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Evaluation of bokashi fermentation leachate as a biofertilizer in urban horticulture

– inorganic plant nutrient content in bokashi leachate and its effect as a fertilizer on pak choi

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Evaluation of bokashi fermentation leachate as a biofertilizer in urban horticulture – inorganic plant nutrient content in bokashi leachate and its effect as a fertilizer on pak choi

Utvärdering av potentialen hos lakvätska från bokashi-fermentering för användning som gödselmedel i hållbar stadsodling

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1. Abstract

The leachate obtained from bokashi fermentation household vessels, are among proponents of the bokashi method believed to be useful as a biofertilizer. The bokashi fermentation method does not lead to foul odours as it is anaerobically fermented in air-tight bins with lactic acid bacteria, among other groups of microorganisms, and is therefore interesting in the light of an increasing interest of urban farming and unexploited resources of plant mineral nutrients within the urban area.

To examine the potential use of bokashi fermentation leachate as a biofertilizer in an urban farming context, leachate obtained from fermentation of food waste from four different sources in Malmö and Lund, Sweden, was tested on pak choi. The leachate was tested in a sand substrate, a garden waste compost substrate and a peat substrate, in order to give a general idea on how the leachate could be applied in actual situations in urban farming projects, with varying use and availability of substrates and soil.

The plant mineral content of the leachates varied depending on food source, although the leachates were generally low in nitrogen, supposedly as a result of denitrification during the fermentation process. Thus, substrates low in nitrogen gave poor growth for all leachate treatments, although significant difference between different leachate treatments, were found in all substrates. All leachates were relatively high in potassium and phosphorous.

The plants were fertilized with two concentrations of leachates diluted in water. Treatments with higher concentration of leachate gave different shoot weight depending on the food waste source of the leachate.

The content of sodium and chloride in the leachates varied remarkably depending on food waste source, and it was concluded that avoidable food waste contained higher amounts than unavoidable food waste, making unavoidable food waste a more appropriate source for production of bokashi leachate fertilizer.

2. Introduction

Purpose and aim of the project

An increased interest for small-scale crop production and urban agriculture in Sweden and globally (Hushållningssällskapet 2011, Specht et al. 2013, Malmö stad 2014, "Gröna skolgårdar" 2014) calls for a broadened understanding and spreading of knowledge of ways to recycle organic wastes within urban farming systems. Urban gardening projects in Rosengård and Seved in Malmö, Sweden ("Xenofilia.se Förlag och prod…" 2014) are examples of such local crop production in Malmö. In urban farming, ecological, social and economic aspects of sustainable development are met to varying degrees, and the field of plant nutrition in urban gardening can be related to all those aspects. Methods for producing biofertilizer and soil conditioner through on site techniques that exploit resources in the immediate surroundings, minimize foul odours, attraction of rodents and insects, and minimize the loss of greenhouse gases, are therefore of interest.

Bokashi-composting is a method of food waste treatment where the waste is fermented and then dug down in the field in order to add organic material, beneficial microorganisms and mineral plant nutrients to the soil. The bokashi method is commercialized with fermentation bins and inoculation material frome a wide range of suppliers, but there is also a widespread do-it-yourself bokashi culture avoiding high cost products and commercialization of the method. The many anecdotal reports and popular beliefs of the positive effects of bokashi are to a considerable extent not confirmed by peer reviewed scientific research.

In bokashi-composting a leachate is produced and tapped from the bottom of the fermentation vessel during the fermentation. This leachate can, according to suppliers of the bokashi products, be used as a plant fertilizer. Similarly, leachate from fermentation of kitchen waste in lactic acid production systems can be utilized as biofertilizer (Wang et al. 2005) as well as composting tunnel leachate in raw or digested form (Romero et al. 2013).

The aim of this study is to explore the possibilities of leachate from bokashi and how the method could be used as a fertilizer strategy in a greenhouse substrate culture. By analysing the mineral nutrient content in leachate obtained from four sources of food waste in Malmö, problems and possibilities with different food waste sources are tested and discussed. Estimates of yields of pak choi when using bokashi fermentation leachate for supply of phosphorous, potassium and other mineral plant nutrients, are calculated from data on bokashi leachate mineral content, amount of produced leachate and plant tissue levels of essential elements.

The question to be answered in this thesis is the following: can bokashi leachate be used as a fertilizer and what needs to be considered when applying this method? Furthermore the scientific credibility of the claims from proponents of the bokashi method, and popular beliefs surrounding the method, are questioned.

3. Background

Food waste generation in Sweden and sustainable urban farming

The amount of food waste from households, restaurants and school kitchens in Sweden 2012 was 971 tonnes in total and 102 kg/person (Naturvårdsverket 2014). Household food waste made up 79.4 % of this amount and increased 91 tonnes from 2010 to 2012 (Naturvårdsverket 2014). The amount of biologically treated household food waste in Sweden was 370 tonnes in 2012, out of which 259 was anaerobically digested for biogas production and 125 tonnes was composted in public composts or home composts (Avfall Sverige 2013).

Food waste can be categorized as avoidable and unavoidable. Avoidable food waste is food scraps and wasted food that could have been consumed. Unavoidable food waste is food waste that is not possible to consume as human food and that is sorted out during the preparation of the food. The avoidable food waste in households has been estimated to 56 kg /person and year, making up ~57 % of the total household kitchen waste in Sweden 2010 (Livsmedelsverket 2011). The plate food waste has in Swedish school kitchens been approximated to 0,06 kg/pupil and day (Livsmedelsverket 2011).

The Swedish government have set an environmental objective of no less than 50 % recycling of all food waste from housholds, schools, restaurants and stores from 2018, in order to biologically treat the food waste for use as biofertilizer ("Ökad resurshushållning i livsmedelskedjan – miljömål.se" 2014). The environmental goals of improved food waste recycling, has among other investigations led to a recently published throrough report on recycling of phosphorous from organic waste resources in Sweden (Naturvårdsverket 2013) and further analysed by Avfall Sverige with respect to accumulation of cadmium as a result of application of food waste based biofertilizer ("B2014:01 – Start" 2014). The subjects investigated in these reports are only two examples of the vast and complex areas of environmental problems that need to be investigated in order to fulfil the Swedish environmental goals, such as the *generation goal*. Therefore, this projects aims at investigating the possibilities of bokashi fermentation leachate in urban farming projects, as an interesting aspect of the possibilities with the vast generation of food waste containing plant mineral nutrients.

The sustainability aspect of urban and peri-urban farming has been discussed and investigated in relation to food security, health and self-suffiency in developing countries as well as with respect to social benefits and educational aspects in developed countries (FAO 2008, Zezza and Tasciotti 2010, Specht et al. 2013). In the perspective of sustainable urban farming, there is an obvious resource of plant mineral nutrients found in food waste, considering the amounts of food waste produced within the city in private households, school kitchens, restaurants, etc. The immediate nearness to potential urban farm sites, such as rooftop gardens and greenhouses in dense cities, makes on site biofertilizer production from food waste desirable, in order to exploit the resource and avoid transport costs.

Fermentation of food waste and bokashi-EM

Effective Microorganisms (EM) is a trademarked product containing a mixed culture of bacteria and yeast for use in a broad range of horticultural and waste management applications, produced by the Japan based company EMRO. The scientific credibility of the vast amount of positive effects of EM claimed by EMRO is questioned by the scientific community and the published research have been criticised for flawed experimental set up and for not being consistent with current scientific knowledge (Cóndor-Golec et al. 2007, Schenck zu Schweinsberg-Mickan and Müller 2009).

EMRO reports that the EM-mixture contains mainly lactic acid bacteria, phototrophic bacteria and yeast, but do not tell the exact composition of microorganisms. EMRO and other proponents of EM claim that these three groups have various positive effects on soil, rhizosphere and plant growth and health. The general idea behind application of EM is to control the fauna of beneficial microorganisms in a directed manner in order to acquire a synergistic effect of the combination of strains and groups of bacteria and fungi. It is claimed by EM-proponents that this means of controlling soil health leads to complex effects on the soil ecosystem that are difficult to empirically test through reductionistic research experimentation (Higa and Parr 1994). When application of EM-bokashi was tested in a 4-year field experiment with potatoes, winter barley, lucerne and winter wheat, considerably higher yields were obtained in treatments with EM-bokashi in comparison with control treatment although sterilized bokashi-substrate gave no significant difference in comparison to unsterilized bokashi-substrate (Mayer et al. 2008). This result implies that the application of bokashi led to increased yield due to the content of NPK and other mineral plant nutrients in the bokashi-material, and that the EM-content had no direct effect on the soil and rhizosphere.

Different compositions within the broader categories of microbes are mentioned in research papers, although no specific strains or proportions are mentioned. The EM-inoculant content is by Xu (2001) reported to be:

Lactic acid bacteria: *Lactobacillus plantarum*, *Lactobacillus casei*, *Lactococcus lactis*
Photosynthetic bacteria: *Rhodopseudomonas palustris*, *Rhodobacter sphaeroides*
Yeasts: *Saccaromyces cerevisiae*, *Candida utilis*
Ray fungi: *Streptomyces albus*, *Streptomyces griseus*
Fungi: *Aspergillus oryzae*, *Mucor hiemalis*
(Xu 2001)

The lactic acid bacteria mentioned as key ingredient above are common in nature and are used in spontaneous and inoculated fermentation of a broad range of fermented foods such as sauerkraut, kefir and yoghurt. *Lactobacillus lactis* and *Lactobacillus plantarum* was found in spontaneous lactic acid fermentation of food waste in proportions 50 % and 10 % after 48 hours (Wang et al. 2001). The *Lactobacillus plantarum* strain TD46 has been concluded to be appropriate for lactic acid production from kitchen waste, for use in industrial applications (Wang et al. 2005).

Aspergillus oryzae is a filamentous fungi used in fermentation of soy sauce, sake, bean curd and vinegar, and has traditionally been used in solid state fermentation in wheat bran, rice grain and soy bean in Japan (Machida et al. 2008). Among the popular methods used for bokashi-preparation, cultivation in wheat bran is common. *Aspergillus oryzae* is like other filamentous fungi capable of secreting high amounts of proteins (Gouka et al. 1997), and can according to Machida et al. (2008) produce ~50 g α-amylas per kg wheat bran in solid state fermentation.

Mucor hiemalis is a soil fungi commonly found in soils from all over the world and is known for being capable of producing a number of enzymes, including uricase (Yazdi et al. 2006).

In EM-bokashi fermentation, food waste is put in an air-tight container and mixed with an EM-inoculant. The typical bokashi bin has a tap in the bottom and the importance of tapping excess liquid is emphasized in instructions for bokashi fermentation. Therefore, the bokashi fermentation can be considered as a solid-state fermentation, similar to the wide spread soild state food fermentation of e.g. soy beans in eastern Asia, termed as *koji* in Japan (Machida et al. 2008).

Solid state fermentation can also be used for production of biogas of solid kitchen waste through methanogenic fermentation of the leachate (Ghanem et al. 2001).

In fermentation of kitchen wastes inoculated with and without EM, Yamada and Xu (2001) found that populations of *Lactobacillus* ssp. increased irrespective of inoculation of EM, but that EM-treated fermentation lead to an increase to 10^8 CFU g^{-1} for 6 weeks while populations of *L.* ssp. in spontaneous fermentation was lower and decreased after 7 days. Similarly, kitchen waste spontaneously fermented without inoculation of lactic acid bacteria (LAB) or regulated through pH adjustment have been shown to lead to increased populations of LAB and concentration of lactic acid (Sakai et al. 2000, Wang et al. 2001, Yamada and Xu 2001).

Root uptake of organic molecules from fermentation leachate

Proponents of the bokashi-method argue that the ability of plants to take up water soluble organic molecules such as sugars and amino acids can be used as a means of recycling organic wastes without decomposing the material fully into inorganic compounds (Higa and Parr 1994). The idea is to save energy in a cropping system, by letting the plants absorb organic molecules and thus letting the plant avoid the necessity to synthesize all amino acids and carbohydrates itself through the uptake of inorganic N and C.

Root uptake of carbohydrates

In a soil environment the plant root passively exudate low weight carbon molecules, mainly glucose and sucrose, in amounts ranging between 1-10 % of the plant's net fixed carbon (Jones and Darrah 1996, Kuzyakov and Domanski 2000). As the exudation happens passively it has been hypothesized that the plant in order to recapture the lost carbon has evolved the capability of taking up carbon through an active proton-mediated transport process (Jones and Darrah 1996, Kuzyakov and Jones 2006, Jones et al. 2009). The recapturing of sugars by roots also can serve as a means of lowering competition for plant nutrients from bacteria and lowering the population of pathogenic bacteria, through prevention of accumulation of sugars in the soil (Jones et al. 2009). The uptake of sugars by roots also has been suggested to act as a complementary energy source to the sugar synthesized by the plant itself (Wright 1962, Jones et al. 2009).

Root uptake of amino acids

During the hydrolysis in anaerobic digestion, proteins are broken down into amino acids leading to an increasing concentration of dissolved organic nitrogen (DON), a process that also occurs in the rhizosphere through secretion of proteases from soil microorganisms (Kerley and Read 1998). The availability of DON in the soil has been suggested to be of importance as a nitrogen pool for plants although high concentrations of amino acids are needed in order to function as a substitute for e.g. nitrate (Jones et al. 2005). Plant roots take up amino acids through energy demanding processes and the availability of certain amino acids affect the uptake of others (Wright 1962). In the rhizosphere, plant roots compete with microorganisms for the amino acids available, and it has been found that the microflora is far more effective in taking up amino acids, partly due to higher total absorbing surface in comparison with plant roots (Owen and Jones 2001). Furthermore, the sorbtion of amino acids and ammonium to the soil solid phase, significantly lowers the diffusion rate of those N species in comparison with nitrate (Owen and Jones 2001), which affects the efficiency of amino acid as a fertilizer.

The ability to utilize DON as a nitrogen source varies between species (Kielland 1994). Pak choi roots absorbs amino acids, but the uptake and effect on plant growth varies with different amino acids and concentration of amino acid (Liu et al. 2002). Liu et al. (2002) found that concentrations of glycine above 2 mM led to decreased growth of roots and that alanine and leucine gave little or none contribution of nitrogen in the plants, while glycine and lysine functioned as a sufficient nitrogen source. Furthermore, the amino acid uptake was not affected by parallel uptake of inorganic nitrogen but application of only nitrate-N gave a significantly higher shoot weight than application of only glycine-N. The difference in shoot fresh weight was partly due to differences in plant water content, which was 94 % in the case of fertilization with nitrate-N and 90 % when fertilized with only Glycine-N (Liu et al. 2002).

Compost teas

Composts extracted in water during a certain amount of time is usually termed *compost tea* or *compost extract*, but more terms are in use and the exact definition for each varies (Scheuerell and Mahaffee 2002). It has been suggested (Scheuerell and Mahaffee 2002) that the term compost tea (CT) should be used for compost extracted in water, which is then fermented under anaerobic or aerobic conditions, while compost extract should be used for compost extracted in any solvent, which is then filtered but not fermented. The CTs are then termed *nonaerated compost tea* (NCT) and *aerated compost tea* (ACT), depending on fermentation conditions.

In fermentation of food waste in bokashi bins the produced leachate is obtained during the fermentation of the fresh food waste, while the compost tea is fermented after the organic material have been aerobically decomposed. Nevertheless, the principles for obtaining food fermentation leachate and CT are similar, especially in the case of NCT, and it is therefore interesting to explore the properties of CT in horticultural production.

Non-aerated compost tea obtained from yard and kitchen waste compost and sprayed on foliar parts of strawberry was found to be useful as a biofertilizer, comparable with addition of solid compost to soil or inorganic fertilizer (Hargreaves et al. 2009), although the concentrations of macro- and micronutrients in NCT varied considerably between compost batches. When tested on pak choi growth, NCT and ACT from vermicomposted chicken manure were found to enhance plant growth, partly due to extracted plant nutrients in the CT (Pant et al. 2009). Pant et al. (2009) found higher concentrations of macro- and micronutrients in pak choi plant tissue treated with NCT, compared with ACT treatment. These studies did not focus on possible contamination with human pathogen bacteria of the tested CTs.

In addition to the nutrient content, studies have shown that compost teas also may contain considerable amounts of phytohormones or phytohormone-like compounds that can influence plant growth. Compost teas prepared through vermicomposting and thermophilic composting of chicken manure and food wastes, showed positive influence on growth of pak choi as a result of gibberellin (GA_4) and mineral N content in the compost tea (Pant et al. 2012). Similarly, Xu et al. (2012) concluded that a significantly increased growth of cucumber after application of compost tea was the result of a high content of humic-like substances that stimulated auxin-like responses in the plants. It is well known that many strains of rhizobacteria are capable of synthesizing IAA, gibberlins and cytokinins (Barea and Brown 1974, Loper and Schroth 1986, Patten and Glick 1996). Exogeneous IAA produced by rhizobacteria can be both beneficial and detrimental to plant growth and health, depending on the endogenous levels of IAA and specific needs of the subjected plant and plant species (Dubeikovsky et al. 1993, Patten and Glick 1996).

Another widespread use of compost teas is foliar treatment or treatment of soil in order to induce systemic resistance or as a biocontrol method for pathogen infected plants. Application of compost teas have been reported to have a suppressing effect on the causing agents of powdery mildew on muskmelon (Naidu et al. 2013), common scab of potato (Al-Mughrabi et al. 2008), and grey mold on geranium and strawberry (Scheuerell and Mahaffee 2006, Welke 2005).

The microbial content of compost teas varies depending on compost feedstock and fermentation method (Scheuerell and Mahaffee 2002). The availability of oxygen in NCT compared to ACT and the duration of the fermentation process will create different circumstances for bacterial growth. The time of the composting of the feedstock has also been discussed for creating an optimal composed tea for plant disease control, and for the breaking down of human pathogen bacteria (Scheuerell and Mahaffee 2002).

Plant growth-promoting rhizobacteria in compost teas

When using CT, organic and inorganic nutrients are applied to roots or foliar parts of the plant, but also a flora of bacteria as a result of the fermentation of the CT. Depending on the method of fermentation - aerated or non-aerated and time of fermentation- leads to different microbial species composition (Scheuerell and Mahaffee 2002). The application of CT to the soil may affect the microbial community of the rhizosphere, which in turn affects the crop plants. Obviously, bacteria and fungi in the soil can be of pathogenic nature, which is popularly believed but not empirically proven to be the result of NTC application (Scheuerell and Mahaffee 2002). The microbes applied via the roots may influence the crop plants in positive ways and thus be classified as *growth promoting*.

Plant growth promoting rhizobacteria (PGPR) are bacteria that promote plant growth and/or serve as a means of plant protection in several ways (Lugtenberg and Kamilova 2009). Plant growth is stimulated from PGPR through the secretion of plant growth hormones such as auxins and through fixation of atmospheric nitrogen and through solubilization of phosphorous (Lugtenberg and Kamilova 2009). Biocontrol from PGPR functions through e.g. secretion of antibiotics, signal interference in the pathogenic bacteria population and competition for nutrients and niches within the rhizosphere (Lugtenberg and Kamilova 2009). Competition of nutrients can also occur with the plant itself, if there is a shortage of one or several nutrients in the rhizosphere (Jones et al. 2009).

Compost tea from food waste in production of Pak Choi

Trials with pak choi treated with vermicompost CT, showed improved growth although growth response varied depending on compost feedstock and production method of the CT (Pant 2012). ACT prepared from food waste vermicompost, gave significantly improved growth and higher tissue content of N, P, K, Ca and Mg in pak choi, compared to control treatments (Pant et al. 2012).

Addition of NCT prepared from vermicompost of chicken manure, gave improved growth, mineral nutrient content and carotenoid content, and did not differ significantly from ACT treatments (Pant et al. 2009).

4. Materials and methods

Fermentation set-up and collection of leachate

Four bokashi bins from ME Gård och Teknik AB was prepared with food waste from four different sources in Malmö and Lund. Food waste was collected from: (A) the school kitchen of Västra hamnens skola in Malmö; (B) food waste collection of households in central Malmö; (C) the school kitchen of Lunds Waldorfskola in Hardeberga; and (D) the hamburger restaurant Tusen & två in Malmö.

The bokashi bins were designed with a tap in the bottom for tapping leachate during the fermentation (figure 1). The food waste was kept in the upper compartment of the bin, which had a volume of 16 l.

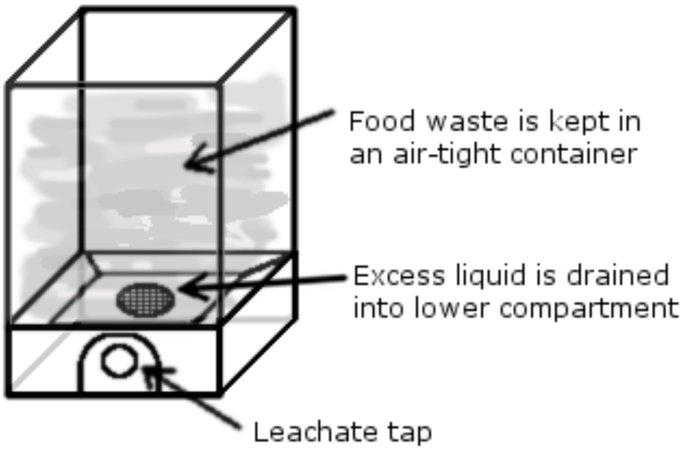


Figure 1. Schematic of bokashi bin. The bin consists of two air-tight compartments. Food waste is kept in upper and larger compartment and excess leachate is drained into the lower part.

The food waste from (A) was mainly made up from food scraps from pupils of the school (age 6-16) and consisted of roughly 50% spaghetti, 20% banana peel and 30 % potato patties, ground meat sauce and crisp bread. The food waste of (B) was the most heterogeneous consisting mostly of banana peels, orange and mandarin peels, shrimp peels, potato peels, boiled potato and used coffee ground. The food waste of (C) consisted mostly of food scraps from the food preparation, mainly cabbage, but also food scraps such as potato patties and salad. The food waste of (D) mainly consisted of fried and deep fried potato, but also small amounts of meat, bread and salad. Approximately 4 kg out of 25.5 kg of the hamburger restaurant food waste were wet paper napkins, which were not used in the bokashi fermentation.

The bins were filled with food waste within 1-3 days from the day of collection from each source. The food waste was put into the bins in layers alternating with EM-1 wheat bran from ME Gård och Teknik AB. Each layer was 1 litre of food waste and 15 ml of EM-1 wheat bran. Another 30 ml of EM-1 wheat bran was put in the bottom of the bin and on top of the last food waste layer. Each layer was compressed by hand with a spatula, making room for 18 layers of food waste in each bokashi bin. In total, 0.315 l EM-1 wheat bran were put in each bokashi bin.

The food waste was fermented for five weeks. Leachate was collected twice a week from fermentation A and B from day 7 of the fermentation. In order to obtain leachate from bin C and D, 0.8 l water was put in bin C and 1.3 l water was put in bin D the third week of fermentation. The fourth and fifth week leachate was collected from all bins twice a week. All of the leachate samples from each bin was mixed and kept at 7 °C. The leachate was used as fertilizer when the collection of leachate was concluded.

Moisture content of the fresh food waste and decrease of fresh weight during fermentation was measured.

Analysis of substrate and leachate

Electric conductivity and pH were measured and the mineral content of the leachates were analysed with ICP-AES and performed by the commercial soil lab *Eurofins Sweden*.

Experimental set-up and substrates

Pak choi was sowed in sphagnum based substrate from Hasselfors in plug trays and transplanted into 9 × 9 × 9.5 cm pots in a substrate volume of 0.5 l, eigth days after emergence. The pak choi plants were grown for 5 weeks after transplantation.

Three substrates were used: quartz sand + 20 % low-humified sphagnum peat; planting soil from Sysav AB containing 70 % medium-humified sphagnum peat and 30 % compost from green waste from gardens and parks in Malmö; and K-jord from Hasselfors containing 90 % low-humified sphagnum peat, 5 % sand and 5 % clay. In this thesis, these substrates will be referred to as *sand substrate*, *compost substrate* and *peat substrate*.

Electrical conductivity (EC) and pH of sand and compost substrates was measured at the beginning of the experiment.

According to the suppliers of compost substrate and peat substrate (Sysav AB and Hasselfors, respectively) the amount of nitrogen in compost substrate was 200 mg/l and in peat substrate 1600 mg/l. Analysis of the plant mineral content of the substrates was not performed in this project.

Leachates from all four bokashi bins were used in the compost substrate. Leachates from bin A and B were also used as fertilizer in the sand substrate. In peat substrate, only leachate from bin A was used.

In sand and peat substrates, two volume concentrations of leachate A and B were used, in which the fermentation leachates were diluted in water in the following proportions: low dose was 1 %; high dose was 2 % week 1-3 from transplantation and 5 % remaining 2 weeks. In all treatments in compost substrate, leachate diluted in water to 1 % of the total biofertilizer volume, was applied. The leachate based fertilizer was applied twice a week in compost and peat substrate, and 3-4 times a week in sand substrate, due to the lower water-holding capacity of the latter.

Each substrate group contained one control treatment where in total 0.05 l of 1 g l^{-2} Superba and 0.05 l of 1 g l^{-2} CalciNit was applied per pot once a week. In total, 13 treatments were tested in the experiment (Table 1).

The experiment was conducted in a greenhouse chamber at Alnarp. Day and night heating temperature was 20 °C. High-pressure sodium lamps were used 14 h per day.

Table 1.
Substrate, fertilizer and concentration of fertilizer of all replicates.

	Substrate	Fertilizer	Dose	n
1.	Sand	School kitchen Västra Hamnen	Low	10
2.	Sand	School kitchen Västra Hamnen	High	5
3.	Sand	Household	Low	10
4.	Sand	Household	High	5
5.	Sand	Control		10
6.	Compost	School kitchen Västra Hamnen	Low	10
7.	Compost	School kitchen Waldorf	Low	10
8.	Compost	Hamburger restaurant	Low	10
9.	Compost	Household	Low	10
10.	Compost	Control		10
11.	Peat	School kitchen Västra Hamnen	Low	10
12.	Peat	School kitchen Västra Hamnen	High	10
13.	Peat	Control		10

Concentration low = 1 % week 1 to 5 after transplantation; high = 2 % week 1 to 3 after transplantation, 5 % week 3 and 4.

Plant harvest and measurement

Plants were harvested 5 weeks after transplantation. Shoot fresh weight and shoot dry weight of petiole and blade were measured. The petioles of pak choi thicken during growth, why the blade to petiole fresh weight ratio was calculated in order to quantify this morphological trait.

Calculations of possible uses of bokashi leachate within Malmö

Statistics from Livsmedelsverket (2011), information from the kitchen staff of where food waste was obtained, data from Taiz and Zeiger (2010) on tissue levels of essential elements in plants, and data on pak choi water content found in this trial, was used to make estimations of the amounts of pak choi that hypothetically can be produced from the amounts of N, P, K, Ca and Mg found in the leachates.

Statistical analysis

The software *Minitab* from *Minitab, inc.* was used to perform an analysis of variance with Tukey's method in order to compare significant difference in plant growth data of the treatments. The analysis was performed with and without control treatment data in order to avoid interference from this data when comparing only fermentation leachate treatments (tables 5 and 6).

5. Results

Properties and amounts of food waste and leachate

The amounts of food waste from the school restaurant of Västra Hamnen (A) consisted of only avoidable food waste while the food waste of Lunds Waldorfskola (C) was mainly unavoidable, according to the informants (Roy Qvarnström, Helena Rosvall). The informant of (A) estimated the amount of food waste to be 10 kg per day, coming from 450 servings of 200 to 250 g each. The amount of food waste from (C) varies from day to day and the obtained amount of 16,6 kg must therefore be considered as a rough approximation of the daily amount of food waste of (C). Additional leachate was produced after week 5 but was not used in the plant growth experiment.

The moisture content of the 4 fermentation feedstocks varied considerably (table 2). pH was slightly higher in leachate B and D and electric conductivity was the highest in leachate B (table 2).

The bokashi composts did not produce any odour during week 1-5 and until the end of the trial, in total 9 weeks of fermentation. The leachates did not have a foul odour.

Table 2.
Moisture content of fresh food waste samples, amount of leachate and loss of mass in each food waste fermentation.

	Moisture content (%)	Amount of leachate, week 3 (ml)	Added water, week 3(ml)	Amount of leachate, week 5 (ml)	pH of leachates, week 5	EC of leachates, week 5 (mS/m)	Loss of mass (FW), week 5 (kg)
A	71.4	610	0	800	3.5	1439	0.23
B	49.8	480	0	570	3.9	1528	0.27
C	61.8	0	800	500	3.5	1420	0.10
D	50.0	0	1300	430	3.9	1135	0.06

A = school kitchen of Västra Hamnens skola; B = households in central Malmö; C = school kitchen of Lunds Waldorfskola; D = hamburger restaurant.

Plant mineral nutrient content in the leachates

The plant nutrient content in the leachates varied depending on source of the food waste. The nitrogen content varied between the four leachates and contained higher amounts of nitrogen than the 1 g/l Superba fertilizer (table 3). The leachates contained mainly ammonium nitrogen, whereas Superba and Calcinit fertilizers contain mainly nitrate nitrogen (table 3).

The leachates from all food waste sources contained considerably higher proportions of phosphorous and potassium in relation to nitrogen than Superba, although the amounts varied among the leachates (table 3). Leachate from the household food waste contained the largest amounts of phosphorous and potassium. Similarly, leachate from the household food waste contained a higher proportion of calcium in relation to nitrogen, than Calcinit fertilizer and the other leachates (table 3).

The amount of sulphur was approximately the same in all four leachates, magnesium and boron was higher for school kitchen and household food waste leachate, while amounts of iron, manganese and zinc were more unevenly distributed among the leachates (table 3).

Table 3.
Plant mineral nutrient content in undiluted leachates, Superba fertilizer and Calcinit fertilizer.

	School kitchen	Household	Waldorf school kitchen	Hamburger restaurant	1 g/l Superba	1 g/l Calcinit
Total nitrogen (mg/l)	161	295	130	210	85	155
Nitrate nitrogen (% of total N)	6.8 %	1.7 %	~0 %	~0 %	88.2 %	93 %
Ammonium nitrogen (% of total N)	93.2 %	98.3 %	~100 %	~100 %	11.8 %	7 %
Phosphorous (mg/l)	680	960	520	590	49	0
Potassium (mg/l)	2800	4300	2400	3400	247	0
Calcium (mg/l)	140	2500	280	82	0	190
Magnesium (mg/l)	300	370	220	210	42	0
Sulphur (mg/l)	160	170	170	140	57	0
Boron (µg/l)	1100	1700	600	640	300	0
Copper (µg/l)	<200	<200	<200	<200	70	0
Iron (µg/l)	7200	2700	4900	7900	1800	0
Manganese (µg/l)	610	920	<500	740	700	0
Molybdenum (µg/l)	200	<200	<200	<200	70	0
Zinc (µg/l)	8300	3000	4400	5100	370	0

Masses of N, P, K, Ca, Mg and S in mg per litre undiluted leachate. Masses of B, Cu, Fe, Mn, Ma and Zn in µg per litre undiluted leachate. Masses in Superba and Calcinit are for water dilutions of 1 g/l.

Total amounts of applied plant mineral nutrients

The amount of applied mineral nutrients in leachate dilutions followed the same proportions as in the undiluted leachates. Thus, the amount of applied nitrogen was remarkably lower in both high and low dose of leachate fertilizer, compared to Superba + Calcinit control treatments (figure 2b). The amounts of applied phosphorous and potassium was remarkably higher than nitrogen in all leachate dilutions (figure 2a). The high dose of leachate from fermented household waste gave similar levels of applied potassium, phosphorous, calcium, magnesium and sulphur as the control fertilization, while the school kitchen leachate gave slightly less amount of potassium and nearly no calcium (figure 2c). The leachate from school kitchen was fairly high in iron and zinc compared to the leachate from household waste and control fertilizer (figure 2d).

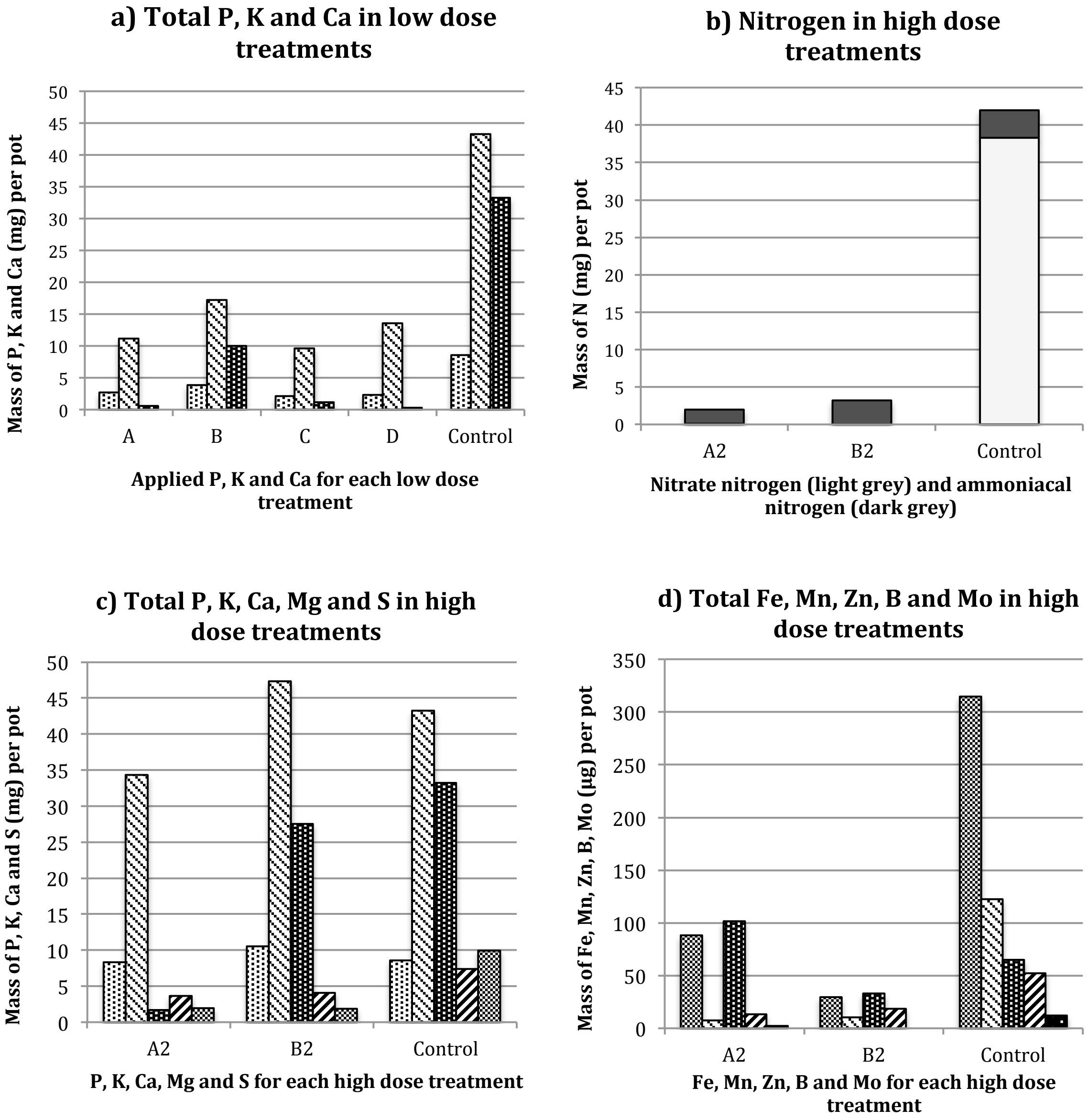


Figure 2. Total masses of applied macro- and micronutrients per pot in leachate treatments and control treatments. A, B, C and D corresponds to low dose of fermentation leachate from school kitchen (A), household (B), waldorf school kitchen (C) and hamburger restaurant (D), respectively. A2 and B2 corresponds to high dose of A and B. Control staples illustrates the content of respective plant nutrient in 1g l^{-1} of 0.05 l Superba and 0.05 l Calcinit per week and pot. Each bar group within the same graph corresponds to the mineral nutrients in the order stated below the x-axis.

Content of Na and Cl in leachates and substrate

Content of chloride was considerably higher in leachate A than the other leachates, while leachate B and D had the lowest Na and Cl content. (table 4). Concentration of Cl was higher than Na in all leachates, although the Na/Cl ratio varied (table 4).

Table 4.
Amount of Na and Cl in leachate and concentration in substrate.

	A	A2	B	B2	C	D
Na and Cl in leachates						
Na (mg/l)	2900		1200		2900	1100
Cl (mg/l)	15000		4300		10000	2600
Na and Cl in substrate						
Na (mM)	0.95	3.09	0.34	1.15	1.01	0.38
Cl (mM)	3.17	10.37	0.79	2.67	2.26	0.59

Concentrations in mg/l are for Na and Cl in leachates A, B, C and D, while concentrations in mM are for Na and Cl in the substrate of leachate treatments A, A2, B, B2, C and D. Concentrations in mM of Na and Cl were calculated from the substrate volume of the pots. Thus, those must be considered as rough approximations, as the soil water content varied during the day.

Content of plant mineral nutrients and EC in substrates

The EC of the compost substrate was measured twice, and the mean of these values was 38 mS/m . The producer of the compost substrate reported an EC of 3,0-5,0, but did not report any unit for the EC. The EC of the peat substrate was reported by the producer to be 25 mS/m. The EC of the sand substrate was 5,5 mS/m.

Plant growth

Significant difference ($P \leq 0.05$) was found between treatments A and B when comparing shoot fresh weight in sand substrate (table 5). The high dose compared to low dose of treatment A led to decreased growth in sand and peat substrate, with a significant difference of dry weight in peat substrate (table 5, table 6). Replicates in sand substrate treatment were to small for giving reliable data on dry weight.

Shoot fresh weight in treatment with high dose of leachate A was slightly lower than low dose of the same leachate in sand and peat substrate, while treatment with high dose of leachate B was slightly higher than low dose with same treatment (figure 3, table 5, table 6). The variation between replicates was higher in low dose treatments than in high dose treatments (figure 3). Control treatment gave remarkably higher growth than fermentation leachate treatments in both sand and peat substrate (figure 3).

Table 5.
Fresh weight and blade / petiole fresh weight of replicates in sand substrate.

	Shoot fresh weight (g)	$\frac{blade\ fresh\ weight}{petiole\ fresh\ weight}$
School kitchen, low dose (A)	0.9 a	2.1 ab
School kitchen, high dose (A2)	0.9 a	2.3 a
Household, low dose (B)	1.3 b	1.8 b
Household, high dose (B2)	1.3 b	2.0 ab

Means sharing the same letters are not significantly different at ($P \leq 0.05$) according to Tukey's test. n=10 for A and B, n = 5 for A2 and B2.

Table 6.
Fresh weight, dry weight and blade / petiole fresh weight of replicates in peat substrate

	Fresh weight (g)	Dry weight (g)	$\frac{blade\ fresh\ weight}{petiole\ fresh\ weight}$
School kitchen, low dose (A)	4.79 b	0.21 a	1.80 a
School kitchen, high dose (A2)	4.66 b	0.10 b	1.62 a
Superba + Calcinit (control)	21.4 a	1.5*	1.17 b

Means sharing the same letters are not significantly different at ($P \leq 0.05$) according to Tukey's test, n = 10.
*Means of dry weight of A and A2 was significantly different when compared without control.

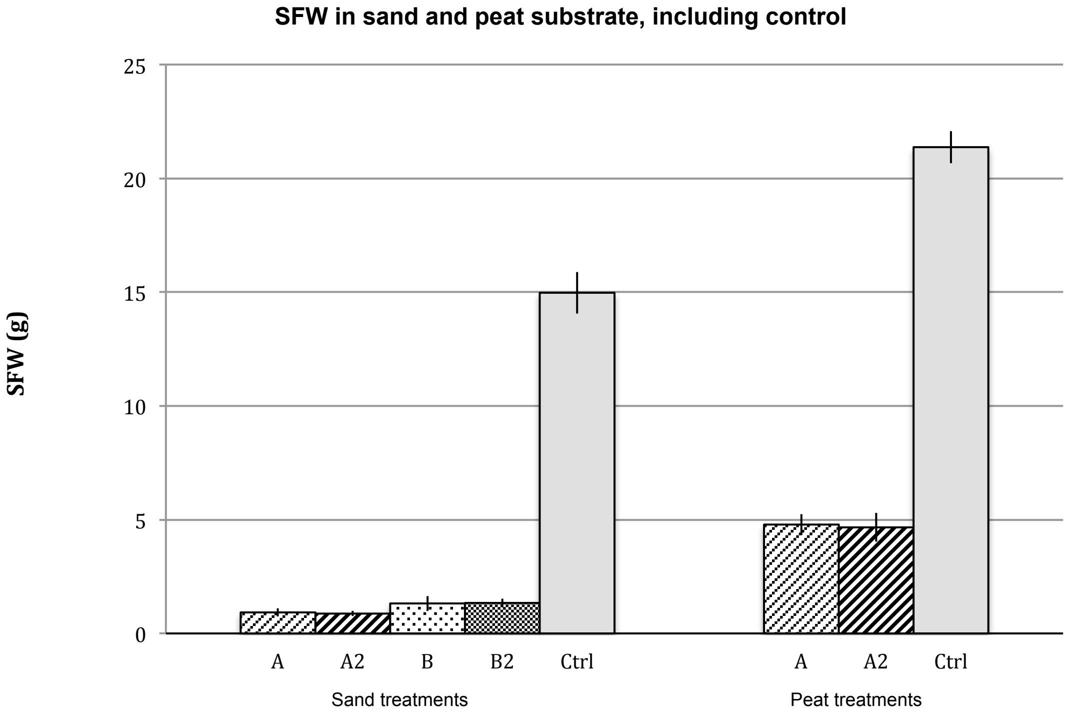


Figure 3. Shoot fresh weights from treatments in sand and peat substrate. A and A2 = low dose and high dose of leachate from school kitchen waste of Västra Hamnen. B and B2 = low dose and high dose of leachate from household waste. Ctrl = control with 0.05 l Superba and 0.05 l Calcinit per pot and week, c = 1 g l^{-1}. n = 10 for A, B and Ctrl in sand. n = 5 in A2 and B2 in sand. n = 10 in A, A2 and Ctrl in peat.

In compost substrate, treatments B and D differed significantly in fresh weight, as well as control treatment compared to all other treatments (table 7). A similar tendency was found when comparing the blade to petiole fresh weight ratio, of which treatments A and B were closer to control, than treatment C and D (table 7). On the contrary, no significant difference was found in shoot dry weight when comparing all treatments, although treatment B and control had higher dry weight than the others (table 7, figure 4). The variation between replicates was higher in treatments A, C and D than treatment B and control (table 7). The variation in all treatments in compost substrate, including control, was higher than in control treatments of the other substrates, in relation to the mean shoot fresh weight (SFW) of each treatment (figure 4).

Table 7.
Fresh weight, dry weight and blade / petiole fresh weight of replicates in compost substrate.

	Fresh weight (g)	Dry weight (g)	$\frac{blade\ fresh\ weight}{petiole\ fresh\ weight}$
School kitchen (A)	23.5 bc	1.53 a	1.15 ab
Household (B)	26.1 b	1.74 a	1.07 ab
Waldorf school (C)	22.4 bc	1.55 a	1.22 a
Hamburger restaurant (D)	20.5 c	1.50 a	1.23 a
Superba + Calcinit (control)	36.2 a	1.85 a	0.95 b

Means sharing the same letters are not significantly different at ($P \leq 0.05$) according to Tukey's test. n = 10. Control was 0.05 l Superba and 0.05 l Calcinit per pot and week, c = 1 g l^{-1}.

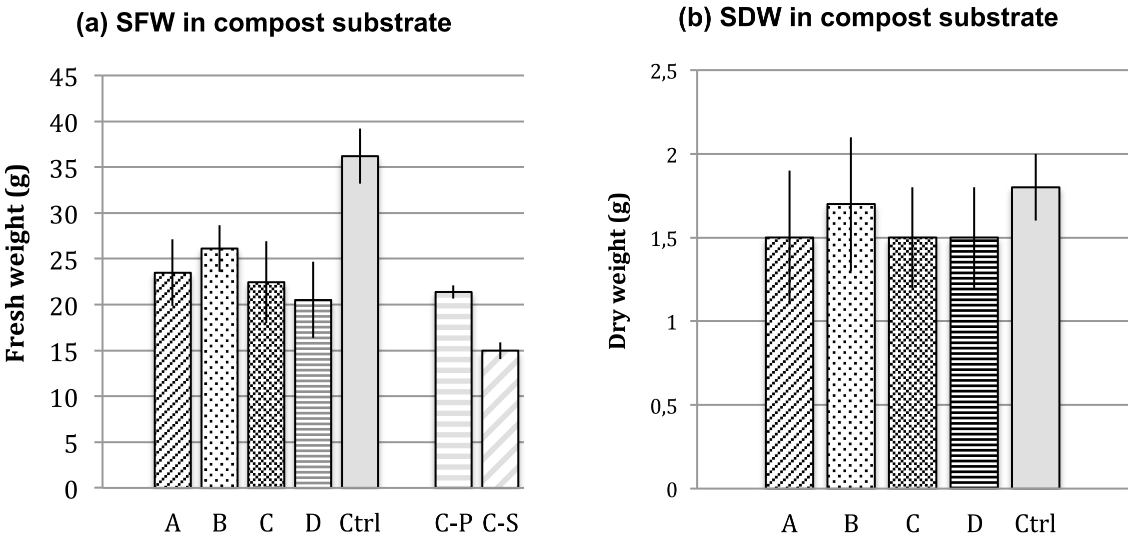


Figure 4. Shoot fresh weights (a) and shoot dry weights (b) from treatments in compost substrate. A = school restaurant waste of Västra Hamnen. B = leachate from household waste. C = waldorf school kitchen waste. D = hamburger restaurant food waste. Ctrl = control. C-S = control in sand treatmeant. C-P = control in peat treatmeant. n = 10. Control treatments were fertilized with 0.05 l Superba and 0.05 l Calcinit per pot and week, c = 1 g l^{-1}, irrespective of substrate.

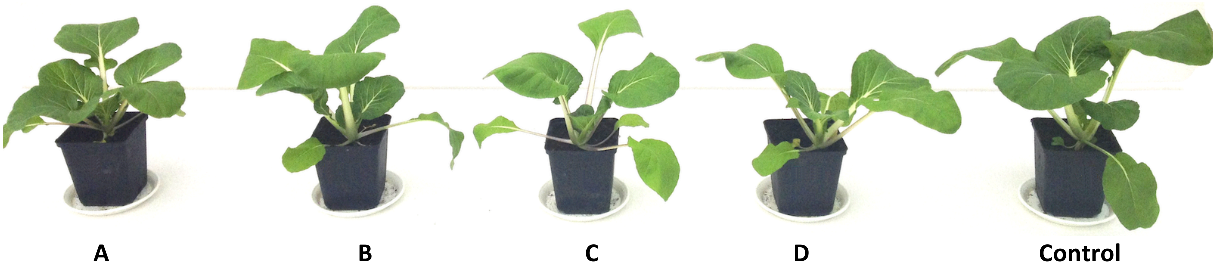
General morphology and visual quality of plants

When assessing differences in growth and morphology between the different treatments in sand substrate, it was clear that leachate B gave higher growth than leachate A, while the control treatment had remarkably higher growth and a higher proportion of petiole compared to blade (figure 5a). Furthermore, both leachate treatments in sand showed early signs of chlorosis and excess anthocyanin synthesis in blades and petioles (figure 5a). Replicates of the leachate treatments in peat substrate showed similar deficiencies, although to a lesser degree (figure 5c).

The visual appearance of compost treatments was more uniform and no nutrient deficiencies were visually detected in none of the treatments, although control and leachate B treatment gave the impression of higher growth (figure 5b).

(a) Sand substrate

(b) Compost substrate



(c) Peat substrate

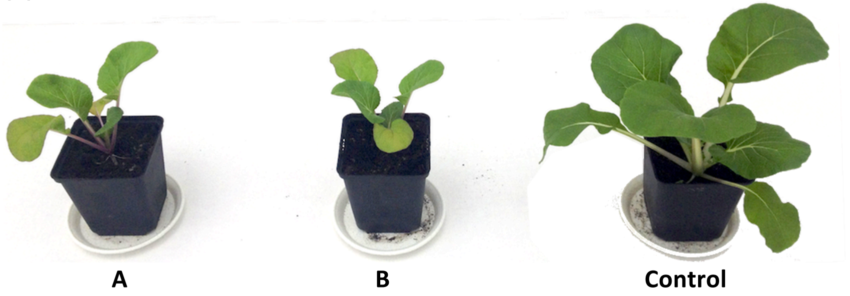


Figure 5. Representative replicates of plants in sand subststrate (a), compost substrate (b) and peat substrate (c). A, B, C and D represents leachates from four different sources: A = school kitchen of Västra Hamnens skola; B = households in central Malmö; C = school kitchen of Lunds Waldorfskola; D = hamburger restaurant. A2 and B2 are leachates A and B in high concentration (see section on materials and methods).

Calculations of hypothetical yields of pak choi

Calculations of the mass of pak choi that hypothetically could be produced with the amount of N, P, K, Ca and Mg found in the leachates, showed not surprisingly that the amount of nitrogen would be sufficient for a remarkably smaller mass of pak choi, than other nutrients (table 8). Phosphorous was the nutrient found to be sufficient for the largest mass of pak choi (table 8), due to the relatively high amount found in the leachates and the compared to nitrogen, calcium and potassium, lower plant tissue levels.

Table 8.
Calculations of approximate masses of fresh pak choi that can be produced with each of four mineral elements separately set as limiting factor. From data on mean plant tissue content of nitrogen, phosphorous, potassium, calcium and magnesium and the amounts of the same elements found in the leachates.

	Mass of pak choi (kg), leachate A fertilizer	Mass of pak choi (kg), leachate B fertilizer	Mass of pak choi (kg), leachate C fertilizer	Mass of pak choi (kg), leachate D fertilizer
3.67 l leachate				
Nitrogen	0.6	1.1	0.5	0.7
Phosphorous	19	26	14	15
Potassium	16	24	13	17
Calcium	2	27	3	1
Magnesium	8	10	6	5
3.93 l leachate				
Nitrogen	0.6	1.2	0.5	0.8
Phosphorous	21	28	15	16
Potassium	17	25	14	18
Calcium	2	29	3	1
Magnesium	9	11	6	6
23679 l leachate				
Nitrogen	4,000	7,000	3,000	5,000
Phosphorous	124,000	170,000	89,000	96,000
Potassium	102,000	152,000	82,000	110,000
Calcium	10,000	177,000	19,000	5,000
Magnesium	55,000	65,000	38,000	34,000

The volumes are calculated from data on food waste production in Västra Hamnen school kitchen and households in Sweden. Appr. 3,67 l of leachate could be produced from 1 week of food waste from the school of Västra Hamnen. Appr. 3,93 l of leachate could be produced from avoidable household food waste per person and year in Sweden. 23679 l of leachate could be produced from avoidable household food waste per week in Malmö. See material and methods for details on data sources.

6. Discussion

Proportions of mineral plant nutrients and NaCl in leachates

The applied leachate fertilizer was very low in nitrogen in relation to other nutrients, when compared to the control treatments. This can be assumed to be the main reason to why the growth of the leachate fertilized plants was far lower than for the control plants in sand and peat substrates. It could also explain the significant higher growth in treatments with household waste leachate compared to other leachates, as the household leachate contained larger amounts of nitrogen (table 3).

When comparing measurements of EC in the compost and sand substrates with the reported EC of the peat substrate, it can be assumed that the content of plant mineral nutrients in general was higher in compost substrate than in peat substrate, and considerably lower in sand substrate. This assumption is also in line with the results of the growth experiment, as the differences in growth in different substrates can be correlated with the differences in EC between the substrates.

The reported content of nitrogen in the compost and peat substrates respectively, contradicts the assumption that differences in nitrogen content between the two substrates led to higher growth in compost substrate, as the latter had a much lower reported nitrogen content. A Spurway analysis of all substrates would have been helpful in order to interpret the plant growth results, but was not performed in this project.

The low concentration of inorganic nitrogen in the leachates can be assumed to be due to denitrification processes taking place during the fermentation, as the food waste was kept anaerobically in air-tight containers, thereby promoting denitrifying bacteria. The fairly low pH in the leachates, 3.5- 3.9 (table 2), could have prevented the prevalence of denitrifying bacteria (Knowles 1982), although this do not seem to have been the case.

The high concentration of Na and Cl in relation to other elements may have had a negative effect on the growth, especially in treatment with high dose of leachate A, which was high in NaCl and had lower growth than other treatments. Interestingly, the leachates acquired from school kitchens had the highest concentration of Na and Cl (table 4). As the food waste from Västra Hamnens Skola to a high degree consisted of avoidable food waste, a high concentration of NaCl in leachate as well is in the food waste was not surprising. The food waste from households consisted mainly from unavoidable food scraps, and could thus be expected to give a lower concentration of NaCl in its fermentation leachate. The difference of NaCl content in leachate from food scraps –avoidable food waste - and uncooked, unsalted food waste – supposedly unavoidable food scraps – should thus be considered when attempting to use fermentation leachate as a fertilizer.

Effect of amino acid and sugar content for plant growth

One important claim concerning the bokashi fermentation method is that amino acids and sugars made available from the food waste in the hydrolysis stage of fermentation, can function as an organic molecule fertilizer. The content of free amino acids and sugars in the leachates was not measured in this experiment. Nevertheless, as inorganic nitrogen was very low in the leachate treatments, the eventual effect of amino acids in the leachate could not be detected from the growth rates of the plants, as those seemed to be correlated with the concentration of inorganic nitrogen in the leachates, especially in sand and peat substrates. Although the growth in the treatments presumably halted due to low inorganic nitrogen, the specific amino acid composition in each of the leachates may not have been the most favourable, as different amino acid differs in efficiency as nitrogen fertilizer for pak choi (Liu et al. 2002).

There may have been an effect of a possible amino acid content in the leachates in the compost substrate treatments, as the lower plant water content found in those treatments are in line with the findings by Liu et al. (2002) on lower plant water content when using amino acids as nitrogen source. In compost substrate, the household leachate treatment led to significant lower shoot fresh weight in comparison with control treatment, while shoot dry weight did not differ in a comparison between these two fertilizer treatments. Thus, the difference can be assumed to have been significant due to higher water content in nitrate nitrogen fertilized plants. Similarly, significant differences were found when comparing shoot fresh weight of the control with the other leachate treatments, while no significant differences were found when comparing shoot dry weight. Thus, the differences in water content between leachate treated plants and nitrate nitrogen treated plants could be found for all leachate treatments but was most clear when comparing the household leachate treatment with control.

Although the mean of SDW of treatment B in compost substrate was lower than the control, a comparison of the variation between those two treatments shows that some replicates had higher SDW in treatment B. All doses of leachate were low in compost substrate treatments and the mineral plant nutrient content was therefore far lower than in the control treatment (figure 2a and b). Thus, other properties of leachate B that was not examined in the experiment may have caused an improved growth with respect to shoot dry weight, such as content of sugars and amino acids taken up by plant roots, or indirect effects from the microbial content in the leachate.

An eventual presence of PGPR in the leachates were perhaps more plausible to positively affect the compost substrate than sand and peat substrates, as the compost assumingly made up a more complex mixture of organic matter than sand and peat substrates and therefore may have constituted a more favourable environment for microorganisms. Larger populations of microorganisms in the compost substrate may also have had an negative impact by being more successful in taking up amino acids and sugars than the plant roots, according to findings on organic molecule uptake by plants roots competing with soil microorganisms in the rhizosphere (Owen & Jones 2001).

The possible high input of sugar into sand substrate may have had a detrimental effect on plant health if competitive and/or potentially pathogenic bacteria present in the substrate were favoured, rather than the crop. The presumably higher content of microorganisms in the compost based substrate, may have hade a buffering effect on the possibly detrimental impact of added sugar from the leachates.

Variation of plant nutrient content depending on waste source

Due to the method of collecting and choosing food waste for fermentation, where the fermentation feedstock was not composed according to a thought-out specific organic waste composition, each leachate must be considered as examples of what can be expected from each source one particular day rather than a statistical representation of the mean content of food waste ingredients during an extended amount of time. Needless to say, the content of food waste from each source, except perhaps the hamburger restaurant, will change from day to day depending on what food has been served. As both school kitchens choose their menu depending on season of the year, this could also affect the mineral content of the leachate.

A disadvantage with the method applied in this experiment is that it will be difficult to reproduce the fermentation feedstocks exactly as they were in this particular situation. The method rather gives hints on what problems and possibilities one can expect from fermentation leachate fertilizer obtained from food waste of schools and homes in Malmö a randomly chosen day. By randomly choosing the food waste available as was from the four sources used in the experiment, following aspects of how the leachate fertilizer product may vary are worth pointing out:

- The Na and Cl content vary remarkably depending on food waste source
- The content of N is generally very low, although there may be a small variation
- The content of P and K is relatively similar, irrespective of food waste source
- The content of Ca may vary remarkably
- The amount of leachate obtained may vary, and water may need to be added to the fermentation bin

Industrial uses of lactic acid from kitchen waste fermentation

The microbial content of the EM inoculants is only loosely defined by EM distributors and proponents, of which lactic acid bacteria is one category (Higa and Parr 1994, “Microorganisms in EM” 2014). Although the concentration of lactic acid bacteria was not measured in this project, earlier analysis of fermentation of organic waste - including rice bran, rapeseed oil mill cake and fish meal – has shown that inoculation of EM lead to a higher concentration of *Lactobacillus* ssp., than in a spontanous fermentation of the same organic content (Yamadu & Xu 2001). The low pH of the leachates in this experiment is therefore presumably the result of lactic acid fermentation. Thus, potential combinations of bokashi leachate production with other uses of lactic acid fermentation of food waste could be of interest.

Lactic acid is of high interest for a wide array of industrial production, e.g. as a preservative, acidulant agent, conditioner and emulsifier in foods, disinfection of *Clostridium botulinum* in preservation of poultry and fish, moisturer in cosmetics, and as a solvent and cleaning agent in various technical processes (John et al. 2007). Polylactic polymer (PLA) is a biodegradeble plastic produced through polymerization of lactic acid, and has gained much interest as a substitute for petroleum based plastics (John et al. 2007, Sakai 2003).

One economic obstacle in production of lactic acid is the cost of substrate for fermentation why kitchen waste has been investigated, as well as a variety of other cheap feedstocks and nitrogen-sources (John et al. 2007, Nolasco-Hipolito et al. 2002, Wang et al. 2005). Investigation and characterization of the most effecient strains of homofermentative lactic acid bacteria is performed in order to maximize the output of lactic acid in kitchen waste fermentation (Wang et al. 2005), in contrast to the EM-bokashi fermenting method where the microbial composition is inexact with respect to lactic acid fermentation. It is possible that a leachate product obtained from lactic acid fermentation of food waste when the lactic acid has been isolated, has similar properties as the leachates obtained in this experiment. Thus, the rest product from e.g. PLA production of food waste, could be used as a fertilizer, thereby exploiting the food waste resource for bioplastic production or other lactic acid uses, as well as for locally produced fertilizer in urban farming.

Effect of EM-inoculant

Several reports have concluded that no effect on the microbial community in the soil or on plant growth has been detected in treatments with EM (Priyadi et al. 2005, Cóndor-Golec et al. 2007, Mayer et al. 2008). Mayer et al. (2008) concluded that the plant mineral nutrient content in the substrate used in bokashi fermentation did give improved yields when applying bokashi to the soil, but that the EM microorganisms gave no effect when comparing sterilized and non-sterilized bokashi treatments. Similarly, in this experiment, the fermentation inoculated with bokashi did lead to leachate without foul odour that contained plant mineral nutrients of significant amounts, with the exception of nitrogen.

Thus, the food waste mineral content can be extracted through lactic acid fermentation, although the inoculation of EM most probably can be replaced by inoculation of other lactic acid bacteria inoculants, such as isolated strain for homofermentative fermentation in comercial production of lactic acid for industrial uses, or a lactic acid culture obtained from any common lactic acid fermented food product.

Suggestions for application of bokashi leachate as a fertilizer method in urban agriculture projects

It is obvious from the results of this experiment that the proportions of plant mineral nutrients in bokashi fermentation leachate irrespective of food waste source, need to be adjusted in order to obtain a functional fertilizer. Bokashi leachate could be combined with a nitrogen rich CT, from e.g. food waste vermicomposts, in order to obtain an organic liquid fertilizer produced from food waste. Thus, rooftop gardens and greenhouses could be provided with plant nutrients extracted from food waste produced from within the same building. As the process of bokashi lactic acid fermentation produce no foul odours, the process is suitable for such an environment (table 9).

The variation of plant mineral content and NaCl related to food waste source, needs to be considered. High NaCl content of food scraps may be problematic and it may therefore may be advisable to avoid high amounts of food scraps in the bokashi bins. In order to obtain a stable content of mineral nutrients, it may also be advisable to strive for variation of food waste during fermentation leachate production.

Due to the lack of evidence for the actual effect of EM and the microbial content of EM-bokashi reported above, the EM-inoculation method should be questioned and an alternative method of lactic acid fermentation leachate production from food waste, should be considered. The economic aspect of using other fermentation inoculants than EM, is also worth considering.

Since the possible presence of human pathogenic bacteria and fungi in the fermentation feedstock may multiply during fermentation and contaminate the leachate product, the risk of contamination of plants grown with food waste bokashi leachate must be taken into consideration. Lactic acid fermentation of food waste have been shown to lead to a significant decrease of *Clostridium* ssp., *Staphylococcus aureus* and *Bacillus cereus* (Wang et al. 2001)*,* which is promising with regard to the food safety aspect of using food waste fermentation leachate as biofertilizer.

The content of heavy metal ions in the leachates was not measured and may constitute a problem when using the leachate as a fertilizer. In comparison to vermicompost, where heavy metal ions have been found to be accumulated in the worm bodies (Urdaneta et al. 2008), there may be a higher risk of contamination with heavy metal ions in the substrate when using the bokashi method as a biofertilization strategy.

Table 9.
Advantages and disadvantages with bokashi leachate as a fertilizer in urban farming.

Advantages	Disadvantages
No smell	Large amount of sodium chloride in food scraps
Applicable in small scale	Low pH if using high concentrations of leachate
Low cost (if avoiding EM-inoculant)	Large variation of plant mineral content depending on food waste source
Microbial content that may enhance plant growth indirectly through the soil or substrate microflora	Cost of fermentation inoculant (if using EM-inoculant)
Possible low contamination of human pathogenic bacteria and fungi due to low pH and microbial antagonism during lactic acid fermentation	Needs to be complemented with other fertilizers
	Possible contamination with heavy metals

Conclusions

Tests with bokashi leachate from 4 different sources of food waste, did not function as a fertilizer when not combined with other fertilizers. This was assumed to be due to the low content of nitrogen and ammonium. Thus, the answer to the questioned initially proposed in this thesis is that bokashi leachate can be used as a fertilizer as it contains sufficient amounts of phosphorous, potassium, magnesium and sulphur, although it needs to be complemented with other fertilizer in order to supply the crop with all essential plant minerals. Combination with fertilizer rich in nitrogen and calcium is especially important, as the bokashi leachates were very low in those elements (except for calcium in one case).

Furthermore, the claims of bokashi proponents on the positive impact of soil microbes and organic molecule fertilization through the use of bokashi, lack scientific support. Fertilization with amino acids is possible, but the efficiency of this method does not seem to be as high as bokashi proponents claim, as it did not function as substitute for nitrate in the experiments of this project, and has earlier been shown to be taken up by soil or substrate microorganisms, rather than plant roots, in competition between the two. In summary, the scientific credibility of the alleged various positive aspects of bokashi, can be considered as low.

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