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The effect of a sandy soil amendment with municipal solid waste (MSW) compost on nitrogen uptake efficiency by plants

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ABSTRACT

The purpose of this work was to determine the influence of municipal solid waste (MSW) compost application on soil properties, nitrogen availability to plants and its uptake efficiency. The paper deals with results of a three-year field experiment where two different MSW composts were non-recurrently applied to sandy soil at rates of 18, 36 and 72 t ha^{-1} (dry mass). Plots without fertilisation as well as plots fertilised each year with mineral forms of NPK were the controls, and spring triticale was cultivated in a monoculture on all plots as a test plant. Soil properties, plant yield and nitrogen content in grain and straw were determined at harvest, and on this basis the applied nitrogen uptake efficiency was calculated. During the first year, only the plots with the highest dose of the better-quality compost had yields similar to the plots fertilised with mineral NPK. Following the years of the experiment, all the plots treated with compost had distinctly lower yields than the plots fertilised with mineral NPK. That decrease was accompanied by a decrease in the nitrogen content in straw and grain, in spite of the fact that the soil material indicated a similar content of total nitrogen to those fertilised with NPK. This indicates that organic matter brought into the soil with MSW compost was intensively mineralised, releasing a considerable amount of nitrogen. However, the plant response indicated a shortage of the plant-available forms of this element. The efficiency of compost-originated nitrogen uptake by plants was very low, at less than 7% of the applied nitrogen. This indicates that plants can take up only a limited amount of nitrogen released from the compost, while considerable amounts are emitted into the atmosphere.

1. Introduction

Municipal solid waste (MSW) may be recycled and applied to the soil after composting, which is considered the most successful technology utilising and transforming organic waste into product suitable for agricultural use (Erhart et al., 2005; Senesi and Plaza, 2007). On the other hand, the continuous decrease of organic matter content in soil, observed especially at intensely cultivated sites (Pan et al., 2010), has pointed to the importance of recycling organic matter and biogenic components. Thus, it is generally accepted that organic waste should be recycled to improve soil properties (Alluvione et al., 2013; Clapp et al., 2007).

There are many papers dealing with the advantages of MSW composts on different soil properties. They contain a considerable amount of organic matter, which is a primary source of nitrogen, and they play a crucial role in improving soil properties. MSW compost can be successfully used to conserve the level of organic matter in soil (Adani et al., 2009; Alvarenga et al., 2009; Barral et al., 2009; Roman et al., 2003), as well as for remediation of polluted soils (Farrell and Jones, 2009; Roman et al., 2003; Tejada, 2009). The application of MSW compost as well as other sources of organic carbon for agricultural and horticultural purposes leads to positive changes in the physical, chemical, physico-chemical and biological properties of soil, and this consequently increases plant yield (Akram Quasi et al., 2009; Iglesias-Jimenez and Alvarez, 1993; Lillywhite et al., 2009; Mamo et al., 1998; Montemurro et al., 2006; Motta and Maggiore, 2013; Naeini and Cook, 2000; Passoni and Borin, 2009; Wolkowski, 2003). However, there is still not enough information on the environmental consequences of MSW application to the soil.

The content of nitrogen is one of the most important properties of MSW composts, improving plant yield (Eriksen et al., 1999; Montemurro et al., 2005; Mylavarapu and Zinati, 2009; Tontti et al., 2009). Several papers have reported the processes of mineralisation of organic matter in MSW composts contributing to changes in nitrogen content (Amlinger et al., 2003; Busby et al., 2007; Elherradi

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Table 1
Climate characteristics.

Year of the trial	Month												Annual
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Precipitation (mm)													
1	16.7	35.8	63.3	46.5	28.2	60.1	147.3	31.0	40.7	24.2	31.3	30.6	556.7[a]
2	36.0	31.2	86.0	29.5	86.6	17.6	117.0	34.1	29.6	8.1	51.9	25.4	555.0[a]
3	19.5	20.9	62.7	38.2	43.9	77.5	180.0	40.3	95.9	20.4	35.8	24.1	662.2[a]
50 years average	31.0	27.2	31.6	38.5	55.5	69.9	83.9	73.5	47.3	39.9	42.2	35.5	576.0[a]
Temperature (°C)													
1	1.6	0.0	5.6	10.1	14.4	16.6	20.2	18.3	16.8	9.3	3.0	1.9	9.8[b]
2	−0.2	3.9	5.0	12.2	15.6	18.3	16.8	18.8	13.1	12.5	7.0	2.7	10.5[b]
3	0.7	1.4	3.4	8.1	15.1	15.3	19.5	19.4	12.4	12.6	3.7	−1.5	9.2[b]
50 years average	−0.7	0.9	4.4	9.9	14.9	17.9	19.6	18.9	14.7	10.2	5.3	1.3	8.2[b]

[a] Sum of annual precipitation.
[b] Mean annual temperature.

et al., 2005; Mamo et al., 1999a; Passoni and Borin, 2009; Sullivan et al., 2003). However, we still know relatively little about the transformation and environmental fate of this element brought with the compost to the soil. After application of MSW compost to the soil, the nitrogen is transformed into mobile forms that may accumulate in the soil, be taken up by plants or be released into the atmosphere or water system. The amount of nitrogen released into the soil solution determines the plant-available form of nitrogen and consequently the nitrogen content in generative and vegetative parts of the plants and the yield. Soil amendment with organic fertilisers that contain readily decomposable organic carbon compounds may trigger denitrification processes. However, there are no field studies dealing with direct measurements of all forms of gaseous nitrogen emission from the soil (Senbayram et al., 2012); thus N_2 emission from MSW compost amended soil may be assessed indirectly. In this work, changes in the nitrogen content in soil as well as triticale grain and straw over a 3-year period after non-recurring application of different doses of different MSW composts were determined. The main purpose of the experiment was to assess the environmental effects of application of MSW composts to sandy soil, including the improvement of soil properties, durability of changes, and the nitrogen uptake efficiency by plants.

2. Materials and methods

Detailed information about the field experiment was provided in a previous paper, which focused on soil properties (Weber et al., 2007). The climate conditions are given in Table 1. The experiment was performed on a Dystric Cambisol derived from loamy sand of slightly acidic reaction (pH_{KCl} 6.05–6.44), with a plough layer of 25-cm depth containing about 5.0 g kg^{-1} of total organic carbon (TOC).

Two different kinds of commercial compost were used for the experiment. Compost from Katowice (CK) was produced according to the MUT-DANO system from non-selectively collected MSW generated in a highly industrialised region. Compost from Zywiec (CZ) was produced according to the HERHOFF system from selectively collected domestic wastes. Due to the different sources of the wastes, the two composts indicated different properties, especially total nitrogen content and its mineral forms (Table 2). The detailed characteristics of the composts are given in Weber et al. (2007). The field experiment was conducted on 15-m^2 plots based on a randomised block design (5 replications). Both composts were non-recurrently applied to the plots according to the following rates (dry mass): 18, 36 and 72 t ha^{-1}. It is well known that application of composts contribute to an increase in soil organic matter, but this change is not stable and loss of organic matter occurs in time. In order to determine the scale of this process, doses used in the

Table 2
Selected properties of Katowice (CK) and Zywiec (CZ) composts (values on a dry matter basis).

Characteristic	CK compost	CZ compost
Total organic carbon – TOC (g kg^{-1})[a]	137	166
Total nitrogen – TKN (g kg^{-1})[a]	8.4	15.7
N mineral (g kg^{-1})	0.22	0.38
N-NH_4 (g kg^{-1})	0.01	0.16
N-NO_3 (g kg^{-1})	0.21	0.22
C/N	16.3	10.6
Ash (g kg^{-1})	725	645
Electrical conductivity (mS cm^{-1})	4.15	5.20

[a] Data from Weber et al. (2007).

experiment were similar to those used in practice as well as far higher than those suggested in routine usage.

These doses corresponded to the following rates of nitrogen (kg ha^{-1}): 151, 302 and 604 for the CK compost, and 282, 565 and 1139 for the CZ compost. Equal or even much bigger doses of MSW composts (up to 270 t ha^{-1}) have been applied to the soil and analysed in several experiments presented in the literature (Adani et al., 2009; Bastida et al., 2007; Eriksen et al., 1999; Garcia-Gil et al., 2004; Giusquiani et al., 1994; Mamo et al., 1999; Montemurro et al., 2006; Wolkowski, 2003). There were two types of control plots: without mineral fertilisation (contr-0), and plots with annual mineral N, P and K fertilisation (80, 30 and 60 kg ha^{-1}, respectively). Spring triticale of the GABO variety (×*Triticosecale* Wittm.) cultivated in a 3-year monoculture was used as the test plant on all plots. During the experiment triticale germination was observed, and plant growth and development were measured. No negative effects of either compost were noticed.

Soil samples were collected each year after harvest from the 0–20-cm layer. Total organic carbon (TOC) was determined with the Ströhlein CS-MATT 5500 analyser, and the total nitrogen (TKN) was determined with the Büchi set by the Kjeldahl method. The yield of triticale was determined relative to total dry mass of grain and straw. Results were estimated using the Yates formula. The nitrogen content in grain and straw was determined by the Kjeldahl method. Experimental results were statistically verified using a Statistica 9.0. Means were compared by the Student test, at a confidence level of $P < 0.05$.

The uptake efficiency of nitrogen applied to the plot was calculated as follows:

$$Ex = [(Ngx + Nsx) - (Ngo + Nso)] \times 100/Nappx$$

where *Ex* – uptake efficiency of nitrogen applied to "*x*" plot (%); *Ngx* – the yield of nitrogen in grain of "*x*" plot (kg ha^{-1}); *Nsx* – the yield of nitrogen in straw of "*x*" plot (kg ha^{-1}); *Ngo* – the yield of nitrogen in grain of contr-0 plot (kg ha^{-1}); *Nso* – the yield of nitrogen in straw