CROP PRODUCTION AND NITROGEN LEACHING RESULTING FROM BIOWASTE AND ONION COMPOST AMENDED SAND

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SUMMARY: Compost application to agricultural land needs to ensure sustainable development. Hence it is important to determine the fertilizer value and soil conditioning ability of composts, and further to assess the risk of adverse environmental effects, such as excessive nitrate leaching. A lysimeter study was undertaken on poor quality sand to determine the effects of biowaste and onion compost application on forage maize production and nitrate leaching, under high drainage rate conditions. The two composts were applied at rates of 100, 250, 400 and 600 kg total N ha^{-1}. Rates of mineral fertilizer N were used as reference treatments. Under the conditions of the study, mineral fertilizer had a poor effect on crop production, while resulted in excessive N leaching losses. The onion compost application (C: N ratio = 10) at rates > 250 kg total N ha^{-1} significantly increased crop yield compared to the control treatment, and the mineral fertilizer treatments. The biowaste compost (C: N ratio = 21) did not enhance crop yield. Both composts did not increase nitrogen leaching losses compared to the control treatment, and they were advantageous over mineral fertilizers from a water quality perspective.

1. INTRODUCTION

Organic waste recycling to land is expected to increase following the implementation of the EC strategy on the prevention and recycling of waste (COM 2003) and the landfill Directive (CEC 1999) which restricts the disposal of organic rich materials in landfills. Composting of organic waste and the land application of the end product is one of the main waste management options, and it may contribute to the improvement of soil fertility, the carbon sequestration, and also to the reduction of methane production from degradation of organic waste in landfills (Smith, Brown & al 2001).

Compost application to agricultural soil needs to support crop production while protecting soil and water quality. The application of biowaste and vegetable waste composts increases soil organic matter and total N content (He, Traina & al 1992; Nevens & Reheul 2003; Hartl & Erhart 2005). The compost N added to the soil is present mostly in organic N compounds. It can be mineralized and thus be taken up by the plants, immobilized, denitrified, and/or leached (Hartl & Erhart 2005). Compost N mineralization depends on several factors including the C: N ratio of the compost (Sims 1990; Mamo, Rosen & al 1999; Wolkowski 2003), soil texture and climate.

The objectives of this study were: a) to evaluate the fertilizer potential of biowaste and vegetable

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residue composts under poor soil conditions, b) to determine the environmental risks of excessive nitrogen leaching from the application of these two compost types to a well drained soil, and c) to evaluate the effect of compost type and application rate on crop production, nitrate leaching, and sand properties.

2. MATERIALS AND METHODS

A lysimeter study was undertaken at the experimental site of Cranfield University, Silsoe, UK. The lysimeters were filled with sand (fine sand for the top 25 cm over lying 40 cm of coarse sand, beneath which was a 20 cm layer of gravel to facilitate drainage). Sand properties are presented in Table 1. The lysimeters diameter was 55 cm. Leachate collection was from a drain pipe at the base of the lysimeters.

The sand was amended with two compost types: the biowaste and the onion compost. The biowaste compost was produced in aerated vessels according to the animal by-products regulations at a municipal composting facility processing source-separated kitchen, garden, paper and cardboard waste. The onion compost was produced from onion residues mixed with straw and composted in uncovered heaps on the production farm site. The two composts were incorporated within the top 15 cm of the sand at four rates corresponding to the application of 100, 250, 400 and 600 kg of compost total N ha^{-1}. The compost application rates along with the corresponding amount of some nutrients applied are summarized in Table 2.

Table 1. Sand properties at the beginning of the experiment

	Texture			Chemical properties						
	Sand (%)	Silt (%)	Clay (%)	pH	OM (%)	Total N (%)	Mineral N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})
Fine sand	99.4	0.6	0.0	7.4	1.36	< 0.03	0	0.5	27.9	16.7
Coarse sand	98.5	0.8	0.7	7.6	1.33	< 0.03	0	0.5	20.7	13.2

Table 2. Biowaste and onion composts: application rates and respective amounts of nutrients and organic matter (OM) applied per lysimeter, and composts C: N ratio

Application rates (kg total N ha^{-1})	Fresh material (g)	Total N (g)	Mineral N (g)	Available K (g)	Available P (g)	OM (g)	C: N ratio
Biowaste compost							21
100	188	2.4	0.0	1.1	0.0	71	
250	471	5.9	0.1	2.8	0.1	177	
400	754	9.5	0.1	4.5	0.2	284	
600	1131	14.2	0.2	6.8	0.3	426	
Onion compost							10
100	495	2.4	0.0	1.7	0.1	48	
250	1238	5.9	0.1	4.2	0.3	119	
400	1980	9.5	0.2	6.7	0.5	190	
600	2970	14.3	0.3	10.1	0.8	285	

Mineral fertilizer (0, 40, 80 and 120 kg N ha^{-1}) treatments were used as reference treatments

(The treatment resulting in the application of 0 kg N ha^{-1} is referred to as 'control' treatment.) Forage maize was used as the monitoring crop. The sand in all lysimeters was amended with mineral P, K and Mg in the beginning of the experiment, in order to supply the necessary macro-nutrients (except for N) for maize growth in such a poor quality soil. The application quantities of P, K, and Mg were the maximum amounts recommended by MAFF 2000 for forage maize production in poor light soils. Each treatment was applied on an individual lysimeter using a completely randomized design with three replicates.

The study initiated on May 18, 2006, when the compost incorporation took place. Forage maize sowing was on June 1 (at a rate of 6 seeds per lysimeter), and the application of the mineral fertilizer N on the following day. On June 26, maize was thinned to 3 plants per lysimeter. On July 16, supplementary fertilization with mineral P and K was applied. Maize harvest was on September 11.

The first leachate sampling was on May 29. Leachate samples were taken on a 2-weeks basis until the crop harvest and after that on a monthly basis for other two months. Measurements of mineral N in the leachate (sum of nitrate-, nitrite-, and ammonium- nitrogen) were undertaken on all samples by segmented flow analysis. Measurements of total soluble N (TSN) were carried out on the samples collected after June 29. The amount of organic soluble N (OSN) in the leachate was estimated as the difference between the TSN and the mineral N measured for each treatment and sampling date.

At harvest, crop above ground dry matter (DM) yield was determined by drying maize cobs at 60 ˚C until constant weight, and the rest of the plant at 105 ˚C for 26 hours. Maize total N concentrations were determined by the use of elemental analyzer, separately for the cobs and the rest maize plant. The DM yield of maize cobs and of the rest maize plant were multiplied by their respective total N content, and then summarized to crop N uptake. Maize total P and K concentrations were also determined, according to MAFF 1986, for the whole maize plant. Crop P and K uptake were also evaluated. Crop DM yield and N uptake were also measured for the plants which were removed at thinning to achieve more accurate calculation of the N budget. N recovery from compost and mineral fertilizers was calculated according to the Equation 1.

$$N\ recovery\ (\%) = 100 \times \frac{Compost\ or\ Fertilizer\ N\ uptake\ -\ Control\ N\ uptake}{Total\ \ ferilizer\ N\ applied} \qquad (1)$$

Sand fertility properties were assessed at harvest. Organic matter content (OM) was determined by the loss on ignition method, pH in the 1/2.5 soil/water extract, total N, total C and C: N ratio by the use of the elemental analyzer. Available P was estimated by the Olsen method. K and Na were extracted by ammonium nitrate and measured by flame photometry (MAFF 1986). The above mentioned parameters were determined for the layer of 0-25 cm depths.

The effects of each treatment and the influence of compost type and application rate on the measured variables were assessed by analysis of variance ($p<0.05$), using the statistical software GenStat (GenStat Release 9.1).

3. RESULTS AND DISCUSSION

3.1 Forage maize production and nutrient uptake

Despite the unfavourable conditions for forage maize production, the crop completed its growth and development. Figures 1 and 2 show the effect of the different rates of biowaste and onion compost application on crop DM yield and N uptake, respectively, at the early stages of plant growth (3^{rd} leaf stage). The measurements were carried out on the thinned plants.

At this early stage of plant growth, both mineral fertilizer and onion compost shown a trend to increase DM yield with increasing application rates. However, only the onion compost applied at the rate of 600 kg total N ha^{-1} gave a significant increase in DM yield. The crop N uptake increased with the mineral fertilizer N and the onion compost applied at the highest rate. The biowaste compost application was not observed to have any benefit on crop DM yield and N uptake. On the contrary, the application of high rates of biowaste compost resulted in lower N uptake.

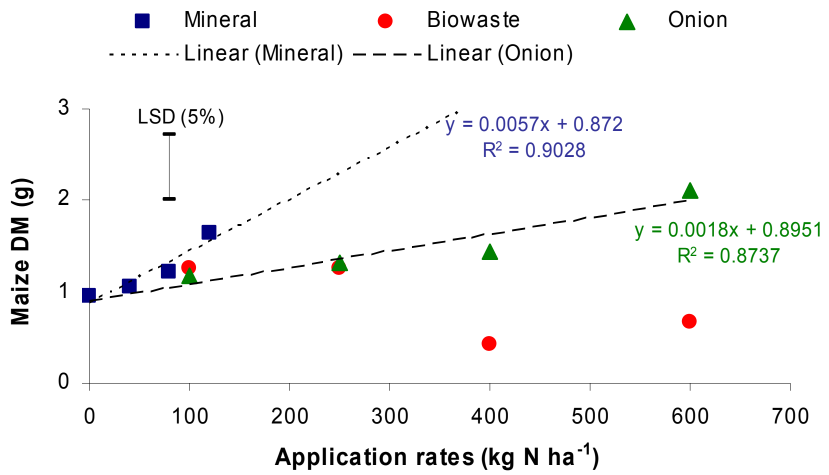

Figure 1. Forage maize DM yield at the 3rd leaf stage resulted from biowaste, onion compost, and mineral fertilizer amended sand.

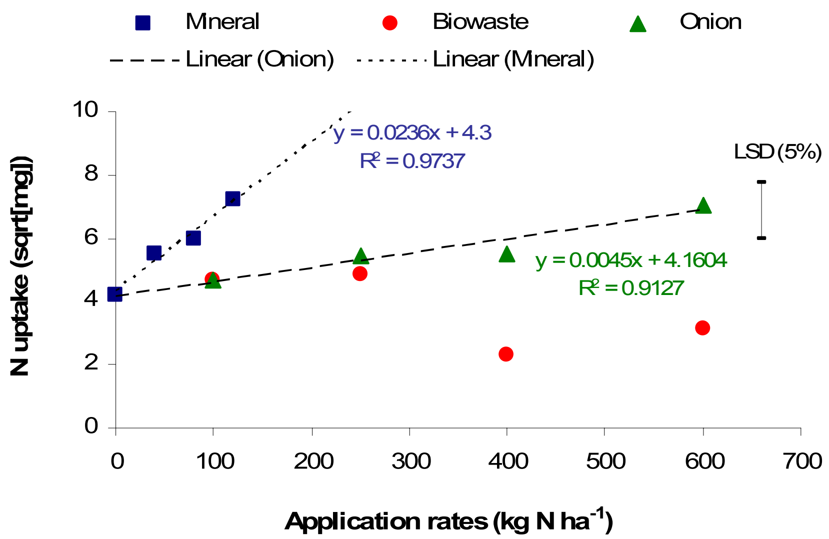

Figure 2. Forage maize N uptake at the 3rd leaf stage resulted from biowaste and onion compost, and mineral fertilizer amended sand. The values shown are the square roots of the measured values.

The crop DM yield and N uptake at harvest are presented in Figures 3 and 4, respectively. Because of the unfavourable soil conditions, maize growth was restricted, but the crop completed its development in all treatments. Figure 3 shows that the mineral fertilization, the biowaste compost application and the onion compost applied at the rate of 100 kg total N ha^{-1} resulted in similar DM yield as the control treatment. Onion compost application at rates > 250 kg total N ha^{-1} significantly increased DM yield. The increase in onion compost application rate resulted in a linear increase in DM yield.

The crop N uptake followed the same trends as the DM yield results. The onion compost (C: N ratio =10) applied at rates ≥ 250 kg total N ha^{-1} significantly increased crop N uptake. The increase of the rate of the onion compost application increased the N uptake linearly.

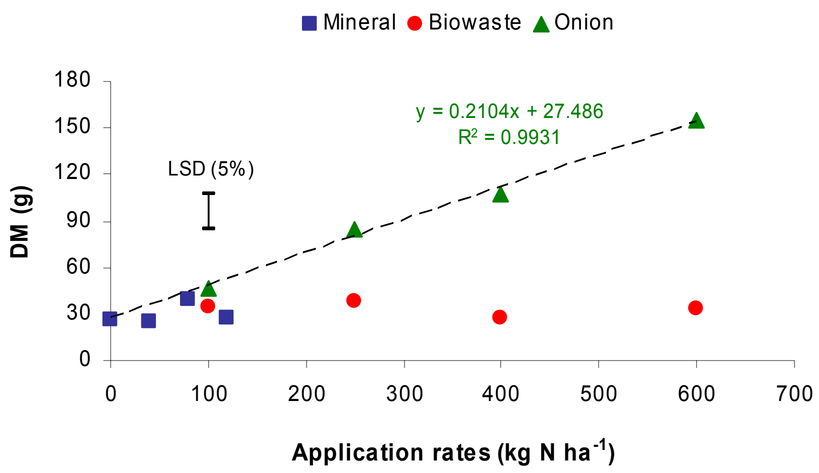

Figure 3. Forage maize DM yield at harvest resulted from biowaste, onion compost, and mineral fertilizer amended sand.

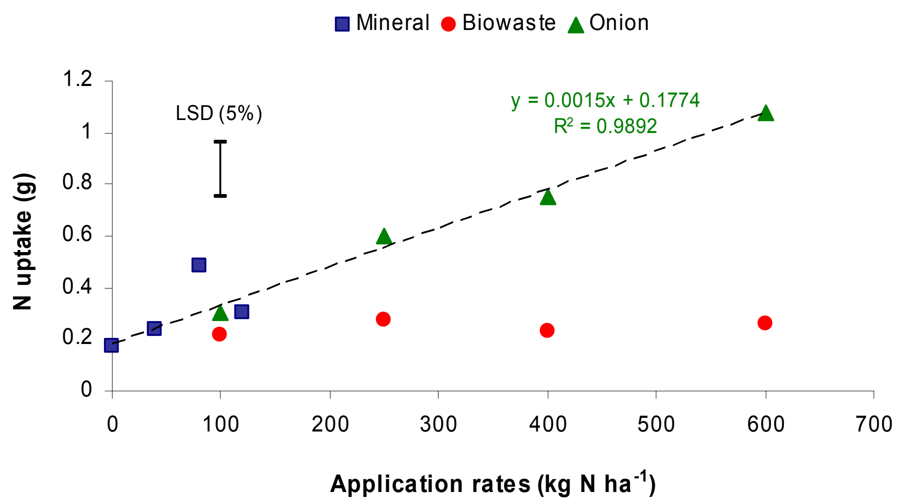

Figure 4. Forage maize N uptake at harvest resulted from biowaste, onion compost, and mineral fertilizer amended sand.

The increase of crop yield with the increase of onion compost application rate is in accordance with the findings of Iglesias-Jimenez & Alvarez 1993, who used compost with C: N ratio <12. The biowaste application resulted in similar N uptake to the control. The poor crop response to the biowaste application indicates immobilization of biowaste compost N. This result supports the findings of Sullivan, Bary & al (2002) who found that composts with C: N ratio >20 result in immobilization of compost N. The mineral N uptake trend is similar to that of the biowaste compost, despite an anomaly at the 80 kg N ha^{-1}.

The N recovery from the onion compost N was found equal to 6.4%, whereas from the biowaste compost N availability equal to 1.1%. Table 3 shows the crop N recovery for the different compost application rates. The N recovery of the mineral fertilizer N was low for all rates of application. It was found equal to 8.4% at the rate of 40 kg N ha^{-1}, 17% at the rate of 80 kg N ha^{-1}, and 5.7% at the rate of 120 kg N ha^{-1}. The low values of crop N recovery found for the compost and mineral fertilizer treatments should be connected to the poor soil conditions which impaired crop growth and consequently N uptake. The low availability of the mineral fertilizer N should also be attributed to the high leaching losses occurred, as shown in paragraph 3.2.

Crop P and K uptake were significantly influenced by compost application. Figure 5 presents the forage maize P uptake resulted from the different treatments. The four reference treatments are summarized in one 'mineral' treatment, since they all received the same amount of P and K. Compost application increased crop P uptake. The increase of compost application rate increased P uptake.

Table 3. N recovery from onion and biowaste compost at the different rates of application.

Application rates (kg total N ha^{-1})	N recovery (%)	
	Biowaste	Onion
100	1.8	5.6
250	1.8	7.3
400	0.4	6.2
600	0.5	6.6

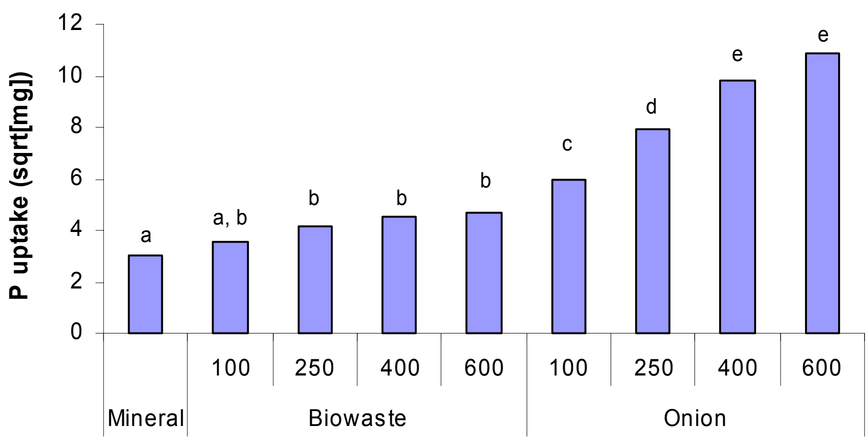

Figure 5. P uptake from the biowaste and onion compost treatments, in comparison to the mean of all reference treatments. The values shown are the square roots of the measured values. Columns labelled with the same letter are not significantly different ($p<0.05$).

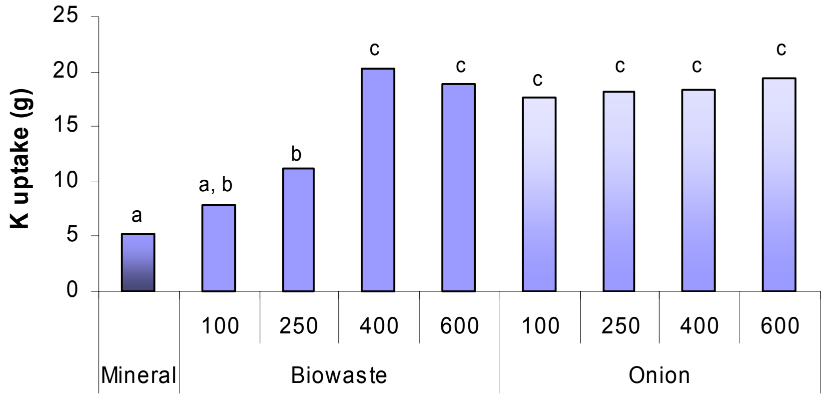

Figure 6. K uptake resulted from the biowaste and onion compost treatments, in comparison to the mean of all mineral fertilizer treatments. Columns labelled with the same letter are not significantly different ($p<0.05$).

Under the conditions of this study the application of mineral fertilization to poor quality sandy soils was not able to advance forage maize production. The application of biowaste compost (C: N ratio = 21) did not increase crop yield. The application of onion compost (C: N ratio = 10) at rates > 250 kg of total N ha^{-1} was found to be the best practise to increase forage maize yield.

3.2 Nitrogen leaching

The mineral N leaching losses which occurred during the study for the different treatments are presented in Figure 7. During the first month of the experiment, both compost and mineral fertilizer treatments resulted in similar N leaching losses with the control. After this period, the mineral fertilizer treatments produced excessive levels of mineral N in the leachate. The increase of the mineral fertilizer application rate increased the mineral N in the leachate. The N leaching losses from the mineral fertilizer treatments occurred during the crop growing season, and therefore limited amount of mineral fertilizer N was available to the crop.

The amount of mineral N leached from the onion and the biowaste compost treatments was found at similar levels with the the control treatment, throughout the measuring period. This finding indicates better N use efficiency and also environmental benefits from a water quality perspective, resulting from compost utilization in forage maize production on well drained sandy soils. The effect of compost application rate on mineral N leached was not observed to be significant.

The amount of mineral N leached from the mineral fertilizer amended sand calculated as a percentage of the mineral fertilizer N applied was found 72 % at the rate of 40 kg N ha^{-1}, 61 % at the rate of 80 kg N ha^{-1}, and 71% at the rate of 120 kg N ha^{-1}. This finding explains the low crop yield response to the mineral fertilizer application, and it shows clearly that in such poor quality sandy soils the application of mineral fertilization constitutes a significant threat to groundwater quality. These excessive mineral fertilizer N leaching should be attributed to the low CEC of the sand, which impeds the available mineral N to be held in the soil, and subsequently it becomes susceptible to leaching. The amount of the mineral N leached from the compost amended sand calculated as a percentage of the total compost N applied was found 0.8% for the onion compost, and 0.3% for the biowaste compost.

The amount of total soluble N (TSN) was also measured in the leachate samples collected after June 29 (Figure 8), in order to determine whether there were any N leaching losses in organic forms from the compost treatments. The TSN in the leachate was found to follow the patterns of the mineral N presented in Figure 7, for the respective measuring period.

The estimated amount of organic soluble N (OSN) in the leachate is presented in Figure 9. Compost application resulted in similar amount of OSN leached, with the control treatment. This finding indicates that compost application did not advance N leaching losses in organic forms.

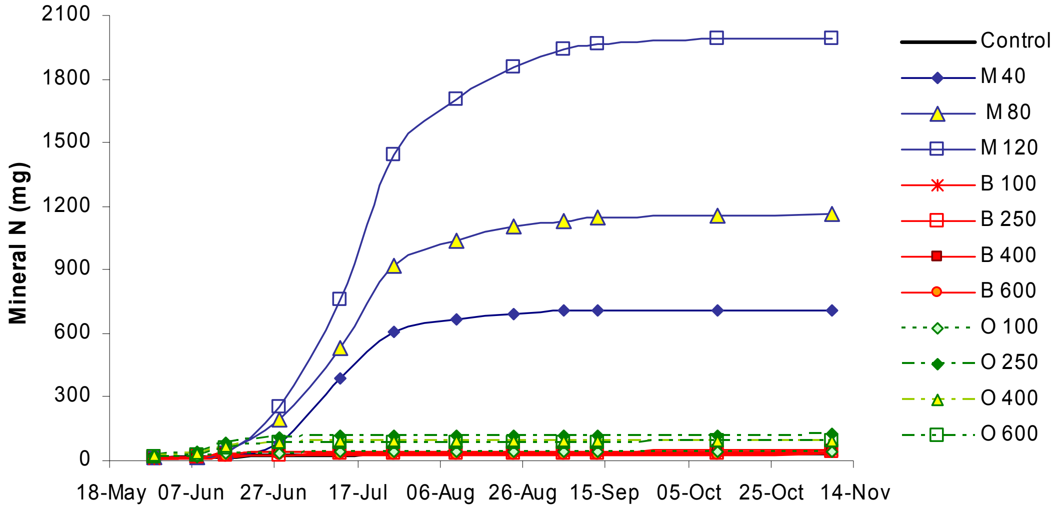

Figure 7. Cumulative mineral N leached from all 12 treatments (M: mineral fertilizer, B: biowaste compost, O: onion compost)

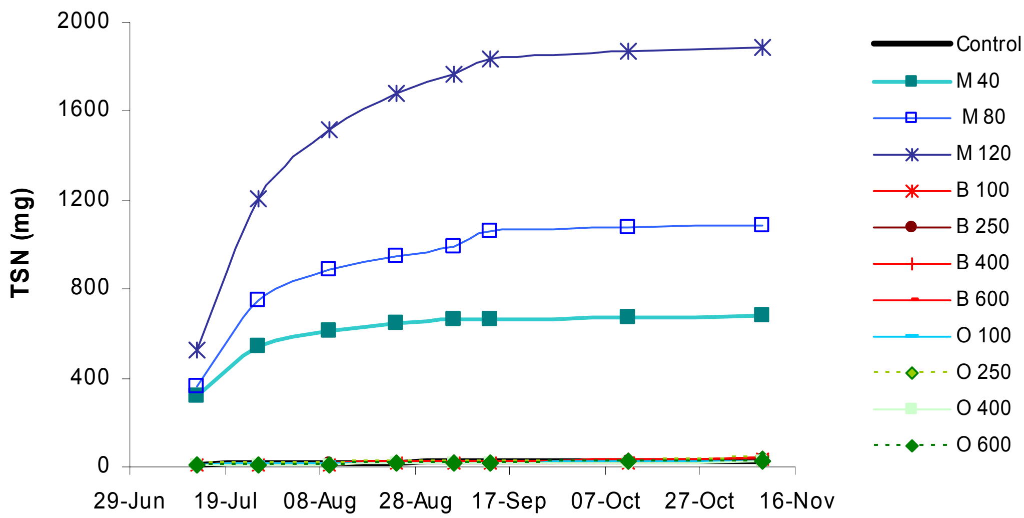

Figure 8. Cumulative TSN leached from all 12 treatments during the period of 29 June to 6 November 2006. (M: mineral fertilizer, B: biowaste compost, O: onion compost)

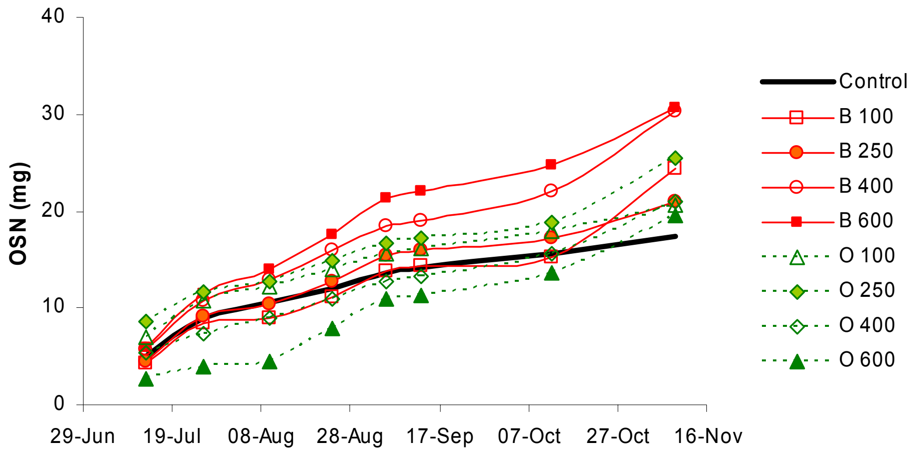

Figure 9. Cumulative OSN leached from the control and compost treatments during the period of 29 June to 6 November 2006. (B: biowaste compost, O: onion compost)

The mineral and organic soluble N leaching losses results suggest that compost application to well drained sandy soils is advantageous over mineral fertilizers, and does not constitute a threat to water quality, at least in the short term.

3.3 Sand fertility parameters

The sand extractable K and Na were increased by the compost application, in comparison to the reference treatments, at a rate of about 20% and 21%, respectively. Both biowaste and onion compost resulted in similar levels of extractable K and Na. Despite the increase of sand Na levels, sodicity problems are not expected under these sandy soil conditions. Compost application also increased the sand available P levels. Onion compost application resulted in higher sand available P levels, compared to the biowaste compost (onion compost increased P levels at a rate of about 770%, compared to the reference treatments, and biowaste at rate of about 50%). The effect of the compost application rate on P, K and Na levels was not significant.

Soil total N content was below 0.03%, which is the lowest detectable limit within the method used. Compost application at rates > 100 kg total N ha^{-1} produced higher total C content, in comparison to the reference treatments. Biowaste and onion compost resulted in similar levels of sand total C content. The increase of compost application rate resulted in increased total C content. Sand OM content and pH were not found influenced by the compost application.

4. CONCLUSIONS

Under the conditions of the study it was shown that in poor quality sandy soils mineral fertilization is not capable of enhancing crop production, and it constitutes a severe environmental threat due to excessive N leaching. Compost application does not result in excessive N leaching losses, thus it is advantegeous over mineral fertilizers from a water quality perspective. Compost application can improve sand fertility, and also it can increase crop K and P uptake. Biowaste compost characterized by a C: N ratio = 21 did not enhance crop yield indicating the immobilization of compost N. The application of the onion compost with C: N ratio = 10 increased the forage maize yield when applied at rates > 250 kg total N ha^{-1}. Crop yield increased with the increase of onion compost application rate.

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