URINE AS A FERTILIZER FOR LETTUCE GROWN IN GREENHOUSE CONDITIONS

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ABSTRACT

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Human urine has a fertilizer value that can be utilized to ensure sustainability in agriculture. This can be successful when the urine is safely used.

In this experiment, urine from the dry toilet of Tampere University of Applied sciences was used to grow Australian Leaf lettuce (*Lactuca sativa*). According to Finnish regulations concerning lettuce fertilization, the recommended amount of nitrogen is 90 kg N/ha. Thus urine treatment with 90 kg N/ha was used. Additionally, two other treatments i.e. double the recommended (180 kg N/ha) and half the recommended (45 kg N/ha) were used. As a control, the lettuce was planted without the use of any fertilizer and artificial fertilizer. The nutrient analysis for the soil was done before and after the experiment together with the growth and yield of the lettuce monitored during the experiment. The results were compared with those of lettuce grown using artificial fertilizer and one with no fertilizer.

Over all, lettuce grown using urine fertilizer showed commendable growth compared to those of artificial fertilizer. The different treatment showed varying results to the degree of the amount of fertilizer added. The double treatment (180kg N/ha) of recommended fertilizer had the highest yield in average weight, height and width. The magnesium content of the leaves was also highest in the double urine fertilizer treatment.

To maximize the assimilation of plants nutrients, the urine fertilizer application mode should be considered prior to planting to ensure minimal loss via evaporation irrespective of the scale of farming. The experiment proved that the use of human urine as a fertilizer can be used all year round even in harsh climatic conditions like the winter in the confines of a greenhouse.

Key words: fertilizer, urine, lettuce, greenhouse.

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Contents

1. INTRODUCTION

1.1 Water supply and sustainable sanitation

The world currently is moving towards sustainable development in every aspect of human living. The pressure exerted to the society by the ever growing world's population is enormous. Human beings are the main players when it comes to environmental degradation in the way we produce, consume and dispose of waste. A lot is yet to be done on the sanitation front to bring about the change that would decrease the negative human impact on environment and health. The millennium development goals of 2000 is one effort geared towards liberating the world's poor from poverty and multiple deprivations (UNDP 2012). To achieve these goals, provision of adequate water and basic sanitation is paramount.

Water supply and sanitation are human basic needs just like food and shelter. Everyone should be able to access these needs. The introduction of sustainable sanitation in both rural and urban areas can tremendously reduce the environmental and health impact brought by human waste. Ecological sanitation attempts to promote the use of human excreta as a resource rather than waste. Safe re-use of human waste not only protects people from diseases but also the environment from pollution and ensures that people are more productive. It also seeks to reduce and maximize the usage of available water which is a scarce resource in many parts of the world (Rosemarin A. Et al 2008).

1.2 Problem overview

The use of inorganic fertilizers over the years has increased yields in agriculture in many parts of the world thus boosting the production of farm products. This is because they provide nutrients in a very fast way. However this has not been without disadvantages. Inorganic fertilizers are produced chemically from mining minerals and therefore are non-renewable resources. Artificial nitrogen fertilizers for instance are manufactured industrially through fixation of nitrogen where it is reacted with hydrogen under high pressure and heated to form NH_3. It can be utilized directly or undergo further processing to produce other forms of fertilizer. On the other hand phosphate rock which is raw material for manufacturing phosphorous fertilizer is a non-renewable resource and has depleted over time. These facts notwithstanding, processes involved require high energy input. Leaching of these products often leads to devastating effects to the environment. Due to the high cost of production, the product is beyond reach for many especially in the developing world. The uninterrupted growing of crops without sufficient restorative practices leads to nutrients depletion in the soil thus the need for artificial fertilizers. (Hartemink and Alfred, 2006)

Civilization has brought the notion that human excreta ought to be discarded and forgotten. This is however with dire consequences to the eco-system. It is an uphill to convince people that the use of urine as a fertilizer is a good way to enrich our soil even though this is what past generations did. This is due to the prejudice and taboos upheld by communities the world over. This has negative effect on the perception and attitude of the people towards the use of human excreta as fertilizers. Many, especially key policy makers shy away from discussing human excreta in public due to the attitude they have. (Niwagamba, 2011)

1.3 Plant nutrition and nutrient cycle

Food consumed by humans contains nutrients which are later excreted as urine and feces. Urine consists of water comprising the body's waste products and excess substances. The disposal of human waste has posed as a great risk and expensive for the ever growing world's population especially in the world's poor. And according to World Health Organization, 2, 5 billion of the world's population lack access to improved sanitation while over 1.1 billion people have to defecate openly which is not only hazardous to the environment but also demeaning (WHO, 2010). This is due to the high cost of treating waste water complicated further by the rural to urban migration, growing population and other factors.

Plants require nutrients for maximum yield and growth. Plants nutrients can be divided into macro and micro nutrients. Macro nutrients comprises of Nitrogen, Phosphorous, Potassium, Calcium, Magnesium, Oxygen, sulphur and carbon. Micro nutrients include Cobalt, Manganese, Boron, Iron, and Copper, lead, Zinc, Molybdenum and chloride. Of this, Nitrogen (N), Phosphorous (P) and Potassium (K) are needed by plants in large quantities (Akinyemi, 2007).

To close this loop, it is necessary to use the human waste in replenishing the soil and also reduce the pollution going into the waterways which is very expensive to maintain. Nutrient cycle otherwise referred as ecological sanitation is a concept which work on the principle of regarding human waste as nutrients required in fertilizing land as opposed to being waste products. Ecological sanitation starts with the containing the excreta in order to sanitize it using various processes and kill all the pathogens. The urine (fertilizer) and feces (soil conditioner) are recycled and used in crop production (Nial Boot, Practical Action, 2007).

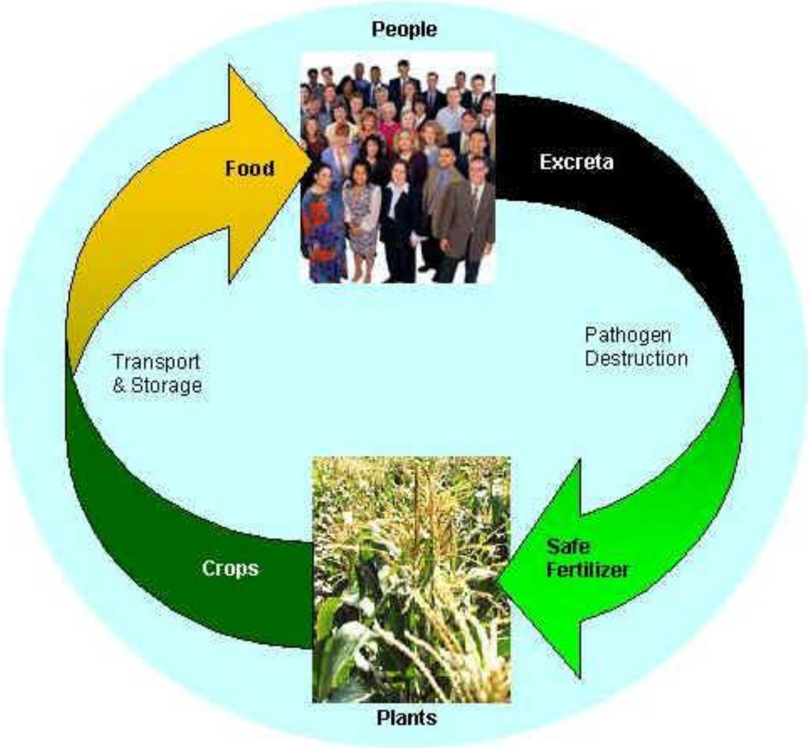

Figure 1: Ecological Sanitation (Nutrient cycle) return the valuable nutrients from human excreta (urine and feces) back to the environment. This avoids pollution and also contributes to food production. (Adapted from African water, 2001)

1.4 Urine as a fertilizer

A normal adult typically produces one to two liters of urine every twenty four hours. 95% of urine is water while 5% is chemicals in solute form. Urine is a source of macro nutrients such as NPK and other trace elements required by plants. A healthy human being will only excrete what they have consumed. Most of the food taken comes from agricultural and animal products. These are broken down, retained in the body to build news cells or excreted as waste. If the waste is disposed inadequately or improperly, it

leads to the contamination of food and water. Urine is organic and therefore does not pose any danger to the environment. Unlike feces, urine does not contain pathogens except intestinal micro-organisms which are almost sterile. When source separated from excrement, it is safe to use following right instructions. (Steinfeld, 2004).
On average, a person produces enough urine to cover 300-400m^2 of land to a level of 20-100kgN/ha. On a yearly basis, the value of nutrients are 3,5kg of nitrogen, 0,5kg of phosphorous, 1,0kg of potassium, 0,5kg of sulphur, 40g of potassium and 100g of calcium. (Feineigle, 2011).

Sanitation determines equity in society and ability to sustain itself. To be able to provide for the needs of the present generation without jeopardizing that of future generations, the sanitation challenge has to be overcome. Ecological sanitation is a sustainable, closed-looped system where human waste is treated as a resource. The excreta are processed at source or elsewhere until free of organisms that would cause diseases and the nutrients contained thereof recycled for use in agriculture. Ecological sanitation diverts urine from the feces in order to use it as a fertilizer. Dry toilets are one way of separating urine from feces. They differ from the flush toilet in that no water or less is used. Depending on the ambient temperatures, urine is stored for two to six months before use. Application can be done either in diluted or undiluted form. The application can be incorporated into the soil during the initial plant growth or just before sowing (Eeva-Liisa SSS workshop 2009).

2 LITERATURE REVIEW.

2.1 Soil science and population growth.

One of the impacts of the world's growth population over time is the increase in demand for agricultural products. To secure the provision of food, it is imperative to conserve and improve the natural resources. Any decline in food chemical fertility of the soil has a negative effect on food production and sustainable management of land resources Hartemink, E. (2003, pg. 10). In 1798, in a book titled, *An essay on the principle of population as it affects the future improvement of society*, by Reverend Thomas Malthus (1766-1834) made three assumptions on food and poverty (Hartemink, 2003 pg. 11). Firstly, food was the sole limiting factor on human population growth and necessary for the existence of man. The second assumption was that human population increases exponentially and thirdly, the production of food could only be increased linearly. Soil science therefore should be an integral part of providing data on soil resources and scenario studies on how soil and land use can affect food production.

2.2 Fertilizers and the environment

When waste water and excess fertilizer runoff to waterways, the results are detrimental to the environment due to leaching. This breaks the nutrient cycle and the way to remedy this is closing the loop by re-use of nutrients. This turns a waste water challenge into an asset (Steinfield 2004).

2.3 Nutrient uptake in plants

When soluble fertilizer dissolves in water, ions are formed. Plants absorb nutrients ions while soil particles adsorb them. Plants absorb nutrients ions from the soil contact with the root surface. This happens through root interception, mass flow and diffusion. In root interception, uptake of nutrients happens when plants roots are in contact with the nutrients. The volume of the roots system affects the nutrients uptake in this mechanism. In mass flow, the uptake of nutrients moves towards the root surface by capillary action. The uptake is however reduced in dry conditions and low temperatures. The mechanism furnishes the harvested crop with better feed and food quality. In diffusion, plant nutrients move from points of high concentrations to lower concentrations. Absorption of nutrients from soil causes a drop in concentration. This triggers migration of nutrients from higher concentrated areas to lower concentrated points. These and other factors such as soil texture, moisture content, light, plant species affect the uptake of nutrients from the soil to the plant. (Edward J. 2005).

2.4 Urine separation and reuse: dry toilets.

Naturally, human bodies keep urine separate and therefore can be collected and used separately (Stenfield, 2004 pg. 39). Throughout history, the re-use of urine has been practiced in many ways and cultures. In Sweden, a water company set to test the use of urine as a fertilizer by first separating fecal material from source. This was done by installing urine-diverting toilets that used little water to flush in a housing project. In-ground fiberglass tanks were used to drain the urine and later transported to a farming location for testing on grain crops. The results proved that urine is as good as mineral fertilizer in plants growing (Steinfield 2004).

2.5 Greenhouse farming

Greenhouse farming is a farming technique that provides favourable conditions for plants. Where there are adverse climatic conditions such as cold, wind, extreme temparatures, insects and diseases, the technology is used to protect plants. While growing plants in a greenhouse, the environmental conditions are altered in such a way that any plant can be grown in any place at any time with minimum labor. The construction and design can be modified to suit the environmental conditions and the income. The advantages of greenhouse farming far exceed the disadvantages. Hydroponics is a farming technique where plants are grown in a soilless medium and mostly used in greenhouses (Winterborne J. 2005). It has advantages in that it reduces the possibility of soil-borne diseases consequently saving on herbicides and pesticides. A farmer can control the growth of the plants since application is done periodically. Water and resources are saved as less is lost through evaporation and into the ground. The nutrients ions are readily available to the plants.

2.6 Aim of study and hypothesis

The aim of this study was to;

1. To ascertain the nutrient value of human urine in plant fertilization
2. To promote the use of ecological sanitation
3. To prove the use of human urine as fertilizer in winter conditions

Hypothesis

‘Human urine can be used as a fertilizer for food crops in a safe and sustainable manner’.

3 METHODS AND MATERIALS

The experiment was undertaken with a purpose of quantitatively and qualitatively proving that urine is a viable and beneficial form of plant fertilization. Urine application was done in eight treatments; two for each treatments of the recommended amount of Nitrogen, U (Rec - 90kg/ha), double the recommended U (DO - 180Kg/ha) and half the recommended U (HA - 45kg/ha). An artificial treatment (AF) and one without any fertilizer (NIL) were used as control for the experiment.
The growing of Australian leaf lettuce was the vegetable of choice as the greenhouse conditions favored it. Lettuce (*Lactuca sativa*) is a temperate annual and is grown as a leaf vegetable. It has a high market demand and is mostly used as a vegetable salad. Lettuce growing is best in high altitude and cooler locations. The green house at TAMK provided the right environment for the purpose of this experiment.

Figure 2: The front view of the green house at Tampere University of Applied Sciences (TAMK) By Catherine Mburu

3.1 Experimental Set-up

The experiment was part of a project undertaken by students of energy and environmental engineering in Tampere University of Applied Sciences (TAMK). The experiment was carried out in the greenhouse of the institute. Australian leaf Lettuce *(Lactuca sativa*) was planted using the recommended amount of Nitrogen per hectare (90kg/ha). Two other treatments were applied to plants, one double (180kg/ha) and the other half

(45kg/ha) of the recommended nitrogen in lettuce growing. Artificial/inorganic fertilizer was also applied to the plants as control together with one with no fertilizer. The urine fertilizer was applied three times, once every week from the time of planting. For the artificial fertilizer, it was applied all at once. Plants progress was observed and recorded every week. Growth was monitored by measuring the width of the widest part of the leaves, the length and wet and dry weight at the time of the harvest. The nutrients in plants soil were also analyzed, at the beginning and at the end of the experiment.

Planting was done on 28.11.2011 and harvesting between 9.01.2012 and 11.01.2012. The experiment took six weeks. Urine was sampled from the dry toilets of TAMK. Total nitrogen, total phosphorous and potassium were tested on the urine and soil before the commencement of the experiment. Physical properties such as soil texture, bulk density and dry matter content were tested on the soil. pH values were analyzed in both the urine and the soil.

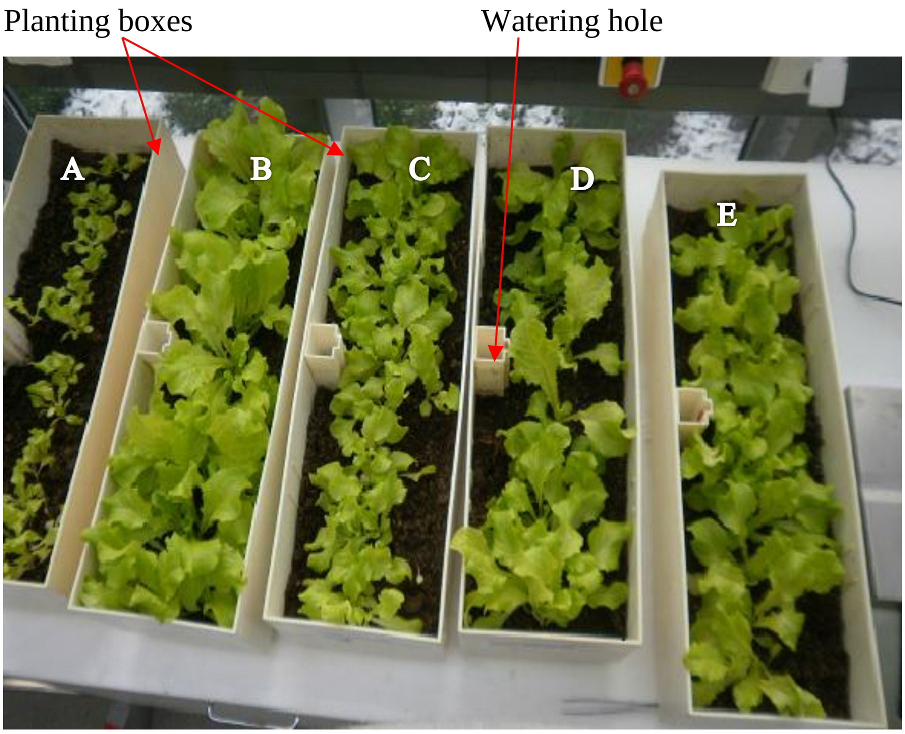

Figure 3: Lettuce (*Lactuca sativa*) in planting boxes arrangement at week three. A = No fertilizer B = Inorganic fertilizer 90kgN/ha, C = urine 45kg N/ha, D = urine180kgN/ha, E = urine 90kgN/ha.

3.2 Growing Medium

Planting was in boxes that had water drainage underneath and measured 0.2m by width and 0.6m by length. The boxes had 13cm deep water drainage. This maintained a water table that allowed water and nutrients to move up the root zone by capillary action. This form of irrigation is referred to as sub irrigation (Delmar, 2006). There were eight boxes in total, two for each urine treatment i.e. Recommended, double and half treatments, one for artificial fertilizer (AF) and another for the control (NIL). The Australian leaf Lettuce seeds were planted directly into the prepared soil on one row at the middle of each box. No weeding was necessary during the growing period. No pesticides were used either. This was possible because of the favorable conditions of the greenhouse. The temperature in the greenhouse was maintained at 17^0C to 22^0C which is perfect for lettuce growing. During the first three weeks, the greenhouse lights were left on a 24hour basis. It was noted that the plants were growing at as fast late and the light henceforth were on at night and switched off during the day for the rest of the growing period.

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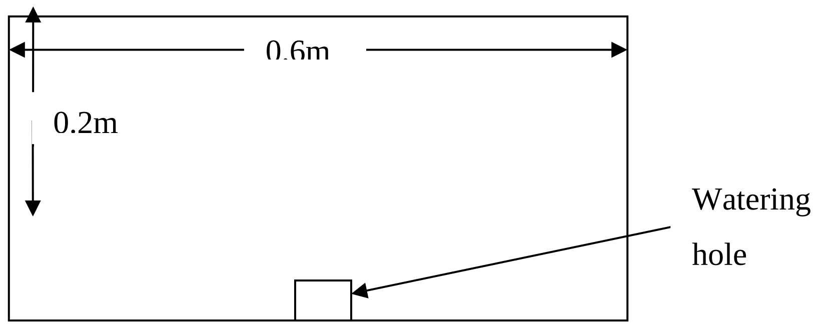

Fig 4: Top view of planting box

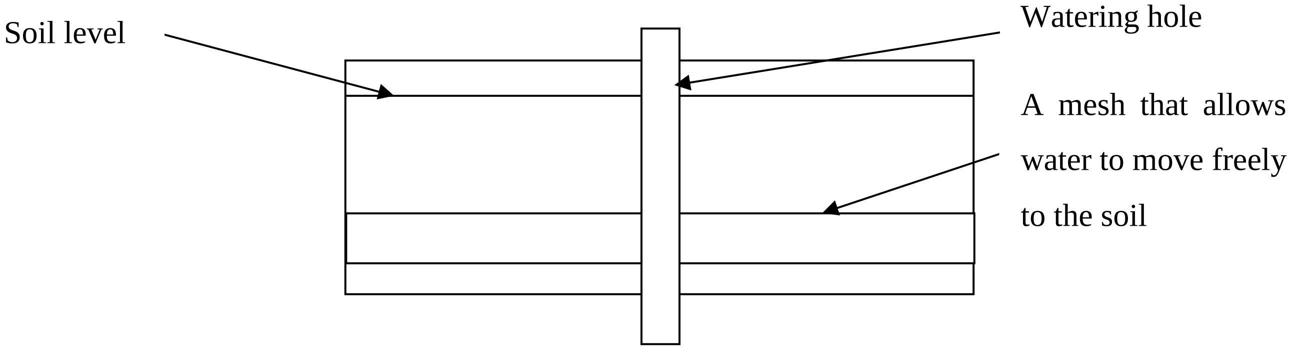

Fig 5: Side view of planting box

Urine was from the school dry toilets. The urine had been stored in the toilets compartments for several months for the purpose of raising the pH level to allow destruction of any harmful micro-organisms. During the urine application period, the urine was stored in a cool place with the container tightly sealed to ensure no evaporation of ammonia.
Lettuce growing requires soil that is loam with a pH of 5, 8 - 6, 8. This was achieved by mixing soil that did not have any fertilizer, peat and sand at a ratio of 1:4:3 respectively. Initial soil pH was 4.6 and therefore below the required for lettuce. This was adjusted upwards to 6.45 by adding 4kg of lime to the mixture. The soil mixture of 15L was added to each of the planting boxes. Bulk density for the soil was determined according to the SFS-EN 13040: 1999 Annex A before and after planting. In the initial application of urine treatment, in one set of each of the recommended, double and half treatments, urine was applied via the hole in the boxes meaning assimilation of nutrients into the soil was from the bottom. In the other set, urine was applied on top of the soil. The subsequent urine fertilizer applications were all done through the hole. The artificial treatment was applied on top of the soil.

3.3 Fertilizer application

Urine was collected from the dry toilets of TAMK University of Applied Sciences. Analysis for the determination of nitrogen, phosphorous and potassium was carried out. The concentration of nitrogen was lower than expected due to water used for maintenance of the toilets going to the same collection facilities. The results can be obtained found in the results section.
For artificial fertilizer, Puutarhan kevät, a type of inorganic fertilizer was used. The following table indicates the amount of nutrient present in percentage per weight.

Nutrient	Concentration (%w/w)
Total Nitrogen (N)	13
Ammonium Nitrogen (NH_4 –N)	5.5
Nitrate nitrogen (NO3N)	7.1
Phosphorous (P)	7
Potassium (K)	20
Magnesium (Mg)	1.2
Sulphur (S)	4.6
Boron (B)	0.02
Zinc (Zn)	0.01
Molybdenum (Mo)	0.002
Iron (Fe)	0.001

Table 1: Nutrient concentration in artificial fertilizer

Plants will grow until restricted by the supply of the essential nutrient. The addition of crop input cannot rectify the deficiency of an essential nutrient. The yield of a crop is determined by the supply of individual nutrient relative to their required levels for best yield. In most soils, nitrogen is typically the nutrient in short supply. In this experiment, nitrogen was used as the limiting nutrient. The required levels of Nitrogen in lettuce 90kgN/ha was therefore utilized to determine the amount to be used.

The amount of Nitrogen expected in urine of a healthy person is between 3-7gN/l. (Steinfeld, 2004) Results of urine obtained from TAMK dry toilets however had lower concentrations of 1,4gN/l. This is due to maintenance reasons as water is used for washing the toilets which is also collected in the urine container thus diluting the concentration.

Amount of Nitrogen required by lettuce = 90kgN/ha which is equivalent to 9gN/m^2.

Nitrogen concentration in urine was 1,4g/l

For a 1m^2 area = 9gN/m2 /1.4g/l

= 6.4 liter would be needed for a 1m^2 area.

The area of the boxes was 0,1134m^2.

Therefore, urine required for one box would be

= 0,1134m^2 * 6,4l/1m^2

= 0,726litres of urine was the total amount of urine required to provide the nitrogen recommended for optimum growing of lettuce for a 0.1134m^2 box.

Since the urine was to be applied three time in the growing period, a third of this amount i.e. 0,242litres was diluted at a ratio of 1:1 with water and applied each week for three weeks. Likewise, the amount of the required quantity was doubled and divided into three portions for every week for a period of three weeks. This was also done for the half recommended dose. In total about 5litres of urine was applied in the different treatments.

Artificial fertilizer contained 13% of Nitrogen equivalent to 130g/kg

For a $1m^2$ it would require

=9gN/m2 /130g/kg

= 0,0692kg

For a box with an area of 0,1134m2

= 0,1134m2*0,0692kg/1m2

= 0,00785kg (7,85g) of artificial fertilizer was used on one box.

For the artificial fertilizer, the application was done once at the beginning of the experiment.

4 ANALYSIS FOR SOIL AND URINE

4.1 pH measurements

The pH of the soil affects the availability of nutrients in the soil. In soils with a low pH (acidic), macronutrients are less available while in soils with a high pH (basic), micronutrients are less available (Clain Jones et al 2005). Initially the pH of the soil was low (4.6). This was raised to the desired range of 6.45 by adding 4kg of lime in the soil mixture.

Soil pH was determined in accordance to the Finnish standards SFS-EN 13037. The pH for soil was measured before the commencement of the experiment and after. Deionized water with a conductivity of less than 0.2ms/cm and a temperature of 22^0C was used to extract the soil.

A ratio of 1: 5 (v/v) was used in extracting the soil. Five samples were taken randomly from the soil sample. 30ml of soil samples were mixed with 150ml of water. The mixture was shaken mechanically by a machine at room temperature for one hour. The contents were allowed to settle and the pH measured from the supernatant layer of the solution. This was according to the SFS –EN 13037 2011. The following table shows the measured pH with the corresponding volume and weight taken.

The pH was also measured from urine directly since it is in liquid form. A pH of 8.82 was realized.

Soil number	Weight of a 30ml soil sample. (g)	Measured pH
1	396	6,43
2	298	6,45
3	290	6,41
4	292	6,45
5	302	6,54
Average	315	6,45

Table 2: Values of pH after adjustment using lime

4.2 Dry matter and moisture of soil

This determination was carried out in accordance to the Finnish standards SFS –EN 13040. Analysis was performed on five incremental samples of the soil before the start of the experiment. The samples were dried at a temperature of 105^0C.

Sample	Dry matter content (%)	Moisture Content (%)
1	95.80	4.2
2	95.93	4.07
3	95.70	4.3
4	96.96	3.04
5	95.75	4.25
Average	96.03	4.0

Table 3: Dry matter and moisture content of soil

4.3 Organic matter content of the soil

Organic matter has direct and indirect role in the soil through its effects on the availability of nutrients for plants growth. It serves as a source of nutrients and promotes good soil structure which in turn improves aeration, retention of moisture and increases the buffering and capacity of soils. The organic matter content was determined in conformation to Finnish Standards SFS-EN 13039. Five incremental samples were analyzed. Samples from dry matter content were further heated in a muffle furnace at 450^0C for one hour. The following values of organic matter content were obtained from the soil samples.

Sample	Organic matter content (%)
1	6,31
2	6,19
3	6,79
4	6,68
5	6,06
Average	6,41

Table 4: Organic matter content results from five incremental samples.

4.4 Soil texture determination

Soil texture affects the retention of nutrients and water in the soil. Organic and clay soils have the ability to hold nutrients than sandy soils.

Soil texture in this experiment was determined by feel method. About one teaspoonful of soil was placed in the palm of hand. Drops of water were added gradually as the soil was being pressed to break the soil particles. The soil did not make a ball shape after squeezing. The soil was placed again between the thumb and forefinger. It was gently pushed with the thumb. The soil did not form a ribbon either.

Further wetting was done on a small pinch of soil in the palm of hand and rubbed with the forefinger. The soil felt gritty which translates to a loam soil ideal for lettuce growing (Steven J. Et al 1979).

4.5 Bulk Density

Expressed in g/cm^3, bulk density is the dry weight of soil divided by its volume. It is an indicator of soil compaction. High soil density may restrict root growth and poor movement of air and water through the soil. (Arshad, 1996). Air dried soil samples were used to determine the bulk density of the soil according to the instruction in Radojevic and Bashkin (1999).

A dried I LT measuring cylinder was weighed and filled with soil without compaction to the top. The contents together with the cylinder were weighed and recorded. This was duplicated twice to affirm the results. The average values were used to calculate the bulk density.

5. NUTRIENT ANALYSIS IN SOIL AND URINE FERTILIZER

5.1 Total Potassium in soil

The analysis was carried out according to the European standards EN-13650. The samples were extracted by wet digesting in a closed system and then quantitatively determined using Flame Ionization Absorption Spectrophotometer according to International ISO 11047. Total Potassium was analyzed at the beginning and at the end of the experiment on all soil treatments, control and the artificial fertilizer.

Samples were prepared by weighing 3 grams into digestion tubes, 10ml of concentrated Nitric acid and 3 ml of concentrated HCl was added. The contents were then heated at 60^{0} C for one hour; the temperature was increased at intervals to the highest temperature of 140^{0} C. At each interval, the samples were allowed to heat for one hour before increasing the temperature.

After digestion the extracted samples were allowed to cool, then dissolved using deionized water and filtered into a 100ml volumetric flask. The samples were then diluted into a ratio of 1:10 and then 1:20 using 0,2% HNO_3 solution. 1ml of 10% Lanthanum chloride (LaCl) was added in the second dilution.

Before measuring the samples a calibration curve was plotted from a series of solutions prepared from a stock solution of KCL containing 1000mg/l K^{+}. The solution was diluted into 100mg/l in a 500ml volumetric flask and then 10mg/l in 100ml flask. Calibration solutions of 0.5mg/l, 1.0mg/l, 1.5mg/l and 2.0mg/l were prepared and diluted each in a 100ml volumetric flask with a solution of 0,2% HNO_3 solution. 1ml of 10% Lanthanum chloride (LaCl) was also added in each. A calibration curve was plotted and then concentration of Potassium in the soil was measured using 0,2% HNO_3 solution as a blank.

5.2 Total Nitrogen in soil

Total Nitrogen was tested on the soil in the beginning and after the experiment using the Kjeldahl method. The principle behind Kjeldahl involves wet digestion of the sample to breakdown the soil matrix using sulphuric acid with the help of a suitable catalyst. This converts the Nitrogen present into ammonia. The ammonia is distilled and trapped into a boric acid solution and titrated using $0.005H_2So_4$.

Soil samples were weighed into the digestion tubes, 20ml of conc. H_2So_4 was added to hydrolyze the organically bound nitrogen. The boiling point was increased by adding an appropriate catalyst. To the digested sample NaOH was added to release Ammonia which was then distilled and collected in boric acid solution. The contents were titrated using 0.0025M of H_2SO_4. The amount of titrant used was noted and recorded.

5.3 Total Phosphorous in soil

For total phosphorous analysis, the samples were prepared the same as for potassium through the wet digestion. After this, samples were diluted at a ratio of 1:20 and then proceeded to analyze using the Hach DR 2800 method of analysis for phosphorous. The principle of the method is that reactive phosphorous obtained after sample treatment reacts with molybdate in an acid medium to produce a phosphomolybdate complex which gives an intense blue color.
10ml sample from the dilution was poured into a sample cell. The contents of one Phosver 3 phosphate powder pillow was added into the sample cell and shaken vigorously for 15 seconds. The sample was left to stand for about 30min. Meanwhile, a blank sample was prepared by adding 10ml of the sample without the reactants. The blank was placed in the cell holder and using the store programme for, the reagent blank was zeroed. The sample was then placed in the holder and concentration measured by pressing the READ knob.

5.4 Total Nitrogen in urine

Since urine is in solution form, the total nitrogen samples were digested using the HT 200S thermostat. This method takes about 35minutes compared to the Kjeldahl that takes two days. This is a faster way of sample digestion. After this the concentration of Total nitrogen was measured using the HACH DR 2800 Spectrophotometer using the HACH Lange analysis kit. The principle of this method is that inorganically and organically bonded Nitrogen is oxidized to nitrate by digestion with peroxodisulphate. The nitrate ions react with 2.6-dimethylphenol in a solution to form a nitro phenol.

5.5 Total Phosphorous in urine

The urine samples were digested using H_2SO_4. Once the samples were digested, the phosphorus values were analysed with HACH DR 2800 Spectrophotometer. The results measured from the HACH are in mg/l of phosphate ion.
25ml of urine sample was pipetted into a 125 Erlenmeyer flask. Potassium persulfate pillow powder was added followed by 2ml of 5.25N H2So4. The contents were gently boiled over a hot plate for a half an hour. The sample was allowed to cool after which 2ml of 5N NaOH was added. The sample was then transferred into a 25ml graduated measuring cylinder and filled to the mark with distilled water. The concentration of phosphorous was measured using the Hach DR 2800 with a blank sample containing only the reagents used to zero the instrument.

5.6 Potassium, Magnesium and Calcium in urine

The determination of these nutrients was done using the Flame Atomization Absorption Spectroscopy (FAAS). The principle of this method is based on absorption of UV or visible light by gaseous atoms. The source of light is a hollow cathode lamp made of the element being analysed. A solution is sucked into a flame made of fuel gas and oxidation gas. Due to the high temperatures, the sample is broken down into free atoms. The flame excites a valence electron to a higher energy orbital. As the electrons fall back to a lower energy state, the atoms emit energy in form of light of the same characteristic wavelength. The intensity of the absorbed light is proportional to the concentration of the element in the flame.
Separately, analysis of potassium, magnesium and calcium were carried out by pipetting 10 to 50ml of the filtered human urine sample into a 100ml volumetric flask. To counter any interference during atomization, 1ml of 10% $LaCl_2$ was added to the samples. The flask was filled to the mark using a solution of 0.2% Nitric acid.
For each nutrient, calibration solutions were prepared from solutions of 1000mg/l and dilutions made similar to calibration curve solutions preparations as for potassium in soil. The calibration samples were subjected to the same treatment as the human urine samples. The concentration of respective elements was then measured using the Perkin Elmer FAAS. For further details on the analysis of urine, please refer to thesis by Claudia Zambeze-Kallio.

5.7 Magnesium analysis in Lettuce leaves

Lettuce plants were air-dried and later crushed into fine powder. Samples weighing 1 gram each were placed into the digestion tubes of the Buchi K – 437 Wet digestion Apparatus for Kjeldahl instrument.10ml of conc. HNO3 and 3ml of conc. HCL was added after which the tubes were closed and heating done in steps. First the temperature was raised to 60^0c over 15minutes and the contents allowed to heat for one hour. The temperature was then raised to 90^0C and heated for one hour. This procedure was repeated for two more steps i.e. at temperatures 120^0C and 140^0C. In total the heating lasted 5hours. Two samples from each fertilizer treatment plus the control were analyzed making a total of nine samples.

The samples were then transferred into a 100ml volumetric flask using de-ionized water. 10ml of this solution was pipette onto a 100 volumetric flask. 1ml of 10% Lanthanum Chloride (LaCl3) was added to eliminate chemical interferences. The solution was then filled to the mark using 02% HNO_3 solution.

For the calibration curve, standard solutions were prepared from a stock solution of 1000mg/l magnesium. From this solution, 50 ml was pipette into a 500ml volumetric flask and topped using 0.2% HNO_3 solution for a 100mg/l solution. A 10mg/l solution was then prepared by taking 10ml from 100mg/l solution and diluting it to 100ml. Solutions of 1mg/l to 5mg/l were then made from 10mg/l solution and a calibration curve plotted. Magnesium concentrations for the leaves were measured using 0.2% solution of HNO_3 as a reagent blank.

6. RESULTS

The nutrient analysis for the urine was carried out together with the test of hormonal residue. Further details can be obtained from Claudia Zambeze-Kallio’s thesis on the same.

Nutrient	Concentration g/l
Nitrogen (total)	1,44
Phosphorus (Total)	(0,39 PO_4^{-3}) 0,13
Potassium	1,36
Magnesium	0, 76 (mg/l)
Calcium	2,5 (mg/l)

Table 5: Nutrient concentrations in urine (Claudia Zambeze)

6.1 Growth evaluation

The growth of the lettuce was evaluated by measuring the height of the plants and the width of the widest part of the leaf. At the end of the experiment, the average wet mass of the plants was used. The leaves were individually placed in a dry place for drying after which they were weighed. Soil was tested for total phosphorous, total nitrogen and total potassium while the crushed leaves were tested for magnesium. From the results in the following figures, lettuce from double application of the recommended nitrogen was the heaviest followed by the recommended urine application. It is worth noting that, the different mode of initial application of urine might affect the growth of the lettuce. These modes of fertilizer application are referred to as Rec 1 and 2 for recommended nitrogen application for lettuce growing with Rec 1 representing initial application done on top of the soil while Rec 2 is for application done thorough the whole of the boxes. This is similar for the rest of treatments.

In all the boxes, the germination of the seedlings was observed within the first four days. However, after one week, the difference could be noted in the various treatments and the control. Where urine application was done on top, it was noted the sprouting was not as complete as those fertilized through the box holes. Those boxes where urine application was done via hole applications had a uniform height of 1cm. Another observation made on the directly applied urine fertilizer application was that they had stunted growth possible due to burning by urine even though it was diluted into a ratio of 1:1 with water before applying. Thought-out there was a difference between the two mode of application though done only in the initial application. This could be explained by the fact that the initial uptake of the nutrients by the plants determines the pace at which the plant is able to grow. Another important observation was the fact that plants in inorganically fertilized box grew faster than the rest. This could be explained by the fact that the application of the artificial fertilizer was done at once which made the plant reach its maximum earlier than the urine treatments. By the time of harvesting, plants in the urine treatments, had not reached their optimum as they showed signs of further growth.

Lettuce grown using urine fertilizer

Lettuce grown using artificial fertilizer

Lettuce grown without fertilizer (control)

Figure 6: Picture of lettuce at harvest time (six weeks) by Catherine Mburu

6.2 Average mass of fresh plants

Harvesting was done after six weeks. The plants were cut from the bottom, weighed and stored in a absorbent paper to dry. Each plant was stored in its own paper, marked and kept in a dry place. After the plants were dry, they were weighed again for dry weight. Mass of the double treatment of urine was the heaviest followed by the artificial fertilizer. This could be so because artificial fertilizer was applied all at once which facilitated for plant to grow faster and reached maturity earlier than for the rest of the treatments.

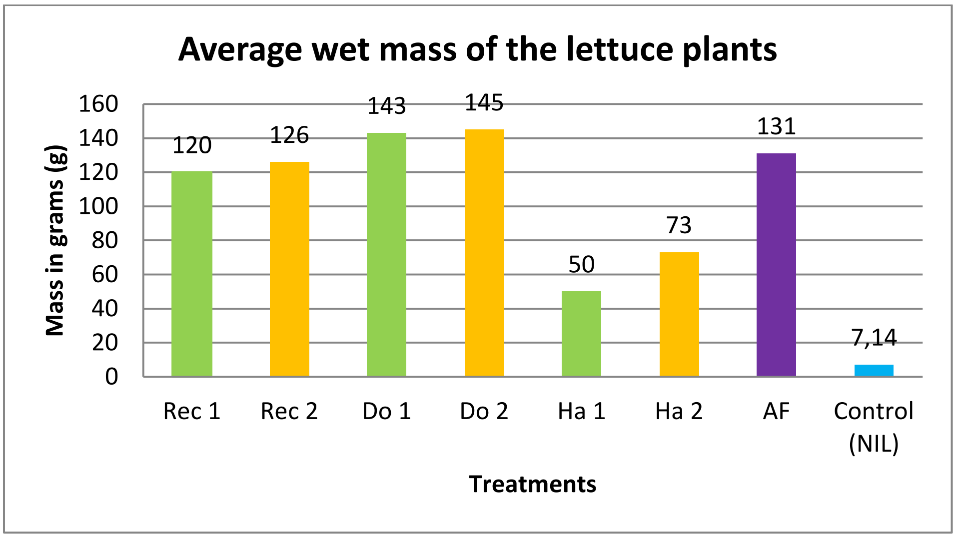

Figure 6: Lettuce growth based on average mass of wet plant.

Rec = Recommended nitrogen fertilizer, Do = Double nitrogen recommendation, Ha= half nitrogen recommendation, AF = Artificial fertilizer, Nil = no fertilizer (control)

6.3 Lettuce yield by height and width

Lettuce height was measured in the first, third and during the harvest time (six weeks). However the width was only measured during the third and harvest time as it was almost the same in all treatments. As Fig 7 shows, the growth of plants fertilized by artificial fertilizer had reached their maximum leaf width growth as very minimal change was noted between the third week and harvest time. However, from urine fertilizer grown lettuce, the plants there was a notable change in the growth of the leaves. This would have continued were the plants allowed more time to grow.

Figure 7: A picture showing different treatments of human urine on lettuce

By Catherine Mburu

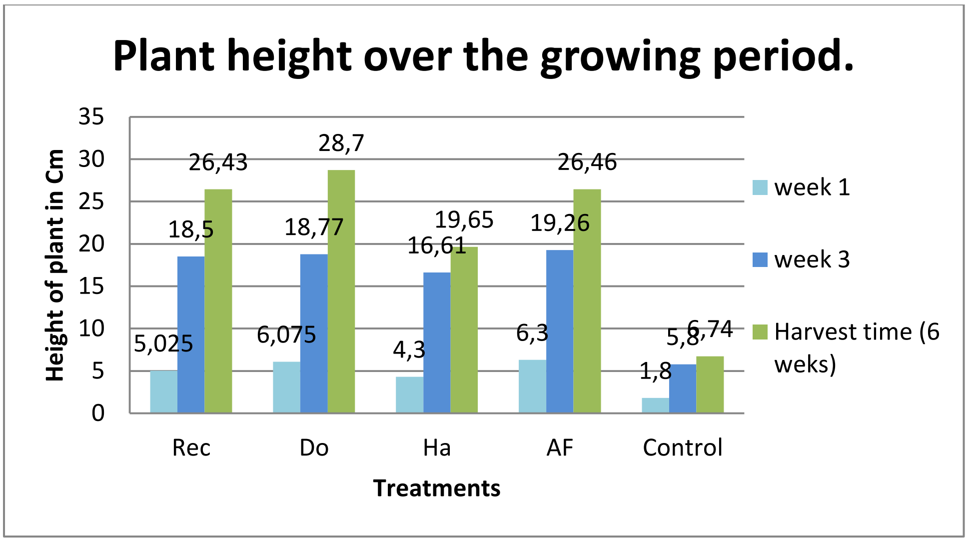

Fig 5: Monitored growth of lettuce plants by height over the planting period of six weeks.

Rec = Recommended nitrogen fertilizer, Do = Double nitrogen recommendation

Ha= half nitrogen recommendation, AF = Artificial fertilizer, Nil = no fertilizer (control)

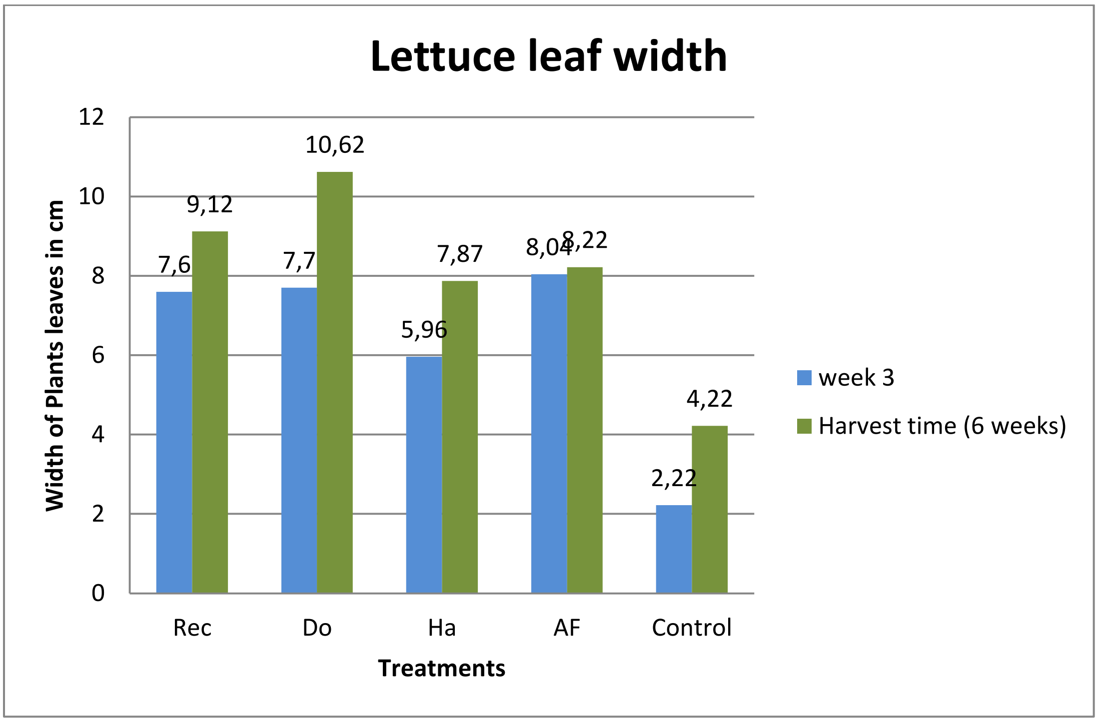

Fig 6: Monitored growth of lettuce by width of the widest part of the leaves.

Rec = Recommended nitrogen fertilizer, Do = Double nitrogen recommendation

Ha= half nitrogen recommendation, AF = Artificial fertilizer, Nil = no fertilizer (control)

6.4 Total nitrogen in the soil

For the nutrients analysis, the effect on growth is shown on Fig 9, 10, 11, and 12 i.e. Total Nitrogen, Total potassium, Total phosphorous and magnesium respectively. Potassium and phosphorous content was tested on the soil before and after the experiment while magnesium was examined on the leaves after drying.

The total nitrogen in the soil before the experiment presented high value followed by the double urine treatment. This could be as a result of the use of peat in the soil mixture

Fig 8: Plants whose initial urine fertilizer application was done on top of the soil. Note the first two are on the left is the control i.e. without fertilizer followed by artificial fertilizer. (At three weeks) Catherine Mburu

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nents followed by half and control. For the double nutrient treatment, as the results shows, there was more excess nitrogen in the soil.

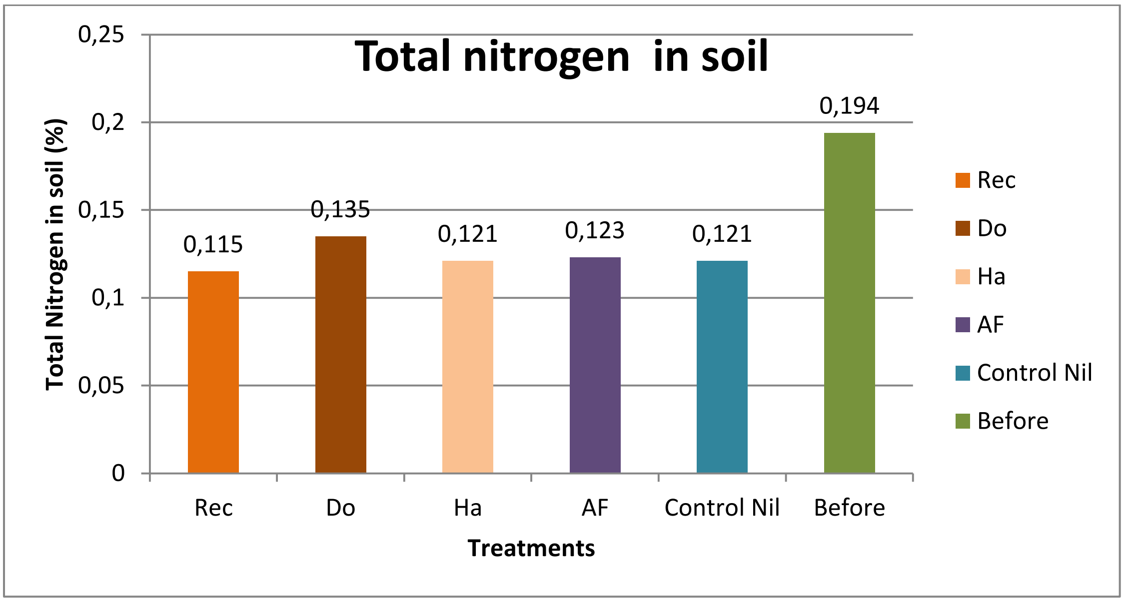

Fig 9: Total Nitrogen (%) in four soil treatments, a control and before planting

Rec = Recommended nitrogen fertilizer, Do = Double nitrogen recommendation
Ha= half nitrogen recommendation, AF = Artificial fertilizer, Nil = no fertilizer (control)

6.5 Total potassium in soil

The concentration of potassium in the soil at the beginning was quite low. This could be attributed to the texture of the soil which was loam. Potassium as an element is positively charged. Loamy soils have less mineral content and fewer negative charges and therefore comprise low levels of plant available potassium. This however changed when the fertilizer was added. The potassium concentration in soil was higher in urine treated soil than in artificially fertilized soil. There was a slight increase in the concentration in the control soil sample which could be due to K^+ exchange in the soil. Ion exchange in soil occurs in pools. So when the available K is taken up by the plants, it is replaced by potassium released from the exchangeable pool.

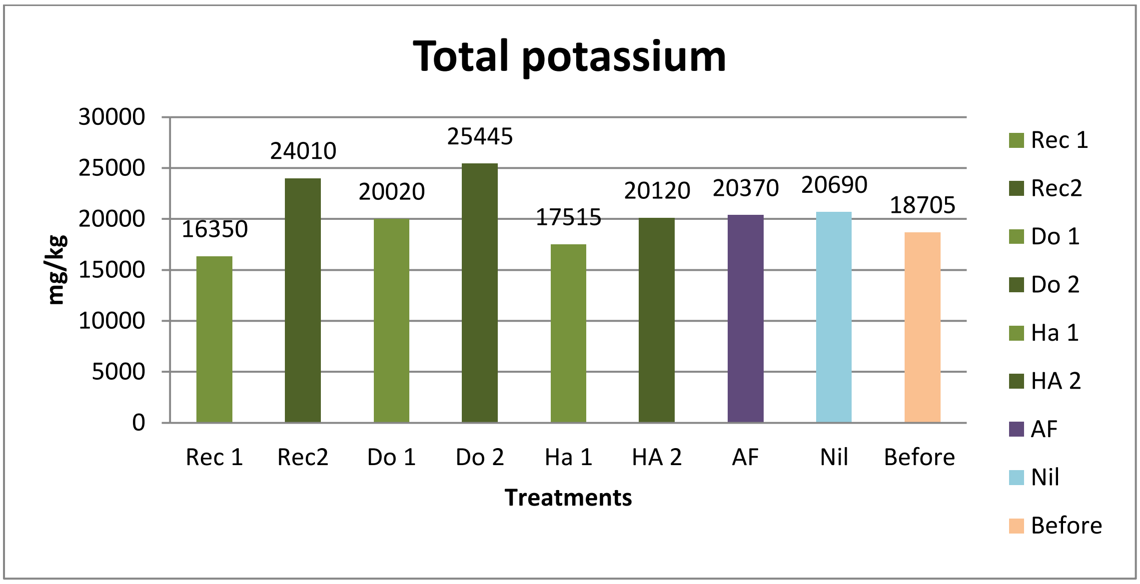

Fig 10: Total potassium (mg/kg) in four soil treatments, a control and before planting

Rec = Recommended nitrogen fertilizer, Do = Double nitrogen recommendation
Ha= half nitrogen recommendation, AF = Artificial fertilizer, Nil = no fertilizer (control)

6.6 Total phosphorus in soil

The amount of phosphorous in AF and in human urine was statistically insignificant. Phosphorous detected at the beginning of the analysis was almost similar in amount as that in the urine treatments**.** Phosphorous in the different mode of urine initial fertilizer initial application showed varying results.

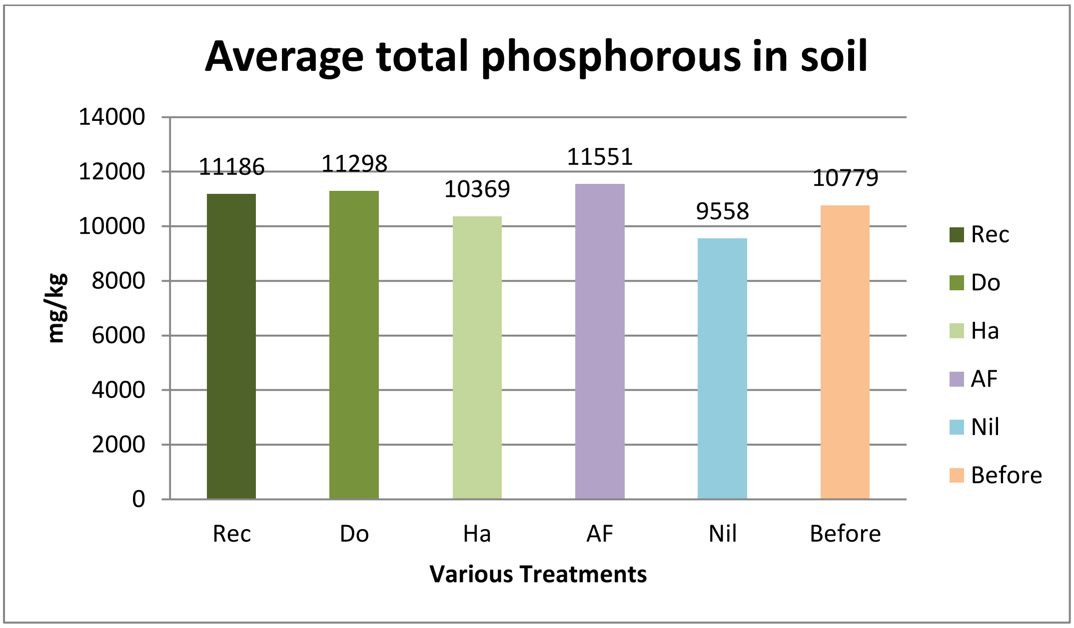

Fig 11: Total phosphorous (mg/kg) in four soil treatments, a control and before planting

Rec = Recommended nitrogen fertilizer, Do = Double nitrogen recommendation

Ha= half nitrogen recommendation, AF = Artificial fertilizer, Nil = no fertilizer (control)

6.7 Magnesium on lettuce leaves

Magnesium content in double nutrient application was high with 3,46g/kg followed by the recommended nutrient application with 3,38g/kg. Artificial application yielded 3,28g/kg while half nutrient application had 2,86g/kg of magnesium. Only 1,30g/kg of magnesium was obtained from the leaves of the control plants.

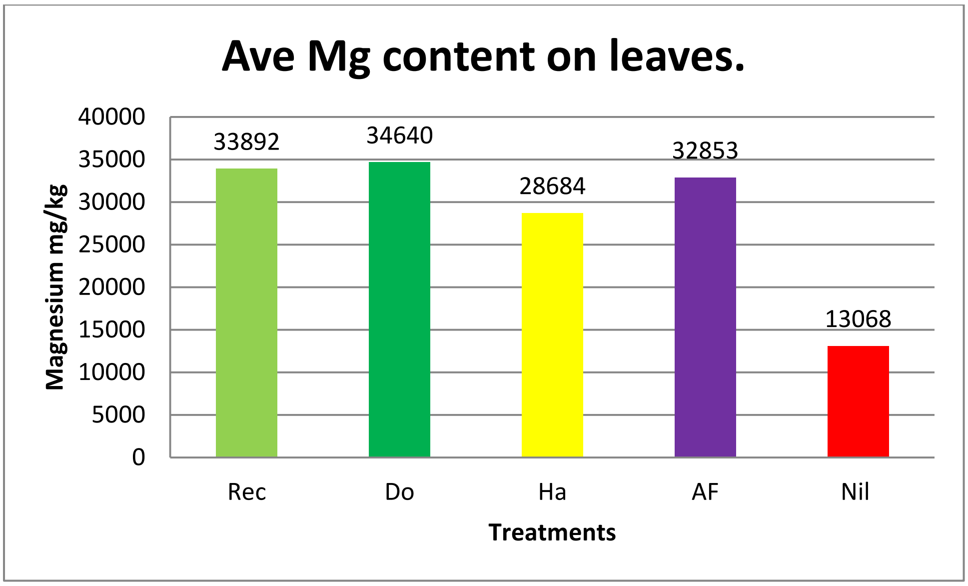

Fig 12: Average magnesium content of leaves (mg/kg) in four plants treatments and control

Rec = Recommended nitrogen fertilizer, Do = Double nitrogen recommendation

Ha= half nitrogen recommendation, AF = Artificial fertilizer, Nil = no fertilizer (control)


Figure 13 Figure 14

Figures 13 and 14: Pictures of Lettuce plants, on the left grown without any fertilizer and on the right fertilized using recommended amount of nitrogen in human urine (Catherine Mburu)

An observation worth noting is the amount of magnesium detected in the different mode of human urine treatment. The following graphs shows the difference in magnesium content in leaves of same amount of nutrient but a different way of applying. In all treatments, the first represent initial applications of human urine on top of soil while the second through the holes of the boxes. Fig 10, 11 and 12 shows the different amount of magnesium obtained from leaves of different urine fertilizer treatments using different modes of application.

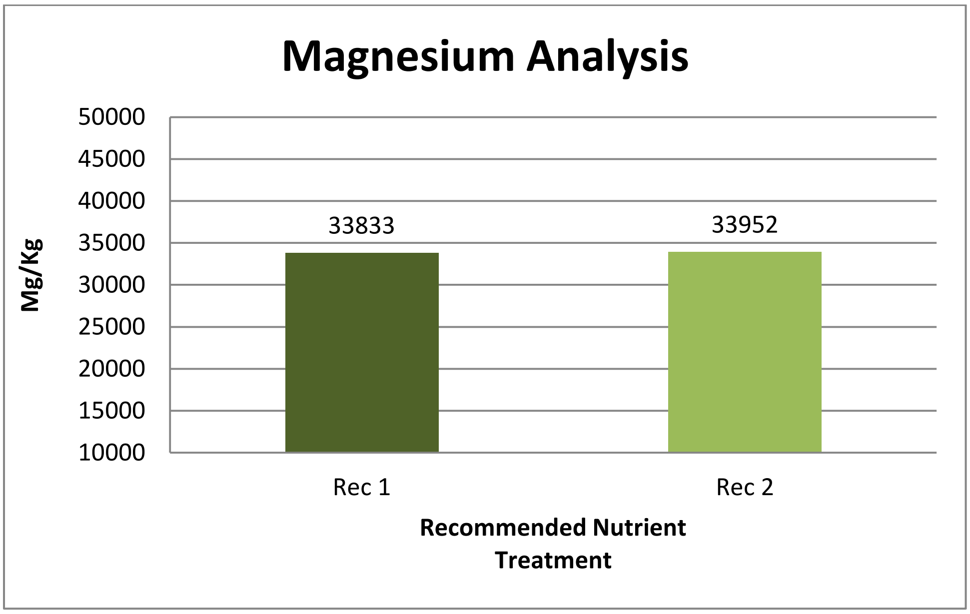

Fig 15 Magnesium concentration in lettuce (Lactuca Sativa) leaves in different irrigation treatments for the recommended nitrogen. Rec 1 = initial fertilizer application done through the hole. Rec 2 = Initial fertilizer application done on top of the soil

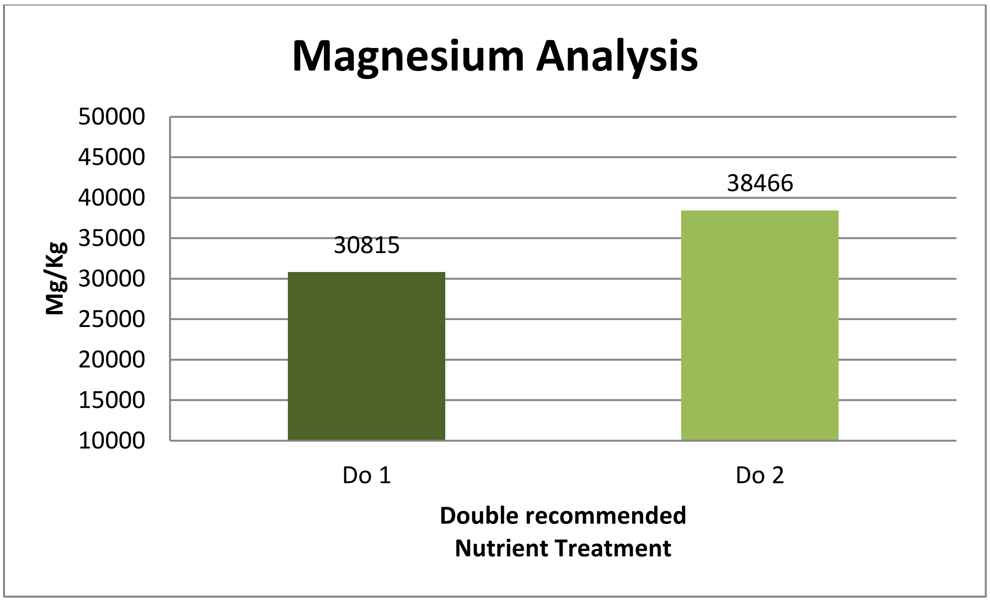

Fig 16 Magnesium concentration in lettuce (Lactuca Sativa) leaves in different irrigation treatments for double recommended nitrogen. Do 1 = initial fertilizer application done through the hole. Do 2 = Initial fertilizer application done on top of the soil

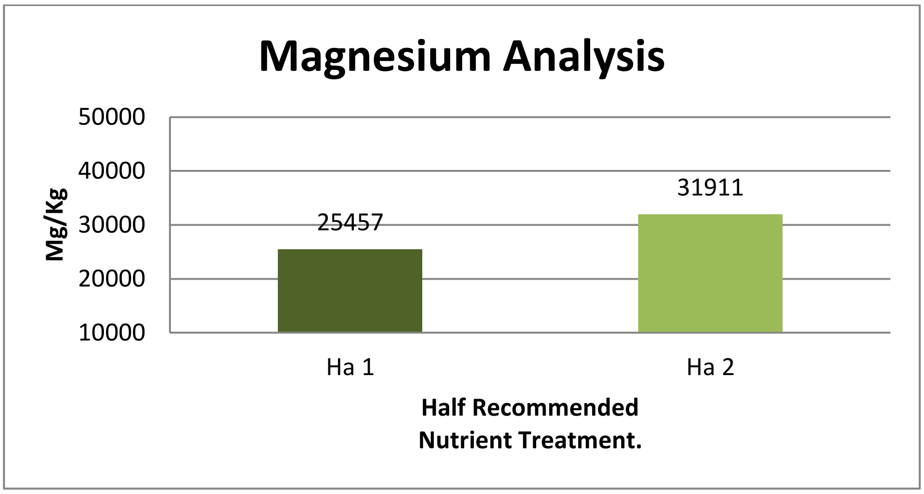

Fig 15 Magnesium concentration in lettuce (Lactuca Sativa) leaves in different irrigation treatments for half recommended nitrogen. Ha 1 = initial fertilizer application done through the hole. Ha 2 = Initial fertilizer application done on top of the soil

7. Discussion

The results of this experiment clearly showed a distinction between the various treatments undertaken. The yield by mass of the plant was higher in the double nitrogen treatment of human urine followed by the artificial fertilizer treatment. At the time of the harvest, the artificially fertilized lettuce plants showed signs of reaching optimum growth as the end of the leaves had started to wither. In the human urine treatment, there were signs of further growth in case growing time would have been extended. This could be explained by the fact that the application of human urine fertilizer was done gradually and so the nutrient were still available for the plants while for the artificial fertilizer, much of the nutrients had been taken up already. In the control, the miniature plants were pale yellow and had signs of drying.

Double nitrogen treated lettuce plants yielded the highest in terms of the average height, 28.7cm followed by both the artificial fertilizer and recommended nitrogen treatment at 26.4cm. It is worth noting the change that occurred between week three and harvest time (week six) on the height of recommended nitrogen treatment and double nitrogen treatment lettuce plants. Recommended nitrogen treated lettuce plants grew at an average rate of 43% (18.5cm to 26.43) while for double nitrogen treated lettuce plants grew by 53% (18.7cmm to 28.7cm). For the artificially fertilized lettuce plants, the growth rate was 37% (19.26 to 26.46). This confirms that the human urine fertilized lettuce had a potential for further growth.

For the width, the double nitrogen treated lettuce yielded the highest with an average width of 10,62cm followed by recommended nitrogen treated plants, 9.12cm. During harvest, lettuce leaves from half nitrogen treatment had almost similar width as those of artificial fertilizer 7.87cm and 8.22cm respectively. This could be due to the same reason as the height in that, the urine fertilized plants had the possibility of growing further.

Addition of nutrients from human urine enhanced nutrients uptake from the soil. At the beginning of the experiment, the total nitrogen present in the soil was 0.194%w/w. Recommended nitrogen treatment absorbed a higher amount of nitrogen nutrient (0.115%w/w was detected in the soil after harvesting) being lower than all other treatments. This may not perfectly quantify the exact amount of total nitrogen absorbed if other factors like leaching and evaporation are considered. When compared with other treatments however, it can be noted that it had least of nitrogen residue. In the control, though no nutrients were supplied, the plants never showed any tangible growth despite taking up the little available nitrogen from the soil.

The results obtained from the analysis of soil after the experiment showed that much of the nutrients provided to the crop in terms of the application of fertilizers were utilized by the plants. However, there was a possibility of continued nutrient uptake if the growing duration was extended especially in the human urine fertilized treatments. In homes gardens especially, harvesting of lettuce is done by removing individual leaves leaving the center to grow. This means that lettuce were capable of taking up more nutrients from the soil had they been allowed.

In potassium soil, nutrients were taken up more in recommended nutrient treated soil. This was repeated also for phosphorous. Though the control soil was not supplied with any nutrients, the uptake of nutrients by lettuce in this control was not maximized. An increase in concentration of nutrients up to the optimal levels promotes the absorption of other nutrients. More nutrients were taken up from human urine treated soils than in artificial fertilized soil.

A number of factors did have influence on the growth rate and the yield of the lettuce. The amount of light provided affected the rate at which the plants grew. This had to be regulated by switching off the lights for a number of hours during the day. The mode of fertilizer application precisely human urine at the initial stages might have had an influence also. By the second week of planting, plants whose fertilizer was applied via the holes displayed a faster growth rate compared to one whose application was done on top. Fertilizer application affects the availability of nutrients for plants uptake (Lamer M. 1985 pg. 64). The rate of nutrients uptake depended on availability. The average height, width, mass of wet plants and the amount of magnesium resulting from various mode of application attest to this fact. There is need however for further studies to be carried to confirm.

Sustainability in sanitation is achievable if the human excreta and especially urine which is easier to use, is diverted and used as a resource rather than waste (Rosemarin A. et al 2008). This closes the nutrient cycle and provides the benefits of protecting the environment, saving on water treatment costs and replenishes the nutrient-deprived soil thus saving on the cost of manufacturing artificial fertilizers whose sources are near extinct. The use of human urine as a fertilizer however needs to be handled with care.

8. Conclusions

The use of urine as a fertilizer is not a new phenomenon. Previous results and history have successfully proved the benefits of using it for plant fertilization. The results of this research affirmed earlier studies.

This experiment was able to prove the viability of the use of urine as a fertilizer in greenhouse condition. This means that the use of urine can be used at the convenience of a home all year round even in harsh weather conditions. The use of source separated urine will help not only in reducing the cost of treating waste water but also closing the loop in nutrient cycle. Ecological sanitation is one way of ensuring sustainability in agriculture. Use of human urine will also replenish the soil with the much needed nutrients that are environmentally friendly.

Hydroponic farming is the growing of plants without soil medium. This was evident in the way nutrients were taken up quickly by plants from the onset by introducing nutrients in the human urine from underneath in the solution. The mode of applying fertilizer does have an effect in the rate of growth of plants. If the urine fertilizer especially is applied on top of the soil and not covered, there is the possibility that ammonia in the urine would evaporate and therefore not available for the plants. Plants absorb nutrients in the same form source notwithstanding. Nutrients in the human urine are readily available for plants uptake. The uptake is a gradual process. Other sources of organic

fertilizers, such as animal manure, household waste, plants materials and compost from combination of these sources take time to decompose which is not the case with human urine. Human urine can be fully utilized since it can be used when needed. Households
With the right information the use of urine as a fertilizer can be an answer especially to farmers in the developing countries who cannot afford the cost of buying artificial fertilizer. Proper information is needed to credit and affirm the use of urine as a resource for agriculture and not as waste. The challenges presented in the use can be used as opportunities of removing stigma and dealing with the taboos associated with use of human excreta. The benefits of urine separation from source are valuable. Waste water comprises of only 1% urine. Resources such as water, energy and labor can be redeemed in the long run. Right strategy with long term projections can help in overcoming challenges standing in the way of achieving the set millennium development goals. The involvement of future generations through school introduction of urine separation will safeguard sustainability especially in the developing countries where there are challenges on waste disposal and cost of replenishing the soil with nutrient which is far beyond the reach of many.

There is a need in continuing with further studies in this project. It would be of interest to be able to see the response of other plants to fertilization with human urine. For instance, plants that take long to mature could be suitable for this purpose in order to allow for time to observe the response when subjected to various conditions. Some suggestions would be the growing of the plants hydroponically using different methods. The methods should be in such a way that can be modified to suit intended households. Since this was conducted on a smaller scale, it would be beneficial for homes to ensure sustainability. However, it is necessary to perform all this with large scale use of human urine in mind.

Suggestions are made to explore the use of other methods of supplying the nutrients safely and efficiently to the plants. One such way is the drip type of irrigation where the urine is diluted in a plastic bottle and then allowed to assimilate into the plants through sipping from under. This is a convenient way of applying the human urine fertilizer in the comfort of home. The number of plastic bottles used in homes can be for this purpose as demonstrated below.

Figure 18: Picture of a drip irrigation bottle (obtained from Amazon)

In greenhouse farming, the use of hydroponic farming is very common and beneficial. This method of farming has many advantages to the farmer, consumer and the environment. When combined with use of human urine as a fertilizer which is organic, the advantages outweigh the disadvantages. Greenhouses can be modifies to suit the economic status and environment. This too can be probed in details and in the various ways applied in hydroponic farming.

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