,025	1	0,1156	0,1	99,37	2,2192	
LIIB	3,146	1	0,1129	0,1	99,37	2,0470	1,9976

Carrot, Zn							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	0,2257	0,1	0,00		
BIA	3,057	1	0,4969	0,1	99,37	8,9271	
BIB	3,034	1	0,4705	0,1	99,37	8,1192	
BIIA	3,017	1	0,4828	0,1	99,37	8,5743	
BIIB	3,025	1	0,4801	0,1	99,37	8,4638	8,5211
KIA	2,981	1	0,5120	0,1	99,37	9,6657	
KIB	3,095	1	0,4847	0,1	99,37	8,4219	
KIIA	3,056	1	0,4868	0,1	99,37	8,5977	
KIIB	3,035	1	0,4606	0,1	99,37	7,7877	8,6183
VIA	3,098	1	0,4624	0,1	99,37	7,6889	
VIB	3,076	1	0,5037	0,1	99,37	9,0950	
VIIA	3,133	1	0,4320	0,1	99,37	6,6259	
VIIB	3,063	1	0,4227	0,1	99,37	6,4726	7,4706
LIA	3,124	1	0,4677	0,1	99,37	7,7948	
LIB	3,090	1	0,4258	0,1	99,37	6,5170	
LIIA	3,025	1	0,4400	0,1	99,37	7,1302	
LIIB	3,146	1	0,4402	0,1	99,37	6,8607	7,0757

APPENDIX 4. Mass Fraction Calculations for Substrates for Growing Barley Sampled in the End of the Experiment

Barley, Cd							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0200	0,1	0,00		
BIA	3,231	1	-0,0196	0,1	99,37	0,0125	
BIB	3,012	1	-0,0174	0,1	99,37	0,0869	
BIIA	2,957	1	-0,0149	0,1	99,37	0,1736	
BIIB	3,223	1	-0,0166	0,1	99,37	0,1062	0,0948
KIA	2,964	1	-0,0137	0,1	99,37	0,2139	
KIB	3,152	1	-0,0157	0,1	99,37	0,1373	
KIIA	2,951	1	-0,0090	0,1	99,37	0,3751	
KIIB	3,001	1	0,0012	0,1	99,37	0,7109	0,3593
VIA	3,052	1	-0,0048	0,1	99,37	0,5012	
VIB	2,976	1	-0,0108	0,1	99,37	0,3111	
VIIA	2,967	1	-0,0231	0,1	99,37	-0,1051	
VIIB	3,128	1	-0,0185	0,1	99,37	0,0483	0,2357
LIA	3,044	1	-0,0127	0,1	99,37	0,2413	
LIB	3,093	1	-0,0115	0,1	99,37	0,2765	
LIIA	3,018	1	-0,0096	0,1	99,37	0,3468	
LIIB	3,056	1	-0,0142	0,1	99,37	0,1910	0,2639
Barley, Cu							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0082	0,1	0,00		
BIA	3,231	1	0,1088	0,1	99,37	3,6440	
BIB	3,012	1	0,1414	0,1	99,37	4,9981	
BIIA	2,957	1	0,0960	0,1	99,37	3,5461	
BIIB	3,223	1	0,0777	0,1	99,37	2,6820	3,7176
KIA	2,964	1	0,1080	0,1	99,37	3,9451	
KIB	3,152	1	0,1055	0,1	99,37	3,6300	
KIIA	2,951	1	0,0882	0,1	99,37	3,2873	
KIIB	3,001	1	0,0636	0,1	99,37	2,4076	3,3175
VIA	3,052	1	0,0585	0,1	99,37	2,1992	
VIB	2,976	1	0,0699	0,1	99,37	2,6409	
VIIA	2,967	1	0,0774	0,1	99,37	2,9033	
VIIB	3,128	1	0,0822	0,1	99,37	2,9083	2,5811
LIA	3,044	1	0,0714	0,1	99,37	2,6315	
LIB	3,093	1	0,0788	0,1	99,37	2,8305	
LIIA	3,018	1	0,0538	0,1	99,37	2,0673	
LIIB	3,056	1	0,1011	0,1	99,37	3,5991	2,7821

Barley, Pb							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0416	0,1	0,00		
BIA	3,231	1	0,0157	0,1	99,37	1,7846	
BIB	3,012	1	0,0465	0,1	99,37	2,9434	
BIIA	2,957	1	0,0283	0,1	99,37	2,3788	
BIIB	3,223	1	0,0879	0,1	99,37	4,0433	2,7875
KIA	2,964	1	0,0393	0,1	99,37	2,7466	
KIB	3,152	1	0,0604	0,1	99,37	3,2565	
KIIA	2,951	1	0,0385	0,1	99,37	2,7315	
KIIB	3,001	1	0,0519	0,1	99,37	3,1353	2,9675
VIA	3,052	1	0,0266	0,1	99,37	2,2487	
VIB	2,976	1	-0,0303	0,1	99,37	0,3821	
VIIA	2,967	1	-0,0166	0,1	99,37	0,8479	
VIIB	3,128	1	0,0122	0,1	99,37	1,7308	1,3024
LIA	3,044	1	0,0246	0,1	99,37	2,1885	
LIB	3,093	1	0,0382	0,1	99,37	2,5963	
LIIA	3,018	1	0,0332	0,1	99,37	2,4941	
LIIB	3,056	1	0,0489	0,1	99,37	2,9801	2,5647
Barley, Ni							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0128	0,1	0,00		
BIA	3,231	1	0,0571	0,1	99,37	2,1771	
BIB	3,012	1	0,0543	0,1	99,37	2,2418	
BIIA	2,957	1	0,0677	0,1	99,37	2,7395	
BIIB	3,223	1	0,0308	0,1	99,37	1,3613	2,1299
KIA	2,964	1	0,0491	0,1	99,37	2,1016	
KIB	3,152	1	0,0446	0,1	99,37	1,8326	
KIIA	2,951	1	0,0460	0,1	99,37	2,0051	
KIIB	3,001	1	0,0552	0,1	99,37	2,2802	2,0549
VIA	3,052	1	0,0736	0,1	99,37	2,8488	
VIB	2,976	1	0,0533	0,1	99,37	2,2351	
VIIA	2,967	1	0,0363	0,1	99,37	1,6653	
VIIB	3,128	1	0,0490	0,1	99,37	1,9882	2,1843
LIA	3,044	1	0,0380	0,1	99,37	1,6794	
LIB	3,093	1	0,0441	0,1	99,37	1,8512	
LIIA	3,018	1	0,0401	0,1	99,37	1,7639	
LIIB	3,056	1	0,0527	0,1	99,37	2,1568	1,8628

Barley, Zn							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	0,0540	0,1	0,00		
BIA	3,231	1	0,5047	0,1	99,37	14,0372	
BIB	3,012	1	0,5635	0,1	99,37	17,0224	
BIIA	2,957	1	0,4557	0,1	99,37	13,6704	
BIIB	3,223	1	0,5078	0,1	99,37	14,1689	14,7247
KIA	2,964	1	0,5113	0,1	99,37	15,5258	
KIB	3,152	1	0,5647	0,1	99,37	16,3046	
KIIA	2,951	1	0,4839	0,1	99,37	14,6598	
KIIB	3,001	1	0,4447	0,1	99,37	13,1011	13,1011
VIA	3,052	1	0,5217	0,1	99,37	15,4210	
VIB	2,976	1	0,4441	0,1	99,37	13,1909	
VIIA	2,967	1	0,4645	0,1	99,37	13,9228	
VIIB	3,128	1	0,5250	0,1	99,37	15,1525	14,4218
LIA	3,044	1	0,4845	0,1	99,37	14,2318	
LIB	3,093	1	0,4913	0,1	99,37	14,2276	
LIIA	3,018	1	0,4522	0,1	99,37	13,2774	
LIIB	3,056	1	0,5080	0,1	99,37	14,9497	14,1716

APPENDIX 5. Mass Fraction Calculations for Substrates for Growing Carrot Sampled in the End of the Experiment

Carrot, Cd							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0200	0,1	0,00		
BIA	3,185	1	-0,0067	0,1	99,37	0,4202	
BIB	2,941	1	-0,0143	0,1	99,37	0,1950	
BIIA	2,915	1	-0,0030	0,1	99,37	0,5869	
BIIB	2,928	1	-0,0109	0,1	99,37	0,3128	0,3787
KIA	3,154	1	-0,0090	0,1	99,37	0,3510	
KIB	3,049	1	-0,0072	0,1	99,37	0,4225	
KIIA	2,928	1	-0,0070	0,1	99,37	0,4468	
KIIB	3,074	1	-0,0070	0,1	99,37	0,4256	0,4114
VIA	3,068	1	-0,0041	0,1	99,37	0,5215	
VIB	2,946	1	-0,0093	0,1	99,37	0,3655	
VIIA	3,025	1	-0,0064	0,1	99,37	0,4524	
VIIB	3,024	1	-0,0070	0,1	99,37	0,4326	0,4430
LIA	3,054	1	-0,0027	0,1	99,37	0,5700	
LIB	3,019	1	-0,0034	0,1	99,37	0,5533	
LIIA	3,021	1	-0,0013	0,1	99,37	0,6229	
LIIB	2,951	1	-0,0028	0,1	99,37	0,5865	0,5832
Carrot, Cu							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0082	0,1	0,00		
BIA	3,185	1	0,1029	0,1	99,37	3,5102	
BIB	2,941	1	0,0987	0,1	99,37	3,6577	
BIIA	2,915	1	0,0478	0,1	99,37	1,9332	
BIIB	2,928	1	0,0715	0,1	99,37	2,7392	2,9601
KIA	3,154	1	0,0708	0,1	99,37	2,5206	
KIB	3,049	1	0,0490	0,1	99,37	1,8879	
KIIA	2,928	1	0,0710	0,1	99,37	2,7220	
KIIB	3,074	1	0,0523	0,1	99,37	1,9805	2,2777
VIA	3,068	1	0,0692	0,1	99,37	2,5387	
VIB	2,946	1	0,0432	0,1	99,37	1,7557	
VIIA	3,025	1	0,0653	0,1	99,37	2,4451	
VIIB	3,024	1	0,0523	0,1	99,37	2,0133	2,1882
LIA	3,054	1	0,0856	0,1	99,37	3,0908	
LIB	3,019	1	0,0587	0,1	99,37	2,2299	
LIIA	3,021	1	0,0647	0,1	99,37	2,4283	
LIIB	2,951	1	0,0589	0,1	99,37	2,2881	2,5093

Carrot, Pb							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0416	0,1	0,00		
BIA	3,185	1	0,1032	0,1	99,37	4,5750	
BIB	2,941	1	0,0642	0,1	99,37	3,6201	
BIIA	2,915	1	0,0705	0,1	99,37	3,8699	
BIIB	2,928	1	0,0783	0,1	99,37	4,1208	4,0464
KIA	3,154	1	0,0664	0,1	99,37	3,4458	
KIB	3,049	1	0,0977	0,1	99,37	4,5975	
KIIA	2,928	1	0,0928	0,1	99,37	4,6191	
KIIB	3,074	1	0,0669	0,1	99,37	3,5519	4,0536
VIA	3,068	1	0,0441	0,1	99,37	2,8110	
VIB	2,946	1	0,0295	0,1	99,37	2,4287	
VIIA	3,025	1	0,0486	0,1	99,37	3,0006	
VIIB	3,024	1	0,0119	0,1	99,37	1,7803	2,5051
LIA	3,054	1	0,0089	0,1	99,37	1,6640	
LIB	3,019	1	-0,0002	0,1	99,37	1,3800	
LIIA	3,021	1	0,0254	0,1	99,37	2,2318	
LIIB	2,951	1	0,0678	0,1	99,37	3,7306	2,2516
Carrot, Ni							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0128	0,1	0,00		
BIA	3,185	1	0,0907	0,1	99,37	3,2701	
BIB	2,941	1	0,0666	0,1	99,37	2,7168	
BIIA	2,915	1	0,0345	0,1	99,37	1,6329	
BIIB	2,928	1	0,0553	0,1	99,37	2,3405	2,4901
KIA	3,154	1	0,0429	0,1	99,37	1,7772	
KIB	3,049	1	0,0277	0,1	99,37	1,3367	
KIIA	2,928	1	0,0342	0,1	99,37	1,6153	
KIIB	3,074	1	0,0538	0,1	99,37	2,1802	1,7273
VIA	3,068	1	0,0452	0,1	99,37	1,9024	
VIB	2,946	1	0,0389	0,1	99,37	1,7660	
VIIA	3,025	1	0,0295	0,1	99,37	1,4072	
VIIB	3,024	1	0,0523	0,1	99,37	2,1664	1,8105
LIA	3,054	1	0,0491	0,1	99,37	2,0396	
LIB	3,019	1	0,0409	0,1	99,37	1,7900	
LIIA	3,021	1	0,0579	0,1	99,37	2,3550	
LIIB	2,951	1	0,0312	0,1	99,37	1,5004	1,9213

Carrot, Zn							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	0,0540	0,1	0,00		
BIA	3,185	1	0,4996	0,1	99,37	14,0788	
BIB	2,941	1	0,4849	0,1	99,37	14,7439	
BIIA	2,915	1	0,3999	0,1	99,37	11,9411	
BIIB	2,928	1	0,4446	0,1	99,37	13,4243	13,5470
KIA	3,154	1	0,4839	0,1	99,37	13,7163	
KIB	3,049	1	0,4128	0,1	99,37	11,8420	
KIIA	2,928	1	0,4791	0,1	99,37	14,6100	
KIIB	3,074	1	0,5023	0,1	99,37	14,6756	13,7110
VIA	3,068	1	0,4977	0,1	99,37	14,5534	
VIB	2,946	1	0,4537	0,1	99,37	13,6531	
VIIA	3,025	1	0,4828	0,1	99,37	14,2646	
VIIB	3,024	1	0,4925	0,1	99,37	14,5921	14,2658
LIA	3,054	1	0,5570	0,1	99,37	16,5741	
LIB	3,019	1	0,4611	0,1	99,37	13,5696	
LIIA	3,021	1	0,4344	0,1	99,37	12,6713	
LIIB	2,951	1	0,4695	0,1	99,37	14,1688	14,2459

APPENDIX 6. Mass Fraction Calculations for Composted Faeces and STS

Cadmium						
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0025	0,1		
Compost 1	3,053	1	0,0165	0,1	0,6224	
Compost 2	3,014	1	0,0190	0,1	0,7134	0,6679
Blank	0,000	1	-0,0246	0,1		
STS 1	3,008	1	0,0569	0,1	2,7094	
STS 2	3,064	1	0,0454	0,1	1,5634	2,1364
Copper						
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0109	0,1		
Compost 1	3,053	1	2,2693	0,1	74,6994	
Compost 2	3,014	1	2,2465	0,1	74,9021	74,8008
Blank	0,000	1	-0,0388	0,1		
STS 1	3,008	5	2,3185	0,1	386,6789	
STS 2	3,064	5	2,2920	0,1	375,2995	380,9892
Lead						
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	0,1182	0,1		
Compost 1	3,053	1	0,1167	0,1	-0,0491	
Compost 2	3,014	1	0,1673	0,1	1,6292	0,7900
Blank	0,000	1	0,1405	0,1		
STS 1	3,008	1	2,4355	0,1	76,2965	
STS 2	3,064	1	2,4077	0,1	73,9972	75,1469
Nickel						
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0169	0,1		
Compost 1	3,053	1	0,2173	0,1	7,6724	
Compost 2	3,014	1	0,2274	0,1	8,1060	7,8892
Blank	0,000	1	-0,0380	0,1		
STS 1	3,008	1	1,7302	0,1	58,7832	
STS 2	3,064	1	1,6783	0,1	56,0168	57,4000
Zinc						
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	0,0491	0,1		
Compost 1	3,053	10	1,5987	0,1	522,1261	
Compost 2	3,014	10	1,6651	0,1	550,8627	536,4944
Blank	0,000	1	0,0279	0,1		
STS 1	3,008	25	1,1014	0,1	913,7600	
STS 2	3,064	25	1,1230	0,1	914,7133	914,2366

APPENDIX 7. Mass Fraction Calculations for Urine

Cadmium						
Sample	**Volume (ml)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (ml)**	**Mass Fraction/ Sample (mg l^{-1})**	**Mass Fraction/ Substrate (mg l^{-1})**
Blank	0,0	1	-0,0150	100		
Urine 1	25,0	1	-0,0169	100	-0,0076	
Urine 2	25,0	1	-0,0274	100	-0,0496	-0,0286
Copper						
Sample	**Volume (ml)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (ml)**	**Mass Fraction/ Sample (mg l^{-1})**	**Mass Fraction/ Substrate (mg l^{-1})**
Blank	0,0	1	-0,0484	100		
Urine 1	25,0	1	0,0052	100	0,2144	
Urine 2	25,0	1	-0,0066	100	0,1672	0,1908
Lead						
Sample	**Volume (ml)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (ml)**	**Mass Fraction/ Sample (mg l^{-1})**	**Mass Fraction/ Substrate (mg l^{-1})**
Blank	0,0	1	0,1446	100		
Urine 1	25,0	1	0,1230	100	-0,0864	
Urine 2	25,0	1	0,0791	100	-0,2620	-0,1742
Nickel						
Sample	**Volume (ml)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (ml)**	**Mass Fraction/ Sample (mg l^{-1})**	**Mass Fraction/ Substrate (mg l^{-1})**
Blank	0,0	1	-0,0507	100		
Urine 1	25,0	1	-0,0204	100	0,1212	
Urine 2	25,0	1	-0,0043	100	0,1856	0,1534
Zinc						
Sample	**Volume (ml)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (ml)**	**Mass Fraction/ Sample (mg l^{-1})**	**Mass Fraction/ Substrate (mg l^{-1})**
Blank	0,0	1	0,0349	100		
Urine 1	25,0	1	0,0699	100	0,1400	
Urine 2	25,0	1	0,0741	100	0,1568	0,1484

APPENDIX 8. Mass Fraction Calculations for Barley

Barley, Cd							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0168	0,05	0,00		
OLI	5,010	1	-0,0136	0,05	92,65	0,0345	
OLII	5,015	1	-0,0166	0,05	92,65	0,0022	0,0183
OKI	5,008	1	-0,0121	0,05	93,65	0,0501	
OKII	5,008	1	-0,0103	0,05	93,65	0,0693	0,0501
OVI	5,013	1	-0,0094	0,05	92,45	0,0798	
OVII	5,008	1	-0,0117	0,05	92,45	0,0551	0,0675
OSI	5,009	1	-0,0121	0,05	92,52	0,0507	
OSII	5,006	1	-0,0127	0,05	92,52	0,0443	0,0475
Barley, Cu							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0147	0,05	0,00		
OLI	5,010	1	0,2457	0,05	92,65	2,8051	
OLII	5,015	1	0,1773	0,05	92,65	2,0662	2,4357
OKI	5,008	1	0,1124	0,05	93,65	1,3550	
OKII	5,008	1	0,1194	0,05	93,65	1,4297	1,3550
OVI	5,013	1	0,2056	0,05	92,45	2,3768	
OVII	5,008	1	0,1495	0,05	92,45	1,7733	2,3768
OSI	5,009	1	0,2651	0,05	92,52	3,0189	
OSII	5,006	1	0,2602	0,05	92,52	2,9678	2,9933
Barley, Pb							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	0,0268	0,05	0,00		
OLI	5,010	1	-0,0159	0,05	92,65	-0,4600	
OLII	5,015	1	0,0180	0,05	92,65	-0,0947	-0,2773
OKI	5,008	1	0,0367	0,05	93,65	0,1055	
OKII	5,008	1	0,0267	0,05	93,65	-0,0011	0,1055
OVI	5,013	1	-0,0046	0,05	92,45	-0,3388	
OVII	5,008	1	0,0492	0,05	92,45	0,2419	-0,0484
OSI	5,009	1	-0,0080	0,05	92,52	-0,3755	
OSII	5,006	1	0,0184	0,05	92,52	-0,0907	-0,2331

Barley, Ni							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0167	0,05	0,00		
OLI	5,010	1	0,0283	0,05	92,65	0,4848	
OLII	5,015	1	0,0129	0,05	92,65	0,3185	0,4016
OKI	5,008	1	-0,0007	0,05	93,65	0,1706	
OKII	5,008	1	0,0130	0,05	93,65	0,3166	0,1706
OVI	5,013	1	0,0144	0,05	92,45	0,3355	
OVII	5,008	1	-0,0190	0,05	92,45	-0,0248	0,1553
OSI	5,009	1	0,0055	0,05	92,52	0,2395	
OSII	5,006	1	0,0006	0,05	92,52	0,1868	0,2131
Barley, Zn							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	5	0,4442	0,05	0,00		
OLI	5,010	5	0,6423	0,05	92,65	29,8102	
OLII	5,015	5	0,6239	0,05	92,65	28,7905	29,3004
OKI	5,008	5	0,5591	0,05	93,65	25,0676	
OKII	5,008	5	0,5021	0,05	93,65	22,0292	25,0676
OVI	5,013	5	0,5294	0,05	92,45	23,7657	
OVII	5,008	5	0,6032	0,05	92,45	27,7745	23,7657
OSI	5,009	5	0,6623	0,05	92,52	30,9363	
OSII	5,006	5	0,7194	0,05	92,52	34,0371	32,4867

APPENDIX 9. Mass Fraction Calculations for Carrot

Carrot, Cd							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0147	0,05	0,00		
PLI	5,002	1	0,0725	0,05	100,00	0,8717	
PLII	5,009	1	0,1063	0,05	100,00	1,2078	1,0397
PKI	5,008	1	0,0956	0,05	100,00	1,1012	
PKII	5,009	1	0,1036	0,05	100,00	1,1809	1,1411
PVI	0	0	0	0	0	0	
PVII	0	0	0	0	0	0	0
PSI	5,002	1	0,4234	0,05	100,00	4,3792	
PSII	5,006	1	0,2031	0,05	100,00	2,1754	3,2773
Carrot, Cu							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0096	0,05	0,00		
PLI	5,002	1	0,0547	0,05	100,00	0,6427	
PLII	5,009	1	0,0549	0,05	100,00	0,6438	0,6433
PKI	5,008	1	0,0594	0,05	100,00	0,6889	
PKII	5,009	1	0,0660	0,05	100,00	0,7546	0,7218
PVI	0	0	0	0	0	0	
PVII	0	0	0	0	0	0	0
PSI	5,002	1	0,0713	0,05	100,00	0,8087	
PSII	5,006	1	0,0736	0,05	100,00	0,8310	0,8198
Carrot, Pb							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	0,0268	0,05	0,00		
PLI	5,002	1	0,0317	0,05	100,00	0,0490	
PLII	5,009	1	0,0423	0,05	100,00	0,1547	0,1019
PKI	5,008	1	0,0126	0,05	100,00	-0,1418	
PKII	5,009	1	0,0643	0,05	100,00	0,3743	0,1163
PVI	0	0	0	0	0	0	
PVII	0	0	0	0	0	0	0
PSI	5,002	1	0,1483	0,05	100,00	1,2145	
PSII	5,006	1	0,0565	0,05	100,00	0,2966	0,7556

Carrot, Ni							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	1	-0,0167	0,05	0,00		
PLI	5,002	1	0,0210	0,05	100,00	0,3768	
PLII	5,009	1	0,0192	0,05	100,00	0,3584	0,3676
PKI	5,008	1	0,0319	0,05	100,00	0,4852	
PKII	5,009	1	0,0339	0,05	100,00	0,5051	0,4952
PVI	0	0	0	0	0	0	
PVII	0	0	0	0	0	0	0
PSI	5,002	1	0,0319	0,05	100,00	0,4858	
PSII	5,006	1	0,0179	0,05	100,00	0,3456	0,4157
Carrot, Zn							
Sample	**Mass (g)**	**Dilution Ratio**	**Conc. (mg/l)**	**Volume (l)**	**Dry Matter Content (%)**	**Mass Fraction/ Sample (mg kg^{-1})**	**Mass Fraction/ Substrate (mg kg^{-1})**
Blank	0,000	5	0,4442	0,05	0,00		
PLI	5,002	5	0,2812	0,05	100,00	9,6142	
PLII	5,009	5	0,2342	0,05	100,00	7,2549	8,4345
PKI	5,008	5	0,2861	0,05	100,00	9,8472	
PKII	5,009	5	0,2740	0,05	100,00	9,2414	9,5443
PVI	0	0	0	0	0	0	
PVII	0	0	0	0	0	0	0
PSI	5,002	5	0,3913	0,05	100,00	15,1170	
PSII	5,006	5	0,3480	0,05	100,00	12,9425	14,0297

APPENDIX 10 Collected Data from 30 Spikes of Barley

Grains					
Substrate	**Number of the Grains**	**Mass of The Grains (g)**	**Mass of 1000 Grains (g)**	**Mass of All Grains (g)**	**Mass of Rest of The Grains (g)**
Fertiliser 1	435	12,5452	28,8395	37,4230	24,8778
Fertiliser 2	499	15,6592	31,3812	59,9642	44,3050
Compost 1	191	6,2025	32,4738	27,2120	21,0095
Compost 2	211	6,9840	33,0995	30,0290	23,0450
Urine 1	296	9,7283	32,8659	52,3180	42,5897
Urine 2	323	11,3792	35,2297	58,8606	47,4814
STS 1	252	8,6471	34,3139	45,3267	36,6796
STS 2	233	8,1211	34,8545	47,3188	39,1977
Grains With Husks and Awns					
Substrate	**Avg. Length of Straw (cm)**	**Avg. Length of Spike (cm)**	**Weight of Fresh Spikes (g)**	**Weight of Dried Spikes (g)**	
Fertiliser 1	76,0	6,9	29,6	17,1	
Fertiliser 2	73,9	7,4	32,9	20,1	
Compost 1	51,8	2,9	12,2	8,2	
Compost 2	53,9	3,0	13,6	8,4	
Urine 1	57,5	3,9	18,4	12,0	
Urine 2	61,4	4,5	22,0	13,9	
STS 1	55,9	3,8	11,2	8,8	
STS 2	57,4	3,5	15,7	10,0	

APPENDIX 11 Collected Data from 50 Carrots

Substrate	Avg. Length of Root (mm)	Avg. Length of Carrot (mm)	Avg. Length of Tops (mm)	Total mass of fresh Carrots (g)	Total mass of Tops (g)	Mass of air dried Carrots (g)
Fertiliser 1	35	46	363	181,4	79,6	29,2
Fertiliser 2	35	49	322	225,2	79,2	36,4
Compost 1	31	43	214	99,5	29,5	15,9
Compost 2	27	41	211	91,6	25,9	14,2
Urine 1	20	6	71	0,7	1,9	0,1
Urine 2	19	25	72	0,5	1,8	0,1
STS 1	24	19	102	3,9	4,9	1,0
STS 2	26	15	80	3,7	3,6	0,7

Substrate	Total mass of fresh Carrots (g)	Mass of air dried Carrots (g)	Dry Matter % of Oven Dried Carrots	Corrected Dry Matter (g)	Dry Matter %	Moisture %
Fertiliser 1	181,388	29,213	92,33	26,972	14,87	85,13
Fertiliser 2	225,232	36,449	93,33	34,017	15,10	84,90
Compost 1	99,457	15,940	91,67	14,613	14,69	85,31
Compost 2	91,628	14,246	94,85	13,512	14,75	85,25
Urine 1	0,671	0,147	100,00	0,147	21,91	78,09
Urine 2	0,454	0,103	90,75	0,093	20,53	79,47
STS 1	3,938	1,030	96,88	0,998	25,35	74,65
STS 2	3,738	0,730	96,05	0,701	18,76	81,24