ASSESSMENT OF SOIL SALINITY INDUCED BY AGRICULTURE VALORIZATION OF HUMAN URINE AS A NITROGEN FERTILIZER

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ABSTRACT

Since two decades, researches in environmental domain are interested to human urine valorization in agriculture as both an ecological and economical approach. Considered as a pure nitrogen (N) fertilizer because of its high nitrogen content and other macro/micronutrients, human urine can substitute commercial fertilizer. However, human urine contains important amounts of sodium, chlorides and other salts that can induce salinity to the soil if applied in a high amount or in dry conditions. The present study aimed to evaluate the soil salinity induced by human urine, applied as nitrogen source to meet crop N requirement.

Tomatoes were planted in pots following three treatments, one using 100% N from urine (urine treatment), and another using 50% N from urine and 50% N from toilet compost (compost+urine treatment) with a control treatment. The soil electrical conductivity was evaluated using field sensors settled in each treatment and a probe for punctual measurements. In additional, treated soils sampled at different depths were analyzed after the trial and the sodium adsorption ratio (SAR) value of samples from the three treatments were determined to compare sodium proportions to other elements. Results showed that the electrical conductivity trend increased more in the urine treatment, followed by the compost+urine treatment during the period of the trial. Results of electrical conductivity of treated soils after harvest increased in urine treatment two (2) times more than the control and was higher 1.3 times more than the compost+urine treatments. The SAR value was higher in the urine treatment than in other treatments. The pH of compost+urine treatment and control were slightly higher than for urine treatment. Hence, the use of human urine as a fertilizer in the soil is a risky, mostly in dry conditions.

Keywords: soil salinity, electrical conductivity, human urine, SAR, compost

RESUMÉ

Depuis deux décennies, des recherches dans les sciences environnementales sont intéressés par la valorisation des urines en agriculture comme une approche économique et écologique. Due à sa concentration élevée en azote et autres macro et micro nutriments nécessaires pour la croissance des plantes, l'urine est considérée comme fertilisant azoté pouvant se substituer aux engrais chimiques. Cependant, l'urine contient aussi des quantités importantes de sodium, de chlore et d'autres sels minéraux qui peuvent induire la salinité du sol si amendé en grande quantité ou dans des conditions arides. La présente étude a consisté en l'évaluation de la salinité du sol induite par l'urine, amendée dans le sol comme source d'azote en quantité nécessaire pour satisfaire les besoins de la plante.

Pour ce faire, les tomates ont été plantées dans des pots suivant trois traitements : le premier utilisant 100% d'N-azote venant de la plante (traitement urine), le second 50% d'N-azote venant du compost et 50% d'N-azote venant de l'urine (traitement urine+compost) et un traitement contrôle. La salinité du sol a été évaluée en termes de conductivité électrique, en utilisant des capteurs installés au terrain sur les trois traitements et une sonde prenant des mesures ponctuelles. Les échantillons de sol des différents traitements ont été collectés et analysés au laboratoire, pour la détermination du taux d'absorption du sodium (SAR).

Les résultats obtenus ont montré que la conductivité électrique dans le traitement urine avait beaucoup plus tendance à croître que dans les deux autres traitements durant la période de l'expérimentation. Les mesures de la conductivité électrique obtenues au laboratoire sur les sols traités ont montré que la conductivité a augmenté dans le traitement urine 2 fois plus que dans le traitement contrôle et 1.3 fois plus dans le traitement compost+urine.

Le SAR était plus élevé dans le traitement urine que les autres traitements comparés à la même profondeur. Les pH du traitement urine+compost et ceux du traitement contrôle comparés à la même profondeur étaient un peu plus élevés que dans le traitement urine. L'utilisation de l'urine humaine est un risque de pollution pour le sol, surtout dans des conditions arides.

<u>Mots clés</u> : salinité du sol, conductivité électrique, urine humaine, SAR, compost

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ACRONYMS

°C	Degree Celsius
2iE	International Institute for Water and Environmental Engineering
Ca	Calcium
Cl/ Cl^-	Chloride
cm	Centimeter
DRB	Dry root biomass
DSB	Dry shoot biomass
EC	Electrical conductivity
FAO	Food and Agriculture Organization of the United Nations
g	Grams
INERA	Institut de l'Environnement et des Recherches Agricoles
kg	Kilograms
l	Litre
MASA	Ministère de l'Agriculture et de la Sécurité Alimentaire
MDG	Millennium Development Goals
Mg	Magnesium
mg	Miligrams
mS	Milisiemens
N	Nitrogen
Na (Na^+)	Sodium
pH	Potential of hydrogen
PVC	Polyvinylchloride
SAR	Sodium adsorption rate
TDB	Total dry biomass
UNICEF	United Nations Children's Fund
WHO	World Health Organization
μS	Microsiemens

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INTRODUCTION

Sanitation crisis is affecting a large part of the world and is a cause of the vicious poverty cycle in which millions of people are trapped. Today, almost 2.5 billion of the world's population do not still have access to improved sanitation services (WHO/UNICEF, 2012). Indeed, the construction of Western style water toilets which are based on continuous access to tap water and wastewater treatment plants is not possible in many areas, since there is not enough fresh water and these devices would be very expensive to build and operate. On the other hand, on-site treatment such as septic tank or pit latrine is also not recommended due to risks of groundwater pollution if it is not properly designed and well managed. In such context, other options of sanitation initiative are necessary in order to reach the millennium development goals (MDGs), number 7C which targets are to halve by 2015 the proportion of people living without sustainable access to safe drinking water and basic sanitation. Thereby, Lopez et al. (2002) have developed on site wastewater differentiable treatment that is based on the concept "Don't collect" and "Don't mix". At household level, faeces, urine, lower-load greywater and higher-load greywater are properly separated and treated. Thus, this new sanitary approach system provides many advantages among which: recovery and recycle of plants nutrients (Nitrogen, phosphorus and potassium), control of micro pollutants and pathogens and reduction of wastewater flow (Esrey, 2001; Heinonen-Tanski et al., 2010).

The recycle and recovery of domestic waste was found beneficial, human urine being the most nutrient abundant part of wastes to increase plant's yield in poor areas (Heinonen-Tanski and Van Wijk-Sijbesma, 2005). In fact, human urine is rich in a multi-component nutrients (N, P, K, S, Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-}) and other micronutrients in amounts that vary depending on the diet (Boh and Sauerborn, 2014). So collected separately to faeces, urine can substitute commercial fertilizers (Germer et al., 2011; Pradhan et al., 2009; Tidaaker et al., 2007). Furthermore, urine is foremost a nitrogen (N) source as it contains disproportionally more of this element than P, K or other nutrients (Germer, 2008). This N appears mostly in organic form as urea $CO(NH_2)_2$. Whereas industries have developed during the last decades urea as the most important industrial nitrogen fertilizer (Granelli, 1995) why not get it from urine?

Thus, Kirchmann and Pettersson (1995) have demonstrated the possibility of using human urine as a fertilizer to amend soils in crop production; it has raised a high attention in agriculture during the last two decades and the agronomic importance has been validated both under controlled conditions (Mnkeni et al., 2008) and by field trials (Germer et al., 2011; Pradhan et al., 2010).

However, some researchers reported a decrease in crop yield on soil amended with human urine and this decline in crop growth was suspected to be due by human urine amendment increasing salinity (Andersson, 2014; Boh and Sauerborn, 2014). But, until to date, there is not many published work proving that really, soil amendment by urine induces soil salinity, especially in sahelian area.

On the other hand, it has been found and demonstrated that phosphorus and organic matter can reduce the effect of salinity on crops due to its values of improving the soil structure, increasing the water holding capacity of the soil and nutrients retention (Benzellat, 2012; Hijikata et al.,2011). Hence, the present study aims to perform a quantitative and qualitative evaluation of soils nutrients and salinity trends as amended with urine. More specifically, the study aims to:

- ✓ evaluate the salinity on soil amended with urine;
- ✓ identify the main type of salt mineral accumulated in soil amended with urine;
- ✓ evaluate the salinity of soil as amended with urine and compost from faeces.

Specific objectives turn around these followings hypothesis respectively:

1) Urine amendment corresponding to the plant need in nitrogen should not increase significantly the global salinity. So the electrical conductivity should not exceed 4 dS/cm the value above which the soil is considered as saline.
2) The main mineral element not retained by plants is sodium from urine. So this cation when not leached out of the soil will probably accumulate, leading to an increase of the Sodium Adsorption Ratio (SAR) of the soil solution compared to the control.
3) Organic matter contained in compost can reduce soil solution global salinity by adsorbing sodium.

Out of the present introduction, the study will be reported in 3 chapters schemed as follow: (1) a literature review, (2) a methodology and (3) results and discussion. A conclusion will close the report.

Before entering in deep interest of the study, it has been found necessary to mention that the present study has been conducted within the framework of AMELI-EAUR project.

AMELI-EAUR in French “Amélioration des conditions d’accès durable à l’eau potable en zone urbaine et rurale au Burkina Faso” is a project for improved sustainable access of drinking water and sanitation in urban and rural areas in Burkina Faso. The project is implemented by the International Institute for Water and Environmental engineering (2iE) in Ouagadougou, Burkina Faso and the Hokkaido University (HU) in japan in partnership with JICA (Japanese International Cooperation Agency), JST (Japan Science and Technology Agency) and MASA (Burkina Faso Ministry of Agriculture and Food Security). The project’s objectives are:

- to treat domestic liquid waste (human excreta and greywater) by developing sanitation technologies oriented to agriculture valorization based on the principle of “don’t mix” collection;
- to develop accommodated technologies of purifying drinking water at household level in sahelian area;
- capacity building of communities in hygiene and sanitation domain;
- capacity building of young researchers in environmental sciences focusing in sanitation.

The project has pilot families at Ziniaré (30 Km) from Ouagadougou and at Kamboinsé (12km from Ouagadougou) where field experimentation are done in order to assess the purifying efficiency of AMELI-EAUR technologies settled there. The project has also an experimental site at 2iE Kamboinsé where the field work of the present study has been conducted.

CHAPTER I. LITERATURE REVIEW

I.1. Sustainable sanitation system

Nowadays, in most countries of the world people have ever increased interest in developing alternative sanitary systems, which would be more sustainable than the conventional one (Berndtsson, 2006). The conventional sanitation concepts, based on flush toilets, has been found as a water wasting technology, and are neither an ecological nor economical solution in both industrialized and developing countries (Langergraber and Muellegger, 2005). The new approach today is to move to an ecological sanitation based on toilets with a diverting system separating urine from faeces (Figure 1b) that may facilitate domestic wastewater treatment and valorization. This approach is a resource minded and represents a holistic towards ecologically and economically sound sanitation (Esrey, 2001; Winblad, 1997), aiming often to reuse the plant nutrients from human excreta as a fertilizer in agriculture (Langergraber and Muellegger, 2005).

(a)

(b)

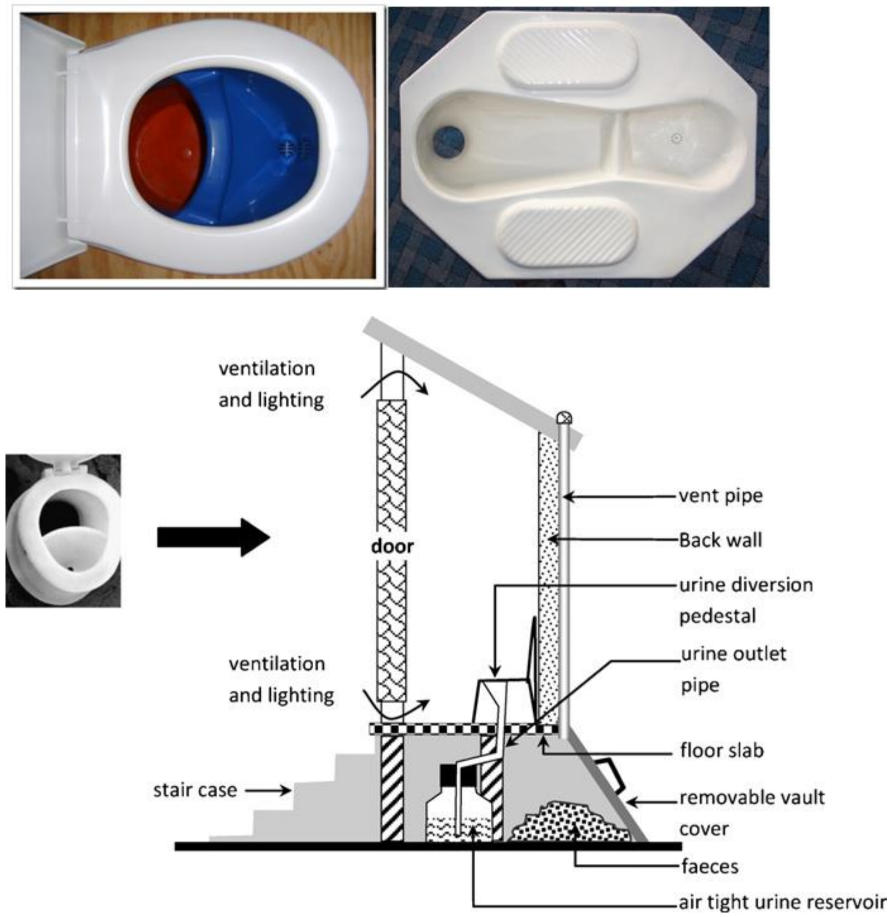

Figure 1: (a) Pictures of source separated toilet interface; (b) Schematic diagram of source separated toilets system (adopted and modified from: Larsen and Gujer, 1996)

I.2. Reuse of human excreta in agriculture

Human excreta, particularly urine are recognized as a resource which should be made available for agriculture reuse. Human urine is a byproduct from the human metabolism excreted by the kidney and contains most of the nutrients present in human food which have not been used for cell growth or metabolism. It's rich in nutrients as nitrogen and phosphorus needed for plant growth and those nutrients are in a readily available form for plant uptake. Adamsson (2000) estimated that about 80% of the nitrogen and 50% of the phosphorous in domestic wastewater originate from human urine, which has a volume of only 1 – 1.5 l per person and day. For that reason, it has been resolved to collect urine separately from faeces and other wastewater because it turns the valorization easy and safe. In agriculture since the ancient times, human urine was a resource used for plant fertilization in intensive farming systems in various parts of Asia (Karak and Bhattacharyya, 2011). Since two decades, researches have been done and proved that urine can be valorized in food production as a nitrogen fertilizer. In fact, among all nutrients and micronutrients found in human urine, nitrogen is the major element. Richert et al. (2001) reported that one liter of undiluted human urine contains 3 to 7 grams of nitrogen. This nitrogen is mainly found in form of urea (Heinonen-Tanski et al., 2007), close to the nitrogen commercial fertilizer formula. The urea is converted in nitrates (the readily form for plant uptake) through following natural reactions within the soil

$$CO(NH_2)_2 + 3H_2O \rightarrow 2NH_4^+ + HCO_3^- + OH^- \quad (1)$$

$$NH_4^+ + 1.5\,O_2 \rightarrow NO_2^- + 1H_2O + 2H^{+-} \quad (2)$$

$$NO_2^- + 0.5\,O_2 \rightarrow NO_3^- \quad (3)$$

Karak and Bhattacharyya (2011) reported many experimental results affirming that human urine is a source of alternative natural fertilizer in agriculture. Heinonen-Tanski et al., (2007) experimenting on a cultivation of cucumber with one treatment using manufactured fertilizer and another one using urine, the results showed that the yield after urine fertilization was similar or slightly better than the yield obtained from control rows fertilized with commercial mineral fertilizer. Pradhan et al. (2007), also conducted an experiment using human urine as a fertilizer in comparison with industrial fertilizer and non-fertilizer treatments on cabbage cultivation; they observed that growth and biomass were slightly higher in urine fertilized cabbage than in industrial fertilized cabbage and very different to non-fertilized cabbage. From these results, the authors stated that urine can be used as a good fertilizer for cabbage and can represents a feasible alternative to industrial fertilizer. Thus, human urine is not only rich in nitrogen which can substitutes commercial fertilizer, but also gives quite comparative yield to those obtained by chemical fertilization. According to Wolgast and Rena (1993) *in* Karak and Bhattacharyya (2011), the annual amount of human urine from one person corresponds to the amount of fertilizer needed to produce 250 kg of cereal which is again the amount of cereal that one person needs to consume per year. Though, besides of being a good nitrogen fertilizer, the presence of other elements like Na, Cl salts and other in human urine are suspected to be a limitation to its use in crop production (Boh et al., 2013). Richert et al., (2010) reported that human urine contains 150ml of NaCl corresponding to 8.8 g per liter. According to works of Mnkeni et al. (2008) conducted on non-saline soils, crops growth declined in plots where urine was used as the only nitrogen source for plants. Mnkeni et al. (2005) and Andersson (2014) works based on different rates of urine application, showed that the lower rate of direct application of urine was the best performing treatment with a mean yield more than double that of the control plot. Plots receiving a higher rate of urine produced slightly lower yields compared to plots with the lower application rate. The authors expected that the depressed crop growth under high rate application could have been caused by salinity induced by the presence of NaCl and other salts within urine as observed in the high electrical conductivity (EC) of the treated soils (13.35 mS/cm form 1.48 mS/cm); and the higher the soil salinity, the lower the yield (Katerji et al., 2000).

Beyond the phenomenon of salinity, Na^+ applied with urine can increase the risk of soil sodicity which is described as the excessive levels of Na than other chemicals in the soil solution (SAR) or on the cation exchange complex of the soil (ESP) (Qadir et al., 2006). SAR represents soil sodicity by the soluble Na^+ concentration relative to the soluble divalent cation concentrations in the soil solution (i.e. the sodium adsorption ratio, SAR; Equation 1), ESP is the exchangeable sodium fraction expressed as a percentage of the cation exchange complex (i.e. the exchangeable sodium percentage ESP; Equation 2).

$$\mathrm{SAR} = \frac{[Na^+]}{\sqrt{\frac{[Mg^{2+}]\, x\, [Ca^{2+}]}{2}}} \qquad (1)$$

$$\mathrm{ESP}(\%) = \frac{[Na^+]}{CEC} \qquad (2)$$

There exist values beyond which a soil is classified to be sodic or not. The US Salinity Laboratory Staff have determined an ESP value ≥ 15 and a SAR value ≥ 13 to define sodic soils (Halliwell et al., 2001).

In fact, plants in large terrestrial areas of the world except some halophytes, do not uptake Na^+ because it is not essential for their growth, in contrast it's a limiting factor to it (Blumwald, 2000). Consequently, successive application of urine will lead to Na^+ accumulation into the soil for it is continually supplied within urine whereas not taken up by plants.

Sene et al. (2013) studying the effect of continuous application of extra urine on plant and soil, showed that the SAR value increased with the increase in urine volume application and observed also a primary salt stress in all urine treatment. Different results showed that too much volume of human urine applied on agriculture land as fertilizer, may cause simultaneously excess of sodium in soil and eventually in plant. It makes difficult to plant to discriminate K+ to Na+ because of the similarity of their hydrated ionic radii (Blumwald, 2000), that is why an excess of Na+ can be found in plants even though toxic. Pradhan et al. (2010) reported that urine fertilization caused competitive uptake of potassium (K) and sodium (Na) in plants (Pradhan et al., 2010) and excessive urine application inhibited plant growth; and Mnkeni et al. (2008) continued to suppose that the depressed growth during the experiment on their previous study could be explained by the high sodium addition into the soil through urine application. Indeed, Sodium inhibits plant growth since disrupting the water uptake in the root, dispersing soil particles, restricting root growth and/or interfering with the uptake of competitive nutrients (Asano et al., 2007).

I.3. Soil salinity and its effects on soil

Soil salinity refers to the presence of major dissolved inorganic solutes in the soil aqueous phase, which consist of soluble and readily dissolvable salts including charged species (e.g., Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^+, HCO_3^-, NO_3^-, SO_4^{2-} and CO_3^{2-}), non-ionic solutes, and ions that combine to form ion pairs (Corwin and Lesch, 2005)

According to Richards (1954) quoted in (Wiegand et al., 1996) , soils are considered saline or salt-affected when the electrical conductivity of water extracted (ECe) from water-saturated soil samples from the root zone exceeds 4 dS/m.

Effects of soil salinity are manifested in loss of stand, reduced plant growth, reduced yields, and in severe cases, crop failure. Salinity may also cause specific-ion toxicity or upset the nutritional balance of plants. In addition, the salt composition of the soil water influences the composition of cations on the exchange complex (CEC) of soil particles, which influences soil permeability and tilth (Feikema and Baker, 2011). Qadir et al. (2001) showed that salt-affected soils deteriorate as a result of changes in the proportions of certain ions present in the soil solution and on the exchange sites. These changes lead to osmotic and ion-specific effects as well as to imbalances in plant nutrition. Such effects may range from deficiencies in several nutrients to high levels of sodium (Na^{+}). Salinity offsets nutritional balance in plants, reducing nutrient uptake in less tolerant crops with a consequent decrease in plant growth (Nandy et al., 2007 in Boh et al., 2013).

The table I resumes thresholds at which a soil is classified as a normal, saline or sodic soil.

Table I: Different Threshold values for salinity and sodicity classification of soils

Class	EC (dS/cm)	SAR	ESP	Typical soil structural condition
Normal	Below 4.0	Below 13	Below 15	Flocculated
Saline	Above 4.0	Below 13	Below 15	Flocculated
Sodic	Below 4.0	Above 13	Above 15	Dispersed
Saline-Sodic	Above 4.0	Above 13	Above 15	Flocculated

Source[1]

I.3.1. Methods of determining soil salinity

There are two main different methods to determine the soil salinity.

According to the US Salinity Laboratory Staff (1954) reported in (Rhoades et al., 1999), salinity is quantified in terms of the total concentration of such soluble salts, or more practically, in terms of the electrical conductivity of the solution. Though, the method based on measuring the electrical conductivity of the soil is generally recognized as the most effective method for the quantification of the soil salinity (Norman et al., 1989 in Bannari et al.). However, if knowledge of a particular solute(s) concentration is needed (such as when soil sodicity or the toxicity of a specific ion are to be assessed) then either a sample of soil, or of the soil water, is required to be analyzed. The latter methods require much more time, expense and effort than the instrumental field methods (Rhoades et al.,1999).

I.3.2. Electrical conductivity

Electrical conductivity (EC) is a numerical expression of the inherent ability of a medium to carry an electric current.

[1] http://extension.uga.edu/publications/detail.cfm?number=C1019

EC is commonly used as an expression of the total dissolved salt concentration of an aqueous sample, it is also affected by the temperature of the sample and by the mobility, valences and relative concentrations of the individual ions comprising the solution (water itself is a very poor conductor of electricity). Furthermore, not all dissolved solutes exist as charged-species; some are non-ionic and some of the ions combine to form ion-pairs which are less charged (they may even be neutral) and, thus, contribute proportionately less to electrical conduction than when fully dissociated.

The determination of EC generally involves the physical measurement of the materials' electrical resistance (R), which is expressed in ohms. The resistance of a conducting material (such as a saline solution) is inversely proportional to its cross-sectional area (A) and directly proportional to its length (L).

A soil is considered salty when it electrical conductivity is above 4 mmhos/mm at 25°C (Benzellat, 2012; Rhoades et al., 1999), knowing that: 1 dS/m= 1 mmhos/cm = 1 mS/cm.

The electrical conductivity value can be converted in salt concentration knowing that:

1mg/l salt = 640 EC dS/m (FAO, 2003)

I.3.3. Different method of Electrical conductivity measurements

There exist different methods to determine the electrical conductivity of a soil. The table below (table II) presents 4 methods of determining the soil electrical conductivity in the laboratory as well as at field level, their advantages and drawbacks comparing to each.

Table II : Different types of measures of electrical conductivity (advantages and inconveniences of each)

Method de EC	Definition	Advantages	Inconveniences
ECa	Electrical conductivity of bulk soil	- Monitoring solute changes with time and characterizing the salinity conditions of extensive areas. - Such immediate determinations are so valuable for salinity diagnosis, inventorying, and monitoring applications (Corwin and Lesch, 2005)	————

ECe	Electrical conductivity of the extract of a saturated soil-paste	Can determine the concentration of a particular solute (such as when soil sodicity or toxicity of a specific ion is to be assessed). (Rhoades et al.,1999)	- not well suited in the field nor for intensive-mapping and monitoring applications - requires much more time and effort than the instrumental field methods (Bannari et al.)
ECw	Electrical conductivity of a soil-water sample	Better method because it consists of analyzing the soil water near the root zone. (Rhoades et al.,1999)	- Only referenced to a specific water content, such as field capacity - Methods for obtaining soil water samples are too labor, time and cost intensive at typical field water contents to be practical
ECp	Electrical conductivity of a saturated soil-paste	ECp can be measured either in the laboratory or in the field using simple or inexpensive equipment. (Rhoades et al.,1999)	______________

Nevertheless, the appropriate method to use depends upon the purpose of the salinity determination, the size of the area being evaluated, the number and frequency of measurements needed, the accuracy required and the available equipment/human resources (Rhoades et al., 1999).

I.4. Effect of organic matter on soil salinity

Furthermore, some researches have demonstrated that the toxicity effect of urine on crop and soil can be reduced and remain positive when supplied with organic matter. Many trials that were done with : applications of urine (1), urine combined with compost (2) and compost only (3); showed that the combination of urine with compost were the best and are the one that gave the best yield of maize, tomato and pepper (Boh et al., 2013; Pradhan et al., 2009, 2010; Shrestha et al., 2013). Results of Boh et al. (2013) study revealed that the application of wood ash (as an organic matter) alone or a combined application of urine and wood ash is beneficial to young maize plants when soil salinity is 4 dS/m or lower.

CHAPTER II. MATERIALS AND METHODS

II.1. Site description

The experiment was conducted at the International Institute for Water and Environmental Engineering (2iE) experimental site located at Kamboinsé (Coordinates: 12°27′39″N and 1°32′56″W), 12 km from Ouagadougou, Burkina Faso. The climate is of the type semi-arid characterized by a long dry season from November to June and short rainy season from July to October. The annual mean rainfall is estimated to 740 mm (INSD, 2006). April is the hottest month with temperature records beyond 40°C. The mean minimal and maximal temperature during the trial period (February to end May) was 26 °C and 40°C, respectively.

II.2. Experimental design

Tomatoes were planted in pots of 50 liter filled with clayey soil sampled from the shallow end of a dam not far from the experimental site. The size of pots was: 50 l of volume, 41 cm top diameter, 32 cm bottom diameter and 47.5 cm of the height (figure 2b). The trial consisted of three treatments included the control, with 3 replicates by treatment making a total number of 9 pots (figure 2a and figure 3). We had three rows of pots; each row had 3 pots from the same treatment.

(a)

(b)

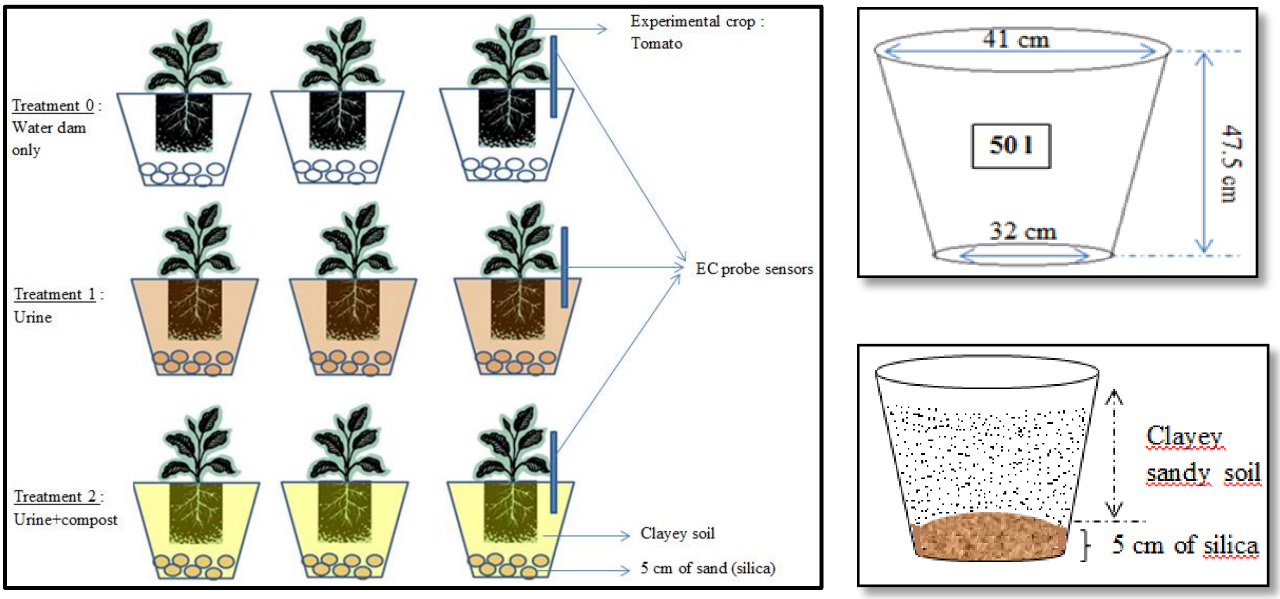

Figure 2: (a) Illustration of the experimental set, and (b) size of pots

The first row with three pots (green color) was for the urine+compost treatment, the second in the middle (brown color) concerned the control and the third one (purple color) was for urine treatment. Pots were separated to 1.20 m from each other. The space between the pair of bricks supporting a pot was 20 cm. The inferior diameter of pots was 32 cm.

Figure 3: View of the experimental set

Each pot was provided with a drainage system in order to facilitate collection of excess water that passes through the barrel and take it for analysis. The drainage system consisted of piercing the center bottom of pots and dispose small pipes leading water to 1 liter bottles connected to them (figure 4).

Figure 4: Leachate collection system

A 5 cm layer of silica (sand) preceded on the bottom of each pot before filling them with soil. This layer of sand had the role of facilitating water drainage.

Pots were separated to 1.20 m from each other. The space between the pair of bricks supporting a pot was 20 cm. The inferior diameter of pots was 32 cm.

Experimental crop

Tomato (Solanum Licopersicum formely Lycopersicon Esculentum): was chosen as the experimental crop for it high sensitivity to soil salinity (Brady and Weil, 1999). The variety used was Tomato Petomech. It's a local variety taking 70 to 80 days from the sowing to harvest of first tomatoes.

According to local fertilizer recommendations from INERA[2] , nutrients demand for tomato is 200-150 kg N/ha, 60-80 kg P/ha and 190-200 kg K/ha. To simplify the quantification of nutrients supply, the mean of these different values were applied as the need of each nutrient for the plant. So, needs were estimated as follow: 155 kg/ha of Nitrogen, 70 kg/ha of Phosphorus and 195 kg/ha of Potassium. In treatment concerning urine application, urine quantity applied was only based on nitrogen requirements, meaning that phosphorus and potassium contain in urine were not taken into account. Phosphorus and potassium were however brought to all treatments using K_2SO_4 and KH_2PO_4 (commercial fertilizers). Referring to the plant requirements, 4g/pot of KH_2PO_4 and 3g/pot of K_2SO_4 were applied directly to cover the plant demand in potassium and phosphorus for the whole growth period.

The daily amount of water needed for irrigation was 1 liter per day (1l/day); value obtained by multiplying the crop coefficient at each growth stage of the plant by the potential evapotranspiration of each month during the period of the trial. Month potential evapotranspiration's were calculated using Cropwat; the input data (climatic data of Ouagadougou: humidity, solar radiation, temperature) were generated on Climwat. The rule of irrigation concerned only to compensate water lost by evapotranspiration. See calculation procedures and sheet for daily water supply on appendix 1. The crop coefficients of tomato at different stage were gotten from Cropwat, FAO software for irrigation. . Plants irrigation was done manually and every day; twice a day: 0.5 liter the morning and 0.5 liter afternoon around 4 pm for the three treatments

Tomatoes were sown on 22th February 2014 in the greenhouse at the experimental site and young seedlings were transplanted outdoors in pots 3 weeks later on 17th march 2014 (22 days

[2] Institut de l'Environnement et des Recherches agronomiques

after sowing) after noon. At the beginning each pot had 5 plant holes with 2 to 3 plants per hole.

Nutrients were supplied to plants as follow:

On April 09th, 24 days after transplantation proportions of Potassium (K) and Phosphorus (P) corresponding to the crop demand were supplied to the soil.

On April 11th, twenty-five (25) days after transplantation urine and compost were applied according to treatment and nitrogen demand for each treatment. For the urine treatment, 250 ml of urine were applied in each of the three pots concerned by the treatment on that day. Knowing that the urine that is used contains 2.7g N/liter and depending on the surface of the pot, we needed 2 g N/pot which make 0.7 liter of urine per pot to satisfy crop demand for the whole growth cycle. But urine was supplied in 3 phases so the 0.7l was divided by 3 which make 250 ml for each application phase. In the urine+compost treatment, 50% of required nitrogen from urine (equaling 125 ml per pot by application) and 50% of nitrogen (equaling 1 g N from compost + 1g N from urine) were applied to the soil. Nitrogen content in compost was 54.7 mg/g making it 18g N/pot if we consider the 50% of the pot requirements. Compost was superficially incorporated into the soil after stirring the soil because it was missed to be brought before transplantation.

The second application of urine was done two (2) weeks after the first application, it was on April 25th and the last was on May 9th two (2) weeks after the second application.

All plants (shoot and root) were harvested on May 21th, almost two (2) weeks after the last urine application for dry biomass determination.

II.3. Sampling and data collection methods

Soil samples were collected before planting and at the end of the trial, almost two (2) weeks after the last application of urine. At the beginning before planting, one composite sample of soil was taken to the laboratory. Samples taken after harvest were collected separately in each pots according to treatments and at three different depth (0-15 cm, 15-25 cm and 25-35 cm) using an auger. After sampling, a composite sample of soil was made from the three pot of the same treatment at the same depth, giving a total of 9 composite samples. All samples were conserved in plastic bags from field to the laboratory. At the moment of analysis; soil samples were air-dried and sieved through a 2 mm stainless steel sieve. Water soluble cations (Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}) and anions (Cl^{-}, NO_3^{-}, SO_4^{2-}, PO_4^{3-}) were determined from a 1:10 soil:water extract after shaking 4 g of air-dried soil in 40 ml deionized water for 1 hour and centrifuged for 10 minutes at 2500 rpm. While soil pH and electrical conductivity were measured in a 1:2.5 and 1:5 soil:water suspension respectively, according to standard method using electrodes connected to WTW 350i multi-parameters reader. The total phosphorus concentration was determined by nitric acidic digestion with hydrogen peroxide then read to a spectophotometer at 880 nm after addition of ammonium molybdo-vanadate (APHA, 1989).

Urine was collected from two pilot-family of the project Ameli-EAUR based at Kamboinsé, where toilets with a diverting system of urine and faeces are installed. Urines were stored in a plastic barrel during 6 months before application on the experimental field and were stirred to take a sample for chemical content analysis prior to use. Undiluted sample was used for electrical conductivity and pH measurements before application. Cations and anions determination were done with a urine sample diluted at a ratio 1:250 urine: deionized water.

Sample of stored compost was collected in a plastic bag for analysis before it use. Compost used in this work was made by faeces collected from urine diversion toilet/composting toilet of pilot families which are at Ziniaré. This compost is a mixture of faeces and sawdust. The mixture is directly done in the composting reactor within the toilet the reactor is emptied once it is full. Compost can be directly used after empting the reactor. Procedures for compost sample analyses were almost the same as for the soil sample except some case of difference where the prepared sample might be diluted for further analysis. The soil pH and electrical conductivity were determined by specific probes after extraction of compost by 1:2.5 and 1:5 ratio compost: water, respectively. 0.2 g of compost was digested by nitric acid for total phosphorus concentration determination following the same procedure as for soil sample.

Dam water as well as leached waters were collected for physiochemical analysis. Leached waters were collected and analyzed at the end of trial after harvest. Though, it is not all leached waters from the drainage system that were analyzed. It rained tree times during the last stage of the trial and some bottles were full of water that spilled out, whereas others were not. We suppose that the overflow of those bottles was due by the presence of tubes in pots that were settled to keep holes that were used for punctual electrical conductivity measurements; and that system made easy the passage of water through them from up to the bottom. This was verified by how much half-filled bottles were concentrated than those which overflowed.

Different parameters determined by sample and methods of analysis are summarized on table III.

Table III: Different parameters and methods of analysis

Parameter	Sample				Method & Instrument
	Soil	Dam water	Urine	Compost	
pH	1:2.5	X	x	1:2.5	pHmeter
Electrical conductivity	1:5	X	x	1:5	Conductimeter
Nitrates (NO_3^-)	x	X	x	x	Spectrophotometer of molecular absorption (HACH spectrophotometer DR 2000) using HACH reagent
Nitrites (NO_2^-)	x	X	x	x	
Ammonium (NH_3)	x	X	x	x	
Orthophosphates	x	X	x	x	
Sulfates (SO_4^{2-})	x	X	x	x	
Total phosphorus	x	x	x	x	Spectrophotometer of molecular absorption(DR 5000) after mineralization
Total nitrogen	x	x	x	x	Khedjal method
Chloride (Cl^-)	x	x	x	x	Titration with $AgNO_3$
Sodium (Na^+)	x	x	1:200	x	Spectrophometer by flame emission JENWAY PFP7 type
Potassium K^+	x	x	1:200	x	
Calcium (Ca^{2+})	x	x	x	x	Titration with EDTA
Magnesium (Mg^{2+})	x	x	x	x	
Bicarbonate and carbonate		x	x		Titration with Sulphuric acid

II.4. Soil salinity monitoring

Soil salinity was first determined by measures of electrical conductivity. The electrical conductivity was assessed in laboratory and on the field. In the laboratory we used a WTW 350i multi-parameters for electrical conductivity measurements. At field level, soil salinity was assessed using two different instruments: (1) an integrated electronic instrument "e+ SOIL MCT (e+ sensor)"(figure 6) for permanent recording, monitoring of soil moisture, conductivity and soil temperature; and (2) an EC-probe set for punctual soil conductivity measurements (figure 7). Both instruments are from the Eiljkelkamp society. The e+sensors were tree (3), one by treatment; they were implanted vertically at the depth of 15 cm. The sensors were first settled to record values every ninety (90) minutes before urine application, and it was brought to every thirty (30) minutes after the first urine application and that frequency of recording remained the same for all the period of the experimentation. Records from sensors were collected using the e+ control device (figure 6). Once data are collected they were transferred to computer to be treated on LDM software.

The standard EC-probe set for soil conductivity measurements consisted of an EC-probe and an earth resistivity meter that served to take punctual measurement of the bulk electrical conductivity of the soil at different depths in all pots.

Some punctual measurements of the bulk electrical conductivity have been done at a frequency of 2 times per week in all the 9 pots of the trial. Punctual measures have been taken at two different depths for the same pot, at 25 cm and at 35 cm (figure 5). With an auger, a hole of 25 cm and 35 cm were dug within each pot for punctual measurement with a probe. Holes were covered with tubes in PVC in order to keep the same hole for future measurements instead of digging each time before to plunge the probe. The purpose was to avoid soil loss while removing the soil with the auger or disturb the soil properties in different depth because it could happen to auger and bring the soil from the upper layer to the bottom or vice versa. Values read on the resistivity meter were the earth resistivity. The following equation was used to get the electrical conductivity value :

$$\mathbf{EC = k * ft / Rt}$$

Where

EC: Soil electrical conductivity in (mS/cm) at 25°C,

k: The empirically established constant or ‘cell constant’ (cm^{-1}) The cell constant of the Eijkelkamp Agrisearch Equipment EC-probe comes to 17.5 cm^{-1},

ft: Temperature correction factor for converting the measured EC to the EC at 25°C.

Rt: Measured resistivity at the prevailing temperature in (Ω)

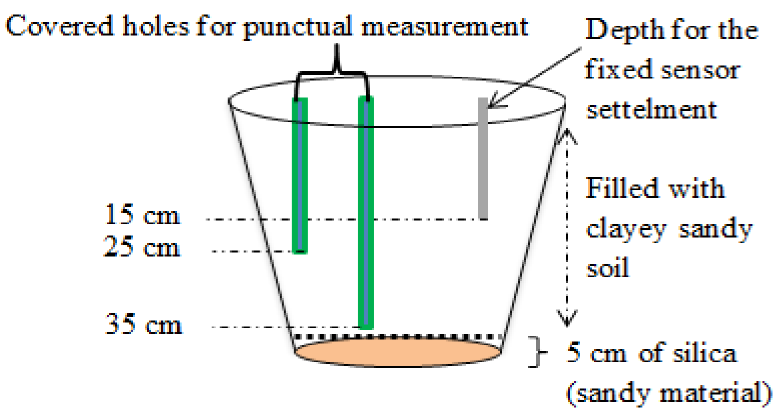

Figure 5: Different depth of sensors and EC probe set

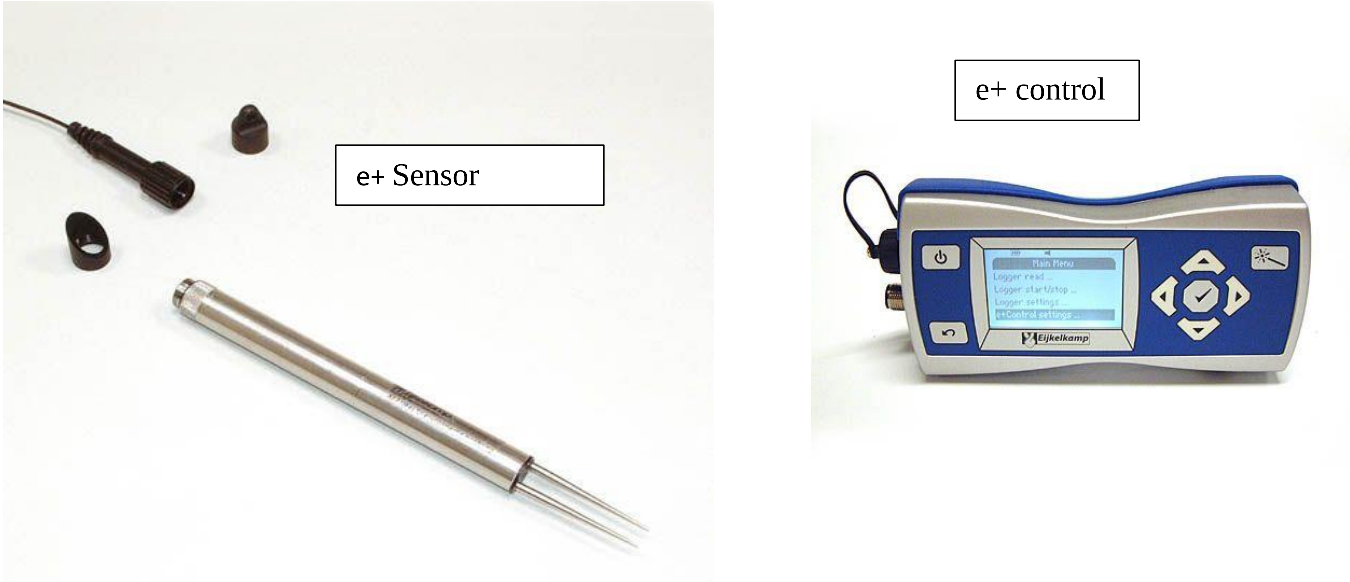

Figure 6: e+ SOIL MCT and e+ control for field electrical conductivity measurements

1. Earth resistivity 2. EC Probe 3. Auger

Figure 7: EC probe for soil resistivity measurements

II.5. Data analysis

After different analysis at laboratory level and gathering data from field, they were analyzed before interpretation. Data analysis for interpretation was done using Excel office, some descriptive statistics and ANOVA tests were done using XLSTAT an excel macros.

CHAPTER III. RESULTS AND DISCUSSION

III.1. Initial soil, urine, compost and dam water characterization

Main chemical and physical characteristics of the soil, dam water, urine and compost sampled before the trial are given on table IV. Urine sample had the highest electrical conductivity 2.5 times more than compost, 5 times more than dam water and 259 more times than the initial soil electrical values. Also, the SAR of urine sample was found to be the most high among others. This is perfectly evident due to the difference in concentrations of Na^{+}, Ca^{2+} and Mg^{2+}. Sodium in urine has been found 46 and 56 more higher than calcium and magnesium, respectively. Table IV resumes results of different analyses which have been done starting the trial.

Table IV : Main chemical and physical characteristics of different matrix

	Soil (mg/kg)	Dam Water (mg/l)	Urine (g/l)	Compost (mg/kg)
pH	6.80	7,54	8.10	
EC (mS/cm)	0.081	0.189	21	8.35
Total Nitrogen	0	0,84	2.7	54.7
Total Phosphorus	48.78	2,8	0.425	194
Potassium	0.57	11.5	3.2	1848
Sodium	2.56	6.4	2.8	565
Calcium	5.6	20.4	0.06	160
Magnesium	2.9	4	0.05	96
Chloride	4	3.15	2.6	497
Surfactants	ND	0	ND	ND
SAR	0.21	0.3	64.2	10.9

III.2. Results of Electrical conductivity

III.2.1. EC measurements results from E+ sensors

Records from sensors helped to study the electrical conductivity trend little by little as urine was applied in the soil. According to measurements read on fixed sensors for each treatment, the EC increased in the urine treatment from minimum and maximum amplitudes of 0.24 mS/cm and 0.34 mS/cm to a min and max amplitude of 0.83 mS/cm and 0.91 mS/cm at the end of the trial (figure 9a). The EC curve for the compost+urine treatment increased from a min and max amplitudes of 0.26 mS/cm and 0.34 mS/cm to a min and max amplitudes of 0.5

mS/cm and 0.6 mS/cm (figure 9b). The EC of the control treatment varied around min and max amplitudes of 0.26 mS/cm and 0.34 mS/cm to min and max amplitudes of 0.28 mS/cm and 0.38 mS/cm. It's been observed that the electrical conductivity varied daily depending on the temperature at each hour of the day (figure 8). Established relation between them two is that EC variation was inversely disproportional to temperature change. When the temperature increased, the EC decreased. This can be explained by the fact that, temperature increase results in soil water evaporation which reduces the soil solution thus concentration of dissolved salts which precipitate.

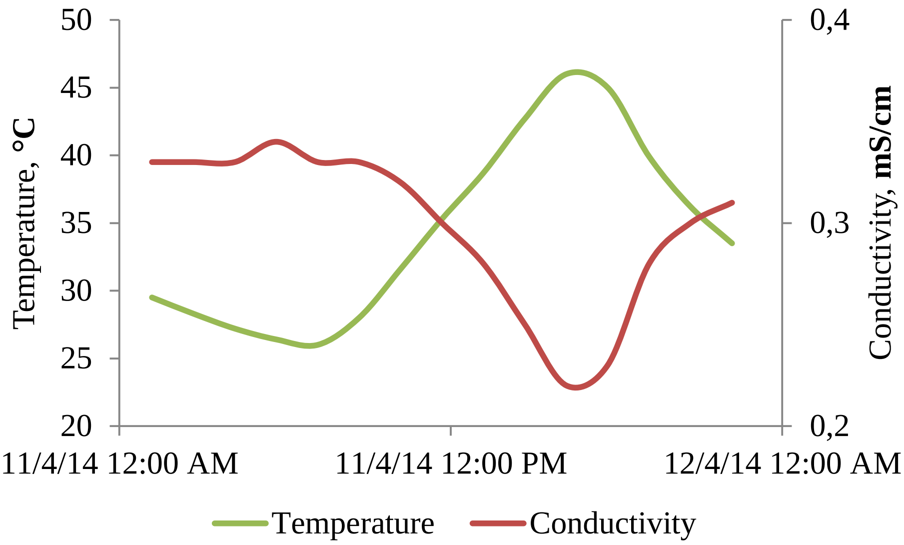

Figure 8: EC variation's curve comparing to daily temperature

Furthermore, except the daily temperature that influenced the soil's daily EC, the EC varied differently between the three different treatments all along the trial. Each curve from the three treatments had different trends divided in sections (figure 9). The first section of the urine treatment EC curve seemed stable. On section 2, after the second application of urine, the EC trend seemed to increase, comparing the slope of the two sections, 1 and 2 the second slope is higher 5.8 more than the first. The EC trend on section three increased significantly. This increase is observed after a rainfall. In fact, it's been observed in results that rain had a great effect on EC trend change. This may be explained by the fact that rain does dissolve the salts contained in undissolved form within the soil, increasing then the concentration of dissolved salts in the soil solution. The EC could also decrease if the rain did dilute the salts concentration, but in this case there has been a phenomenon of dissolution. On the fourth section, the trend decreased a bit whereas urine was applied for the third time. This decrease can be explained by the temperature increase during those days (appendix 2: a) resulting to the phenomenon of evaporative recovery which would reduce the soil solution, inducing then the decline of the dissolved salts concentration in other words salts precipitation. The trend increased again on section 6 after the rain. Again, this reveal that salts were precipitated in the soil due to evaporative recovery in the previous section, then rainwater did dissolute salts resulting in a high concentration of dissolved salts in the soil solution. The increase of electrical conductivity after a rain period can also be due by salt inward into the soil., this can explain the increase of EC after each rain period.

The EC curve of compost+urine had a slight increasing trend after the first application of urine and compost, and got stable after for some days with a little positive trend (section 1). For the second section, the curve suddenly had a decreasing trend after the rain and third urine application. Though, the maxima EC values for this section were high in comparison to the previous one. The hypothesis face to this situation can be that the decrease of the trend is caused by the variation of the minima values changing day by day with temperature resulting in high level of water evaporation. Referring to temperature curve on appendix 2b, temperature on that section had maximum values reaching 45°C with minimum values of 28°C whereas on the previous and followed section the two extremes are equilibrated, still this situation may be due to high level of evaporative recovery. The section 3 behaved also as the second third after a high increase of the EC value after a rain, the trend relapsed. The reason may be the same reason as on the third section. The trend increased significantly on the fifth section after a rain of 51 mm to decline again on the sixth section where the temperature increased again. According to the EC curve of the control, the highest value that the EC attained is 0.38 mS/cm during the whole trial period. Phenomenon of evaporative recovery decreasing the EC is observed on the curve of the control treatment but they are not important as for the other two treatments. Figure 9 represents the trend variation of the EC curve for the three treatments.

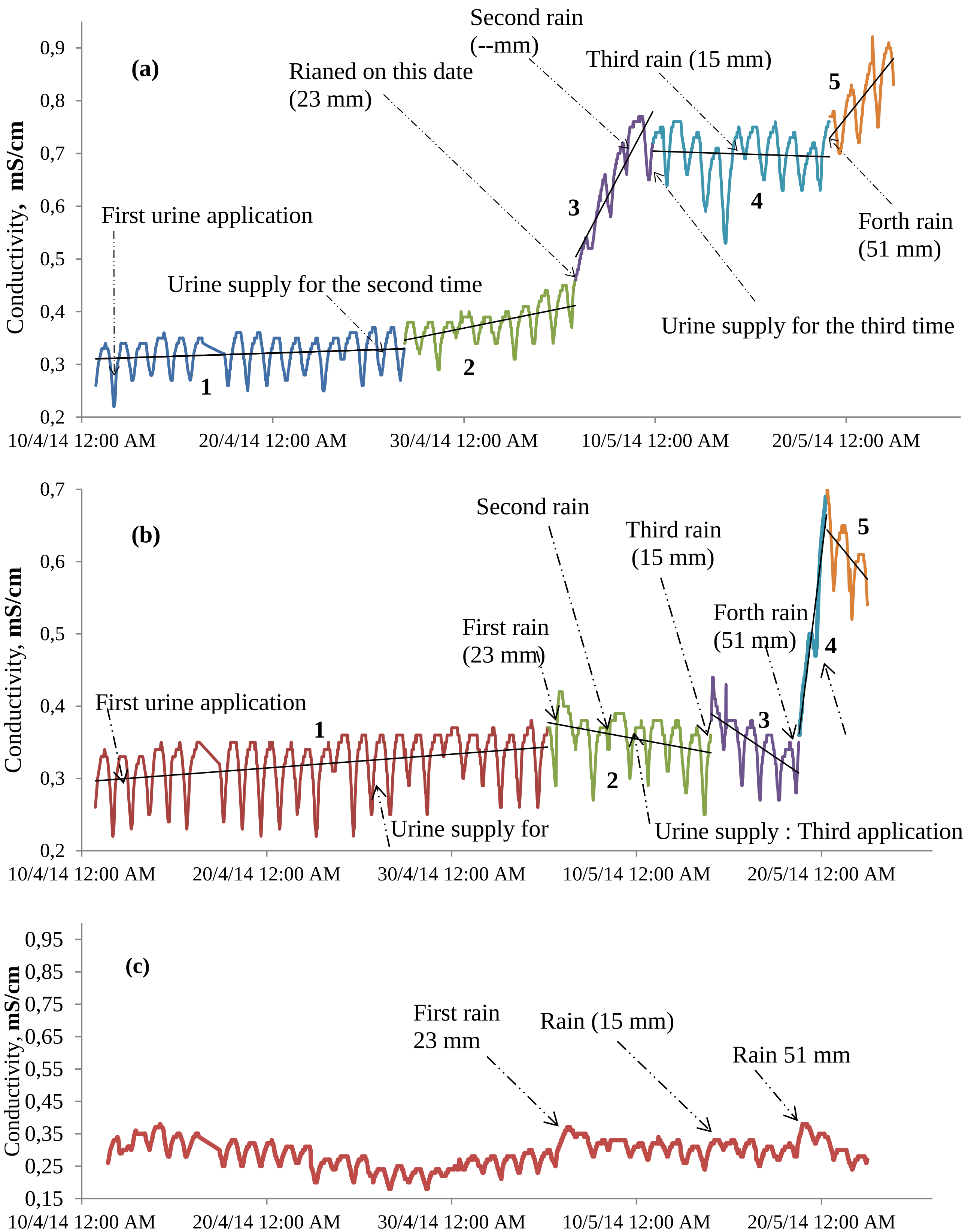

Figure 9 : Different trends of the EC curve divided in sections (a) urine treatment and (b) compost+urine (measures taken at 15 cm of depth, from 10th April 2014 to 22th may 2014 with a frequency of half hour)

Table V : Equations of different trends of the EC curve for the urine and compost+urine treatments.

Section	Urine treatment	
1.	y = 0.0012x- 49.13	R^2 = 0.0243
2.	y = 0.0073x-305,33	R^2 = 0.3343
3.	y = 0.0683x-2852.8	R^2 = 0.7878
4.	y = -0.0012x+50.798	R^2 = 0.00047
5.	y = 0.004x -187	R^2 = 0.5454

Section	Compost +urine treatment	
1.	y = 0.019x-79.566	R^2 = 0.1081
2.	y = -0.0047x+198.68	R^2 = 0.1337
3.	y = -0.0172x+720.18	R^2 = 0.4423
4.	y = 0.2046x-8547.3	R^2 = 0.901
5.	y = -0.0311x+1300.9	R^2 = 0.2704

III.2.2. Results of EC's punctual measurement using the EC probe

The EC probe was used to compare electrical conductivity of the soil in different layers of the soil. Measures done at 25 cm and 35 cm in each treatment revealed that the EC of the soil moved downward little by little from the upper layer to the lower layer at the beginning, and after the EC values were higher during the last stage of the trial in the lower layer than the upper layer of comparison. This can be explained by the fact that, salts were retained on upper layer due to evaporation and the downward movement was induced by rain. It's a leaching phenomenon.

III.2.3. Electrical conductivity of treated soils after harvest

Results of EC from treated soils sampled after harvest are presented on table VI after a descriptive statistic of data.

Table VI : $EC_{1:5}$ results of the treated soils

Treatment	Depth (cm)	Min(μS/cm)	Max(μS/cm)	Mean(μS/cm)	Std
Control	0-15	170,4	179,1	173,37	4,97
	15-25	126,9	211	160,03	44,8
	25-35	130,2	284	185,97	85,17
U	0-15	255	295	273,67	20,13
	15-25	225	245	235,67	10,07
	25-35	145,7	175,2	163,57	15,71
Compost+Urine	0-15	217	229	222,33	6,11
	15-25	144,6	163,3	152,97	9,5
	25-35	134,6	140,4	137,53	2,9

Comparison of EC values of the three treatments at depth 0-15 cm (figure 10a), revealed that urine treatment had the highest electrical conductivity, followed by the compost+urine treatment and came last the control treatment. The same comparison made at the depth of 15-

25 cm (figure 10b) resulted to the same response. At 0-15 cm, urine treatment had an electrical conductivity 1.2 more times higher than the compost+urine treatment and 1.6 more higher than the control.

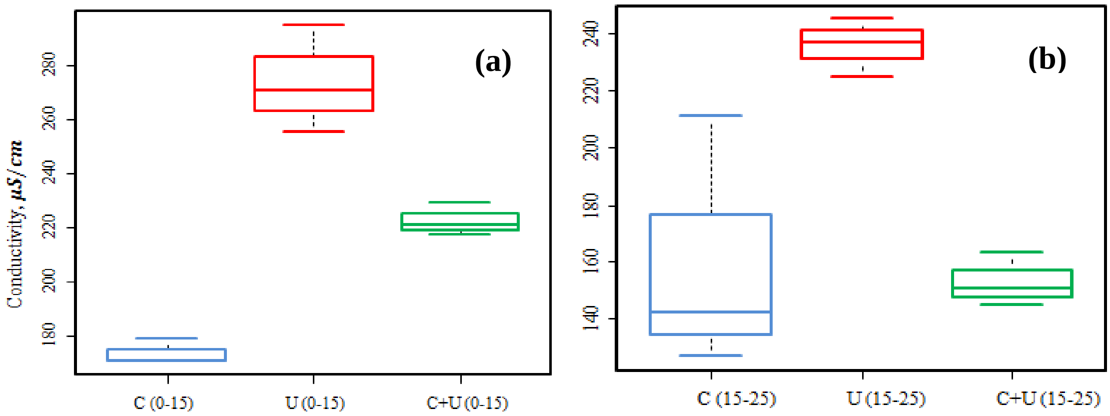

Figure 10: EC of the three treatments at depth 0-15 cm (a) and 15-25 cm (b)

Box plots in blue are for the control treatment, in red is for urine treatment and in green for compost+urine treatment.

These results with those obtained from sensors helped to conclude the assertion that human urine increase soil salinity.

By curiosity, in other to know how the electrical conductivity varied at different depth of each treatment, a comparison of electrical conductivity was done at different depths for each treatment. The results showed that the electrical conductivity changed with high values at the upper layer decreasing to the lower layer. Values of electrical conductivity of urine treatment at the two first layers were both higher than the EC of the compost+urine treatment at the upper layer as shown on figure 11.

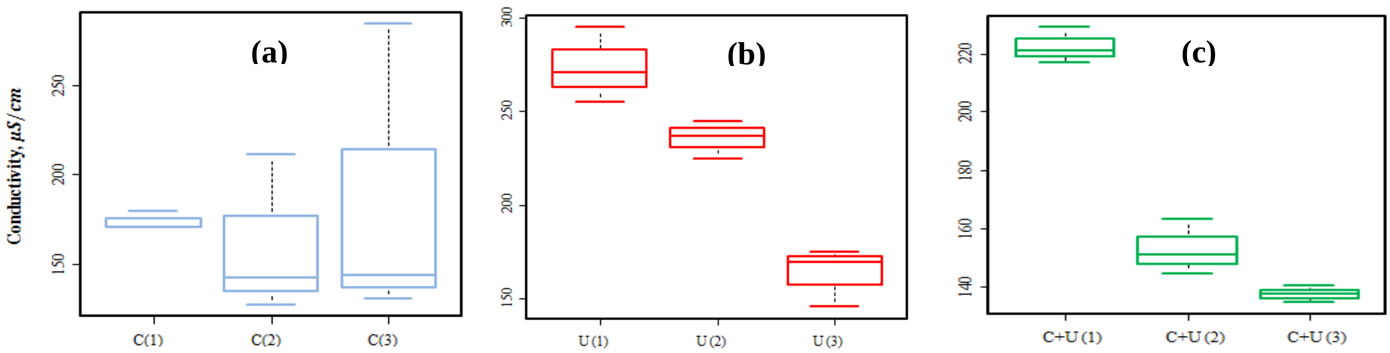

Figure 11 : EC values at the three depths for (a) control, (b) urine and (c) compost+urine treatment.

This figure 11, help to interpret salts distribution in each treatment. Distribution of dissolved salts concentration between the three different depths of each treatment was different from each treatment. Dissolved salts were more concentrated on the upper layer for the compost+urine treatments than on it other low layers with a difference of 45% whereas in for urine treatment the difference of EC value at the two first layers was 16%. The control treatment had some high values which may be wrong.

III.3. Results of different soil parameters after harvest

III.3.1. Soil pH

Results of pH are presented on table VII. The soil pH increased slightly after the trial compared to the initial pH = 6.8. This may be due to additional water (control treatment), urine (urine and compost+urine treatments) and compost (compost+urine treatment).

Table VII: Soil pH results after harvest

Treatment	Depth (cm)	Mean	Std.dev
Control	0-15	7,37	± 0,033
	15-25	7,72	±0,1
	25-35	7,2	±0,03
Urine	0-15	7,42	±0,074
	15-25	7,22	±0,011
	25-35	7,26	±0,025
Compost+Urine	0-15	7,48	±0,05
	15-25	7,38	±0,182
	25-35	7,81	±0,053

Comparing the pH between treatments, it was observed that compost raised more the soil pH than in other treatment. The urine treatment has been found to be the treatment that had low pH mean value. This may be due by the escape of ammonia gas leaving an H^+ in the soil increasing then the soil acidity. Figure 12 shows the box plots of the soil pH by treatment.

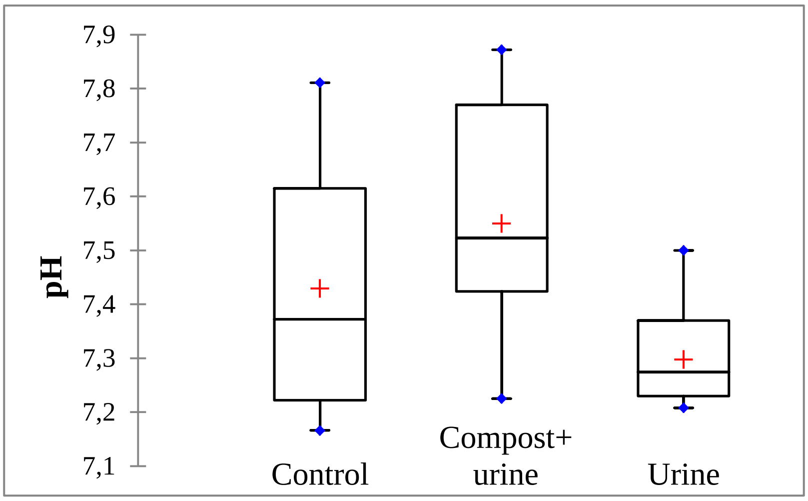

Figure 12: pH of soil per treatment after harvest

As urine treatment had a low pH in comparison to compost treatment, the mixture of compost and urine could make a good treatment to deal with the pH of the soil for the better growth of crops.

III.3.2. Concentration in micronutrients in the treated soils

Results of analyses of different nutrients contents in the treated soils are presented on appendix 3. Na was more concentrated in the upper layer (0-15 cm) of the urine and compost+urine treatments, 20 mg/l and 16 mg/l respectively than in the control treatment and lower layers (15-25 cm and 25-35 cm) of the three treatments.

III.3.3. Sodium Adsorption ratio of the soil

Table VIII present results of the sodium adsorption ratio. Results showed that the SAR of treated soils at the upper layer increased more in urine treatment with a value 10 times higher than the initial soil SAR (=0.21). It increased also in compost+urine treatment 7.5 times more than in the initial soil. For the control treatment, the SAR increased 3.6 times more than the initial soil.

Table VIII : Results of the soil SAR

Treatment	Depth (cm)	SAR
Control	0-15	0,76
	15-25	0,43
	25-35	0,34
Urine	0-15	2,14
	15-25	0,53
	25-35	0,65
Compost+Urine	0-15	1,59
	15-25	0,77
	25-35	0,40

Results of SAR as presented on table VIII and figure 13 revealed that its value was higher in upper layers of all treatments with a decreasing trend to lower layers. Analysis of variance showed that there was a significant difference ($p < 0.0001$) on the SAR variation between the depth of 0-15 cm to 15-25 cm and 0-15 to 25-35. The SAR variation between the depth of 15-25 to 25-35 was not significantly different $p = 0.86$. The highest SAR value was 2.14 from the urine treatment at the upper layer (0-15 cm) of the soil followed by the compost+urine treatment 1.58 at the layer (0-15 cm). Though, the difference was not significant when looking on values and the graph.

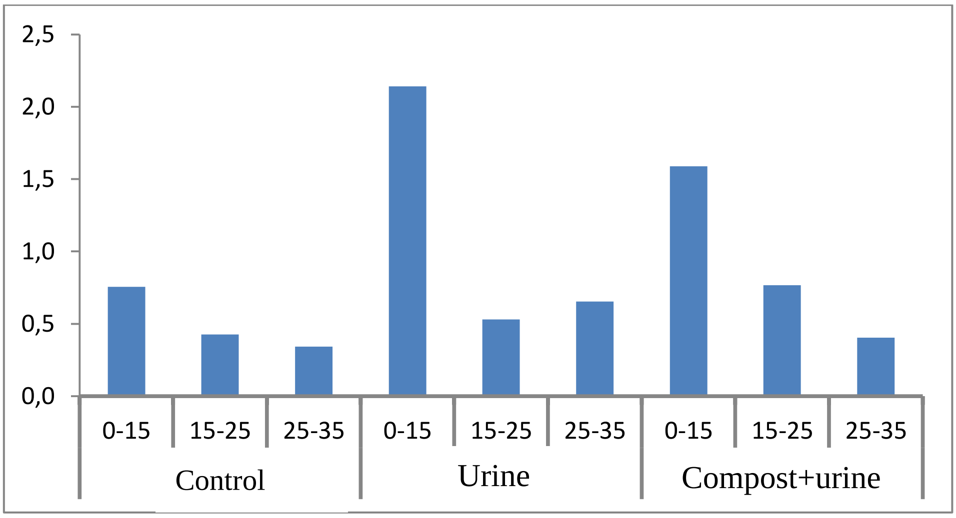

Figure 13 : SAR presentation of the three treatments at different depths.

The SAR value varied from 0.5 (at lower layer) to 2.14 (upper layer) for urine treatment, from 0.4 lower layer to 1.56 upper layer for compost+urine treatment and from 0.3 at the lower layer to 0.88 at the upper layer for control treatment. Figure 14 resumes the descriptive statistics of data of SAR within each treatment.

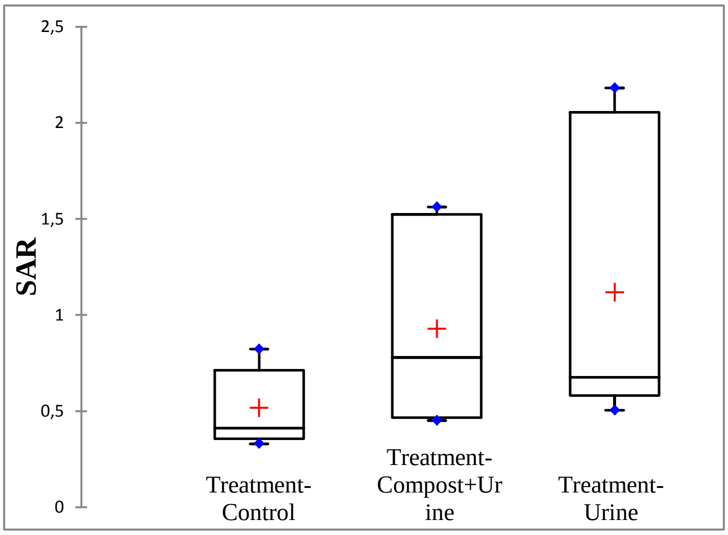

Figure 14 : SAR presentation of the three treatments

III.4. Agronomic parameters results

The analysis of variance (ANOVA) of the dry root biomass (DRB), total dry biomass (TDB) and the dry shoot biomass (DSB) revealed that there was a significant difference between control treatment versus compost+urine ($p< 0.05$), and control versus urine ($p = 0.035$). Though, the difference was not significant between urine and compost+urine treatments ($p = 0.199$). The given p-values are for TDB. Tukey test results for DRB and DSB are on appendix 5.

Results of the dry total, shoot, and root biomasses of the compost+urine treatment were the worst. These results are in contrary to results found by Shrestha et al. (2013), Boh et al. (2013) and Pradhan et al., (2010) where the compost+urine treatment had best yield. Though, Shrestha et al., 2013 reported that the lower response of tomatoes to the compost+urine treatment may due by the slow release of nutrients and its unavailability at the critical stage of plant’s requirement, this could be among other reason of failure of the crop in this treatment. In fact, compost was applied in the soil at the same time as urine, three weeks after transplantation. It is supposed that compost took time to release nutrients for the crop. Also, another thing is that before compost application the soils were stirred using a weeding hoe, maybe the roots were touched, resulting to growth retard. The absence of fruit in all treatments may be due by high temperature during the trial period. In fact, Adams et al. (2001) studying an effect of temperature in growth of tomato using different temperature conditions found poor fruit at higher temperature (26°C) and confirmed Sato et al. (2000)'s suggestion that poor fruits set at high temperatures was due to the effect of temperature on pollen grain release and germination.

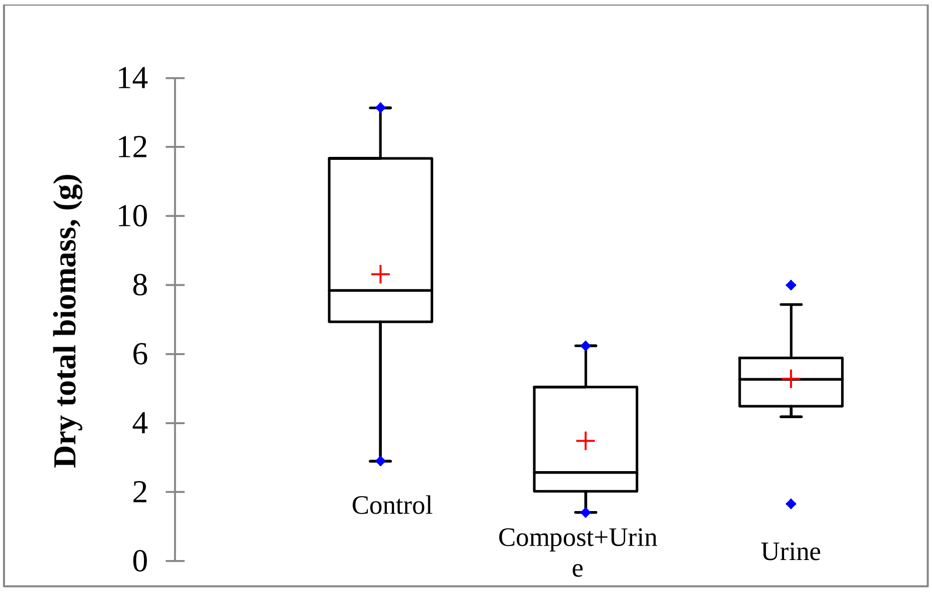

Figure 15 : Comparison of DTB of crops from the three treatments

CONCLUSION AND SUGGESTIONS

The present study focused on the evaluation of soil salinity induced by agricultural valorization of human urine as a nitrogen fertilizer source in dry conditions was conducted using field sensors and laboratory analysis of soil and crop samples. Three different treatments based on nitrogen source supply were used to evaluate the global salinity in the soil and plants response for the three treatments.

Results of sensors revealed that the electrical conductivity of urine treatment raised 3.5 times more than in the initial soil making a difference of 40 % compared to the increase in compost+urine treatment. With results of the same trend for the laboratory analysis of electrical conductivity for the three treatments, the conclusion for the first hypothesis is that urine applied at a rate corresponding to plant need in nitrogen do increase the soil salinity compared to other treatments. But, the application in one season cannot make a soil to be saline where the electrical conductivity is 4 dS/cm.

The sodium adsorption ratio increased by 10 in the urine treatment, meaning that sodium concentration was higher after urine application. These results confirm the second hypothesis of the second objective which was to identify the type of salt mineral accumulated in soil amended with urine. The salt mineral is sodium.

As results showed that the electrical conductivity and sodium adsorption ration increased more in urine treatment than in compost+urine treatment, the conclusion is that organic matter contained in compost can reduce soil salinity which confirm the third hypothesis.

The global conclusion is that, reuse of human urine in agriculture increase the soil salinity and sodium accumulation on upper layer of the soil, and the consequences may be worst seen at longterm.

The present study highlights also the effect of temperature on salt accumulation on the upper layer of the soil due to high rate of soil evaporation.

After concluding that human urine induces soil salinity, and knowing that it contains a valuable amount of crop nutrients we suggest that:

- A study aiming to perform an evaluation of the necessary time to reduce salt concentration through leaching at a level acceptable for plant should be conducted.
- Other studies should be conducted in order to find a solution of soil remediation or to develop technics aiming to remove salt in urine before use.
- We suggest also that the same study may be conducted again but with different types of soil and crop species. The study may be conducted in the greenhouse so that rain will not disturb the trial.

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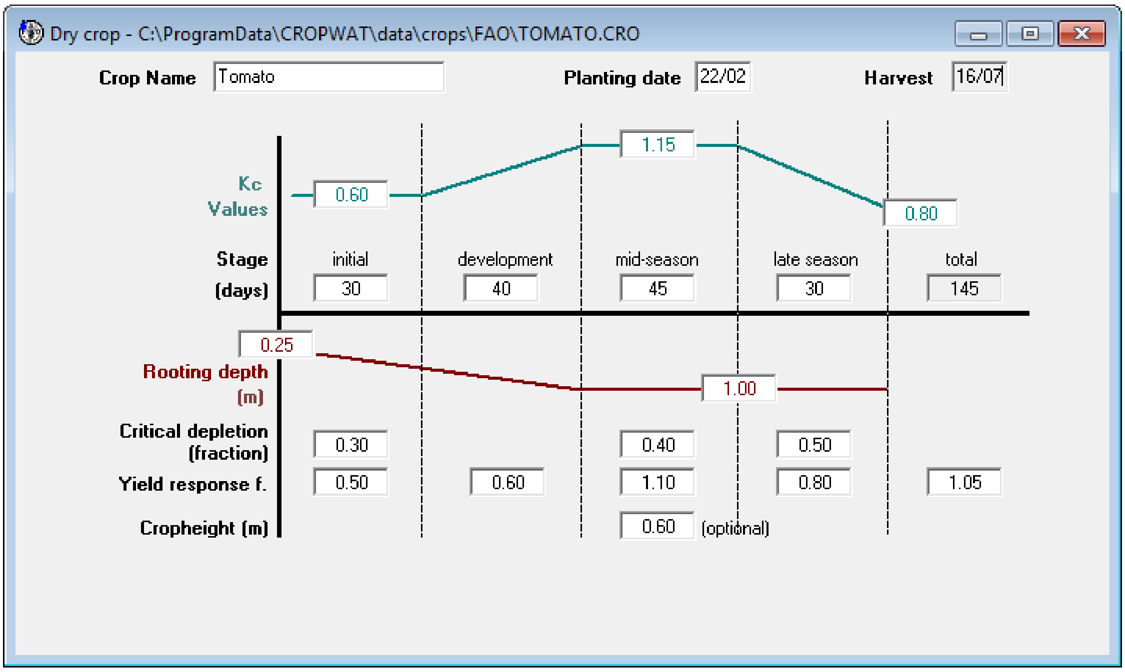
APPENDICES

List of appendices

Appendix 1. Calculation of the daily water requirements for crop

On FAO software for water requirement estimation, the crop coefficients for the four stage growth of tomato were given from the sowing to the end. Each stage was determined by the number of days and its crop coefficient during the stage as mentioned on the figure below.



Depending on the period of cultivation, the software gives number of days in a month belonging to a stage of growth and gives the corresponding Kc.

Month	Decade	Stage	Kc
			coeff
Feb	3	Init	0.60
Mar	1	Init	0.60
Mar	2	Init	0.60
Mar	3	Deve	0.64
Apr	1	Deve	0.79
Apr	2	Deve	0.92
Apr	3	Deve	1.06
May	1	Mid	1.15
May	2	Mid	1.15
May	3	Mid	1.15
Jun	1	Mid	1.15
Jun	2	Late	1.14
Jun	3	Late	1.04
Jul	1	Late	0.91
Jul	2	Late	0.82

We went from those numbers of days per month in a given stage divided by 30 multiplied by the Kc of the stage plus other number of days of the same month but belonging to another growth stage divided by 30, to determine the monthly crop coefficient. That's produced on the table below.

	Initial	Development			Mid-saison		Late season
	Mars		Avril		Mai	Juin	
Number of days/month	20	10	30		30	10	20
Kc/stage of growth	0,6	0,64	0,72	0,92	1,15		1,09
Kc/month	0,6		0,9		1,2	1,1	

Kc/Month = $\left[\left(\frac{20}{30}\right) * 0.6\right] + \left[\left(\frac{10}{30}\right) * 0.64\right]$ This is an example

20: number of days of March belonging to the initial stage

30: number of day in a month

0.6: Kc for the initial stage

10: number of day of March belonging to the development stage

0.64: Kc for the development stage.

		March	April	May	June
A	Days	30,0	30,0	30,0	30,0
B	ET0 (mm/day)	7,1	7,4	6,9	5,6
C	kc	0,6	0,9	1,1	1,1
D = B*C	ETP (mm/day)	4,3	6,6	7,3	6,3
E = D*30	ETP (mm/month)	128,2	199,3	218,8	189,2
F	Pe (mm)	0,0	0,0	0,0	89,3
G = -(F-E)	Irrigation water requirement (mm)	128,2	199,3	218,8	99,9
H=G*10	Irrigation water requirement (m3/ha)	1281,6	1992,6	2187,8	998,7
I=H*0.00013	Irrigation water requirement (m3/pot/month)	0,0167	0,0259	0,0284	0,0130
J=I*1000	Irrigation water requirement (l/pot/month)	16,7	25,9	28,4	13,0
H = J/30	Irrigation water requirement (l/pot/month)	0.6	1	1	0.4

Climatic data generated on climwat

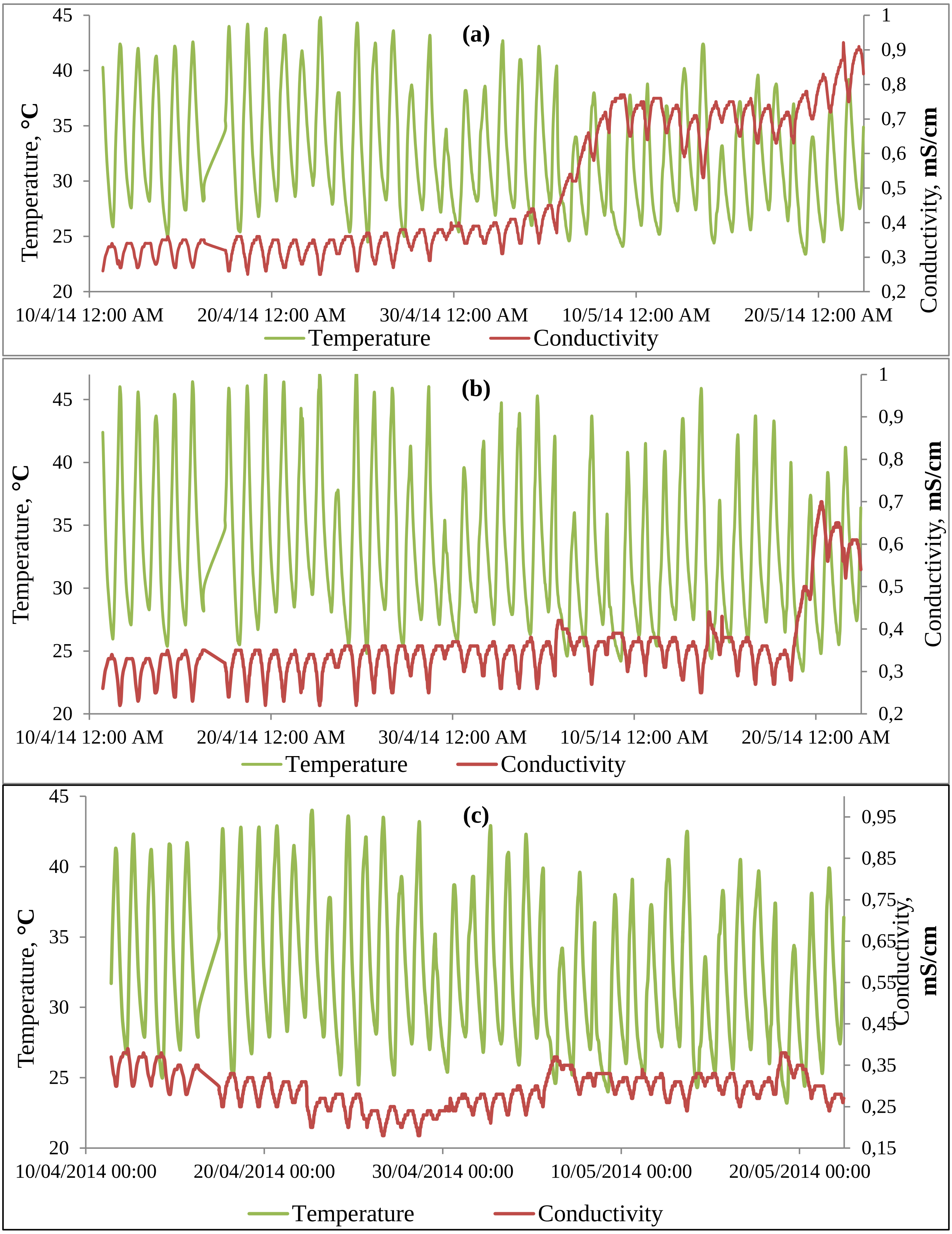
Pays: Location 5 Station: OUAGADOUGOU

Altitude: 306 m. Latitude: 12.35 °N Longitude: 1.51 °O

Mois	Temp Min °C	Temp Max °C	Humidité %	Vent km/jour	Insolation heures	Ray. MJ/m^2/jour	ETo mm/jour
Janvier	16.1	33.3	32	199	8.2	18.9	5.77
Février	19.1	36.2	32	199	8.1	20.2	6.38
Mars	23.1	38.3	33	207	8.0	21.3	7.12
Avril	25.9	38.9	41	233	7.1	20.5	7.38
Mai	25.6	37.2	58	268	7.8	21.3	6.88
Juin	23.7	34.2	70	251	7.6	20.6	5.63
Juillet	22.4	31.8	87	225	6.8	19.6	4.29
Août	21.9	30.8	85	190	6.1	18.8	4.06
Septembre	21.9	32.0	79	164	6.5	19.1	4.33
Octobre	22.6	35.3	63	164	8.2	20.5	5.29
Novembre	19.3	35.8	47	156	8.6	19.6	5.38
Décembre	16.8	33.6	41	173	8.2	18.3	5.22
Moyenne	21.5	34.8	56	202	7.6	19.9	5.64

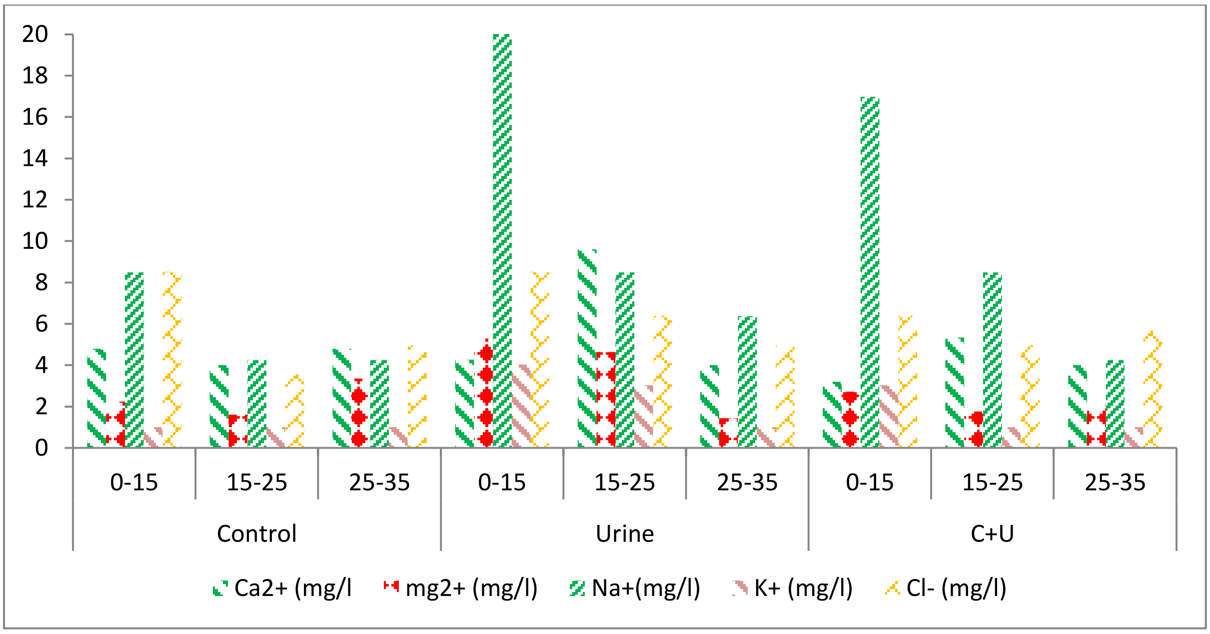
Appendix 2. Conductivity and temperature curves for the trial

(a) Urine treatment (b) Compost+urine treatment (c) control



Appendix 3. Micronutrients concentration in the treated soils

Treatment	Depth	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	Cl^{-} (mg/l)
Control	0-15	4,80	2,24	8,49	1,01	8,52
	15-25	4,00	1,60	4,24	1,01	3,55
	25-35	4,80	3,36	4,24	1,01	4,97
Urine	0-15	4,27	5,28	21,22	4,03	8,52
	15-25	9,60	4,64	8,49	3,02	6,39
	25-35	4,00	1,44	6,37	1,01	4,97
CU	0-15	3,20	2,72	16,98	3,02	6,39
	15-25	5,33	1,76	8,49	1,01	4,97
	25-35	4,00	2,08	4,24	1,01	5,68



Appendix 4. Agronomic parameters results

Treatment	Sample	Fresh biomass	Fresh shoot	Fresh root	Dry biomass	Dry shoot	Dry root	Dry Shoot/Dry Root
C	Pot 1	55	48	7	12,39	9,47	2,92	3,25
		37	33	4	7,84	6,43	1,42	4,53
		39	35	4	7,62	6,15	1,48	4,16
	Pot 2	60	51	9	11,67	9,13	2,54	3,59
		35	31	4	6,93	5,66	1,27	4,44
		17	14	3	4,42	3,41	1,01	3,36
	Pot 3	68	58	10	13,14	11,04	2,10	5,26
		38	32	6	7,92	6,04	1,88	3,22
		12	11	1	2,90	2,48	0,42	5,98
U	Pot 1	30,5	27,5	3	5,22	4,38	0,84	5,24
		30	26	4	5,36	4,39	0,97	4,52
		16	15	1	4,19	3,26	0,92	3,53
	Pot 2	36	32	4	7,44	6,28	1,16	5,39
		32	28	4	5,89	4,90	0,99	4,94
		32	28	4	7,99	6,35	1,64	3,87
	Pot 3	23	20	3	4,49	3,46	1,03	3,35
		26	22	4	5,27	4,05	1,21	3,34
		8	7	1	1,66	1,20	0,46	2,63
C+U	Pot 1	8	7	1	1,43	1,14	0,29	3,92
		13	11	2	2,02	1,84	0,19	9,78
		6	5	1	1,41	1,02	0,39	2,61
	Pot 2	31	27	4	5,81	5,00	0,81	6,17
		25	22	3	6,24	5,17	1,07	4,84
		10	9	1	2,57	2,01	0,56	3,60
	Pot 3	25	23	2	4,33	3,66	0,67	5,46
		29	26	3	5,05	4,13	0,92	4,48
		12	11	1	2,51	2,04	0,47	4,33

Appendix 5. Tukey test results for agronomic parameters

- **Dry Shoot Biomass (tukey test)**

Contraste	Difference	Standardized difference	Critical value	Pr > Diff	Significance
C vs CU	3,756	3,832	2,498	0,002	Oui
C vs U	2,393	2,442	2,064	0,022	Oui
U vs CU	1,362	1,390	2,064	0,177	Non

- **Total Dry Biomass (tukey test)**

Contraste	Différence	Standardized difference	Critical value	Pr > Diff	Significance
C vs CU	4,830	4,041	2,498	0,001	Oui
C vs U	3,038	2,542	2,498	0,046	Oui
U vs CU	1,792	1,499	2,498	0,309	Non

- **Dry Root Biomass (tukey test)**

Contraste	Différence	Standardized difference	Critical value	Pr > Diff	Significance
C vs CU	1,074	4,444	2,498	0,000	Oui
C vs U	0,645	2,668	2,498	0,035	Oui
U vs CU	0,429	1,776	2,498	0,199	Non