EFFECTS OF MUNICIPAL SOLID WASTE COMPOST ON SOIL PROPERTIES AND VEGETABLES GROWTH

G.V. Giannakis, N.N. Kourgialas, N.V. Paranychianakis*, N.P. Nikolaidis, N. Kalogerakis

School of Environmental Engineering, Technical University of Crete, 73100 Chania, Greece

Tel.: +30 28210 37823

*Corresponding author, E-mail address: niko.paranychianakis@enveng.tuc.gr

Abstract:

This work investigates the impacts of municipal solid waste compost (MSW-compost) application (0, 50 and 100 t/ha) on the growth, and on nutrient and trace elements content in lettuce and tomato plants grown in large, 40-L, pots. Our findings showed inhibition of plants' growth with increasing dose of MSW-compost, compared to plants receiving conventional fertilization. Growth inhibition was associated with a sharp decrease in soil NO_3–N content. On the other hand, a slower decrease in soil NO_3–N content occurred in non-planted pots amended with MSW-compost. These findings provide evidence that N immobilization and/or decreased N mineralization were responsible for inhibited growth by constraining N availability. With regard to the other macro-nutrients, K, P, Mg, Ca, and Fe, their contents in leaves of both crops were maintained at optimum levels. Higher zinc and cooper content was measured in leaves of both crops but they did not exceed the optimum range for growth. No accumulation of trace elements was found in the fruits. The content of heavy metals in the tissues of plants grown in MSW-compost amended soil, remained at levels similar to those of the non-amended soil, suggesting that they do not pose a significant risk either for plant growth or the public health. The findings of our study suggest that further emphasis should be given on the investigation of the factors regulating N mineralization and availability in order to avoid reductions in crop yield.

Keywords: organic amendments, compost application, vegetables' growth, heavy metals, nitrogen

INTRODUCTION

The decline of soil organic matter (SOM), as a consequence of the application of intense soil cultivation practices, has been identified as one of the most important threads to soil quality (Lal, 2007; Batlle-Bayer *et al.*, 2010). Depletion of SOM, is accompanied by a cascade of adverse impacts, including decreases in soil fertility and productivity, decreased biodiversity, lower microbial activity, instability of aggregates, and reductions in infiltration rate followed by increased runoff and erosion which further stimulate soil degradation (Martin *et al.*, 2010). To reverse these impacts, various practices have been employed including the adoption of non-tillage practices and application of manure and biosolids (de Araújo *et al.*, 2010; Neto *et al.*, 2010; Rigane and Medhioub, 2011).

The use of municipal solid waste or sewage sludge composts in agriculture, has been increasingly promoted by environmental agencies as it provides strong environmental and economic advantages, in contrast to traditional biosolids' management practices such as combustion and landfill disposal (Hargreaves *et al.*, 2008). In addition, they contribute to SOM restoration, soil structure improvement, microbial activity stimulation, and they supply crops with essential nutrients, decreasing production costs (García-Gil *et al.*, 2000). However, potential ecological and health risks may arise due to nutrient transport to ecologically sensitive receptors and accumulation of trace elements in the soil profile and their entry in food chain (Pierzynski and Gehl, 2005; Smith, 2009). These issues should be carefully addressed in order to mitigate the environmental impacts and optimize compost use in agriculture. For these reasons, many states/countries have developed specific guidelines regulating its safe use, although they are still under discussion (Barral and Paradelo, 2011).

MSW-composts are often characterized by increased contents of trace elements and heavy metals, due to the inadequate separation of biodegradable fractions from non-degradable or inert materials (Smith, 2009) and published studies have shown increased accumulation of

Cu, Pb and Zn in plant tissues (Achiba *et al.*, 2009; Smith, 2009; Paradelo *et al.*, 2011). However, the accumulation of trace elements in plant tissues depends on their availability which in turn is affected by composting method, soil properties and plant species/cultivar. Additional issues that should be considered include increases in soil electrical conductivity and changes in pH and nitrogen availability (Mkhabela and Warman, 2005; Walter *et al.*, 2006; Zhang *et al.*, 2006; Hargreaves *et al.*, 2008). Particular concern has been addressed on N availability which has been found to be very low in the first application period (Eriksen *et al.*, 1999). Decreased yield in crops grown in MSW-compost amended fields, have been associated with low release of N (Iglesias-Jimenez and Alvarez, 1993; Mkhabela and Warman, 2005). To compensate this low N availability arising from low N mineralization rates and N immobilization by microbial biomass, elevated rates of MSW-compost are commonly used in agriculture (García-Gil *et al.*, 2000).

The objectives of this study were to investigate the effects of MSW-compost on : i) growth and yield of two vegetable crops (tomato and lettuce plant), ii) potential risks for crop yield and public health, if any resulting from the accumulation of potentially harmful toxic elements, and finally iii) soil chemical properties and nutrient status. The information provided is expected to contribute in the optimization of adopted application rates of MSW-compost, development of safe recycling criteria and the elimination of ecological and public health risks.

MATERIALS AND METHODS

Experimental design

In August 5, 2010, 40-Liter cylindrical (d=20cm, h=31.5cm) pots were filled with soil and placed outdoors in an open field located at the Technical University of Crete, Chania, Greece.

The soil used is a representative soil (eutric regosol) of the area surrounding the campus and it has been subjected to severe degradation due to intense tilling practices imposed in the last decades. Before filing the pots, the soil was passed through a 4 mm diameter screen. The soil was characterized as clay-loam with pH: 7.7, electrical conductivity (EC): 0.12 dS/m, total nitrogen (TN): 0.08%, NO_3–N: 34 mg/kg, NH_4–N: 6.55 mg/kg, organic matter (OM): 0.22%. The pots were spaced 1.0 m within and between rows and were irrigated regularly until August 15 when MSW-compost, derived from the Municipality of Chania, was incorporated to the soil. The compost treatments included: i) non-amended soil treated with conventional fertilizer ("controls"), ii) soil amended with 50 t/ha of MSW-compost, and iii) soil amended with 100 t/ha of MSW-compost. The incorporation of MSW-compost took place in the first 15 cm of soil depth to simulate field conditions. The pots were planted on August 19 and 26 with tomato plants and lettuce, respectively. Since lettuce has a shorter growing cycle compared to tomato plants, pots planted with lettuce were replanted on October 15, one week after the first harvesting in order to compensate for differences in growing cycle and biomass production between crops. Additional treatments of compost amended pots (50 and 100 t/ha) but not planted, were included in the experimental design to investigate the role of vegetation, if any, in C and N cycling, nutrient cycling and (heavy) metal availability. The only nutrients that treatments with MSW-compost were received for their fertilization, were those found in the compost itself, while "control" pots received a conventional fertilizer (NPK plus micronutrients) at the rate of 15 g N/pot, applied with irrigation at weekly intervals that corresponded to 68% of the N applied with compost in the highest compost treatment (100 t/ha). The composition of MSW-compost is shown in Table 1. The pots were arranged in a randomized block design with six replicates per treatment and sampling was limited to the internal four pots. In addition, two additional pots series planted with tomato plants were placed on the sides (left and right) to eliminate any border effect. Care was given to maintain soil moisture close to field capacity by installing tensiometers on some pots and it was never allowed to fall below the -30 kPa, so that plants do not experience water stress. The irrigation water had a low (0.2 ds/m) EC. Finally, weeds were regularly removed from the pots manually.

Soil Sampling and Chemical Analyses

With regard to soil sampling, samples were taken from 0-15 and 15-30 cm depths at approximately monthly intervals throughout the study (August to February). Sampling, preparation of samples and chemical analyses were performed according to the Methods of Soil Analysis (1982). The soil particle size analysis was carried out by the Bouyoucos hydrometer method (Bouyoucos, 1962). pH and EC were measured in saturated soil paste extracts. The Walkley and Black (1934) wet-digestion method was used for the determination of soil organic matter (SOM). Total Kjeldahl nitrogen (TKN) was measured by a macro-Kjeldahl device. Soil samples were extracted using 2M KCl and the solution was measured for ammonium and nitrates by the Cd-reduction and Nessler methods respectively (Methods of Soil Analysis1982), using a Perkin-Elmer Lambda 25 spectrophotometer. The available-P was analysed according to Olsen (1954). Pseudo-total concentrations of macro- (Ca, Mg, Fe, K) and trace elements (Zn, Mn, Cu, Ni, Cr, Cd, Hg and Pb) in soils and MSW-compost were analysed by ICP-MS (7500cx coupled with an autosampler Series 3000, Agilent Technologies) after microwave enhanced acid digestion (Microwave Digester, Synthos 3000, Anton Paar) according to EPA method 3051 (USEPA, 1995). The available fraction of trace elements was assessed after Synthetic Precipitation Leaching Procedure (SPLP), EPA Method 1312 (USEPA, 1994), followed by ICP-MS as described previously.

Crop Biomass, Yield and Nutrient and Trace Element Content

At the end of each growing cycle for lettuce (October 11 and December 1) and on December 10 for tomato plants, whole plants (3 plants/treatment) were harvested, weighted for fresh weight, and subsamples were air-dried to constant weight to assess biomass production. Mature tomato fruits were regularly collected throughout the growing period weighted and air dried to constant weight to assess yield. Then subsamples were ground to fine powder and stored for nutrient and metal analysis. Plant tissues (tomato and lettuce leaves and tomato fruits) were acid-digested in a microwave oven, according to the application notes of manufacturer and analysed by ICP-MS for the macro- and trace elements. N content in plant samples was measured using the Kjeldahl Method and total P was measured colorimetrically with the ammonium molybdate-ascorbic acid method.

Statistical analysis

Statistical analysis was performed using 17.0 SPSS program. The effect of the plant species and soil depth on soil parameters was carried out by using General Linear Model, Univariate Analysis of Variance (UNIANOVA). Finally, post hoc pair wise comparisons among compost dose, plant species or soil depths were examined by Tukey's Honestly Significant difference (HSD) test.

RESULTS

Crop yield

Tomato plants receiving conventional fertilizer produced more biomass compared to that of the compost amended treatments (Fig. 1a). Differences in biomass were more pronounced for fruits compared to leaves and stems (Fig. 1a). Tomato plants amended with 50 and 100 t/ha compost produced 48% and 35% lower biomass respectively, compared to the no compost treated plants (conventional fertilization). With regard to lettuce, in the first growing cycle, plants treated with commercial fertilizer produced similar biomass to those treated with 100 t/ha compost and higher than lettuce plants treated with 50 t/ha compost (Fig. 1b). In the second growing cycle however, compost amended treatments produced significantly lower biomass compared to plants treated with conventional fertilizer (Fig. 1b).

Soil organic matter

Overall, no significant differences were observed in SOM content between planted and unplanted pots amended with compost. Soil organic matter content decreased gradually in both planted and unplanted treatments in the upper soil layer (Fig. 2a, b, and c). In the deeper soil layer, SOM content maintained relatively constant at levels similar to those of pots not-amended with compost, indicating that minor amounts of organic matter were transported downward (Fig. 2a, b, and c). It decreased gradually from 1.7% to 1.4% at the upper soil layer (0-15 cm) in the pots treated with 100 t/ha compost. A slighter decline, from 0.9% to 0.7% was assessed in pots treated with 50 t/ha compost (Fig. 2a, b, and c).

Nitrogen transformations and availability

Compost application affected N transformations and its availability to the crops. With regard to TN, a sharp decrease was observed in both planted and unplanted treatments (Fig. 3a, b, and c) during the first month after compost application in the 0-15 cm soil layer. Then, soil TN content remained constant in all treatments by the completion of the study (Fig. 3a, b, and c). By contrast no change in soil TN content was observed in the 15-30 cm soil layer with the progress of time (Fig. 3a, b, and c).

Significant differences in soil NH_4–N content were observed between planted and unplanted treatments (Fig. 4a, b, and c). Ammonium content maintained constant at the 0-15 cm soil depth in the unplanted pots treated either with 50 or 100 ton/ha compost throughout the study period (Fig. 4a). By contrast, NH_4–N content in the corresponding soil layer of planted treatments decreased from 12 to 8 mg/kg within 30 days following compost application and then maintained constant by October 19 (third sampling). Later, a recovery of NH_4–N content to its initial levels took place followed by a slight decline to 12 mg/kg by the end of sampling period (January 17) (Fig. 4a, b, c). In pots amended with 50 t/ha compost, soil NH_4–N content remained relatively constant by October 19, then it increased to 10.5 mg/kg and followed a slight decline similar to that observed in 100 t/ha for both crops. No significant differentiation occurred in the deeper soil layer (15-30 cm) (Fig. 4b and c). In the not-amended with compost, soil NH_4–N content was not affected by soil depth and maintained, relatively constant throughout the period of the study, at levels comparable to those measured at 15-30 cm soil depth at compost treated plants (Fig. 4b and c).

With regard to NO_3–N, it decreased gradually in unplanted pots and this decline depended on compost application rate (Fig. 5a). Pots treated with 100 t/ha showed higher concentrations of NO_3–N compared to pots treated with 50 t/ha in the 0-15 cm soil depth, but in the 15-30 cm soil layer significant differences among compost treatments were only observed in the first (August 21) sampling (Fig. 5a). In the planted pots soil NO_3–N content decreased sharply, an effect attributed to crop uptake (Fig. 5b and c). Particularly, in pots planted with lettuce, NO_3–N content in the upper soil layer approached its minimum values in the second sampling and was maintained at these levels by the completion of the study. In that sampling, NO_3–N content at 0-15 cm soil layer was found to be lower compared to that at the 15-30 cm, an effect probably arising from the shallower root system of lettuce which limited uptake to the upper soil layer compared to pots planted with tomato plants. In pots with tomato plants however, NO_3–N content remained higher in the upper soil layer by the third sampling at the highest application rate, but thereafter no differences were observed among compost application rate or soil depth. In neither compost application, crop nor soil depth, a recovery of NO_3–N took place after the harvesting of crops which performed on December 1 and 10 for lettuce and tomatoes, respectively (Fig. 5a, b, c). In pots not amended with compost, soil NO_3–N content was not affected by soil depth and maintained relatively constant throughout the period of the study at levels comparable to those measured at compost treated plants (Fig. 5b and c).

Available Phosphorus

Compost application improved the status of available soil P, but the increase was not proportional to application dose (Fig. 6). Increasing application rate, from 50 to 100 t/ha resulted only to a slow increase in the available-P. The highest P content was measured at 0-15 cm soil depth (Fig. 6). In that soil layer, content of available P was similar to that of the non-amended treatments (data not shown). Finally, no change in soil P content was observed from September 11 to November 30.

Heavy Metals/Trace elements

Overall, compost application had a minor effect on soil trace elements content (Fig. 7). Cd and Hg contents remained below the detection limits, while the contents of As and Se maintained close to the soil background levels. Compost application at the rate of 50 t/ha increased soil Ni from 0.022 to 0.12 mg/kg and Cr content from 0.09 to 0.18 mg/kg. Increases were also found for Cu and Zn from 0.14 to 0.21 and from 0.6 to 6.0 mg/kg respectively (Fig. 7).

pH and electrical conductivity

Compost application increased soil pH from 7.8 to 8.1 and to 8.2 in the 50 t/ha and 100 t/ha application rates respectively, at the 0-15 cm soil layer. An influence on the 15-30 cm soil depth was only observed in pots treated with the highest compost dose (Fig. 8). Finally, plant species did not affect soil pH.

Increased values of saturated paste soil EC were measured in compost amended pots. A decline however was observed throughout the growing season that was greater in the planted compost treatments. At the end of the study, these differences were significantly decreased and nearly eliminated (data not shown).

Nutrient and Metals in Plant tissues

Compost had a strong effect on crop nutrient status. In the first growing cycle, lettuce plants treated with inorganic fertilizer or 100 t/ha compost showed higher leaf-TKN contents compared to those treated with 50 t/ha. In the second growing cycle, the leaf-TKN content of lettuce plants treated with 50 and 100 t/ha compost was lower compared to those treated with commercial fertilizer (Table 2). A similar effect was observed for tomato plants. On September 15, higher leaf-TKN content was measured in plants treated with inorganic fertilizer compared to those treated with compost, while tomato plants treated with 100 t/ha showed higher leaf-TKN content than plants treated with 50 t/ha compost. On December 10, lower leaf-TKN contents were again measured in compost treated tomato plants, but at this date no difference was observed between two compost doses. Lower TKN contents were also observed in the fruits of tomato plants treated with compost (Table 2).

Compost increased leaf-K content in lettuce plants compared to plants treated with inorganic fertilizer in both growing cycles. A similar influence for tomato plants was observed on September 15, when tomato plants treated with 100 t/ha compost, showed higher leaf-K content compared to plants treated with 50 t/ha compost or treated with commercial fertilizer. However, on December 10, leaf-K content in compost treated plants declined (Table 2). The increase of K content in fruits in compost treated plants may imply a transport of K from leaves to fruits possibly due to earlier completion of their growth cycle compared to plants treated with commercial fertilizer which continued to grow actively.

With regard to the leaf-P content, tomato plants treated with compost showed lower contents compared to plants treated with inorganic fertilizer in the first sampling (September 15), but these differences were disappeared in the following samplings. Similarly, no differences among treatments were found in the fruit P content. A similar effect was also found for lettuce plants (Table 2). Compost increased leaf-Mg content in tomato plants, but there was no effect in the fruits. By contrast, lettuce leaf-Mg content was not affected by compost application.

With regard to trace elements, compost application rate did not affect iron content in tomato plants, while a slight increase was observed in lettuce plants (data not shown). However, Zn content increased with compost application rate in the leaves of tomato plants, but not in the fruits (Table 2). A similar effect was observed for lettuce in the first growing cycle, but in the second, Zn content declined, probably implying a decrease in its availability with the progress of time. Higher Cu contents were measured in the leaves of tomato plants in both samplings but not in the fruits and only in the second growing cycle for lettuce (Table 2). Slightly higher content of Cr was measured in the leaves of tomatoes treated with 50 t/ha and in lettuce plants in the first sampling. Chromium however, just above the detection limits, was also assessed in tomato fruits (Table 2). Cadmium, at levels just exceeding the detection limit, was detected only in the first sampling in tomato leaves (data not shown). With regard to As and Pb they were not detected in the tissues of both crops investigated in this study (data not shown).

DISCUSSION

There has been increasing concern in the last few years on the factors affecting soil quality (Mkhabela and Warman, 2005; Batlle-Bayer *et al.*, 2010). The decline of SOM has been recognized as a significant cause of degradation, rendering soils more vulnerable to erosion and desertification and decreasing their productivity (Viaud *et al.*, 2010). These phenomena are more intense in (semi)-arid climatic zones. As a consequence, appropriate management practices are urgently required in order to restore/maintain soil quality and to improve its long term productivity. Compost application can contribute for achieving these targets, but apparently more research is required to eliminate potential environmental impacts, adverse effects on crops and risks to public health, (Hadas and Portnoy, 1997; Hargreaves *et al.*, 2008; Murray *et al.*, 2011).

Overall, compost application decreased yields for both crops investigated in the present study, and this decrease was greater in the low compost dose (50 t/ha). These findings provide evidence that crop performance was rather constrained by the availability of essential to growth nutrients than by potential toxic effects arising from the increased availability of trace elements or toxic metals the contents of which remained unchanged or slightly increased with compost dose.

Plant tissue analysis confirmed that leaf-K and -Mg contents maintained within the optimum range for growth in compost-amended soils (Campbell, 2000; Gent, 2002; Bumgarner *et al.*, 2011). With regard to the leaf-P, lower contents than the suggested optimum ranges were measured particularly in the second sampling in tomato plants, but it maintained at levels similar to those of plants treated with commercial fertilizer, which did not show any growth inhibition. It can therefore be inferred that P availability was not responsible for growth inhibition and thus the lower leaf-P contents could be attributed to environmental factors or to the genotypes used. Overall, the decreases in leaf-nutrient and metal content observed in the second sampling for tomato plants and in the second growing cycle for lettuce treated with compost could be attributed to a decline in their availability and this hypothesis is consistent with the general trend observed in EC values in saturated paste extracts. Differences in environmental conditions prevailed may have also contributed to this effect and particularly in lettuce. Fernandez et al. (2012), for instance, reported seasonal changes in leaf nitrate content, with the highest concentrations measured during the autumn growing cycle compared to that of spring. A detailed however explanation of this differential response is constrained by the potential interactive effects of climatic parameters, nutrient availability, and plant developmental stage.

On the other hand, the lower leaf-N content in the compost-amended soils, and the rapid depletion of soil NO_3–N with the progress of time could be well linked to crop yield decreases (Campbell, 2000; Bumgarner *et al.*, 2011). The decline in N availability became more intense with the progress of time (Figs 4 and 5) and can be considered as the main reason for different response of lettuce to compost treatment (Fig. 1b). Decreased yields of potatoes, corn, squash and barley in soils treated with MSW-compost compared to fertilizer-treated soils have been also associated with a decline in N availability (Rodd *et al.*, 2002; Mkhabela and Warman, 2005). Nitrogen availability in MSW-compost has been on average low during the early stages of incorporation to the soil (Hargreaves *et al.*, 2008) and it has been estimated to range from 10% to 20% during the first year of application (Hadas and Portnoy, 1997; Eriksen *et al.*, 1999; Zhang *et al.*, 2006), which is in accordance with the findings of this study. Immobilization of N, due to the increase of soil microbial biomass, is thought to be responsible for observed low N availability in soils amended with MSW-compost (Hadas and Portnoy, 1997) and this immobilization effect is greater in soil with a high clay content (Alvarez and Alvarez, 2000). Indeed, MSW-compost increased soil C biomass by 10% and 46% when applied at rates of 20 and 80 t/ha, respectively (García-Gil *et* *al.*, 2000). The decline in soil NO_3–N content in the unplanted compost treatments throughout the study period (Fig. 4a) provides strong evidence that such an influence has also occurred in this study. A subsequent study, indeed documented the occurrence of N immobilization during the first two months following MSW-compost application (Paranychianakis et al., 2013).

Compost treated pots showed a higher NH_4–N content in the upper soil layer compared to the lower one and the non-amended pots throughout the study period. Since neither EC nor metal content reached levels suggested as toxic to nitrifiers (Giller *et al.*, 2009), this effect can be rather attributed to an increased sorption of NH_4–N on organic colloids.

In addition to N immobilization, the low degradability of organic matter of MSW-compost may have delayed the release of nutrients and particularly N. After a rapid decrease in SOM content during the first month after MSW-compost application which can be attributed to the biodegradation of easily degradable substrates (Thuriès *et al.*, 2002), SOM maintained constant by the end of the study indicating the recalcitrance of MSW-compost C which has been also reported in previous studies (Pedra *et al.*, 2007). The low C/N ratio of MSW-composts in this study may explain this effect since low ratios of C/N have found to improve the stability of organic amendments to the soil and this hypothesis is supported by previous findings which have shown lower respiration rates in soils amended with MSW-compost compared to other organic substrates (Pedra *et al.*, 2007). These findings suggest that MSW-composts may have long-lasting protective effects on soil quality by maintaining SOM, improving physical properties, and favoring aggregates development and stability. The application rate of MSW-compost to maintain soil organic carbon after 25 years was calculated to range from 4.0 to 7.2 t/ha and from 8.5 to 15.6 increase it to 3.5% (Barral *et al.*, 2009).

Compost application increased soil pH by 0.2 and 0.4 units in 50 t/ha and 100 t/ha compost treatments respectively at the surface soil layer. This finding is in accordance to previous findings which reported proportional increases of pH with MSW-compost application rates (Zheljazkov and Warman, 2004; Zhang *et al.*, 2006) which were attributed to the production of OH^- and the release of basic cations (Mkhabela and Warman, 2005). The greater production of these ions in pots treated with the highest compost dose and their transport downward may be responsible for the increase in pH observed in the 15-30 soil layer in these pots. This increase in soil pH may also have a contribution to the low availability of trace elements and metals measured in the soil.

Compost increased substantially the EC, immediately after its incorporation to the soil that reached in the highest application rate the value of 2.0 dS/m. These values however are not considered detrimental for either crop performance or soil biological activity (Irshad *et al.*, 2005; Brady and Weil, 2008). Thereafter, a decline was observed with the progress of time. Although similar effects have been reported in previous studies (Iglesias-Jimenez and Alvarez, 1993; Walter *et al.*, 2006), the decline has been attributed to leaching and crop uptake (Zhang *et al.*, 2006). In our study however, no leaching occurred and uptake by crops cannot account for the observed decline in EC taking into account that similar decline was also observed in the non-planted treatments. It can therefore be inferred that additional factors were involved in EC decrease. Release or sollubilization of ions during compost incorporation may have resulted in the increased values of EC observed at the beginning of the study. However, with the progress of time a proportion of these cations may sorbed in soil-OM colloids, a hypothesis consistent with the high biosorption capacity of MSW-compost (Paradelo and Barral, 2012) and the increase in soil cation exchange capacity with MSW-compost application (Ozores-Hampton et al., 2011).

Increased concentrations of trace elements and heavy metals have been often reported in the tissues of crops growing in soils amended with MSW-compost (Smith, 2009). Their accumulation on crops depends on numerous factors including soil properties, plant species, compost application rate and compost content in metals (Pinamonti *et al.*, 1999; Zheljazkov, 2004). Particular concern has been given on the availability of Zn and Cu and their accumulation in plant tissues (Smith, 2009). MSW-compost increased both Zn and Cu in the tissues of both crops, but their contents were maintained within the optimum range for growth, except for lettuce treated with the highest dose, suggesting that compost could be safely used as soil conditioner. Similar leaf-Cu and -Zn contents were also reported for basil, and Swiss chard in MSW-compost treated soils (Zheljazkov, 2004). No accumulation of As, Pb, Ni, and Cr in the leaves and fruits was observed, in agreement with their low metal availability in the soil as it was assessed by SPLP extraction and hence it can be concluded that they do not pose any risk for crop yield or public health. Likewise, concentrations of Pb in Swiss chard, tomato, squash fruit, and basil tissues were not affected by MSW-compost (Ozores-Hampton *et al.*, 1997; Zheljazkov and Warman, 2004). The basic pH of the soil, its high clay content, and the low metal content of MSW-compost (Fig. 7) which was attributed to the lack of intensive industrial activities in the city of Chania are considered responsible for the low metal availability in the soil.

CONCLUSIONS

In conclusion, application of MSW-compost to the land, increased SOM and following an initial reduction attributed to the mineralization of easily decomposable substrates it maintained relatively constant throughout the study period (six months). Both crops treated with compost showed a lower performance compared to the commercial fertilizer treated crops. This adverse influence of compost on crop performance was associated with the low availability of NO_3-N probably resulted from N immobilization as has been indicated in earlier studies. These findings suggest that more emphasis should be given on the investigation of the factors regulating N mineralization in order to efficiently sustain crop yield. On the other hand, leaf-content in Ca, Mg, Fe, Zn, and Cu maintained within the optimum suggested range for crop growth. In the short-term, amending soils with MSW-compost, even at the highest application rate (100 t/ha), did not increase the availability of toxic elements and their accumulation in crop tissues at such levels that could be harmful for crop yield or public health. Apparently, more studies are required to confirm that the potential risks remain also low after long-term treatment of soils with MSW-compost.

ACKNOWLEDGEMENTS

Funding for this work was provided by the Project “Improving the Reclamation and Reuse of the Organic Fraction of Municipal Solid Wastes in Agriculture and Environmental Applications” (EL.00031) co-funded by the Greek Ministry of Economy & Finance and the European Economic Area (EEA) Grants. The authors are grateful to Ms M. Lilli and Dr. S. Voutsadaki for metal analysis in ICP-MS and optimizing soil P analyses methodology, respectively.

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Figure Legends

Figure 1: The effect of compost application rate on crop yield: (a) tomato plants biomass and yield (15/8-15/12) and (b) lettuce plants biomass during the first (25/8-15/10) and the second growing cycles (20/10-01/12).

Figure 2: The effect of compost application rate on soil organic matter: (a) in unplanted pots, (b) in pots planted with lettuce, and (c) in pots planted with tomatoes.

Figure 3: The effect of compost application rate on total nitrogen content matter: (a) in unplanted pots, (b) in pots planted with lettuce, and (c) in pots planted with tomatoes.

Figure 4: The effect of compost application rate on soil NH_4–N content: (a) in unplanted pots, (b) in pots planted with lettuce, and (c) in pots planted with tomatoes.

Figure 5: The effect of compost application rate on soil NO_3–N content: (a) in unplanted pots, (b) in pots planted with lettuce, and (c) in pots planted with tomatoes.

Figure 6: The effect of compost application rate on soil available P in the upper soil layer (0-15 cm). In the lower soil depth the soil available P content did not differ among treatments and maintained at levels similar to those of the non amended treatments.

Figure 7: The effect of compost application rate on soil available trace elements in the surface (0-15 cm) soil layer.

Figure 8: The effect of MSW-compost application rate on soil pH. Since no differences were found among planted and unplanted treatments or between plant species, the cumulative effect of compost is shown.

Table 1. MSW-compost characterization

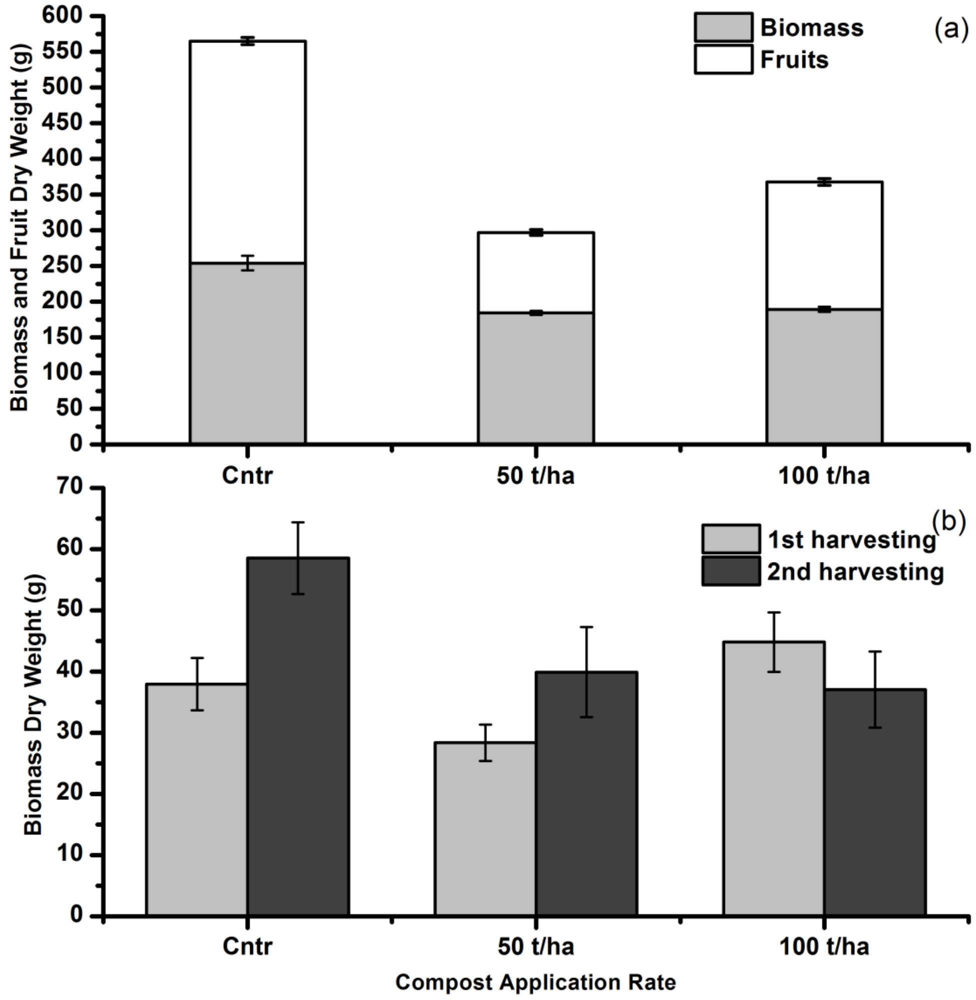
pH	7.54±0.12	**Ca** (mg/kg)	78786±2783	**Zn** (mg/kg)	736±102
EC (dS/m)	0.146±0.08	**Mg** (mg/kg)	5001±512	**Cr** (mg/kg)	26.6±8
OM (%)	15.7±0.6	**P** (mg/kg)	3453±292	**Ni** (mg/kg)	31.3±13
TN (%)	2.2%±0.3	**B** (mg/kg)	97.6±14	**As** (mg/kg)	4.18±2.6
NH_4-N (mg/kg)	124.28±16	**Fe** (mg/kg)	7246±917	**Se** (mg/kg)	2.96±0.8
NO_3-N (mg/kg)	1723±184	**Na** (mg/kg)	468±36	**Hg** (mg/kg)	2.16±0.65
K (mg/kg)	9730±655	**Cu** (mg/kg)	177±23	**Pb** (mg/kg)	115±34

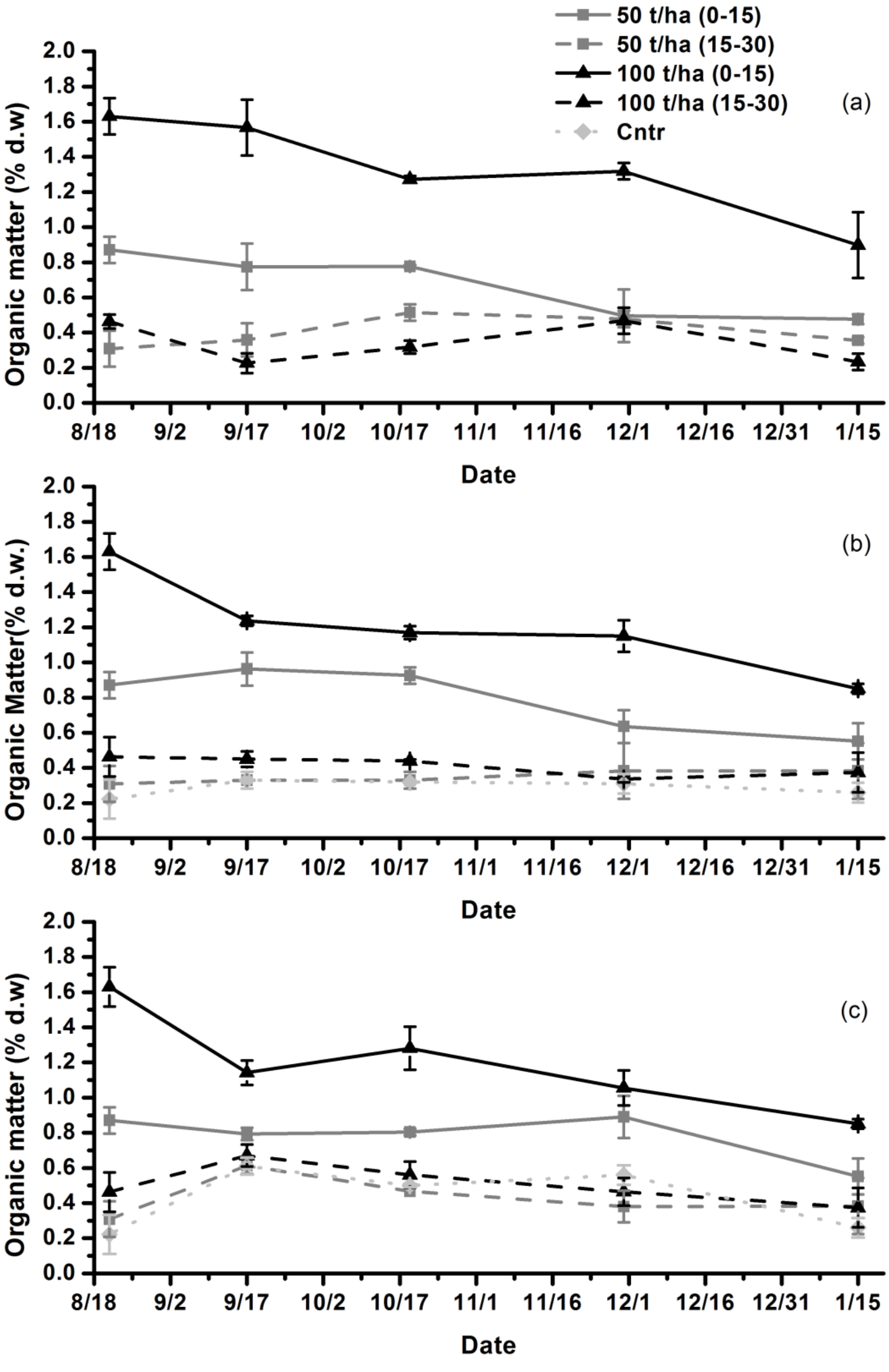
Table 2. Accumulation of nutrients (% d.w.) and trace elements (ppm) in leaves of tomato and lettuce plants and in tomato fruits treated with municipal solid waste compost.

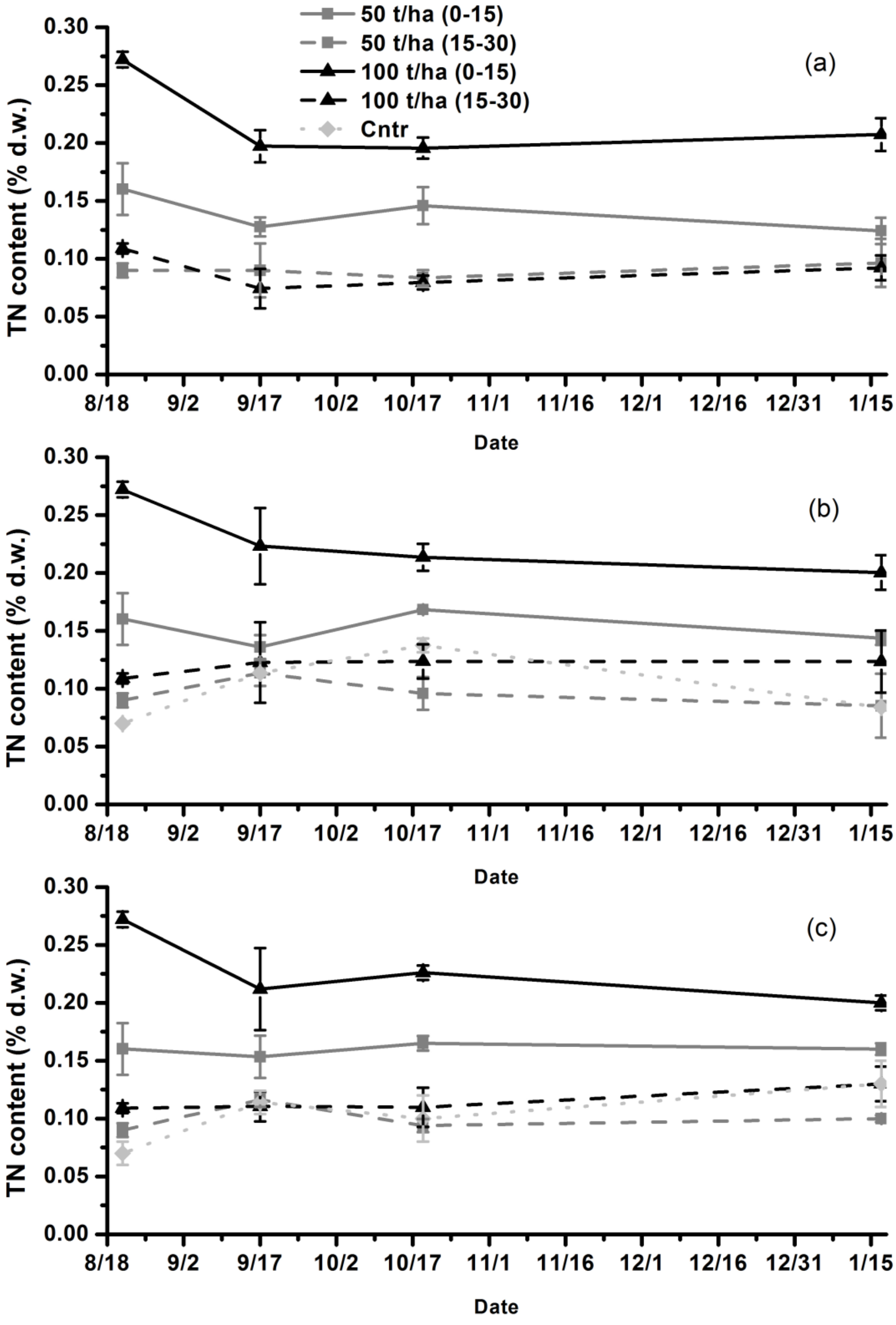
		Elements						
Crop	**Treatment**	**TKN**	**P**	**K**	**Mg**	**Zn**	**Cu**	**Cr**
Tomato	0 t/ha	3.26a	0.23a	2.88	0.56b	14c	10b	1
(leaves)	50 t/ha	1.94c	0.10c	2.86	0.86a	36a	21a	2
01/10/10	100 t/ha	2.20b	0.18b	3.18	0.71c	21b	18a	1
	Signif.	**	**	ns	**	***	**	ns
Tomato	0 t/ha	1.47a	0.08	2.60a	0.55b	13c	6a	1
(leaves)	50 t/ha	1.14b	0.10	1.24c	0.60b	27b	10b	1
10/12/10	100 t/ha	1.17b	0.10	2.03b	0.84a	52a	12c	1
	Signif.	**	ns	**	**	***	***	ns
	Time	**	*	***	*	**	**	ns
	Time×Treatment	**	**	***	**	**	ns	ns
Tomato	0 t/ha	2.23a	0.01	4.02b	0.16	27	4.5	<DL
(fruits)	50 t/ha	1.65c	0.02	4.73a	0.18	19	6.5	0.3
10/12/10	100 t/ha	1.79b	0.02	4.76a	0.18	24	6	0.6
	Signif.	**	ns	*	ns	ns	ns	ns
Lettuce	0 t/ha	2.33a	0.21a	3.50c	0.37a	20c	10	2.6b
(1st harvest)	50 t/ha	2.06b	0.13b	5.50b	0.25b	40b	11	6.8a
11/10/10	100 t/ha	2.44a	0.13b	6.71a	0.28b	76a	11	3.9b
	Signif.	**	**	***	**	***	ns	*
Lettuce	0 t/ha	4.22a	0.12	3.01b	0.25	27b	2.0b	0.52
(2nd harvest)	50 t/ha	1.62c	0.12	4.52a	0.23	32b	3.0b	0.82
01/12/10	100 t/ha	2.03b	0.12	5.17a	0.22	44a	6.2a	0.34
	Signif.	***	ns	***	ns	**	**	ns
	Time	*	ns	***	*	**	**	ns

Time×Treatment	**	*	***	*	**	ns	ns

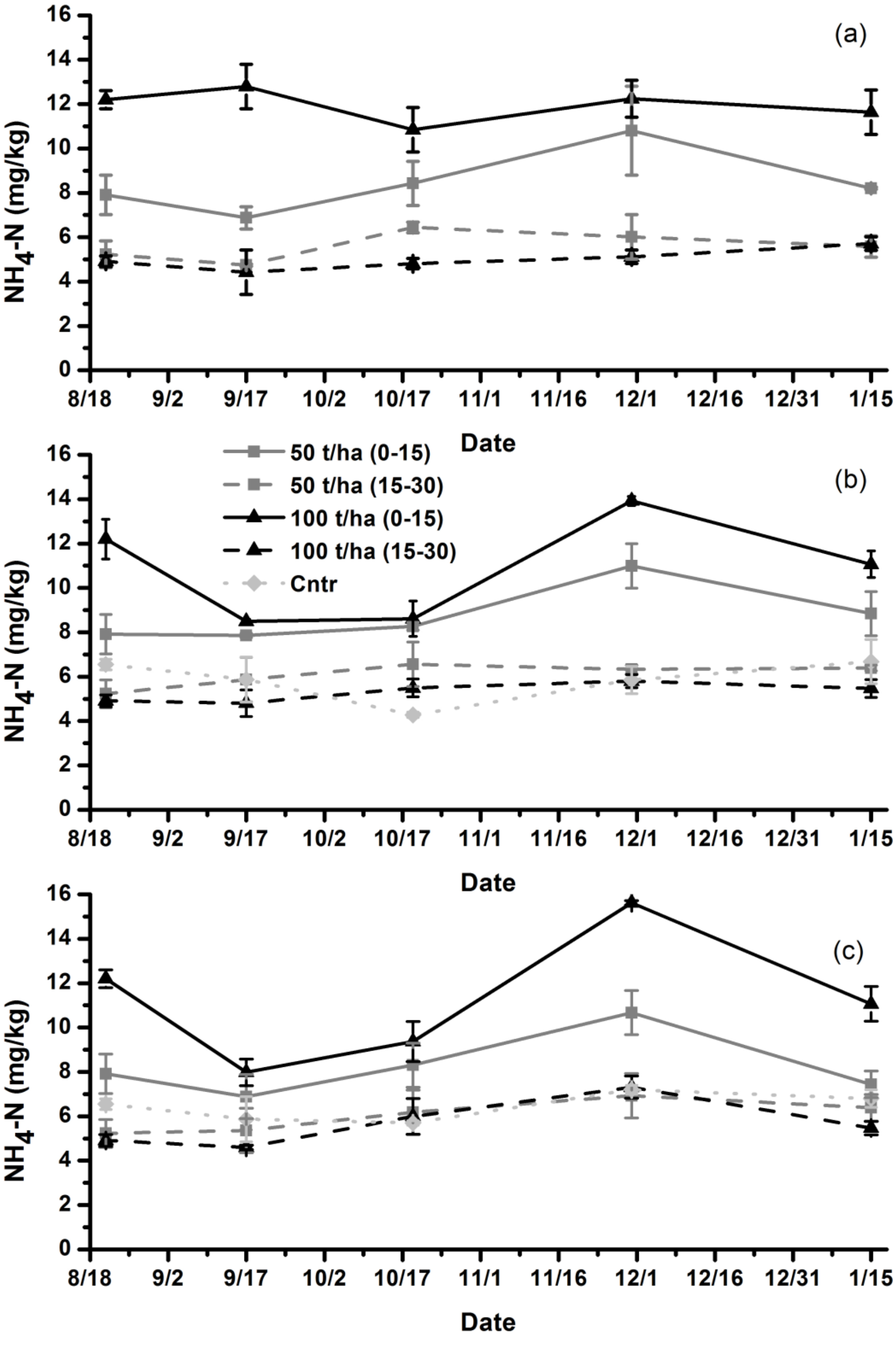
<DL: bellow detection limits, ns: not significant, *P<0.05, **P<0.01, ***P<0.001 Numbers with different letters differ significantly at the 5% level by Tukey's significant difference.

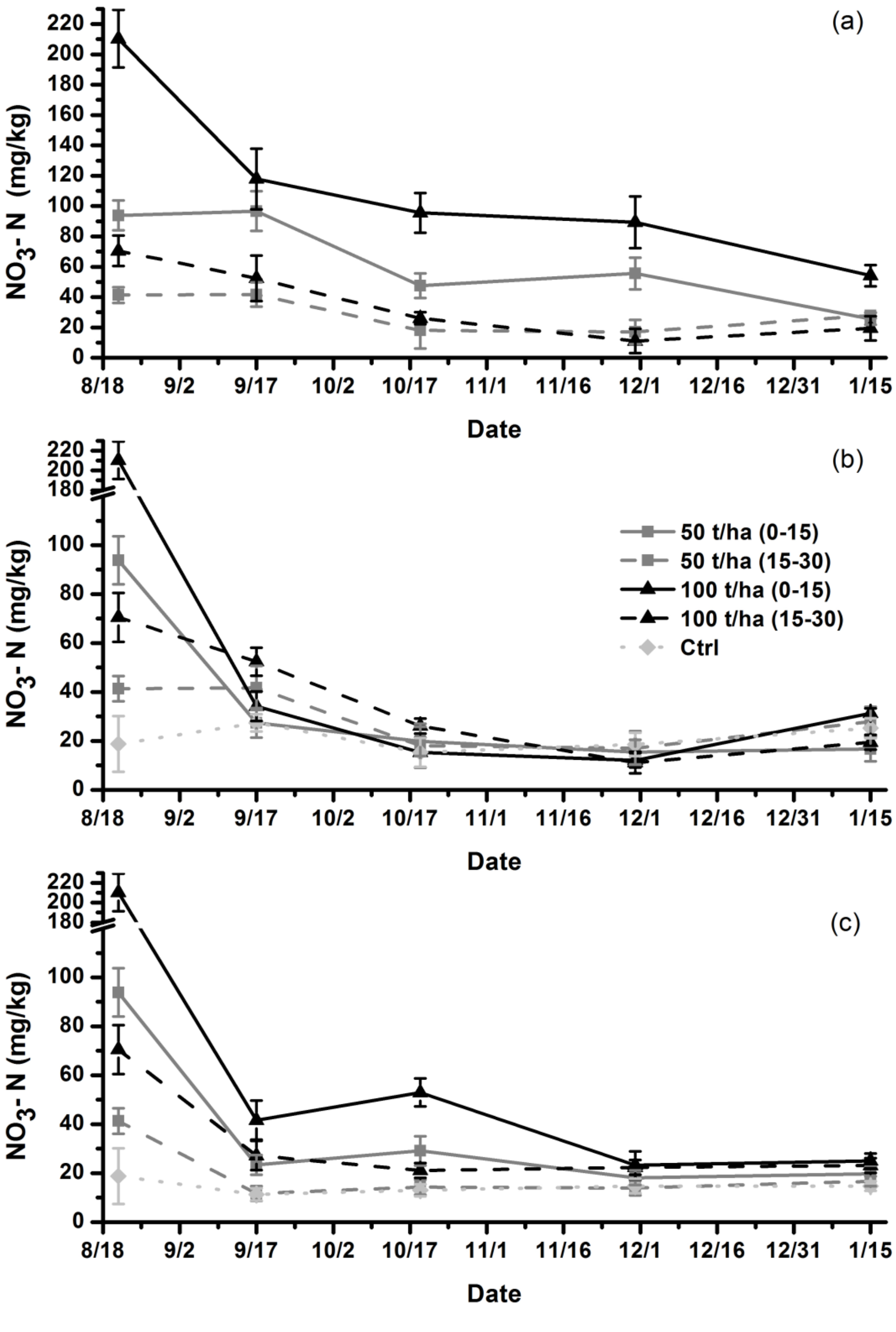


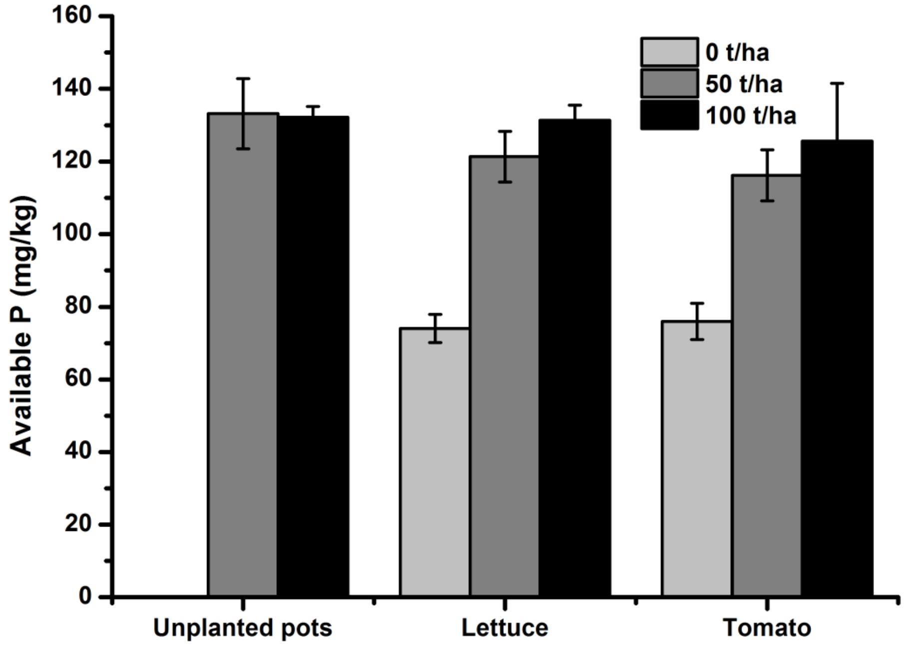

50 t/ha (0-15)
50 t/ha (15-30)
100 t/ha (0-15)
100 t/ha (15-30)
Cntr
(a)
Organic matter (% d.w)
Date
(b)
Organic Matter(% d.w.)
Date
(c)
Organic matter (% d.w)
Date
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
8/18
9/2
9/17
10/2
10/17
11/1
11/16
12/1
12/16
12/31
1/15


50 t/ha (0-15)
50 t/ha (15-30)
100 t/ha (0-15)
100 t/ha (15-30)
Cntr
(a)
(b)
(c)
TN content (% d.w.)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
8/18
9/2
9/17
10/2
10/17
11/1
11/16
12/1
12/16
12/31
1/15
Date

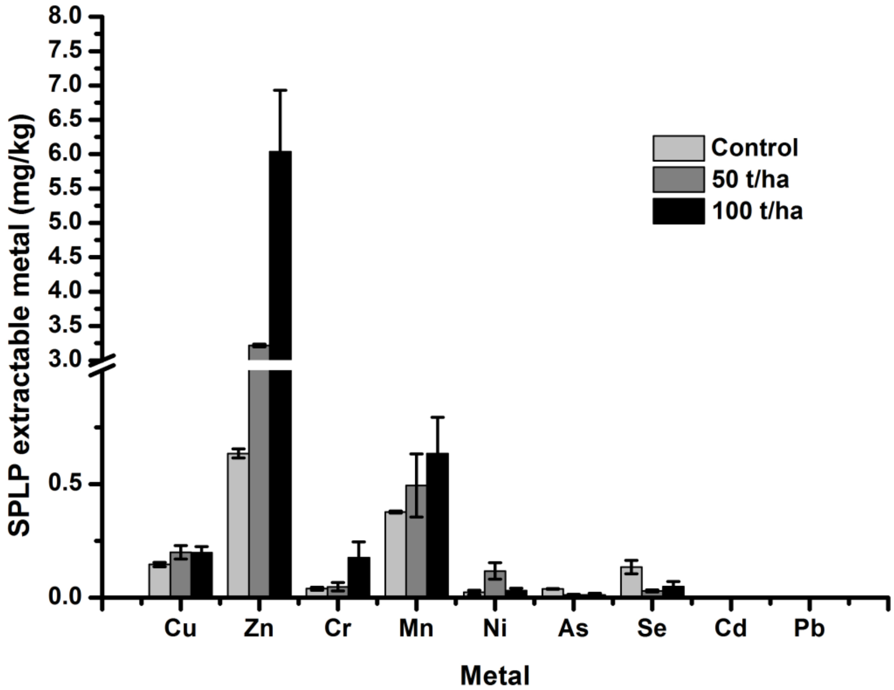
574


(a)
(b)
(c)
NH_4-N (mg/kg)
Date
16
14
12
10
8
6
4
2
0
8/18
9/2
9/17
10/2
10/17
11/1
11/16
12/1
12/16
12/31
1/15
50 t/ha (0-15)
50 t/ha (15-30)
100 t/ha (0-15)
100 t/ha (15-30)
Cntr

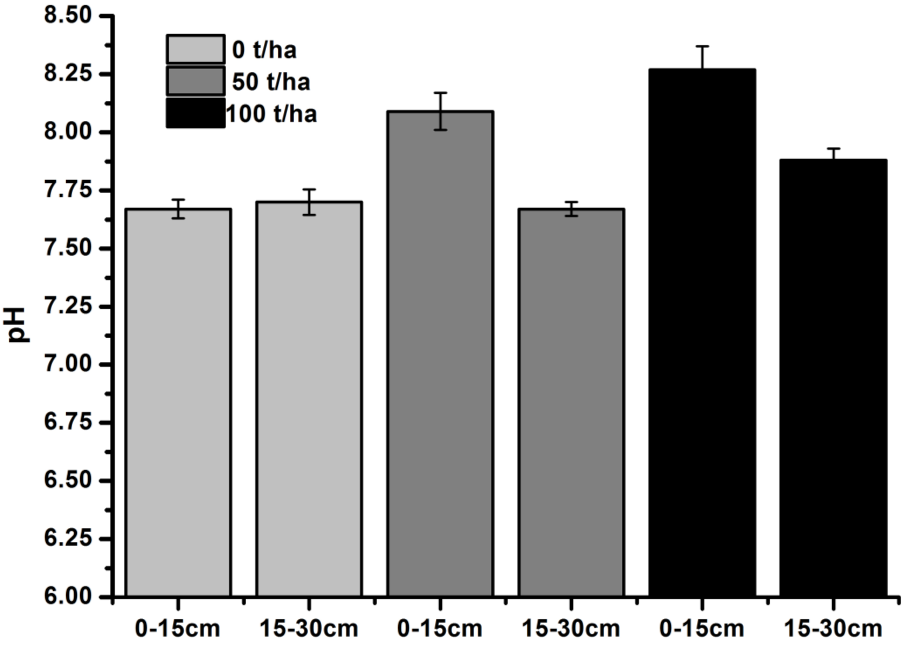

(a)
(b)
(c)
NO_3- N (mg/kg)
Date
8/18
9/2
9/17
10/2
10/17
11/1
11/16
12/1
12/16
12/31
1/15
50 t/ha (0-15)
50 t/ha (15-30)
100 t/ha (0-15)
100 t/ha (15-30)
Ctrl


160
140
120
100
80
60
40
20
0
Available P (mg/kg)
0 t/ha
50 t/ha
100 t/ha
Unplanted pots
Lettuce
Tomato

578


8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
0.5
0.0
SPLP extractable metal (mg/kg)
Control
50 t/ha
100 t/ha
Cu
Zn
Cr
Mn
Ni
As
Se
Cd
Pb
Metal

579


8.50
8.25
8.00
7.75
7.50
7.25
7.00
6.75
6.50
6.25
6.00
pH
0 t/ha
50 t/ha
100 t/ha
0-15cm
15-30cm
0-15cm
15-30cm
0-15cm
15-30cm

580