TAMPERE POLYTECHNIC, UNIVERSITY OF APPLIED SCIENCES
Environmental Engineering

Final Thesis

Sisli Piisilä

NUTRIENT CONTENTS 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
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Sisli Piisilä	Ohran ja porkkanan kasvualustojen ravinnepitoisuudet saostuskaivolietteellä, virtsalla ja käymäläkompostilla lannoitettuna
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TIIVISTELMÄ

Tämän tutkimuksen tarkoituksena oli selvittää ihmisperäisen käymäläkompostin, saostuskaivolietteen ja virtsan vaikutukset porkkanan ja ohran lannoitteina. Verrokkina käytettiin kaupallisia epäorgaanisia lannoitteita. Uudet säännökset saostuskaivolietteen käytöstä ja käsittelystä antavat aiheen tutkia myös vaihtoehtoisia ja ekologisempia käyttötapoja, kuten saostuskaivolietteen käyttämistä lannoitteena. Päätutkimuskohteet olivat taudinaiheuttajat, ravinteet, raskasmetallit ja niiden siirtyminen ja vaikutukset tutkittaviin kasveihin. Tämä osa tutkimuksesta keskittyy typpi-, fosfori- ja kaliumpitoisuuksiin lannoitteissa ja kasvualustoissa, sekä kasvien typpipitoisuuksiin. Käytetyt analyysimetodit olivat Kjeldahl-typen määritys märkäpoltolla, tislauksella ja titrauksella; liukoisen fosforin (ortofosfaatit, 0-2.50 mg L^{-1} PO_4^{-3}) määritys mekaanisella ravistajalla, imusuodatuksella ja kenttäspektrometrillä; ja vaihtokykyisten kaliumionien (K^+) määritys mekaanisella ravistelulla, analyyttisellä suodatuksella ja AAS-spektrometrialla. Maanäytteet sisälsivät kaliumia tyydyttävästi, eniten kaliumia oli käymäläkompostikäsittelyn näytteissä. Liukoisen fosforin määrä maanäytteissä oli pieni tai olematon, mihin vaikutti tosin myös näytteiden pitkä säilytysaika ennen analyysiä. Maanäytteiden Kjeldahl-typpipitoisuudet ylittivät orgaanisen typen levitykselle asetetun raja-arvon (170 kg ha^{-1}) kaikissa porkkanan käsittelyissä. Ohran käsittelyissä kasvatuskokeen alussa otetut näytteet eivät ylittäneet raja-arvoa, STS:ä lukuun ottamatta. Typpeä löytyi eniten STS:llä viljellyistä näytteistä. Typen välittyminen kasveihin jäi puutteelliseksi johtuen ainakin osittain käytetyn kasvualustan puhtaudesta. Kasvuvaiheessa lannoitteiden erot näkyivät selkeämmin porkkanalla kuin ohralla. Lannoitteista käymäläkomposti osoittautui parhaaksi kasvihuoneviljelykäytössä, vaikka sato oli selkeästi vähäisempi kuin verrokilla. Lisätutkimukset käytetyistä lannoitteista ovat tarpeen, kuten myös kasvatuskokeet, jotta kasvihuoneviljelyn ja ulkoviljelyn sekä kasvualustan koostumuksen merkitys lannoitteiden ravinteiden siirtymiseen voitaisiin selvittää paremmin. Myös typen jakeet vaativat lisätutkimuksia.

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Piisilä Sisli	Nutrient Contents in a Growing Medium of Barley and Carrot Fertilised with Septic Tank Sludge, Urine and Composted Faeces
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ABSTRACT

The aim of this study was to survey the effects of composted faeces, septic tank sludge and urine of human origin used as fertilisers for barley and carrot. Inorganic commercial fertilisers were used as a 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 studied plants. This part of the study concentrates on nitrogen, phosphorus and potassium contents in fertilisers and substrates and nitrogen contents in final products. Methods of analysis were Kjeldahl-N determination with wet digestion, distillation and titration; Reactive phosphorus (orthophosphate, 0-2.50 mg L^{-1} P tot, PO_4^{-3}, P_2O_5) determination with mechanical shaker, Büchner filtering and portable datalogging spectrometer; and K^+ (exchangeable potassium) determination with mechanical shaker, analytical filtering and AAS. Soil samples included potassium in sufficient amounts, potassium was present to largest extent in composted faeces treatment soil samples. Amount of orthophosphates in soil samples was small or exiguous, which was affected also by the long storage time of samples before analysis. Kjeldahl-N contents in soil samples exceeded the limit set for organic nitrogen to be spread (170 kg ha^{-1}) in all carrot treatments. In barley the soil samples taken in the beginning of growing experiment were below the limit value, excluding STS treatment. Nitrogen was present to largest extent in STS treated samples. Transfer of nitrogen to plants was deficient, partly due to the clearness of substrate used. During plant growth period the differences between treatments were more visible with carrots than with barley. Composted faeces was proved to be the best fertiliser for greenhouse cultivation use, although crop yield was clearly lesser than with control. More study is needed on the fertilisers used, as well as with field experiments, in order to clarify the effects of substrate composition and cultivation in a greenhouse or outdoors environment to transfer of nutrients from fertilisers. Also fractions of nitrogen need more research.

LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrometry
CEC	Cation Exchange Capacity
HDPE	High Density Polyethylene
IC	Inorganic Carbon
ISO	International Organization for Standardization
LECA	Light Expanded Clay Aggregate
MTT	Agrifood Research Finland, Maa- ja elintarviketeollisuuden tutkimuskeskus
PP	Polypropylene
RH	Relative Humidity
STS	Septic Tank Sludge; residual sludge from septic tanks and other similar installations for the treatment of sewage
TC	Total Carbon
TOC	Total Organic Carbon

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1 INTRODUCTION

Eutrophication of water bodies and its effects on water quality, vegetation and fauna have raised concerns about nutrient emissions from agriculture. European Council Directive 91/676/EEC for the protection of waters against pollution caused by nitrates from agricultural sources was set for this purpose. The directive implementation includes that after year 2001 the yearly maximum of nitrogen fertilisers spread is 170 kg organic nitrogen per hectare. Also nutrient balance, manure storage and analyses of soil and manure should be taken into account as directed. |*30*|

Share of agriculture for human origin phosphorus pollution is now 60 % and it has been assumed to rise due to new stricter regulations imposed in 2004 for waste water treatment of sparsely populated areas in Finland. At the same time many authentications have been made about degradation in quality of cultivated soils due to the yearly tillage of arable land. The humus content of soil diminishes, which lessens soil fertility, physical structure and also crop yields. |*1,2,19*|

Fertilising and soil enrichment values of human origin STS, urine and faeces have been shown in several case studies. Applications of sludge have improved soil structure (aggregation), humus content, cation exchange capacity (CEC), water holding capacity and permeability. In addition to this, sludge provides also the essential nutrients for plant growth. This strongly proposes the use of human excreta for plant production if not as the only fertiliser at least in the form of supplemental nutrients. Also human origin waste should be considered for use in enhancing the chemical and physical properties of soil. |*2,8,19,21,29*|

1.1 NUTRIENTS IN HUMAN EXCRETA

In a study conducted by Schouw, N.I. et al. in Thailand the composition of human excreta was studied with 15 selected test persons. From their results it can be interpreted that of total solids in excreta around 11.8 % is nitrogen, 2.4 % phosphorus and 4.0 % potassium. In the same study the composition of septic tank

sludge of 395 persons was studied, in which the N-P-K contents of total solids were 15.5 %, 3.5 % and 3.7 %. |*23*|

Nutrient components in sludge are usually of slow-release character. There is both inorganic and organic nitrogen present in the sludge but the organic share has been estimated to be as high as 70 %. Inorganic nitrogen is in forms of NO_3^- and NH_4^+, ammonia is the prevailing form of these two. Inorganic N is taken up by plants but can be lost for leaching, denitrification and volatilisation. It has been estimated that 50-90 % of inorganic N is lost by volatilisation when applied and soon after. Organic N isn't lost but must be mineralised to inorganic N for uptake by plants. This means that the true agronomic value of sludge is not only dependent on the composition of sludge to be used but also on the balance between the mineralisation - immobilisation processes rate of soil. |*29*|

1.2 FERTILISER EXPERIMENTS

In Petersen et al's study (2003) sewage sludge was applied to arable land in a three year period. Satisfactory yields were obtained with and without supplementary mineral nitrogen. There were no adverse effects of applying sewage sludge. |*21*|

In a Kuisma, Lehtonen & Tontti study conducted by MTT (Maa- ja elintarviketalouden tutkimuskeskus) in 2003, bio waste and sludge composts were applied to a Finnish clay soil with cultivation of barley, clover grass and hay grass. Application rate was as phosphorus storage cultivation and amount of composts were not limited to the extent of European Council Directive 91/676/EEC. Results showed that bio waste and sludge composts can be applied to enhance soil properties, although in short term use these properties weren't significant, and to provide needed phosphorus and sufficient amounts of potassium for plant cultivation. Nitrogen fertilising was suggested to be reinforced at least on cultivation years after compost application to have crop yields competitive with artificial fertilizer yields. Composts applied provided generously total nitrogen and total phosphorus but scarcely soluble nitrogen and phosphorus. Using only compost for plant fertilising led to nutrient deficiencies and stunted growth as the nitrogen sources from composts did not release fast enough in Finnish environment.

Although application of composts provided large amounts of nutrients at once to soil they were mostly in insoluble forms. In long-term use this could pose a threat to ground waters and environment as the limits of nitrate directive may be exceeded. |*19*|

In a study conducted by Antolín et al. sewage sludge was applied to a semiarid Mediterranean region agricultural soil, cultivated with barley in a three year period. Cumulative applications of sewage sludge increased grain size. Higher dry matter yield and leaf protein concentrations were obtained in the plants from beginning of development to ear emergence. Increased TOC as well as CEC values were found and soil microbiological properties were enhanced. Residual effect of sewage sludge was stated positive but short. |*2*|

In Finland and other Nordic countries characteristic to extreme weather conditions, sparse inhabitation and long distances, the requirement of STS treatment at centrally planned waste water treatment plants (WWTP) or dumping of STS to landfills leads to both economical and ecological disadvantages. Emptying of septic tanks is not even possible throughout the year without trouble as accessibility of country roads worsens during winter and early springtime due to snow and frost damages. |*26*|

Enrichment of soil could be done with the use of human excreta. This can be justified through both ecological and economical reasons. Use of human excreta gives back the nutrients from end-production to primary production while improving the soil quality in the long run. This lessens need for disposal of sewage sludge to waste water treatment plants, incineration plants or landfills, depending on the national legislation for sludge treatment. |*19*|

1.3 LEGISLATION AND REGULATIONS

Present Finnish legislation sets several limitations to the fertiliser use of human excreta and in some cases also forbids it. The use of STS is regulated by European Council directives, which give the framework for national regulations and statutes that can be even stricter.

Statute 931/2000 of the Council of State, limiting the amount of nitrate access to water from agricultural sources, is based on the EC Directive 91/676/EEC. Statute includes regulations for storage and spreading of manure. In addition to the yearly maximum limit of organic N there are limitations due to soil characteristics, crop plant type and the cropping zone of application. Nitrogen fertilising should be done according to average yield level, cropping zone and rotation so that target is to maintain the nutrient balance of soil. In field fertilising the limits for maximum nitrogen amounts are the same for commercial fertilisers, manure and for organic fertilisers and are dependant of soil type, cropping zone and also as an exception to fertiliser type. If the amount of N spread exceeds the limit of 170 kg ha^{-1} it's spreading should be done in two parts with a pause of minimum two weeks in between. The limit values are shown in Table 1. |*33*|

Table 1. Limit values for Nitrogen fertilising, kg/ha/year. (Council of State Statute 931/2000)

Crop Type	Other characteristics	Yearly N amount (kg ha^{-1})	To be spread in autumn (N kg ha^{-1})	To be spread in spring (N kg ha^{-1})
winter grain	-	200	30	170
winter grain	**FT:** methylene urea	200	40	160
potato	-	130	-	-
grass, pasture, ensilage, horticultural plants	-	250	-	-
spring grain, sugar beet, oil plants and others (1)	-	170	-	-
spring grain, sugar beet, oil plants and others (2)	**ST:** medium fine sand and rougher grained mineral soils	120	-	-
grain, sugar beet	**ST:** peat soil	110	-	-
grain, sugar beet	**CZ:** in the operation ranges of regional environmental centers of Lapland, North Ostrobothnia and Kainuu	110	-	-
grass	**ST:** peat soil	120	-	-

ST = Soil Type; FT = Fertiliser Type; CZ = Cropping Zone

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 and fleshes out Statute 931/2000 on many areas. Decision also takes into account Water Act (264/1961) and the Public Health Act (469/1965). Based on the EU

directive the decision has same values and targets for sludge usage but some articles are stricter. Use of sewage sludge is forbidden if untreated, when treated the treatment should be done with digestion, lime stabilisation or other method that reduces content of pathogens, odours and other negative impacts to environment and health. What is more important about this decision is that it states that **sludge may only be used for cereal crops, oil plants, sugar beet or crops used for other purposes than human nutrition or animal feed-stuff. Cultivation of potatoes, root crops and vegetables is forbidden for five years after sludge application on a patch.** Limits are also set for heavy metal concentration and pH values and for pace of analyses to be carried out. |*32*|

Other directives concerning STS and the protection of environment include the European Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil. According to the directive 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. STS should be used in a controlled environment without harming environment, man, animals or plants. When considering the usage of STS as fertiliser one should also take into account council directives;

- 75/442/EEC on Wastes (Amended by directives 91/156/EEC, 91/692/EEC and by commission decision 96/350/EC)
- 91/689/EEC on Hazardous waste
- 75/440/EEC on The quality required of surface water intended for the abstraction of drinking water (Amended by directives 79/869/EEC, 80/778/EEC and by 1985 Act of Accession); and;
- 80/68/EEC of the protection of groundwater against pollution caused by certain dangerous substances.

Use of human origin urine and composted faeces for fertilising was defined from a legal point of view by Ministry of Agriculture and Forestry (Department of Foodstuff and Health) in their response to Global Dry Toilet Club of Finland (9 January 2007). Treatment of composted faeces and urine should be done according to the Waste Act (1072/1993) and its regulations. In sparsely populated areas this sort of waste should be taken into a treatment plant or treated according to the

instructions of the municipality's environment and health protection authority. After this treatment the waste could be used to fertilise garden. This means that human origin urine and composted faeces can be used only in terms of national environmental legislation. A farm operating without environmental licence can use STS and composted faeces for field fertilising if they are first treated with lime stabilisation, thermophilic digestion, composting or thermic dehydration. Composted faeces and human urine cannot be given for free or sold unless the product qualifies the requirements given for fertiliser products in the Fertiliser Product Act (359/2006). |*28*|

These legislative issues critically limit and in some cases forbid the use of human excreta as fertilisers. Scientific background for these directives is not clearly stated. Limitations for pollution from agricultural sources should be clearly set for environmental and health reasons but these limitations should be sound enough also for the recovery of nutrients from wastes and their recycling. Directives imposed give the impression that the emphasis on decisions has been on environmental and health issues only, instead of considering also the usage possibilities of human excreta for plant production, the fertilising values of human excreta and their economical and ecological values.

2 GROWING EXPERIMENT

This study was conducted at Tampere Polytechnic, University of Applied Sciences, as a short-term greenhouse cultivation experiment, time period three months which corresponds to the yearly growth season in Finnish environment. This thesis concentrates on the nutrient contents [Kjeldahl Nitrogen; Soluble Reactive Phosphorus; Exchangeable Potassium (K^+)] in substrates, fertilisers and plants to fathom the fertilising values, usage possibilities and effects of STS, urine and composted faeces of human origin in plant production.

The substrates were made of unfertilised horticultural peat and sand (pH stabilised with lime) to assure no nutrients, heavy metals, microbiota or fauna was present in order to examine the true fertilising values, heavy metal traces and pathogens from single application of septic tank sludge, composted faeces and separated urine.

Application amount was calculated to be in relation to the recommended application amount of artificial fertilizers, Kevätviljan Y3 -fertiliser for barley; Puutarhan kevät -fertiliser for carrot.

Human origin fertilisers of use were septic tank sludge from private households in municipality of Kangasala, composted faeces with bio waste from a separating dry toilet from private household and separated urine from the same source. Faeces were composted and urine was stored for one year before the beginning of this experiment. The composting period included wintertime which freezes the compost and stops most if not all microbial activity for that time.

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 began autumn 2005 and preparation of substrates already in the middle of 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 2.

Table 2. The timetable of the experiment.

Date	Time		Action	End
	Weeks	Days		
12.10.2005	-4	-27	Mixing peat and lime	12.10.2005
4.11.2005	-1	-4	Mixing peat and sand	4.11.2005
7.11.2005	0	-1	Sampling soil samples I	
8.11.2005	0	0	Growing experiment	20.2.2006
8.11.2005	0	0	Sampling of STS	
8.11.2005	0	0	Sowing	
9.11.2005	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
7.12.2005	5	29	TC of soil samples I	
9.12.2005	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	8.1.2006
8.1.2006	9	70	Greenhouse door closed	
17.1.2006	11	71	Sampling 30 spikes of barley	
20.1.2006	11	74	Barley harvested	
26.1.2006	12	80	Kjeldahl-N analysis of substrates I	27.1.2006
2.2.2006	13	87	Sampling 50 carrots	
9.2.2006	14	94	Carrots picked	10.2.2006
16.2.2006	15	101	Sieving soil samples II, barley	
20.2.2006	16	105	Sampling soil samples II, carrot	
22.2.2006	16	107	Sieving soil samples II, carrot	
9.3.2006	18	122	Dry mass of barley	
9.3.2006	18	122	Sampling of composted faeces	
9.3.2006	18	122	Dry matter STS	10.3.2006
12.3.2006	18	125	Exchangeable potassium (K^+) analysis of substrates I	13.3.2006
13.3.2006	19	126	Sieving of composted faeces	
15.3.2006	19	128	TC of STS and composted faeces	
15.3.2006	19	128	Exchangeable potassium (K^+) analysis of substrates II	16.3.2006
20.3.2006	20	133	Exchangeable potassium (K^+) analysis of substrates III	21.3.2006
23.3.2006	20	136	Kjeldahl-N analysis of substrates II	24.3.2006
30.3.2006	21	149	Mass of 1000 grains	
30.3.2006	21	149	Kjeldahl-N analysis of substrates III	31.3.2006
4.4.2006	19	154	Moisture content of barley	5.4.2006
5.4.2006	19	155	Drying of carrot	7.4.2006
7.4.2006	19	157	Grounding barley and carrot	
17.5.2006	26	190	Kjeldahl-N analysis of substrates IV	18.5.2006
17.5.2006	26	190	Kjeldahl-N analysis of fertilisers & substrates	18.5.2006
4.7.2006	33	238	Kjeldahl-N analysis of plants	5.7.2006
5.11.2006	51	362	Exchangeable potassium (K^+) analysis of fertilisers	7.11.2006
8.11.2006	51	365	Reactive phosphorus analysis of substrates I	10.11.2006
27.11.2006	54	384	Reactive phosphorus analysis of substrates II	1.12.2006
27.11.2006	54	384	Reactive phosphorus analysis of fertilisers	1.12.2006

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 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.

Figure 1. Greenhouse in the beginning of growing experiment.

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.

Fungi 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 aired 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 airing 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 3.

Table 3. 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.

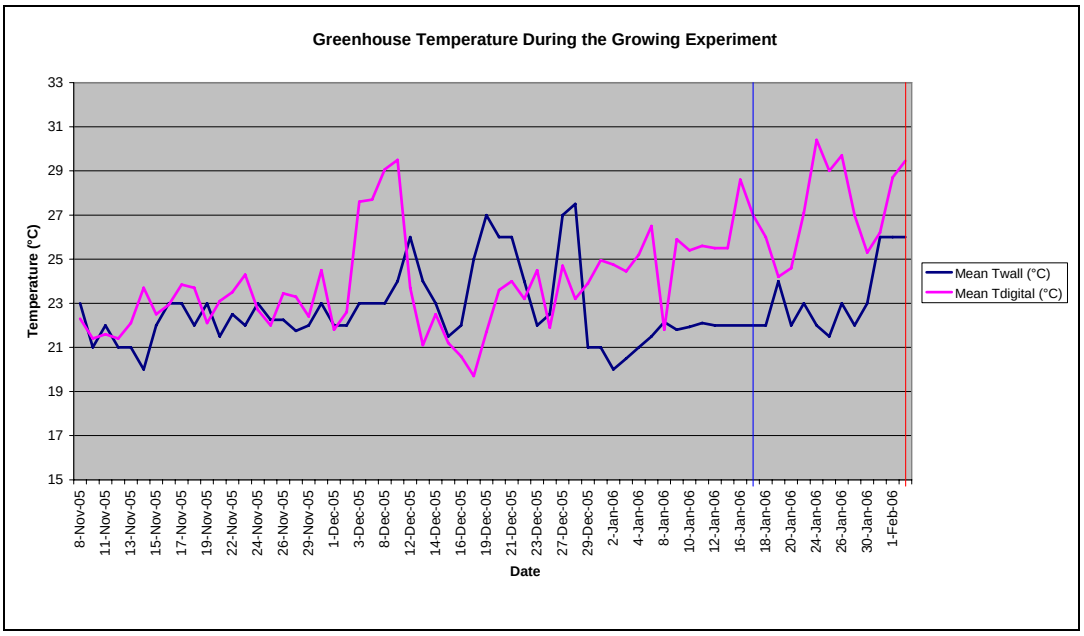


Figure 2. Greenhouse temperature variation during growing experiment.

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.

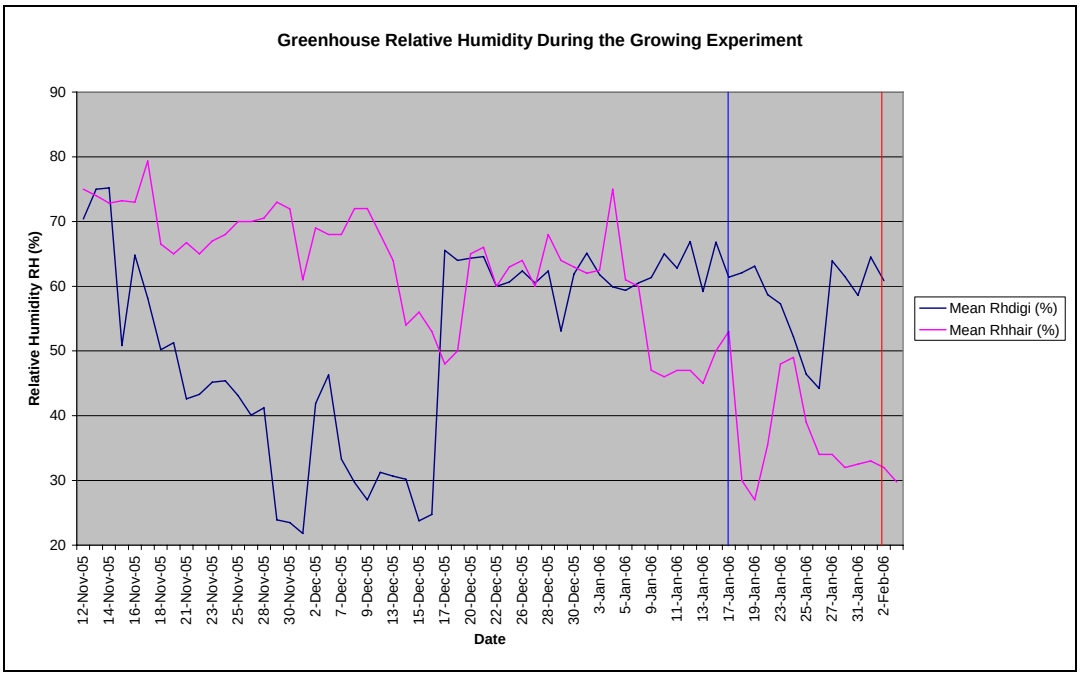


Figure 3. Greenhouse relative humidity (Rh) variation during growing experiment.

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.

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, made from PP) 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. Figure 3 shows the placement of the crates.

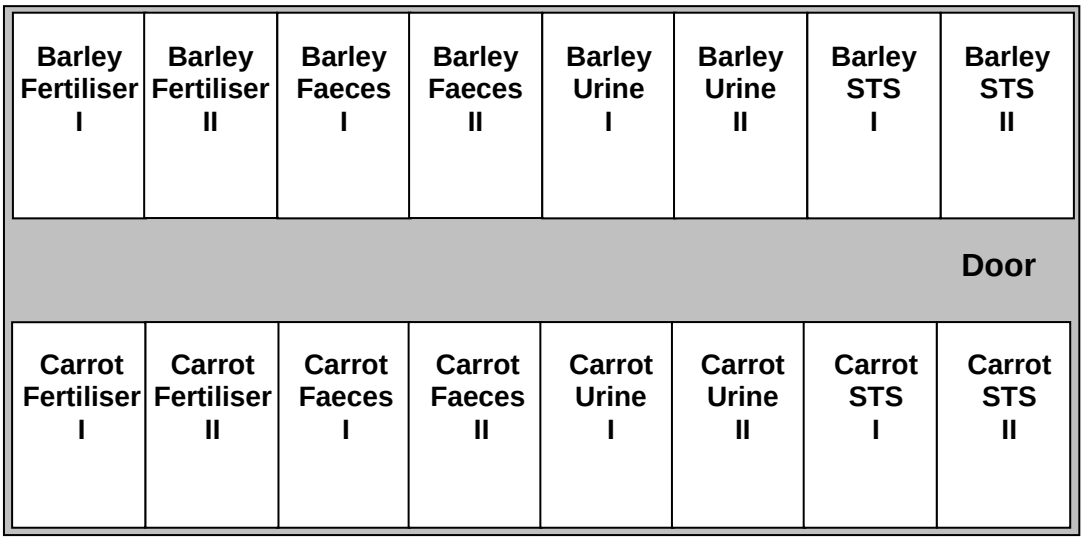


Figure 3. Placement of the crates in the greenhouse.

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 4.

Table 4. Nutrient concentrations of the fertilisers on percentage of weight.

Nutrient	Puutarhan kevät	Kevätviljan Y3
Total Nitrogen (N)	8,00	20,00
Ammonium Nitrogen (NH_4-N)	5,50	11,40
Nitrate Nitrogen (NO_3-N)	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. |*10*|

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}. |*20*|

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 5 and 6.

Table 5. 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 6. 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.

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 about 6–7 seedlings per 10 cm. Barley was singled out with hands and tweezers so that there were about 6 seedlings per 10 cm.

2.9 CROP YIELD

In general the control substrates fertilised with artificial fertilisers grew fastest and produced highest yield.

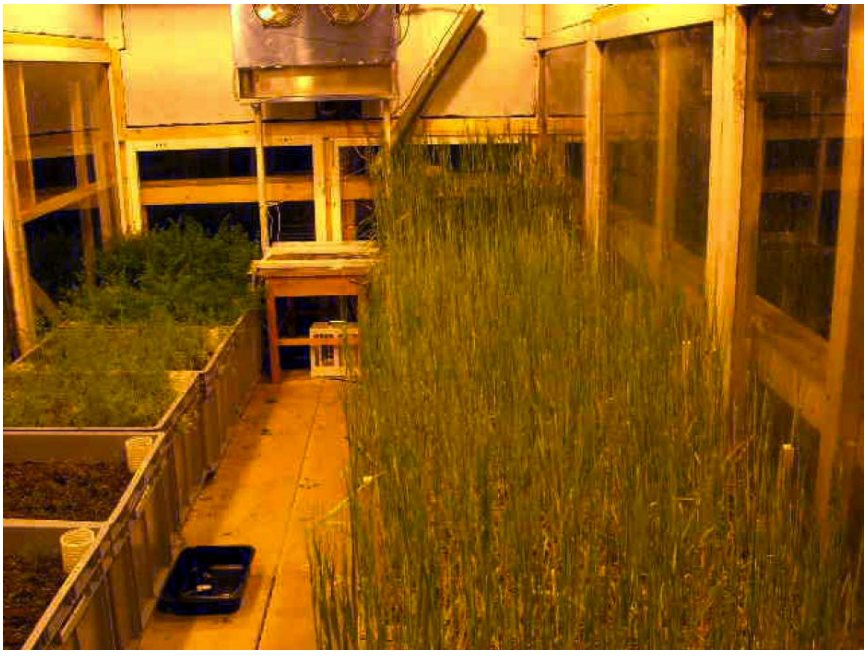


Figure 4. Crop yield, end of experiment. Best growth can be detected with rearmost crates which were the control. In front of those are composted faeces treatment crates with second best growth.

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.

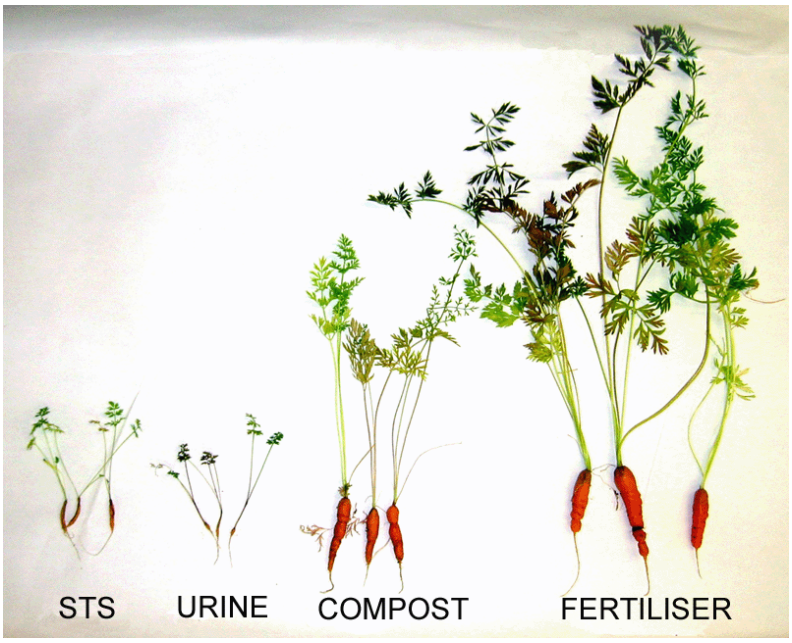


Figure 5. Carrots grown with STS, separated urine, composted faeces and commercial fertiliser.

2.9.2 BARLEY YIELD

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

3 METHODS FOR SUBSTRATES AND FERTILISERS

3.1 SAMPLING AND PRETREATMENT OF SUBSTRATES

Pre-treatment 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. All samples were bagged and tagged accordingly.

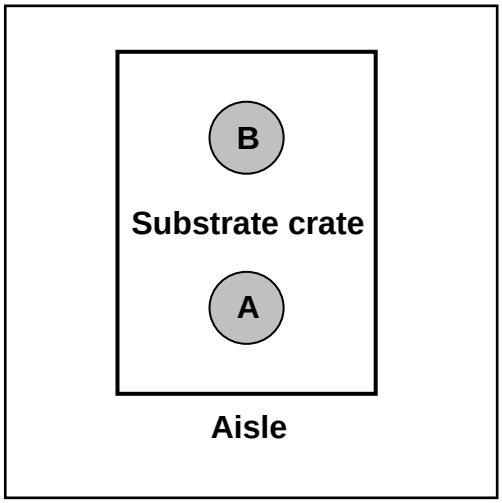


Figure 6. Sampling places in substrate crates.

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 sub samples 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 7 and 8.

Table 7. Weights of the first substrate samples before and after sieving.

Sample	Weight (g)	
	Total	< 2 mm
Barley, blanc, IA	192,5	138,1
Barley, blanc, IB	147,5	123,5
Barley, blanc, IIA	224,5	187,8
Barley, blanc, IIB	161,5	132
Carrot, blanc, IA	141,5	115,6
Carrot, blanc, IB	175,0	143
Carrot, blanc, IIA	179,5	147,5
Carrot, blanc, IIB	147,0	119,4
Barley, compost, IA	158,5	131,6
Barley, compost, IB	152,5	124,8
Barley, compost, IIA	151,0	125,4
Barley, compost, IIB	157,0	131,2
Carrot, compost, IA	171,0	134,7
Carrot, compost, IB	133,0	103,2
Carrot, compost, IIA	134,0	106,8
Carrot, compost, IIB	205,0	168,7
Barley, urine, IA	200,0	164
Barley, urine, IB	177,5	151,2
Barley, urine, IIA	177,0	149,7
Barley, urine, IIB	153,0	127,6
Carrot, urine, IA	176,0	146,5

Carrot, urine, IB	181,0	151,8
Carrot, urine, IIA	203,0	172,7
Carrot, urine, IIB	176,5	176
Barley, STS, IA	133,5	104,9
Barley, STS, IB	117,5	95,2
Barley, STS, IIA	103,0	80,6
Barley, STS, IIB	144,0	116,1
Carrot, STS, IA	153,5	124,3
Carrot, STS, IB	134,5	107,1
Carrot, STS, IIA	129,0	103,2
Carrot, STS, IIB	125,5	101,5

Table 8. Weights of the second substrate samples before and after sieving.

Sample	Weight (g)	
	Total	< 2 mm
Barley, fertiliser, IA	283,0	241,5
Barley, fertiliser, IB	321,0	271,2
Barley, fertiliser, IIA	459,5	384,0
Barley, fertiliser, IIB	374,0	308,9
Carrot, fertiliser, IA	479,5	396,5
Carrot, fertiliser, IB	533,5	415,3
Carrot, fertiliser, IIA	745,0	556,0
Carrot, fertiliser, IIB	476,5	371,1
Barley, compost, IA	440,0	372,5
Barley, compost, IB	568,0	484,0
Barley, compost, IIA	511,5	426,0
Barley, compost, IIB	478,0	400,9
Carrot, compost, IA	590,5	461,6
Carrot, compost, IB	541,0	420,5
Carrot, compost, IIA	562,5	448,7
Carrot, compost, IIB	542,5	422,2
Barley, urine, IA	600,0	512,7
Barley, urine, IB	496,0	423,5
Barley, urine, IIA	594,5	512,0
Barley, urine, IIB	463,5	394,0
Carrot, urine, IA	825,0	647,4
Carrot, urine, IB	663,5	531,5
Carrot, urine, IIA	683,5	563,3
Carrot, urine, IIB	623,5	519,3
Barley, STS, IA	407,0	316,3
Barley, STS, IB	368,5	291,1
Barley, STS, IIA	445,5	350,1
Barley, STS, IIB	357,5	283,2
Carrot, STS, IA	520,0	380,8
Carrot, STS, IB	364,0	256,6
Carrot, STS, IIA	359,0	265,3
Carrot, STS, IIB	237,0	179,6

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 4 M H_2SO_4 was added and the sample was preserved in refrigerator for further analysis, as according to SFS standard 5505. |*4,5*|

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 pre-treated 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. |*12*|

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 9.

Table 9. 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. |*13*|

The dry matter and the water contents are shown in Table 10.

Table 10. 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**

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 pre-treated STS. About 100 mg of sludge was used for determining the dry matter content. The masses, dry matter and water contents are shown in Table 11.

Table 11. 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**

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 in order to find out the carbon nitrogen (C/N) ratio. 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 of TC content were not expected to take place. Measurements were done with Shimadzu

TOC 5000A. The amounts of TC and their comparable amounts in 3 g of soil samples are in Table 12.

Table 12. 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**

3.6 DETERMINATION OF TOTAL CARBON OF FERTILISERS

Determinations of total carbon were done according the International Standard ISO 10694. The amounts of TC and their comparable amounts in 3 g of soil samples are in Table 13. |*7,11,14*|

Table 13. 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	

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

4 ANALYSES FOR SUBSTRATES AND FERTILISERS

4.1 KJELDAHL NITROGEN DETERMINATION OF SUBSTRATES

Kjeldahl nitrogen, sometimes also described as total organic nitrogen (TON, Tot-N), determination was done according to the European Standard SFS-EN 13342, using a Büchi Distillation Unit K-314, Büchi Digest System K-437, Büchi Scrubber B-414 and Metrohm 775 Dosimat & 728 Stirrer. Determination was done by batches of 16 samples along with 1 blank for samplings in the beginning and in the end of the growing experiment. Because the standard used is intended for

Kjeldahl nitrogen determination from sludge the reagent volumes and concentrations used had to be diminished for the determination of substrates.

Substrate samples from different treatments were weighed to mass 2.000-2.010 g with an analytical balance Precisa 300M. K_2SO_4 Kjeldahl tablets were used as a catalyst; two tablets per sample. 10 mL of concentrated *pro analysis* H_2SO_4 was added with a 5 mL FinnPipette. After the Büchi Scrubber B-414 was put into operation the Büchi Digest System K-437 was heated in segments in order not to damage the heating vessels, first to 250 °C and then to 370 °C, after which heating continued at 370 °C for 1 hour. Samples were left to cool down in their vessels in the heating block over night so that vessels wouldn't break down.

Figure 7. Büchi Digest System K-437and Büchi Scrubber B-414 in use.

Next day 25 mL of distilled water was added to every vessel. One vessel at a time was set to Büchi Distillation Unit K-314. A receiving flask was attached to its place with 30 mL of 2 % boric acid solution and 2-3 drops of Sher indicator. 30 mL of 32 % NaOH was added to the heating vessel and then sample was distilled for a minimum of 4 minutes. After distillation samples were titrated with Metrohm 775 Dosimat & 728 Stirrer until the equivalence point, in which colour turned to a

shade of greyish brown. 0.05 and 0.005 mol/l H_2SO_4 solutions were used for titration.

The results given from this analysis are expressed in mg kg^{-1}, which represent the sum of organic-N and ammonium-N in the sample. Most of nitrate-N and nitrite-N are lost during digestion, but as the concentration of inorganic-N in soil is normally low the result could be assumed to represent both organic-N and total-N. |*22*|

4.2 KJELDAHL NITROGEN DETERMINATION OF FERTILISERS

Nitrogen determinations of STS and urine were done using Finnish National Standard SFS 5505 and European Standard SFS-EN 13342. For composted faeces European Standard SFS-EN 13342 was used with fixed amounts and concentrations of reagents. Although different standards were used all fertilisers were analysed in a batch also with some substrate samples. Büchi Distillation Unit K-314, Büchi Digest System K-437, Büchi Scrubber B-414 and Metrohm 775 Dosimat & 728 Stirrer were used. |*5,6*|

4.2.1 URINE AND STS

Determination of Kjeldahl Nitrogen for STS and urine was done from two parallel 50 mL samples. First sample was a dilution with ratio of 1:10 and second of 1:100. One K_2SO_4 Kjeldahl tablet was used per sample as a catalyst. 2 mL of H_2SO_4 was added to each sample with a 5 mL FinnPipette. A dash of Devardan mixture was added to samples. Digestion was done as in determination of substrates. 2 mL of distilled water was added to each sample next day. 20 mL of 2 % boric acid with 2-3 drops of Sher indicator was put in the receiving flask that was set to its place in distiller. 14 mL of NaOH was added before distillation of minimum four minutes. Then solutions were titrated with 0.005 M H_2SO_4.

4.2.2 COMPOSTED HUMAN FAECES

Determination of Kjeldahl Nitrogen for composted human faeces was done also with two parallel samples. This was to check if results vary with different reagent volumes. Sample 1 was treated with 10 mL of H_2SO_4, two K_2SO_4 Kjeldahl tablets,

30 mL 2 % boric acid and 30 mL of NaOH. Sample 2 was treated with 20 mL of H_2SO_4, two K_2SO_4 Kjeldahl tablets, 60 mL 2 % boric acid and 60 mL of NaOH.

4.3 EXCHANGEABLE POTASSIUM (K^+) ANALYSIS OF SUBSTRATES

Exchangeable potassium (K^+) determination of substrates was done according to CEC measurement instructions by Radojevic & Bashkin (1999). The method used measures the amount of NH_4^+ ion adsorbed by the soil from an added solution (ammonium acetate). At the same time naturally present exchangeable cations (K^+) are displaced.

Analysis was done in several batches of samples and one blank because only 12 bottles could be shaken at the same time in mechanical shaker Certomat MO (B. Braun Biotech International).

5.000-5.010 g of samples were weighed with an analytical balance Precisa 300M. Samples were inserted into plastic 100 mL bottles. 25 mL of 1 M ammonium acetate was added to each sample with a glass metering device attached to the bottle. Mixtures were shaken in mechanical shaker Certomat MO (B. Braun Biotech International) for one hour. Supernatants were filtered with Schleicher & Schuell 589³ Blue Ribbon ashless filter paper circles (110 mm or 125 mm in diameter) and analytical funnels to 100 mL volumetric flasks. If needed rest of the supernatant was sucked with a Pasteur pipette to filter, trying not to let soil get on the filter paper. Unfortunately the high humus content of peat made this impossible.

20 mL of 95 % ethanol was added with a 20 mL glass metering device attached to the ethanol bottle. The bottles were shaken and left to settle in order to decant. Supernatant was filtered again to the same 100 mL volumetric bottle as before. This operation of washing, shaking and filtering was repeated twice more, each time carefully in order to avoid soil sample from getting to filter. In cases necessary the rest of supernatant was sucked with a Pasteur pipette and filtered. After the final filtering, extracts were made up to the mark with distilled water.

After extraction samples were analysed with Solaar AA Series Spectrometer. A set of calibration solutions was made for AAS. These were done from K^+ stock

solution (concentration 1000 mg/L), with intermediate dilutions of 100 mg/L (volume 100 mL) and 10 mg/L (volume 100mL). From 10 mg/L K^+ solution the calibration liquids of 0.5 mg/L; 0.8mg/L; 1.0 mg/L; 1.5 mg/L and 2.0 mg/L concentrations were made to 100 mL volumetric bottles. All of these dilutions were made with glass pipettes.

Concentrations of potassium were measured with AAS in the following order: blank sample; calibration solutions from smallest to largest concentration and samples. If the absorption of a sample was larger than absorption of the calibration liquid with largest concentration, the sample was diluted to one tenth and analysed again.

4.4 EXCHANGEABLE POTASSIUM (K^+) ANALYSIS OF FERTILISERS

Exchangeable potassium was measured according to the same principle as substrates. Composted faeces used was dried and sieved to 2 mm size. STS and urine were taken in liquid form; sample volume 10 mL. STS and composted faeces samples had to be filtered twice because of visible turbidity noted in the sample, composted faeces was filtered three times, last filtering through a 0.45 µm membrane filter.

4.5 REACTIVE PHOSPHORUS (ORTHOPHOSPHATE) ANALYSIS OF SUBSTRATES

In order to find out the reactive phosphorus contents in substrates the orthophosphate content was measured. Device of use was HACH DR/2010 Portable Datalogging Spectrophotometer, which can be used to measure reactive phosphorus contents (P_2O_5, PO_4^{3-}, P total) from 0 to 2.50 mg L^{-1}.

The samples were prepared for HACH by extracting the easily soluble phosphorus out of the substrate, as according to the instructions of Finnish National Board of Education for spectroscopic analysis of freely soluble phosphorus from a soil sample. |*31*|

Substrate samples were measured to a volume of 25 mL by using a volumetric flask which had a line drawn to the specific volume level. After filling the flask it was

clacked against a table three times in order to remove possible air passages. Sample was moved to a 500 mL Erlenmeyer flask, 200 mL of acidic acetate extraction liquid was added, flask was covered with thin plastic foil and shaken with a mechanical shaker Certomat MO (B. Braun Biotech International) for one hour. The acidic acetate extraction liquid is an ammonium acetate solution that has a content of 0.5 M acetic acid and 0.5 M ammonium acetate and pH 4.65. First the analysis was done in batches of 12 samples, later the sample size was diminished to 10 mL substrate, 90 mL acidic acetate extraction liquid. This could be done because the sample volume required for phosphate analyses is very small, 20 mL for one HACH analysis. As sample size was diminished the sampling technique was changed in order to have homogenous and fair samples. Every substrate sample was first poured into a small crate, one crate was used for each substrate, where the sample was mixed thoroughly, divided into four parts and the sample was composed by taking some soil from each part.

After one hour of shaking the samples were left to steady for a while in order to decant the sample liquid to filtering with Büchner funnels and Schleicher & Schuell filter papers. Filter paper was moistened with the acetate extraction liquid and the sample was poured trying to avoid soil from getting on the filter. Büchner funnels were attached to suction bottles, which had tubes attached to water network. After filtering the suction bottle was rinsed carefully with acetate extraction liquid and poured through a funnel to 250 mL (sample size 25 mL) or 100 mL (sample size 10 mL) measuring bottle. Bottles were filled until the mark with acetate extraction solution and stored in a fridge until analysis.

Filtered samples were analysed with HACH DR/2010 Portable Datalogging Spectrophotometer according to instructions. Sample was poured into a 10 mL analysis bottle, one pillow of PhosVer 3 phosphate powder was added, sample was stirred for mixing and a reaction time of 2 minutes was measured. The set of values for analysis were zeroed with a blank sample of 10 mL sample liquid with no phosphate powder pillow, then the sample with PhosVer 3 was put inside the spectrophotometer and the value of orthophosphate was read.

4.6 REACTIVE PHOSPHORUS (ORTHOPHOSPHATE) ANALYSIS OF FERTILISERS

Orthophosphates from fertilisers were analysed with same principles as the substrates. STS and urine had a liquid volume (10 mL), composted faeces a dry mass volume (10 mL). STS and urine were not shaken as the phosphorus was already in liquid form, otherwise their treatment did not differ from other samples. Due to the extremely low levels of reactive phosphorus detected from soil samples it was assumed that reactive phosphorus contents in fertilisers would be low as well, so fertiliser samples were not diluted at all.

5 METHODS FOR BARLEY AND CARROT SAMPLES

5.1 SAMPLING AND PRETREATMENT

Sampling and pre-treatment was done by adapting the principles by Radojevic & Bashkin (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 not to grow strong enough making it to be flattened and thou forcing us to harvest them earlier than we would have liked 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. |*22*|

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 recorded.

Determination of the mass of 1000 grains was done according the international standard ISO 520. |*15*|

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. |*22*|

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 14. |*22*|

Table 14. 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. |*16*|

The dry matter and the water contents are shown in Table 15.

Table 15. 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 from carrots was not determined because of oven drying used in the pre-treatment. Moisture content was expected to be 0 %.

6 ANALYSES FOR BARLEY AND CARROT

Due to small yield the amount of barley and carrot for plant analyses was very slight. Only total organic nitrogen analyses (Kjeldahl nitrogen) were carried out as nitrogen contents were of main interest in this study. Plant analysis was done according to Radojevic & Bashkin (1999) following the same principles as for soil samples. |*22*|

7 RESULTS

7.1 EXCHANGEABLE POTASSIUM CONTENTS IN SUBSTRATES

Potassium ion contents of carrot and barley substrates can be seen in figures 8 and 9:

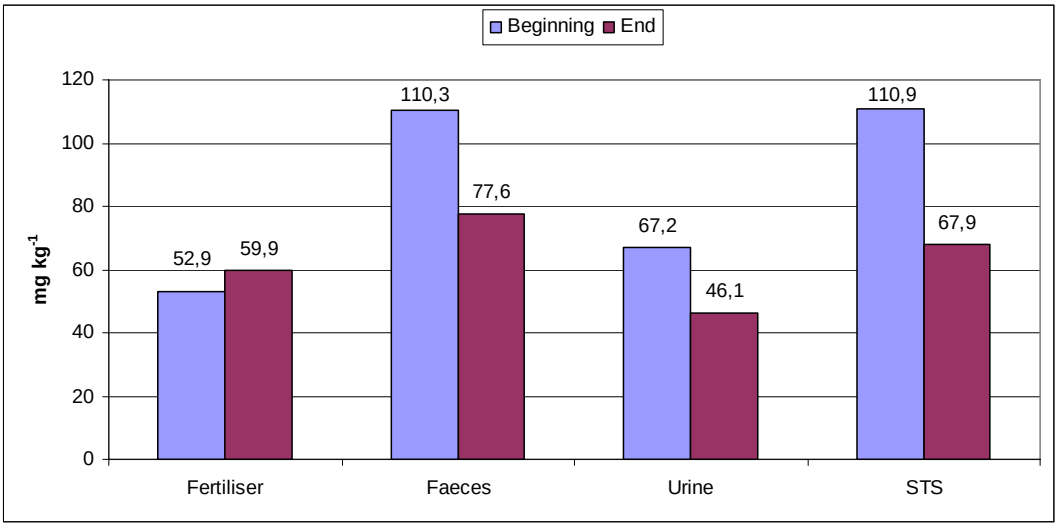


Figure 8. Exchangeable potassium (K^+) contents in carrot substrates. Comparison between samplings in the beginning and in the end. NB. Samples taken in the beginning from artificial fertiliser treated crates had the sole substrate, no fertiliser.

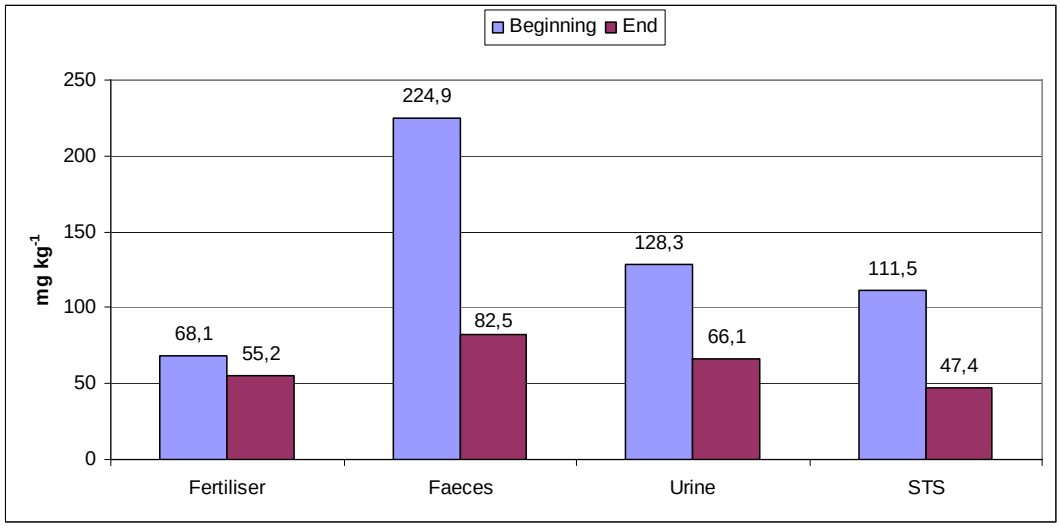


Figure 9. Exchangeable potassium (K^+) contents in barley substrates. Comparison between samplings in the beginning and in the end. NB. Samples taken in the beginning from artificial fertiliser treated crates had the sole substrate, no fertiliser.

The amounts of exchangeable K^+ were on average higher in barley substrate samples than in those of carrot, except for STS and commercial fertiliser end result for barley. Largest differences between beginning and end samplings were with STS and composted faeces.

Productivity of Finnish soils has been monitored beginning from the 1950s by soil research department of Maatalouskoelaitos and later by Viljavuuspalvelu Oy which was launched for this purpose. Density of sampling is 0.04 samples for field hectare a year. |*27*|

Potassium levels and their development in Finnish soils are shown in table 18:

Table 16. Potassium contents in Finnish field soils, years 1955-2000. |*27*|

	K (mg L^{-1})
1955-60	120
1961-65	123
1966-70	140
1971-75	141
1976-80	148
1981-85	161
1986-90	146
1991-95	149
1996-2000	144
Average (45 years)	123,0

The results are in milligrams K a litre while results from these analyses are milligrams K^+ a kilogram. This gives still some indication about general potassium levels in cultivated soils. Results from this experiment range from 46 to 224 mg kg^{-1}. Potassium was present in sufficient amounts in the substrates. Variation between beginning and end sampling results is high. End values are generally lower than values from samples taken in the beginning which means that potassium has been also used by the plants.

In principle, exchangeable potassium means K electrostatically bound to the surfaces of humic substances, readily exchanged with other cations and readily available to plants. Amount of exchangeable potassium in a soil depends on the rate and direction of reactions between different forms of potassium (solution, exchangeable, non-exchangeable, and mineral). Electrostatic attractions in the soil affect the availability as different types of soils fix and retain potassium in different rates. Soil composition and its charge density, degree of interlayering, moisture content, and concentration of K^+ ions and of competing ions and the soil solution pH also have an effect on the degree of K fixation and of K release. Low clay content of the soil could generally mean fewer fixations, but humus is also known to be a very colloidal soil type which may add to the rate of fixation. Liming may have influenced the cation exchange capacity of soil which would mean enhancement of K retention and less leaching. |*25*|

The effect of fertilisers to soil pH was not measured or monitored in any way so possible acidification of soil during the experiment can be suspected considering the yields obtained. In this growing experiment it can be estimated that reactions between different forms of potassium could be only due to possible pH fluctuation as the substrate composition included no microbiota (except what fertilisers may have provided), only poor soil fauna and no additional biomass from plant residues or such.

7.2 EXCHANGEABLE POTASSIUM CONTENTS IN FERTILISERS

Potassium ion contents in fertilisers can be seen in table 19.

Table 17. Exchangeable potassium (K^+) from STS, urine and composted faeces used as fertilisers in the growing experiment.

Exchangeable potassium (mg/L)		
Urine*	**STS***	**Faeces****
5,657	0,488	86,993

* dilution factor 1:100
** average of two values (dilution factors 1:500, 1:200)

The dilution factors used have been included in result calculations.

The variance between results was very high which sets questions about the accuracy of used AAS equipment in small concentrations. Long storage time may have affected the results as well. Approximately 50-80 % of potassium emitted by human is in urine, yet the amount of potassium present in composted faeces was over 17 times higher than in urine. The potassium contents of urine and STS also seem rather low compared to K^+ contents of substrates, in which the poorest source of exchangeable potassium was commercial fertiliser; probably due to its granular composition and application method. |*9*|

In a study conducted by Heinonen-Tanski et al. (2005) the potassium contents measured from urine were on average 1145 g l^{-1}. It must be noted that this value is for total potassium, not exchangeable potassium (K^+). In Jönsson et al. study the average amount of potassium (total) in urine was 1000 mg l^{-1}. |*9,17*|

7.3 REACTIVE PHOSPHORUS (ORTHOPHOSPHATE) CONTENTS OF SUBSTRATES

The variation in orthophosphate results of substrates was rather high. The method used requires immediate analysis for best results and the storing of samples should not take more than 48 hours. In this experiment the analysis was conducted from dried and sieved samples. Results are shown in figures 10, 11:

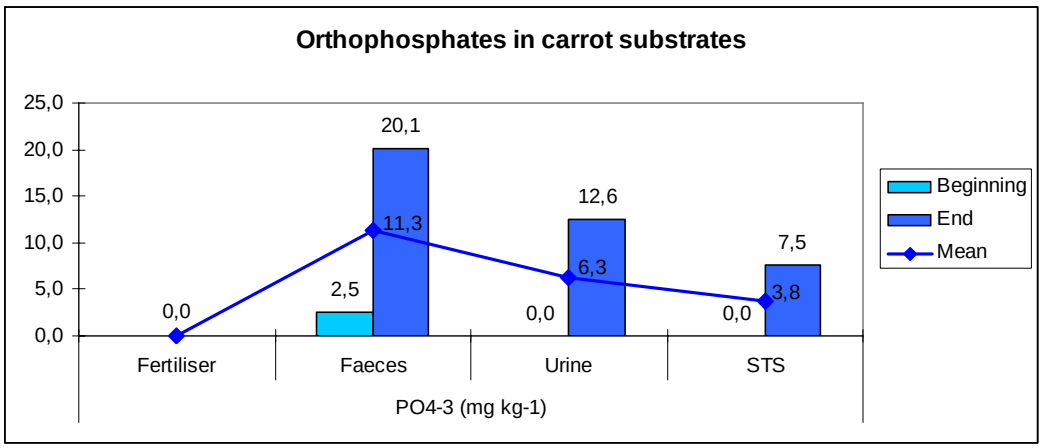


Figure 10. Reactive phosphorus contents (PO_4^{-3}, mg kg^{-1}) in barley substrates.

The sampling done in the beginning for carrot substrates shows little (2,5 mg kg^{-1} in composted faeces treated substrate samples) or no orthophosphates present. Results for commercial fertiliser treated substrates are all nonexistent due to application method used. Highest results from end sampling were with composted faeces treated substrate samples; second highest results were with urine treatment.

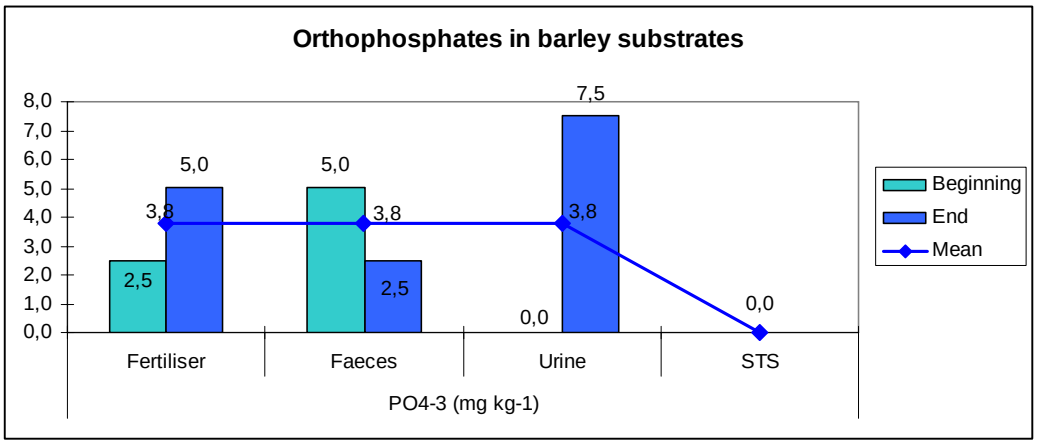


Figure 11. Reactive phosphorus contents (PO_4^{-3}, mg kg^{-1}) in barley substrates.

In barley substrates the zero results were obtained from STS treated substrate samples. Barley substrate samples that were taken in the beginning of the experiment show 2,5-5,0 mg kg^{-1} reactive phosphorus present. The artificially fertilised crates could have K^+ present only due to contamination . The end sampling shows significantly lower values for barley substrates than for carrot substrates.

Phosphorus is present naturally in soils (from plant residues, animal manure etc. sources) in low concentrations, ranging averagely from 100 to 3000 mg P kg^{-1}. Also the low solubility (<0.01 mg P L^{-1}) is critical when considering effects of phosphorus as a fertiliser. The highest result obtained in this growing experiment was 1739 mg kg^{-1} (With sample Carrot, PO_3^{-4}, Faeces, end), although measurement was for orthophosphates and not total phosphorus. Results ranged from poor to sufficient. |*24*|

In Finnish mineral soils the average amount of phosphorus present is about 3000 kg P ha^{-1} in the arable layer, in both organic and inorganic forms. It has been estimated that of total phosphorus the share of organic forms is 40 % in mineral soils and 60 % in peat soils. The average amount of soluble phosphorus in Finnish soils was 13.9 mg P L^{-1}on study period 1996-2000, with average value of pH 5.72. |*1*|

The amount of phosphorus depends highly of the soil type, as seen in table 22:

Table 18. Phosphorus contents of fine sands, sandy clays and humic soils in five year periods, 1981-2000. |*27*|

P mg L^{-1}	1981-85	1986-1990	1991-95	1996-2000
Fine sands	11,5	12,4	14,9	15,9
Sandy clays	10,9	8,2	11,3	11,6
Humic soils	8,0	6,3	8,5	10,1
All soils	11,8	12,3	12,4	13,9

The orthophosphate values measured represent the amount of phosphorus available for plant uptake. Uptake of different types of phosphorus is highly dependant of soil pH which unfortunately was not measured.

Several factors besides pH have an effect on phosphorus availability, such as temperature, compaction, moisture, aeration, type and amount of clay and nutrient status of soil. There was no clay present in the soil and nutrient status of soil was nonexistent. Sandy soils with no clay present are known to fix less P than soils with high clay content. Soil composition thus hasn't mitigated the results. If soil temperatures are low during early plant growth, P uptake is reduced. Plant seeds

were two days without light and warmth as sowing was November 8 and lights arrived November 10. This time may have had an effect on early phosphorus uptake but because the duration was short and later on the temperature was rather high it can be said that effect was negligible. Substrates were pressed quite tight to the crates by hands and by walking on the substrates. This has added compaction, which is known to reduce pore space, decrease amount of water and O_2, which in turn reduce P uptake. Five brandling worms (*Eisenia fetida*) were added per crate but their part in mitigating the effects of compaction is to be considered minor. Soil pH was neutralised in the beginning of the growing experiment with lime, which increases P availability and crop yield, but again the effect of fertilisers on pH is not known. Phosphorus uptake is also enhanced if NH_4^+ is present as it creates an acid environment due to nitrification and NH_4^+ uptake, which may interfere with or delay P fixation reactions, lengthening the availability of phosphorus. This applies mostly to inorganic phosphorus fertilisers, while in this case the fertilisers were organic. |*24*|

Animal manure is a good source of phosphorus for plant cultivation. Major proportion of animal manure is usually organic (25-50 %), thus the biological processes in soil have a great role on determination of P availability. P availability from animal manure fertilisers is usually prolonged when compared to inorganic P fertilisers which are more readily soluble. Thus the effects of using animal manure fertilisers are the same as with nitrogen uptake: P is available in smaller amounts but for a longer period. Because P is quite immobile inside the soil profile the placement of fertilising should be at root level to establish maximised fertiliser effectiveness. In this study the fertilisers were mixed throughout the substrate, except for urine which was added by irrigation. The different type of application cannot be interpreted from the results. |*24*|

7.4 REACTIVE PHOSPHORUS (ORTHOPHOSPHATE) CONTENTS IN FERTILISERS

The orthophosphate contents in fertilisers are shown in figure 12:

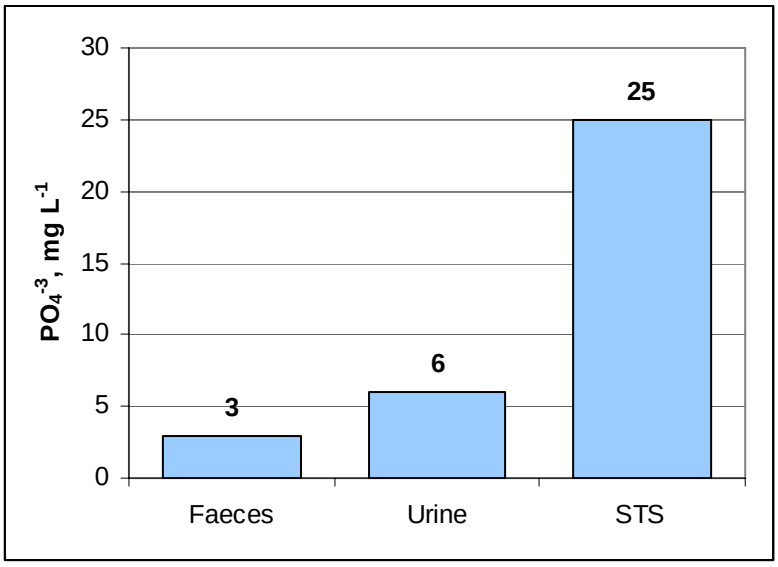


Figure 12. Reactive phosphorus contents in fertilisers.

The largest orthophosphate contents were found in STS, which nevertheless had weakest yield in both barley and carrot.

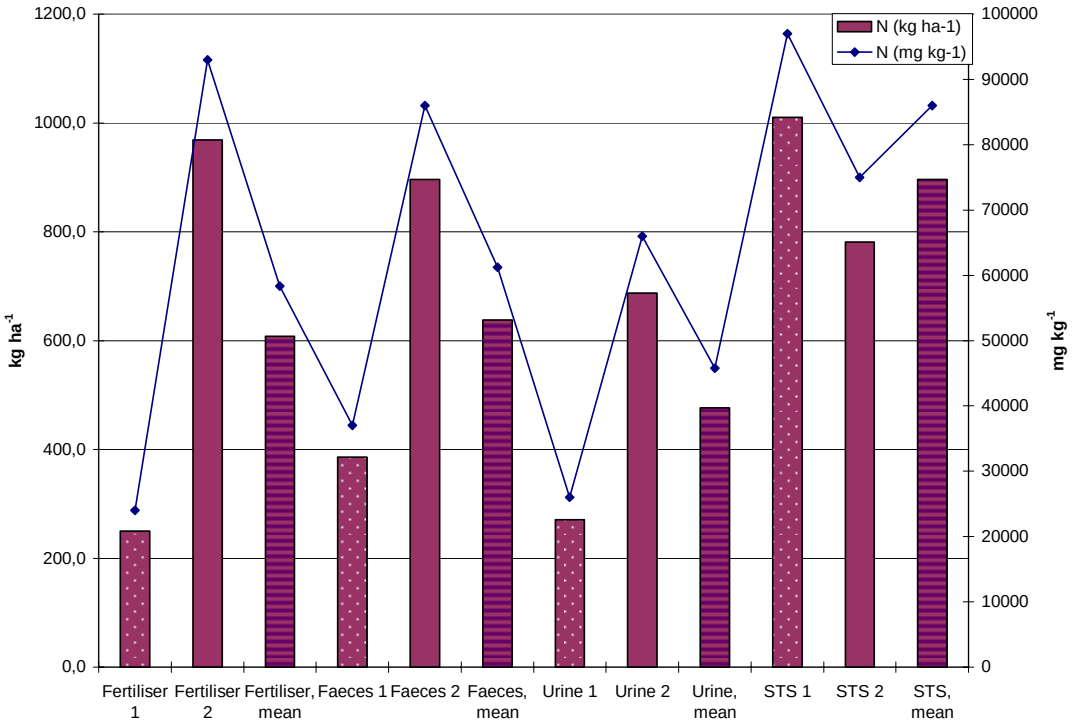
According to Schouw, N.I. et al. (2001) there is about 2.4 % phosphorus in excreta (total solids). In STS the phosphorus content of total solids is 3.5 %. The orthophosphate contents measured from this experiment were much lower, especially with excreta. |23|

7.5 KJELDAHL NITROGEN CONTENTS IN SUBSTRATES

Results of nitrogen analysis were controversial. In all treatments except for STS fertilised substrates the amount of Kjeldahl-N present was larger in the end than in the beginning. Results are expressed in kilograms per hectare and in milligrams per kilogram. Results in kilograms per hectare were calculated using bulk density of samples sieved to less than Ø 2 mm size (More information in chapter *7.8 Bulk Density*) and they represent the amount of Kjeldahl-N in the soil to depth 25 cm, that is, the arable layer.

Results from carrot substrates are shown in figure 13:

Figure 13. Kjeldahl-N contents in a growing medium of carrot.
1 = Sampling in the beginning, 2 = sampling in the end.

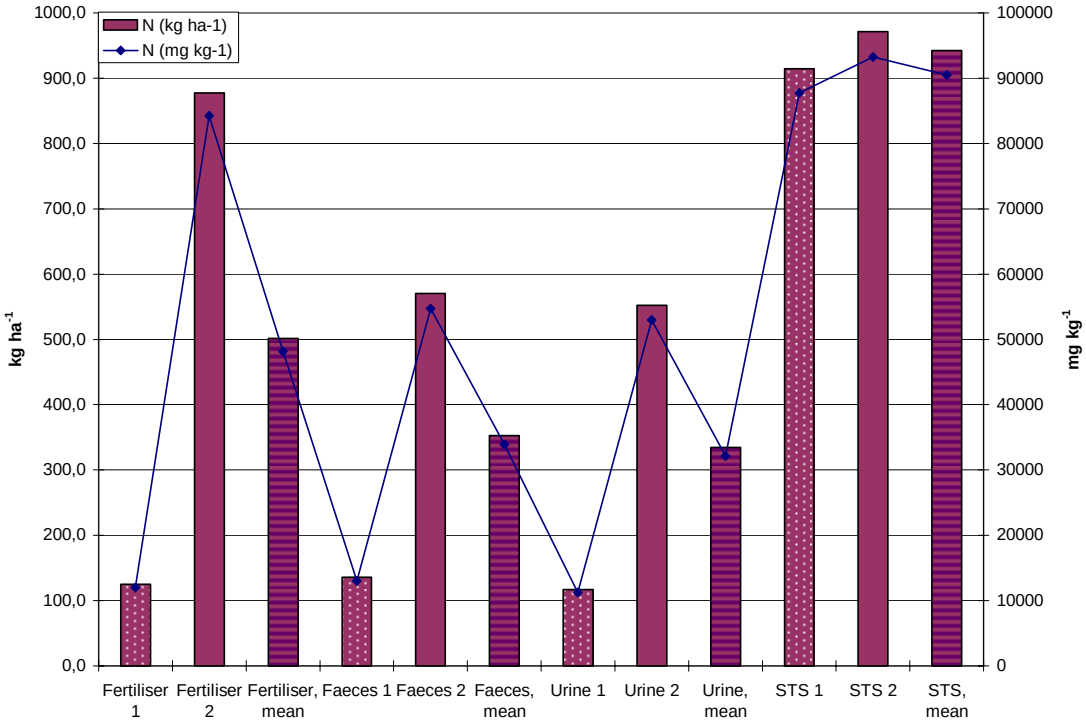


All results from carrot substrates exceed the limit value set for maximum amount of organic nitrogen (170 kg ha^{-1}) to be spread on a field. The highest exceeding is with STS 1, 840.4 kg N ha^{-1}. It must be remembered that these results aren't fully comparable with the limit value as the measured nitrogen values are Kjeldahl-N, which measures the sum of organic-N and ammonium-N in the sample. Most of nitrite-N and nitrate-N are lost in the wet digestion.

Urine was the poorest source of Kjeldahl-N for carrots. Poor availability of nitrogen for plants could be noted also by the crop which was in the level of roots, not carrots. Losses due to ammonia volatilization have probably been large due to the application method and the moist and warm greenhouse environment. Kjeldahl-N from STS samples had the smallest variation between samplings and it was the only one where values dropped from beginning. The high level measured in the beginning suggests that STS might not be retained by the colloidal structure of soil to the same extent as with composted faeces and urine.

Results from barley substrates are shown in figure 14:

Figure 14. Kjeldahl-N contents in a growing medium of barley.
1 = Sampling in the beginning, 2 = sampling in the end.



In barley substrates the highest exceeding value is again with STS but this time with the end sampling, 801.4 kg N ha^{-1}. Results from the samples taken in the beginning don't exceed the limit value, except for STS 1.

In barley substrates the amounts of Kjeldahl-N were generally smaller than with carrot substrates. Faeces and urine samples had quite similar values both in the beginning and in the end. The amount of Kjeldahl-N in STS treated substrates was much higher than in faeces and urine.

Early ripening of barley in urine and STS treated substrates suggests a deficiency of soluble nitrogen. Barley in composted faeces treated substrates was ripened by about four fifth while the barley in commercial fertiliser treated substrates was still growing steadily. The amounts of nitrogen in substrates were sufficient but represent total nitrogen instead of nitrogen available for plant uptake. It can be assumed that nitrogen has been retained to some extent as well that the majority of nitrogen present has been in organic, insoluble forms.

7.6 KJELDAHL NITROGEN CONTENTS IN FERTILISERS

The amounts of Kjeldahl-N present in fertilisers are shown in figure 15:

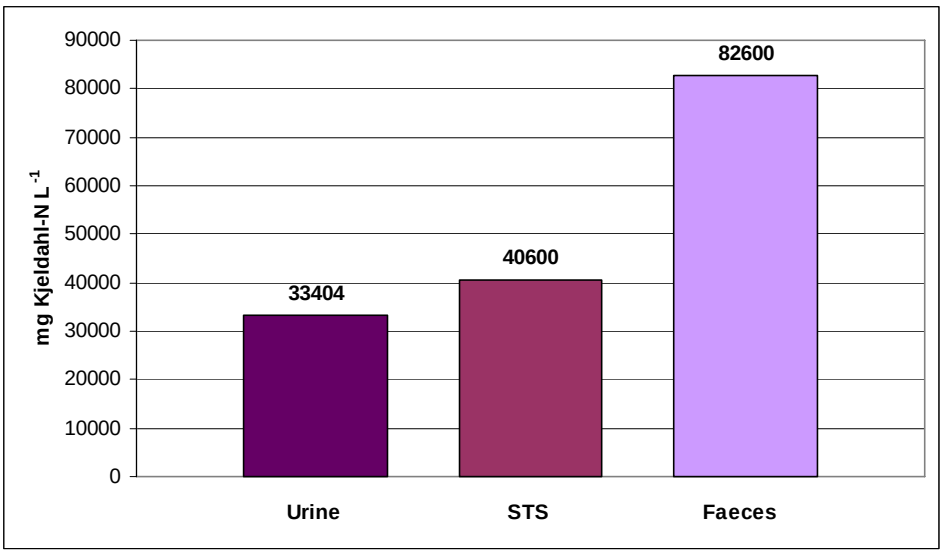


Figure 15. Nitrogen contents in fertilisers.

According to Oksjoki (2004), the average amount of nitrogen in STS is approximately 44 g L^{-1}. The Kjeldahl-N content in STS in these analyses was 40.6 g L^{-1}. This means that the poor growth rate in STS fertilised crates cannot be explained by poor nutrient content of STS used but by the amount and pace of applications. |*20*|

The average amount of nitrogen in urine is 1 % which is equal to 10 000 mg L^{-1}. This is the value reported for European ecotoilets with water flushing. |*10*|

Concentration of total nitrogen in source separated urine (no water flushing) was reported to be 2.3 kg/m3 on average, analysed from seven different separating systems in Sweden. This is equal to 23 000 mg L^{-1}. |*18*|

The literature values are rather low compared to the nitrogen amount detected from urine used in this experiment. Still, the growth on urine fertilised crates was poorest. Ammonia volatilization has been likely during urine application.

It must be noted that the method was based on standard SFS 5505, which is meant for samples with nitrogen contents in range 1-30 mg L^{-1} while these results were at lowest around 30 g L^{-1}. Urine and STS samples were diluted with ratios 1:10 and

1:100 but the dilution ratios should have been probably even higher when comparing the results and the operating range of SFS 5505. Composted faeces was analysed based on standard SFS-EN 13342 in which the operating range was not defined.

7.7 KJELDAHL NITROGEN CONTENTS IN PLANTS

The Kjeldahl-N contents from plant analysis are shown in figure 16:

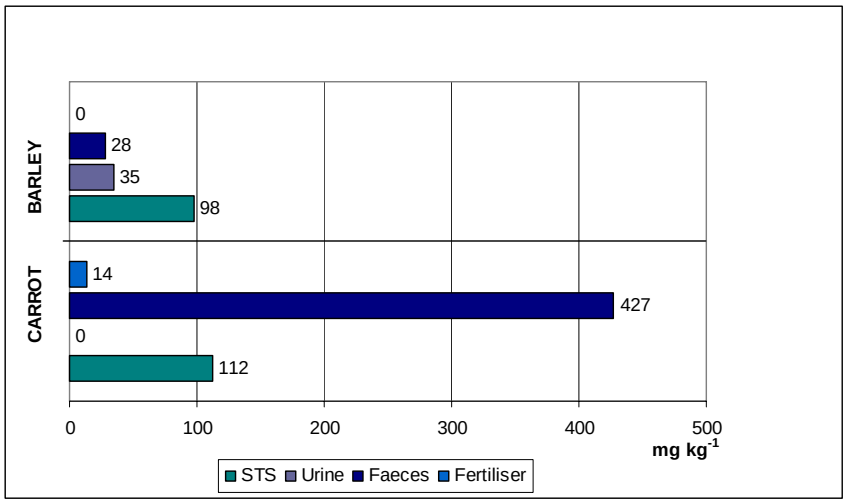


Figure 16. Kjeldahl-N contents in plants, dry weight.

Plant analyses could not be conducted for urine fertilised carrots because yield did not provide enough plant material for samples. The amounts of Kjeldahl-N detected from plants are exiguous. According to Radojevic & Bashkin the typical concentrations of nitrogen in cereal crops (grain) on a dry weight basis are around 20 g kg^{-1} which is equivalent for 2 %. Typical concentration values for root crops were not given. Amount of Kjeldahl-N from these plants was around 0,001 %.

Sampling time was not the best for plant analyses as according to Radojevic & Bashkin plants shouldn't be sampled when past full maturity, instead sampling should be done at the beginning of the plant's reproductive stage or just before. Only the control (artificial fertilising) was not fully ripened. This has probably had much influence in results. Nitrogen deficiency in barley could be noted by the premature curing of STS, urine and composted faeces treatments and also from smaller plant sizes compared to control. |3|

7.8 C/N RATIO

Carbon nitrogen ratio of treatments is shown in table 27:

Table 19. Soil C/N ratio of different treatments.

Sample	TC Conc. (%)	Comparable amount in 3 g of soil (g)	N Conc. (%)	Comparable amount in 3 g of soil (g)	C/N ratio
Fertiliser	4,9	0,15	0,05	0,16	94
Faeces	2,3	0,07	0,05	0,14	49
Urine	3,6	0,11	0,04	0,12	94
STS	4,5	0,13	0,09	0,26	49
Avg.	**3,8**	**0,11**	**0,06**	**0,17**	**64**

The common C/N ratio in organic matter of arable land ranges from 8:1 to 15:1, which is extremely low compared to the average result obtained from this growing experiment. Kjeldahl-N has been assumed to represent total-N in order to be able to calculate a C/N ratio for substrates. According to Radojevic & Bashkin (1999) the concentration of inorganic-N forms in soil is considerably less than that of organic-N and thus the result of Kjeldahl-N may be assumed to represent both organic-N and total-N. |*3*,*22*|

7.9 BULK DENSITY

Bulk density was calculated as an average of 36 mass volumes obtained in the pre-treatment of substrate samples for soluble reactive phosphorus analyses. All of these samples were air-dried and sieved to >2mm size. Sample volume was 25 mL. The bulk density was determined to be 0.997 g cm^{-3}. Bulk density of a soil ranges usually between 0.8 and 1.7 g cm^{-3}, with peat soils the densities are generally lower (0.1-0.3 g cm^{-3}). High bulk density soils have usually low pore space, permeability and infiltration. These soils are also inhibitory to root penetration. The substrate density is on average level and rather high for being mostly composed of horticultural peat. The small grain size of samples used for bulk density has raised the bulk density but not to great extent as the share of soil sieved to grain size >2 mm is 80 % of whole mass, comparing the weights of sieved and unsieved substrate samples. |*22*|

7.10 RESULTS OF BARLEY YIELD

Comparison of plant yield characteristics can be done with aid of figures 17-19:

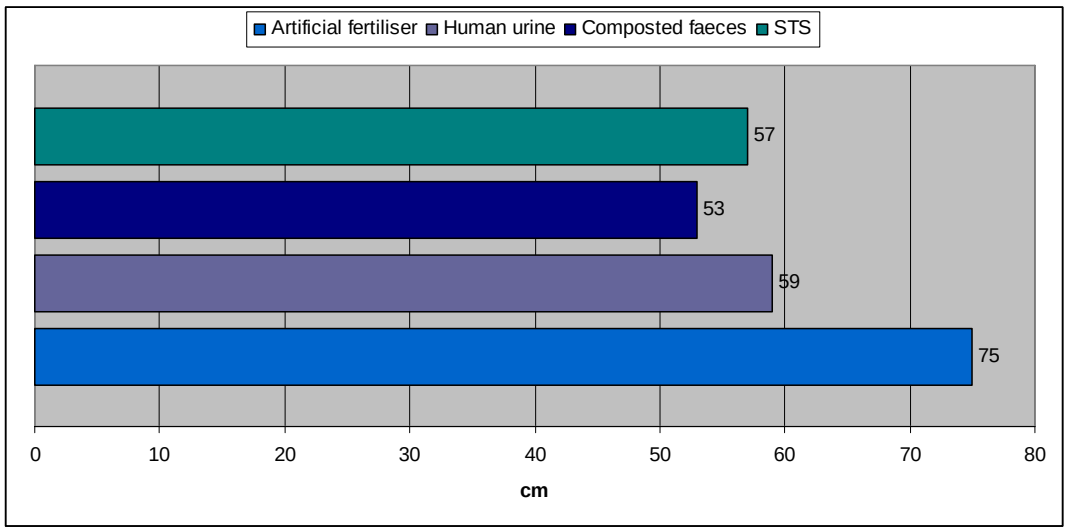


Figure 17. Average length of straw for barley, comparison of treatments.

Longest straws were with control (artificial fertiliser), 75 cm. Variation between STS, human urine and composted faeces treated substrates was low.

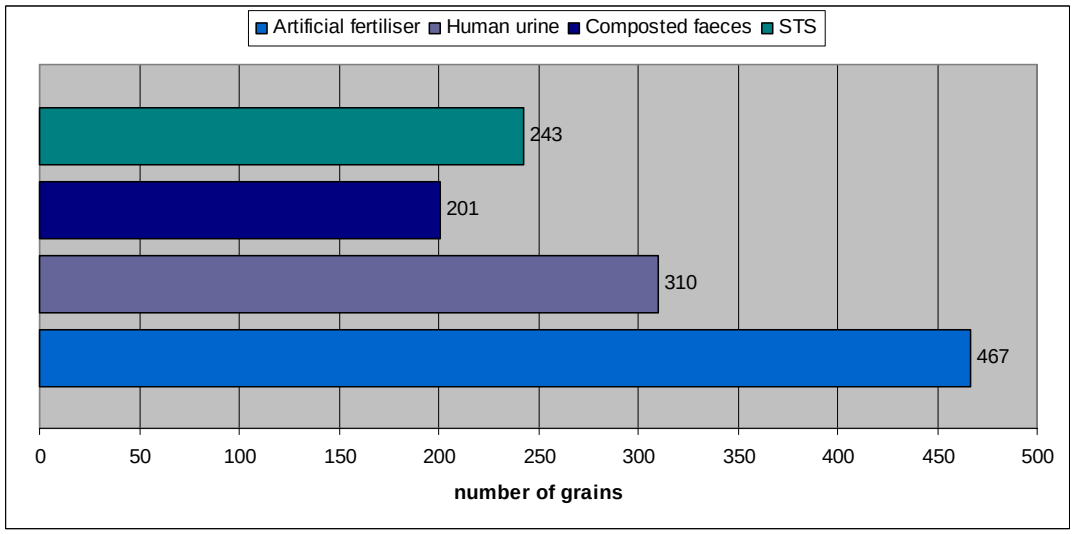


Figure 18. Number of grains, comparison of treatments.

Artificial fertiliser produced over twofold more than composted faeces, which produced the smallest amount of grains. Second best in number of grains was human urine, although difference with STS was not large.

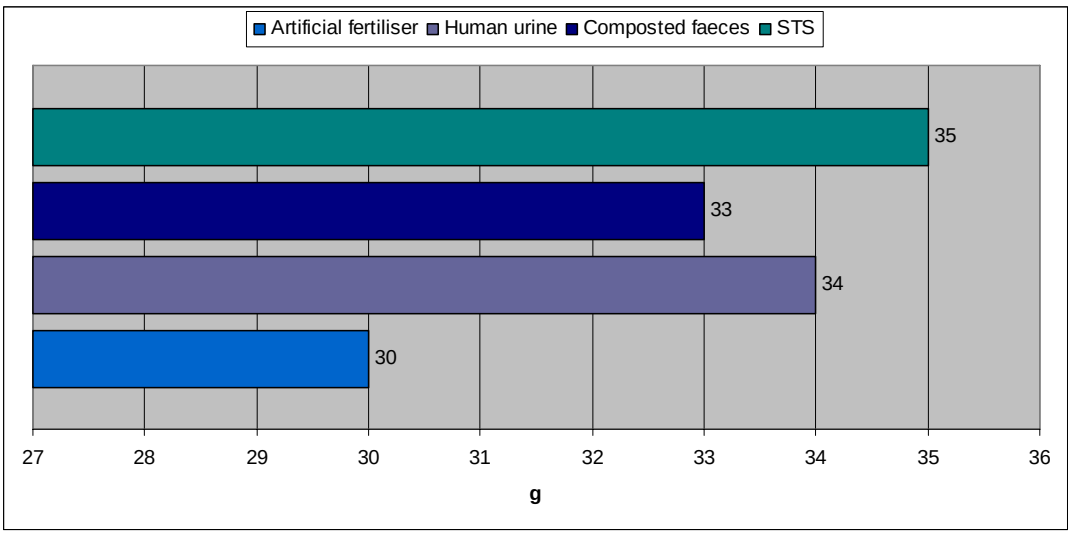


Figure 19. Mass of grains, comparison of treatments.

Artificial fertiliser had smallest mass of grains due to harvesting when not ripened, which meant also a higher moisture content. Variation with mass of grains was small.

7.11 RESULTS OF CARROT YIELD

Average length of carrots and total mass of fresh carrots were measured for a treatment comparison. Results are presented in figures 20 and 21:

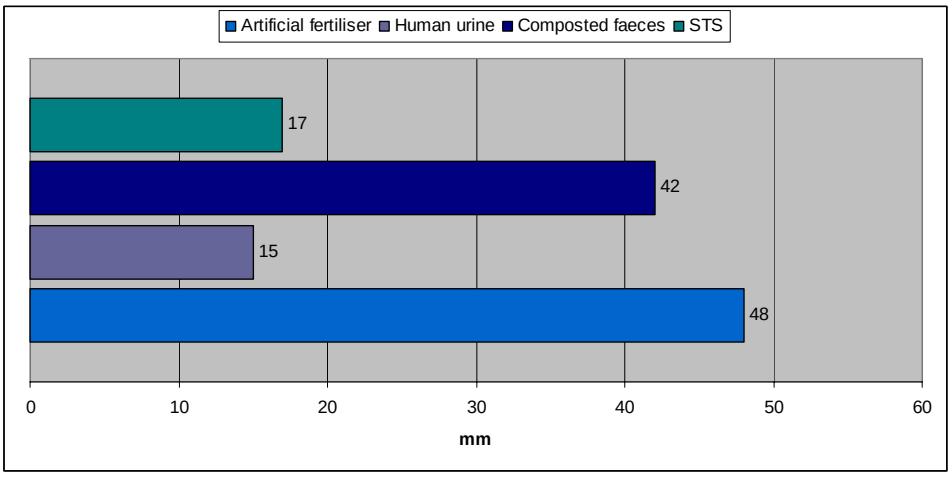


Figure 20. Average length of carrot, comparison of treatments.

Artificial fertiliser produced the best carrot yield which is also shown on the average length of carrot. Composted faeces were not much worse with length, only 6 cm less. STS and human urine produced both weak yields.

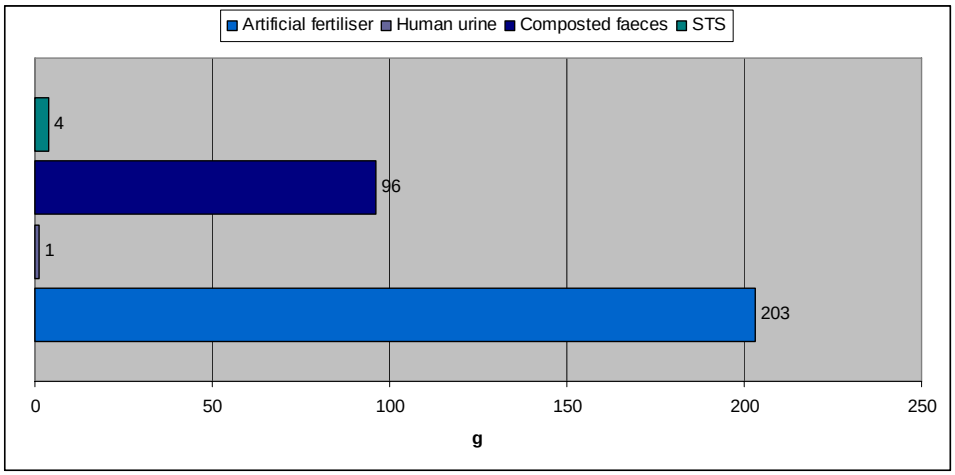


Figure 21. Masses of 50 carrots, comparison of treatments.

Largest masses were produced in control substrate with artificial fertiliser treatment, which was at least twice more than with the rest. Composted faeces also produced a sufficient mass of carrots. STS and urine had the weakest yields, urine yield was nonexistent.

8 DISCUSSION AND CONCLUSIONS

8.1 NUTRIENTS

The nitrogen contents in fertilisers were sufficient. Nitrogen contents of substrates exceeded given limit value for organic nitrogen in all of carrot substrate samples. In barley substrates the samples taken in the beginning of experiment did not exceed the limit value except for STS.

The amounts of fertilisers used were calculated with literature values of nutrients to correspond the limit value 170 kg ha^{-1}. It must be remembered when comparing these results with the limit value that Kjeldahl-N is, according to SFS-EN 13342, “nitrogen that is contributed by free ammonia, inorganic ammonia compounds and those types of organic nitrogen compounds that are converted to ammonium sulphate by the digestion process.” |*6*|

The levels of Kjeldahl-N were higher in the end sampling than in the beginning. Rise in nitrogen content might be due to the colloidal structure of peat sand mixture which may have adsorbed the nitrogen in the beginning of growing

experiment. Inorganic nitrogen may have assimilated into organic nitrogen during the growing experiment.

Nitrogen contents in substrates were ranging from poor to sufficient although this could not be interpreted that well from carrot and barley yields. Effect of pH can be suspected to have mitigated the yield, as well as the lack of soil activities due to small amount of soil invertebrates and micro-organisms present.

Variance between samples for orthophosphate contents of substrates was extremely high. The huge number of zero results was probably due to the long storage time of samples before analysis. Samples were dried, sieved and stored for half a year before analysis, although orthophosphate should be measured immediately for best results. Then again in some samples the orthophosphate values were over 1000 mg kg^{-1}. Effect of pH can be suspected to be one of the causes. Liming affects the results of acetate extraction method greatly as the acidic extraction solution may otherwise dilute also the more insoluble, strongly adsorbed phosphorus. Also the soil type and humus content should be considered when analysing the results from an acetate extraction analysis. In this case the substrate was limed but effect of fertilisers on pH is unknown. It may well be possible that pH has risen to a level which has diluted the more stabile phosphorus to the sample as well. |*34*|

Acetate extraction method, which was used for pre-treatment of reactive phosphorus samples before spectrophotometric analysis, has been studied in comparison with water extraction and diffusion methods by Into Saarela (2004). Acetate extraction method is indicator of intensity which shows the amount of nutrients at the time of measurement but not the capacity of nutrients potentially available for use. For the two peat soils analysed in the study acetate extraction method showed to sufficient extent the biological availability of phosphorus. In a coarse limed fine sand soil the acetate extraction method gave too large values compared to amount of P taken up by plants. Acetate extraction method was considered only indicative for measurement of P uptake and P contents in plants due to its poor detection levels (18-65 % for P uptake, 41-78 % for P contents in plants). In order to study the reaction between phosphorus contents of soil and effects of fertilising and the optimal fertiliser amount the water extraction method

and diffusion method were considered better than acetate extraction at least in mineral soils. |*34*|

Orthophosphate contents in fertilisers were rather high and showed probably also the more stabile phosphorus that isn't normally available to plant uptake. Contamination of orthophosphate samples is also very possible due to phosphate detergent used for the glassware. Unfortunately due to time restrictions and amount of glassware available, acid washing was not possible.

The potassium ion results from substrates show the overall controversy of substrate sample results. Nutrient contents measured from commercial fertiliser treated substrate were low, amount of zero results was high and the plant uptake values were usually the lowest for artificial fertiliser treated substrates. The yield for artificial fertiliser treated substrates was the best. While STS and composted faeces were mixed thoroughly to the substrates, urine was spread with a watering can and artificial fertiliser was spread as small grains to rows between the seedling rows, that is, on top of the substrate. This explains the low result values.

In carrot STS the potassium uptake was highest although yield was pettiest. Composted faeces had large uptake values in both barley and carrot, which suggests it a good source of exchangeable potassium. Bio waste added to the compost may have improved this factor. In barley the results of urine and STS are on same level; as were the yields. With composted faeces the uptake was highest, 145.4 mg kg^{-1}.

Largest content of potassium present in fertilisers was detected from composted faeces, although majority of potassium emitted by human should be present in urine. Bio waste may have provided potassium to larger extent than usually detected from composted faeces. Composted faeces sample used was measured by dry weight while the rest of fertilisers were measured by volume. Potassium ions may have been in more concentrated form in the composted faeces sample as well, which would explain the extremely high amount of potassium detected compared to urine and STS.

8.2 OBSERVATIONS CONCERNING THE EXPERIMENT

Aim of this study was achieved only partly. The nutrient contents of plants were impossible to examine due to lack of study material as the yields obtained were insufficient. Another drawback was that the fertilisers were not analysed thoroughly before the beginning of experiment and their nutrient level could only be assumed to be of same level as in reference literature. This was critical especially with composted faeces which in this case had also bio waste mixed with it. This may have affected its characteristics strongly. Also when conducting analyses of nutrient levels in plants it would be necessary to measure both soluble and total fractions of nutrients for reasons of comparison. This would help to analyse the potential uptake level of nutrients from soil.

Substrates were made mixing limed horticultural peat and sand. The only micro-organisms present in substrates were those that fertilisers may have provided. Unfortunately this also mitigated the fertilising value of human urine, composted faeces and STS as most of the nitrogen in them is organic and micro-organisms are essential in soil chemical functions. Losses with inorganic nitrogen may be high when STS or urine is applied. STS was applied to the substrate and mixed thoroughly but urine was applied on top of the substrate with watering can. It is likely that this has had an effect on urine treated substrates' soil fertility. Losses of nitrogen from urine also may have been enhanced by the high temperature values combined with air ventilation.

High temperature values were also a major issue in the experiment. Excessive growth in the beginning leaded to lodging of plants. Maturing of plants happened earlier than expected and harvest had to be done although not all of the barley was ripened. Early ripening of STS, urine and composted faeces treated barley occurred probably partly also due to nutrient deficiencies (N, P). The air ventilation of greenhouse was not sufficient enough to cool down temperatures to the range of Finnish summertime. Also there was no expertise on the air ventilation system and there was confusion if the greenhouse door should be kept open or closed to provide best operation conditions for the fan cooler system with condensation tank.

pH of the substrates was limed to stabilise the acidic peat in the beginning of experiment but after this there was no monitoring or pH analysis done although it is known that STS, urine and composted faeces may have acidifying effects on soil. This is a significant factor that affects plant uptake of nutrients and also the chemical and physical reactions in soil.

The analyses conducted were insufficient to measure the nutrient fractions and to compare results with reference literature and limit values. EC directive 91/676/EEC was set to control nitrate pollution from agricultural sources. Unfortunately the Kjeldahl-N analysis also takes into account ammonia while most of nitrate and nitrite is lost during decomposition of organic matter. Another problem with Kjeldahl-N analysis was that wet digestion was done with Büchi Digest System K-437 attached to Büchi Scrubber B-414. Digestion vessels in this digest system are interconnected by a gas collection lid that sucks out and neutralises acid fumes released during wet digestion. This may have also caused contamination of samples to small extent. Another reason for contamination may have been also due to human errors during experiment. Substrates were compacted by hands and walking on the substrates, which may have also added compaction to the soil too much for ideal nutrient uptake. It may be that also the measuring equipment used for temperature monitoring has not been cleaned well enough between measurements from different crates. All in all, unreliability in results due to human errors is most likely of insignificant value.

8.3 RECOMMENDATIONS FOR IMPROVEMENTS

Study concerning fertiliser use of human urine, composted faeces and STS has only begun in Tampere Polytechnic, University of Applied Sciences. This pilot study has given some ideas how to improve and develop analysis methods for future studies:

- More thorough understanding of soil microbial activity is needed in order to adjust the amounts of fertilisers in form of STS, human urine or composted faeces. Because much of the nitrogen in these fertilisers is in insoluble form the future study will be conducted as outdoor cultivation. If possible, the microbial activity should be studied in addition to pathogen analysis.

- Greenhouse cultivation could and should still be studied as hydroponics and using a mineralizing agent at the same time in order to provide the nitrogen in soluble form. This would show the true fertilising values of urine, composted faeces and STS as the role of physical and chemical reactions in soil would be mitigated. Use of composted faeces in hydroponics would be tricky if not impossible. Use of urine with hydroponics should be studied, also STS usage might be possible by sedimentating the STS and injecting only the supernatant, in this case the fertilising value variation between supernatant and sediment should be studied as well.

- In case of greenhouse cultivation the illumination should be selected considering the heating effects. Fluorescent lamps are a more ecologically and economically sound solution for illumination. Fluorescent plant lamps provide better illumination quality than high-pressure sodium lamps but less light intensity, which means that they must be kept closer to plants. This may require more attendance of greenhouse keeper depending on the installation method selected for fluorescent lamps.

- More thorough analysis of nutrient fractions could be done. There isn't much information available about nutrient fractions of sludge or composted faeces. This also would help to understand better the soil activities and role of soil microbiota and fauna in nutrient uptake of plants.

- pH of substrates should be monitored several times during the experiment and neutralised if necessary in order to ensure best growth conditions for plants.

- Digestion system used in analyses should not be interconnected in order to avoid sample contamination.

- Phosphorus analysis should be done of both total phosphorus and phosphorus available to plants. There should be phosphate-free detergent for washing of glassware in order to avoid contamination in phosphorus analysis.

- Nutrient analysis of fertilisers should be done already before experiment.

- The effects of fertiliser application rate, amount and placement should be studied more and adjusted.

- Efficiency and usefulness of analysis methods should be stressed more.

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APPENDIXES

APPENDIX 1. MASS FRACTION CALCULATIONS FOR ORTHOPHOSPHATE CONTENTS OF BARLEY SUBSTRATES.

	Orthophosphate content calculations (PO_4^{-3})				
Sample Tag	**Concentration (mg L^{-1})**	**Volume (ml)**	**Mass Fraction (mg kg^{-1})**	**Mass Fraction (mg kg^{-1}), average for crate**	**Mass Fraction (mg kg^{-1}), average for treatment**
Artificial Fertiliser					
O1 L1A	0,01	100	0,01004	0,00502008	0,00251004
O1 L1B	0	250	0		
O1 L2A	0	100	0	0	
O1 L2B	0	250	0		
O2 L1A	0	100	0	0	0,00502008
O2 L1B	0	100	0		
O2 L2A	0,02	100	0,02008	0,010040161	
O2 L2B	0	100	0		
Composted Human Faeces					
O1 K1A	0	100	0	0,00502008	0,00502008
O1 K1B	0,01	250	0,01004		
O1 K2A	0	100	0	0,00502008	
O1 K2B	0,01	250	0,01004		
O2 K1A	0	100	0	0,00502008	0,00251004
O2 K1B	0,01	100	0,01004		
O2 K2A	0	100	0	0	
O2 K2B	0	100	0		
Human Urine					
O1 V1A	0	100	0	0	0
O1 V1B	0	250	0		
O1 V2A	0	100	0	0	
O1 V2B	0	250	0		
O2 V1A	0	100	0	0	0,00753012
O2 V1B	0	100	0		
O2 V2A	0	100	0	0,015060241	
O2 V2B	0,03	100	0,03012		
Septic Tank Sludge					
O1 S1A	0	100	0	0	0
O1 S1B	0	100	0		
O1 S2A	0	100	0	0	
O1 S2B	0	100	0		
O2 S1A	0	100	0	0	0
O2 S1B	0	100	0		
O2 S2A	0	100	0	0	
O2 S2B	0	100	0		

APPENDIX 2. MASS FRACTION CALCULATIONS FOR ORTHOPHOSPHATE CONTENTS OF CARROT SUBSTRATES.

	Orthophosphate content calculations (PO_4^{-3})				
Sample Tag	**Concentration (mg L^{-1})**	**Volume (ml)**	**Mass Fraction (mg kg^{-1})**	**Mass Fraction (mg kg^{-1}), average for crate**	**Mass Fraction (mg kg^{-1}), average for treatment**
Artificial Fertiliser					
P1 L1A	0	100	0	0	0
P1 L1B	0	250	0		
P1 L2A	0	100	0	0	
P1 L2B	0	250	0		
P2 L1A	0	100	0	0	0
P2 L1B	0	100	0		
P2 L2A	0	100	0	0	
P2 L2B	0	100	0		
Composted Human Faeces					
P1 K1A	0	100	0	0	0,00251004
P1 K1B	0	250	0		
P1 K2A	0	100	0	0,00502008	
P1 K2B	0,01	250	0,0100402		
P2 K1A	0	100	0	0,00502008	0,020080321
P2 K1B	0,01	100	0,0100402		
P2 K2A	0,07	100	0,0702811	0,035140562	
P2 K2B	0	100	0		
Human Urine					
P1 V1A	0	100	0	0	0
P1 V1B	0	250	0		
P1 V2A	0	100	0	0	
P1 V2B	0	250	0		
P2 V1B	0	100	0	0	0,012550201
P2 V2A	0	100	0		
P2 V2B	0,05	100	0,0502008	0,025100402	
P2 VIA	0	100	0		
Septic Tank Sludge					
P1 S1A	0	100	0	0	0
P1 S1B	0	100	0		
P1 S2A	0	100	0	0	
P1 S2B	0	100	0		
P2 S1A	0	100	0	0,015060241	0,00753012
P2 S1B	0,03	100	0,0301205		
P2 S2A	0	100	0	0	
P2 S2B	0	100	0		

APPENDIX 3. MASS FRACTION CALCULATIONS FOR KJELDAHL NITROGEN CONTENTS OF CARROT SUBSTRATES.

Sample Tag	Volume of H_2SO_4 used (ml)	Analysis Date	H_2SO_4 Concentration (mol L^{-1})	Volume of H_2SO_4 used for blank (ml)	N (%)	N (mg kg^{-1})	Average N (%, crate)	Average N (mg kg^{-1}, crate)	Average N (%, treatment)	Average N (mg kg^{-1}, treatment)
Artificial Fertiliser										
P1 L1A	0,740	27.1.2006	0,05	0,142	**0,042**	**41860**				
P1 L1B	0,176	18.5.2006	0,005	0,086	**0,001**	**630**	**0,021**	**21245**		
P1 L2A	0,870	27.1.2006	0,05	0,142	**0,051**	**50960**				
P1 L2B	0,112	18.5.2006	0,005	0,086	**0,000**	**182**	**0,026**	**25571**	**0,024**	**23408**
P2 L1A	9,872	24.3.2006	0,005	1,032	**0,062**	**61880**				
P2 L1B	15,242	29.3.2006	0,005	0,900	**0,100**	**100394**	**0,081**	**81137**		
P2 L2A	13,232	24.3.2006	0,005	1,032	**0,085**	**85400**				
P2 L2B	18,818	29.3.2006	0,005	0,900	**0,125**	**125426**	**0,105**	**105413**	**0,093**	**93275**
Composted Human Faeces										
P1 K1A	1,022	27.1.2006	0,05	0,142	**0,062**	**61600**				
P1 K1B	0,330	18.5.2006	0,005	0,086	**0,002**	**1708**	**0,032**	**31654**		
P1 K2A	1,332	27.1.2006	0,05	0,142	**0,083**	**83300**				
P1 K2B	0,254	18.5.2006	0,005	0,086	**0,001**	**1176**	**0,042**	**42238**	**0,037**	**36946**
P2 K1A	11,634	24.3.2006	0,005	1,032	**0,074**	**74214**				
P2 K1B	9,530	31.3.2006	0,005	0,762	**0,061**	**61376**	**0,068**	**67795**		
P2 K2A	14,200	24.3.2006	0,005	1,032	**0,092**	**92176**				
P2 K2B	17,166	31.3.2006	0,005	0,762	**0,115**	**114828**	**0,104**	**103502**	**0,086**	**85649**
Human Urine										
P1 V1A	7,010	31.3.2006	0,005	0,762	**0,044**	**43736**				
P1 V1B	0,258	18.5.2006	0,005	0,086	**0,001**	**1204**	**0,022**	**22470**		
P1 V2A	0,950	27.1.2006	0,05	0,142	**0,057**	**56560**				
P1 V2B	0,160	18.5.2006	0,005	0,086	**0,001**	**518**	**0,029**	**28539**	**0,026**	**25505**
P2 VIA	11,612	24.3.2006	0,005	1,032	**0,074**	**74060**				
P2 V1B	9,502	31.3.2006	0,005	0,762	**0,061**	**61180**	**0,068**	**67620**		
P2 V2A	7,570	24.3.2006	0,005	1,032	**0,046**	**45766**				
P2 V2B	12,502	31.3.2006	0,005	0,762	**0,082**	**82180**	**0,064**	**63973**	**0,066**	**65797**
Septic Tank Sludge										
P1 S1A	1,140	27.1.2006	0,05	0,142	**0,070**	**69860**				
P1 S1B	16,170	31.3.2006	0,005	0,762	**0,108**	**107856**	**0,089**	**88858**		
P1 S2A	1,330	27.1.2006	0,05	0,142	**0,083**	**83160**				
P1 S2B	18,824	31.3.2006	0,005	0,762	**0,126**	**126434**	**0,105**	**104797**	**0,097**	**96828**
P2 S1A	7,060	24.3.2006	0,005	1,032	**0,042**	**42196**				
P2 S1B	11,868	29.3.2006	0,005	0,900	**0,077**	**76776**	**0,059**	**59486**		
P2 S2A	13,816	24.3.2006	0,005	1,032	**0,089**	**89488**				
P2 S2B	14,224	29.3.2006	0,005	0,900	**0,093**	**93268**	**0,091**	**91378**	**0,075**	**75432**

APPENDIX 4. MASS FRACTION CALCULATIONS FOR KJELDAHL NITROGEN CONTENTS OF BARLEY SUBSTRATES.

Sample Tag	Volume of H_2SO_4 used (ml) = V1	Analysis Date	H_2SO_4 Concentration (mol L^{-1})	Volume of H_2SO_4 used for blank (ml) = VB1	N (%)	N (mg kg^{-1})	Average N (%, crate)	Average N (mg kg^{-1}, crate)	Average N (%, treatment)	Average N (mg kg^{-1}, treatment)
Artificial Fertiliser										
O1 L1A	0,602	27.1.2006	0,05	0,142	**0,032**	**32000**				
O1 L1B	0,236	18.5.2006	0,005	0,086	**0,001**	**1000**	**0,017**	**16500**		
O1 L2A	0,340	27.1.2006	0,05	0,142	**0,014**	**14000**				
O1 L2B	0,114	18.5.2006	0,005	0,086	**0,000**	**0**	**0,007**	**7000**	**0,012**	**11750**
O2 L1A	16,060	24.3.2006	0,005	1,032	**0,011**	**10500**				
O2 L1B	11,656	29.3.2006	0,005	0,900	**0,075**	**75000**	**0,090**	**42750**		
O2 L2A	10,268	24.3.2006	0,005	1,032	**0,065**	**65000**				
O2 L2B	14,042	29.3.2006	0,005	0,900	**0,092**	**92000**	**0,078**	**78500**	**0,061**	**60625**
Composted Human Faeces										
O1 K1A	0,640	27.1.2006	0,05	0,142	**0,035**	**35000**				
O1 K1B	0,270	18.5.2006	0,005	0,086	**0,001**	**1000**	**0,018**	**18000**		
O1 K2A	0,356	27.1.2006	0,05	0,142	**0,015**	**15000**				
O1 K2B	0,280	18.5.2006	0,005	0,086	**0,001**	**1000**	**0,008**	**8000**	**0,013**	**13000**
O2 K1A	10,024	24.3.2006	0,005	1,032	**0,063**	**63000**				
O2 K1B	8,646	31.3.2006	0,005	0,762	**0,055**	**55000**	**0,059**	**59000**		
O2 K2A	8,216	24.3.2006	0,005	1,032	**0,050**	**50000**				
O2 K2B	8,066	31.3.2006	0,005	0,762	**0,051**	**51000**	**0,051**	**50500**	**0,055**	**54750**
Human Urine										
O1 V1A	0,474	27.1.2006	0,05	0,142	**0,023**	**23000**				
O1 V1B	0,176	18.5.2006	0,005	0,086	**0,001**	**1000**	**0,012**	**12000**		
O1 V2A	0,430	27.1.2006	0,05	0,142	**0,020**	**20000**				
O1 V2B	0,166	18.5.2006	0,005	0,086	**0,001**	**1000**	**0,010**	**10500**	**0,011**	**11250**
O2 V1A	8,812	24.3.2006	0,005	1,032	**0,054**	**54460**				
O2 V1B	9,714	31.3.2006	0,005	0,762	**0,063**	**62664**	**0,059**	**58562**		
O2 V2A	8,250	24.3.2006	0,005	1,032	**0,051**	**50526**				
O2 V2B	7,034	31.3.2006	0,005	0,762	**0,044**	**43904**	**0,047**	**47215**	**0,053**	**52889**
Septic Tank Sludge										
O1 S1A	1,238	27.1.2006	0,05	0,142	**0,077**	**77000**				
O1 S1B	13,198	31.3.2006	0,005	0,762	**0,087**	**87000**	**0,082**	**82000**		
O1 S2A	1,654	27.1.2006	0,05	0,142	**0,106**	**106000**				
O1 S2B	12,288	31.3.2006	0,005	0,762	**0,081**	**81000**	**0,093**	**93500**	**0,088**	**87750**
O2 S1A	10,812	24.3.2006	0,005	1,032	**0,068**	**68000**				
O2 S1B	19,802	29.3.2006	0,005	0,900	**0,132**	**132000**	**0,100**	**100000**		
O2 S2A	11,924	24.3.2006	0,005	1,032	**0,076**	**76000**				
O2 S2B	14,770	29.3.2006	0,005	0,900	**0,097**	**97000**	**0,087**	**86500**	**0,093**	**93250**

APPENDIX 5. MASS FRACTION CALCULATIONS FOR EXCHANGEABLE POTASSIUM (K^+) CONTENTS OF BARLEY SUBSTRATES.

Sample ID	Average Absorption	Concentration (mg/L)	Report Date	Amount of K^+ (mg/kg)	Sample ID	Average amount of K^+ (mg/kg) in a crate	Average amount of K^+ (mg/kg) in a treatment
Artificial Fertiliser							
O1 L1A	0,134	1,3242	16.3.06	66,210			
O1 L1B	0,146	1,5792	21.3.06	78,960		**72,585**	
O1 L2A	0,123	1,1975	16.3.06	59,875	**Barley, beginning**		
O1 L2B	0,125	1,3478	21.3.06	67,390		**63,633**	**68,109**
O2 L1A	0,107	1,1483	21.3.06	57,415			
O2 L1B	0,113	1,2156	21.3.06	60,780		**59,098**	
O2 L2A	0,109	1,1725	21.3.06	58,625	**Barley, end**		
O2 L2B	0,083	0,8811	21.3.06	44,055		**51,340**	**55,219**
Composted Human Faeces							
O1 K1A 1/10	0,059	0,5023	16.3.06	251,150			
O1 K1B 1/10	0,019	0,1761	21.3.06	88,050		**169,600**	
O1 K2A 1/10	0,054	0,4496	16.3.06	224,800	**Barley, beginning**		
O1 K2B 1/10	0,064	0,6710	21.3.06	335,500		**280,150**	**224,875**
O2 K1A 1/10	0,015	0,1342	21.3.06	67,100			
O2 K1B	0,173	1,8796	21.3.06	93,980		**80,540**	
O2 K2A	0,118	1,1955	13.3.06	59,775	**Barley, end**		
O2 K2B 1/10	0,031	0,2181	13.3.06	109,050		**84,413**	**82,476**
Human Urine							
O1 V1A	0,160	1,6085	16.3.06	80,425			
O1 V1B 1/10	0,028	0,1598	16.3.06	79,900		**80,163**	
O1 V2A 1/10	0,040	0,2928	16.3.06	146,400	**Barley, beginning**		
O1 V2B 1/10	0,041	0,4128	21.3.06	206,400		**176,400**	**128,281**
O2 V1A	0,093	0,9986	21.3.06	49,930			
O2 V1B	0,157	1,7083	21.3.06	85,415		**67,673**	
O2 V2A	0,141	1,5297	21.3.06	76,485	**Barley, end**		
O2 V2B	0,098	1,0533	21.3.06	52,665		**64,575**	**66,124**
Septic Tank Sludge							
O1 S1A	0,181	3,4308	16.3.06	171,540			
O1 S1B 1/10	0,051	0,4101	16.3.06	205,050		**188,295**	
O1 S2A 1/10	0,013	0,0028	16.3.06	1,400	**Barley, beginning**		
O1 S2B 1/10	0,016	0,1360	21.3.06	68,000		**34,700**	**111,498**
O2 S1A	0,111	1,1944	21.3.06	59,720			
O2 S1B	0,145	1,4971	13.3.06	74,855		**67,288**	
O2 S2A	0,064	0,5877	13.3.06	29,385	**Barley, end**		
O2 S2B	0,058	0,5140	13.3.06	25,700		**27,543**	**47,415**

APPENDIX 6. MASS FRACTION CALCULATIONS FOR EXCHANGEABLE POTASSIUM (K^+) CONTENTS OF CARROT SUBSTRATES.

Sample ID	Average Absorption	Concentration (mg/L)	Report Date	Amount of Potassium (mg/kg)	Sample ID	Average amount of Potassium (mg/kg) in a crate	Average amount of Potassium (mg/kg) in a treatment
Artificial Fertiliser							
P1 L1A 1/10	0,015	0,0143	16.3.06	7,150			
P1 L1B	0,136	1,4706	21.3.06	73,530		**40,340**	
P1 L2A	0,156	1,5643	16.3.06	78,215	**Carrot, beginning**		
P1 L2B	0,098	1,0541	21.3.06	52,705		**65,460**	**52,900**
P2 L1A	0,132	1,3496	13.3.06	67,480			
P2 L1B	0,109	1,0848	13.3.06	54,240		**60,860**	
P2 L2A	0,085	0,8241	13.3.06	41,205	**Carrot, end**		
P2 L2B 1/10	0,027	0,1534	13.3.06	76,700		**58,953**	**59,906**
Composted Human Faeces							
P1 K1A 1/10	0,059	0,5026	16.3.06	251,300			
P1 K1B 1/10	0,024	0,1165	16.3.06	58,250		**154,775**	
P1 K2A	0,180	1,8244	16.3.06	91,220	**Carrot, beginning**		
P1 K2B 1/10	0,021	0,0809	16.3.06	40,450		**65,835**	**110,305**
P2 K1A	0,163	1,7667	21.3.06	88,335			
P2 K1B	0,118	1,1964	13.3.06	59,820		**74,078**	
P2 K2A	0,127	1,2885	13.3.06	64,425	**Carrot, end**		
P2 K2B	0,186	1,9549	13.3.06	97,745		**81,085**	**77,581**
Human Urine							
P1 V1A 1/10	0,018	0,0493	16.3.06	24,650			
P1 V1B 1/10	0,036	0,2501	16.3.06	125,050		**74,850**	
P1 V2A 1/10	0,020	0,0771	16.3.06	38,550	**Carrot, beginning**		
P1 V2B	0,149	1,6130	21.3.06	80,650		**59,600**	**67,225**
P2 V1A	0,084	0,8058	13.3.06	40,290			
P2 V1B	0,108	1,0841	13.3.06	54,205		**47,248**	
P2 V2A	0,134	1,4509	21.3.06	72,545	**Carrot, end**		
P2 V2B 1/10	0,016	0,0350	16.3.06	17,500		**45,023**	**46,135**
Septic Tank Sludge							
P1 S1A 1/10	0,029	0,1709	16.3.06	85,450			
P1 S1B 1/10	0,045	0,3470	16.3.06	173,500		**129,475**	
P1 S2A	0,173	1,7446	16.3.06	87,230	**Carrot, beginning**		
P1 S2B	0,191	1,9459	16.3.06	97,295		**92,263**	**110,869**
P2 S1A	0,140	1,4426	13.3.06	72,130			
P2 S1B	0,193	2,0335	13.3.06	101,675		**86,903**	
P2 S2A	0,106	1,0510	13.3.06	52,550	**Carrot, end**		
P2 S2B	0,093	0,9066	13.3.06	45,330		**48,940**	**67,921**

APPENDIX 7. MASS FRACTION CALCULATIONS FOR KJELDAHL NITROGEN CONTENTS OF FERTILISERS.

Sample Tag, Dilution Ratio (if used)	Sample volume (ml)	Consumption of H_2SO_4 (ml)	Date of analysis	Concentration of H_2SO_4 (mol L^{-1})	N (g L^{-1})	Average (g N L^{-1})	N (mg L^{-1})
Urine 1:10	50	0,272	18.5.2006	0,005	5,208		
Urine 1:100	50	0,306	18.5.2006	0,005	61,600	33,404	33404
STS 1:10	50	0,246	18.5.2006	0,005	4,480		
STS 1:100	50	0,360	18.5.2006	0,005	76,720	40,600	40600
	Sample mass (g)				**N %**	**Average (N %)**	**N (mg L^{-1})**
Faeces 1	2	0,274	18.5.2006	0,005	0,132		
Faeces 2	2	0,134	18.5.2006	0,005	0,034	0,082600	82600
Blank	-	0,086	18.5.2006	0,005			

APPENDIX 8. MASS FRACTION CALCULATIONS FOR ORTHOPHOSPHATE CONTENTS OF FERTILISERS.

Sample Tag	Device Reading (PO_4^{-3}, mg L^{-1})	Date of measurement	Sample volume (ml)	Total volume of extract (ml)	PO_4^{-3}, mg L^{-1}
Faeces	0,03	1.12.2006	10	100	3
Urine	0,06	1.12.2006	10	100	6
STS	0,25	1.12.2006	10	100	25

APPENDIX 9. MASS FRACTION CALCULATIONS FOR EXCHANGEABLE POTASSIUM (K^+) CONTENTS OF FERTILISERS.

Sample Tag, Dilution Ratio	Absorbance	Concentration	Analysis Date	K^+ (mg L^{-1})
Urine 1:100	0,070	0,5657	7.11.2006	56,570
STS 1:100	0,006	0,0488	7.11.2006	4,880
Faeces 1:500	0,196	1,7568	7.11.2006	86,993

APPENDIX 10. MASS FRACTION CALCULATIONS FOR KJELDAHL NITROGEN CONTENTS OF PLANTS.

	Sample Tag	Volume of H_2SO_4 used (ml)	Analysis date	H_2SO_4 Concentration (mol L^{-1})	/m*1000 = N(%)	N (mg kg^{-1})	Average N (mg kg^{-1})
CARROT	STS1	0,098	5.7.2006	0,005	**0,000**	**112**	
	STS2	N/A	N/A	N/A	**N/A**	**N/A**	**112**
	Urine1	N/A	N/A	N/A	**N/A**	**N/A**	
	Urine2	N/A	N/A	N/A	**N/A**	**N/A**	**N/A**
	Faeces1	0,084	5.7.2006	0,005	**0,000**	**14**	
	Faeces2	0,202	5.7.2006	0,005	**0,001**	**840**	**427**
	Fertiliser1	0,084	5.7.2006	0,005	**0,000**	**14**	
	Fertiliser2	0,082	5.7.2006	0,005	**0,000**	**BDL**	**14**
	B	0,082	5.7.2006	0,005			
BARLEY	STS1	0,098	5.7.2006	0,005	**0,000**	**112**	
	STS2	0,094	5.7.2006	0,005	**0,000**	**84**	**98**
	Urine1	0,084	5.7.2006	0,005	**0,000**	**14**	
	Urine2	0,09	5.7.2006	0,005	**0,000**	**56**	**35**
	Faeces1	0,086	5.7.2006	0,005	**0,000**	**28**	
	Faeces2	0,08	5.7.2006	0,005	**0,000**	**BDL**	**28**
	Fertiliser1	0,074	5.7.2006	0,005	**0,000**	**BDL**	
	Fertiliser2	0,082	5.7.2006	0,005	**0,000**	**BDL**	**BDL**

APPENDIX 11. GROWING EXPERIMENT LOG.

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 / 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 a crate, carrots 4.5 l a crate for substrates fertilised with urine and composted human faeces, 2 l a 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 a crate. One spray bottle of watered down growth regulation was sprayed to barley. Later on the same day all substrates were watered 2 l a 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 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 a crate. Barley crates were dryish 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 a 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 cold tube was insulated. All crates were watered 3 l per crate.

12 December 2005 the condense container had an overflow due to the suction tube not aspirating. 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 a crate, for carrot Kevät and carrot Compost 1,5 l a crate. Carrot Urine and Carrot STS were moist and thus left without watering.

27 December 2005 all barley crates were watered 2.5 l a 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 a 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 a 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 a crate.
4 January 2006 all barley crates were watered 3 l a crate and carrot crates 1.5 l a crate.

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

9 January 2006 all crates were watered 5 l a 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 a 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 a 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.