Journal of Ecological Engineering
Volume 16, Issue 4, Oct. 2015, pages 168–175
DOI: 10.12911/22998993/59378

Research Article

EFFECT OF COMPOST FROM BY-PRODUCT OF THE FISHING INDUSTRY ON CROP YIELD AND MICROELEMENT CONTENT IN MAIZE

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Received: 2015.06.06
Accepted: 2015.08.31
Published: 2015.10.01

ABSTRACT

A pot experiment was conducted to compare the effects of compost from fish waste with mineral and manure fertilization on the yield and chemical composition of the overground parts of maize (*Zea mays* L.). The experiment comprised two series: I – composts at a dose of 1 g of compost per pot, and II – composts with 0.5 g of urea. The treatments were conducted on the following types of composts: compost 1: fish waste (80% d.m.), sawdust (20% d.m.); compost 2: fish waste (80% d.m.), straw (20% d.m.); compost 3: fish waste (80% d.m.), bark (20% d.m.); compost 4: fish waste (79.3% d.m.), sawdust (19.7% d.m.), lignite (1% d.m.); compost 5: fish waste (79.3% d.m.), straw (19.7% d.m.); lignite (1% d.m.); compost 6: fish waste (79.3% d.m.), bark (19.7% d.m), lignite (1% d.m). The contents of Ni, Zn, Cr, Cu and Cd were determined in an air-acetylene flame using the flame atomic absorption spectrophotometric method. The average crop yield of the overground parts of maize in the series without additional mineral fertilization and with mineral N-fertilization was higher compared to objects without mineral N-fertilization. The highest crop yield was noted in the case of compost containing fish waste and straw with addition of lignite and with bark and lignite. The addition of lignite to the compost mass in the series with mineral N-fertilization had stronger influence on the content of cadmium, chromium, nickel and zinc in the overground parts of maize.

Keywords: compost, fish waste, maize (*Zea mays* L.), microelements, yield.

INTRODUCTION

Composting is one of the most effective methods of recycling organic waste with possible use in agriculture. The application of all sorts of organic waste products by turning them into composts has, above all, an economic-ecological value and is regarded to be environmentally friendly [Castaldi et al. 2004, Deguchi et al. 2009]. It enables obtaining a valuable organic fertilizer, which is a substrate of humus, and applying it, among others, in crop production for consumption purposes [Ranalli et al. 2001]. Compost application may enhance the role of physical properties such as total porosity, available water content and saturated hydraulic conductivity, and may increase soil organic matter content [Celik et al. 2004]. Compost input into contaminated soils containing microelements reduces the overall bioavailability of metals due to sorption processes and thus provides an effective soil remediation technique [Brown et al. 2004]. Inorganic fertilizers are costly and unable to sustain soil fertility; they also pose environmental risk of nitrate pollution of groundwater [Camargo and Alonso 2006].

The Regulation (EC) of the European Parliament and the Council on health rules concerning animal by-products not intended for human consumption describes products derived from aquatic animals, including fish, as removed e.g. by incineration or co-incineration, fermentation, composting or transformation into biogas.

Animal waste, which includes the by-products of fishing industry, i.e. half-dead fish or products left over after processing fish for consumption purposes, may be an excellent component for compost production [Laos et al. 1998, López-Mosquera et al. 2011]. Compost should be sanitarily safe and rich in humic and biogenic substances, without destructive effect on the environment and be possible to apply to soil [Seki et al. 2008]. The rate of compost application to ensure maximum crop yield with minimal environmental degradation varies depending on the crop species, as well as on the types of the compost used. There is a published report on the composting of offal from chicken slaughter [Pisa and Wuta 2013]; it shows that composting can be used successfully to manage chicken offal, although the compost quality was not determined in the report.

The aim of the presented research is to determine the influence of composts produced from by-products of the fishing industry added to the soil on the crop yield and selected microelements content in the overground parts of maize (*Zea mays* L.).

MATERIAL AND METHODS

Composting trials

Composts used in the experiment came from an outdoor experiment set up in 2010, conducted in specially constructed wooden crates measuring 50×60×60 cm (W×L×H). The basic substrate for obtaining the compost were small cyprinid fish from Lake Kortowskie (Olsztyn, Poland): common bleak (*Alburnus alburnus*), common roach (*Rutilus rutilus*), common bream (*Abramis brama*) and white bream (*Blicca bjoerkna*). The effect of composting depends largely on the quantity and proportions of the components; wheat straw, which is a basic component, was applied as a structural additive. Other substrates included waste products of the foresting industry, i.e. sawdust, due to its ability to absorb moisture and a structure ensuring adequate compost porosity, as well as pine bark. A variant with the addition of lignite was also tested. After grinding, all substrates were placed in layers. The top layer always consisted of organic substances, which were applied to protect the compost from excessive drying up and from the unfavourable effect of atmospheric conditions.

In order to achieve the assumed study aims, an experiment was carried out using the following types of compost: Compost 1: fish waste (80% d.m.), sawdust (20% d.m.); Compost 2: fish waste (80% d.m.), straw (20% d.m.); Compost 3: fish waste (80% d.m.), bark (20% d.m.); Compost 4: fish waste (79.3% d.m.), sawdust (19.7% d.m.), lignite (1% d.m.); Compost 5: fish waste (79.3% d.m.), straw (19.7% d.m.), lignite (1% d.m.); Compost 6: fish waste (79.3% d.m.),

Table 1. Chemical characteristics of the applied composts and manure

Parameter	Compost[a]						Animal manure
	C_1	C_2	C_3	C_4	C_5	C_6	
Total Organic C ($g \cdot kg^{-1}$ dry mass)	425.7	418.6	382.8	413.4	428.7	369.9	358.3
Total Nitorgen ($g \cdot kg^{-1}$ dry mass)	9.21	12.13	11.46	9.93	12.59	12.22	17.51
C/N Ratio	46.2	34.5	33.4	41.6	34.1	30.3	20.5
Phosphorus ($g \cdot kg^{-1}$ dry mass)	2.61	2.56	2.43	2.53	2.49	2.50	15.4
Potassium ($g \cdot kg^{-1}$ dry mass)	3.07	3.74	3.77	3.15	3.95	3.99	14.1
Magnesium ($g \cdot kg^{-1}$ dry mass)	0.60	0.62	0.65	0.61	0.67	0.63	2.42
Sodium ($g \cdot kg^{-1}$ dry mass)	0.30	0.31	0.33	0.31	0.34	0.35	5.10
Calcium ($g \cdot kg^{-1}$ dry mass)	3.75	3.19	3.17	4.04	3.70	3.68	18.6
Copper ($mg \cdot kg^{-1}$ dry mass)	13.3	21.31	13.9	11.9	26.6	12.4	14.9
Cadmium ($mg \cdot kg^{-1}$ dry mass)	1.52	1.23	1.42	1.41	1.17	1.36	0.88
Chromium ($mg \cdot kg^{-1}$ dry mass)	5.40	7.21	6.11	9.8	13.3	12.8	4.68
Nickel ($mg \cdot kg^{-1}$ dry mass)	9.91	6.30	15.3	17.6	12.3	24.3	10.4
Zinc ($mg \cdot kg^{-1}$ dry mass)	159.9	121.6	180.4	201.0	190.8	210.3	86.5

[a] C_1: fish waste (80% d.m.), sawdust (20% d.m.); C_2: fish waste (80% d.m.), straw (20% d.m.); C_3: fish waste (80% d.m.), bark (20% d.m.); C_4: fish waste (79.3% d.m.), sawdust (19.7% d.m.), lignite (1% d.m.); C_5: fish waste (79.3% d.m.), straw (19.7% d.m.), lignite (1% d.m.); C_6: fish waste (79.3% d.m.), bark (19.7% d.m), lignite (1% d.m).

bark (19.7% d.m), lignite (1% d.m). During the composting process, the humidity of the materials was maintained at a constant level of 60–70% and the compost mass was mixed once a week for aeration. Characteristics of the composts are presented in Table 1.

Pot experiment

The experiment was established in the glasshouse of the University of Warmia and Mazury in Olsztyn (Poland) at a natural day/night conditions; during the day, the air temperature was 26±3°C and approximately ten degrees lower (16±2°C) at night, relative humidity 75±5%. PCV pots filled with 9.5 kg of soil mixed with composts in accordance to the study procedure were used for this purpose. Soil used in the experiment was characterized by a granulometric composition with 86% of sand (2.0–0.05 mm), 11.2% of silt (0.05–0.002 mm) and 2.2% of the suspended fraction (< 0.002 mm); the soil was collected from the arable layer of a farm field. The soil samples were air-dried and passed through a 5-mm sieve prior to the greenhouse pot experiment. Agrochemical parameters of the used soil are shown in Table 2.

The experiment consisted of two series, each conducted in four replicates. In the first one, the composts were applied in the amount of 1 g N of compost per pot. In the second series, 0.5 g of mineral N in the form of urea [$(NH_2)_2CO$] was additionally applied to the compost. The control objects did not contain compost additives. The effect of fertilization was tested on maize (*Zea mays* L. cv. San). The density was 6 plants per pot. Maize was picked after 66 days of vegetation during the phase of intense stalk growth.

Table 2. Agrochemical parameters of the soil

Parameter	Value
pH_{KCl}	5.7
Hydrolytic acidity (HAC) (mmol$^{(+)}$ kg^{-1})	21.31
Sum of exchangeable bases Ca^{++}, Mg^{++}, K^+, Na^+ (TEB) (mmol$^{(+)}$ kg^{-1})	84.29
Cation exchange capacity (CEC) (mmol$^{(+)}$ kg^{-1})	105.60
Base saturation (BS) (%)	79.82
Organic carbon (g·kg^{-1})	6.30
Total nitrogen (g·kg^{-1})	0.54
Ammonia (mg·kg^{-1})	15.40
Nitrate (V) (mg·kg^{-1})	4.02
Phosphorus (mg·kg^{-1})	84.76
Potassium (mg·kg^{-1})	57.89
Magnesium (mg·kg^{-1})	76.37
Cadmium (mg·kg^{-1})	3.02
Nickel (mg·kg^{-1})	3.58
Zinc (mg·kg^{-1})	32.30
Chromium (mg·kg^{-1})	11.36
Copper (mg·kg^{-1})	8.89

Measurements and statistical analysis

The collected plant samples were analyzed in order to determine the yield of the overground parts from each pot. The harvested plants were washed with tap water and rinsed with double deionized water, fragmented and oven-dried at 60 °C for 48 h. The contents of trace elements: cadmium – Cd, nickel – Ni, zinc – Zn, chromium – Cr, manganese – Mn, copper – Cu and cobalt – Co were determined in an air-acetylene flame, following the flame atomic absorption spectrophotometric method (FAAS) on a SpecrtAA 240FS atomic absorption spectrophotometer (VARIAN, Australia) using a Sample Introduction Pump System (SIPS) in extracts obtained after microwave digestion of plant samples in nitric acid hydrogen (analytically pure HNO_3) at a concentration of 1.40·g·cm^{-3}, poured into HP500 Teflon vessels and placed in a MARS-5 microwave oven (CEM Corporation, USA). The mineralization conditions, i.e. volume of nitrogen acid and mineralization temperature, were set as described in the methodology given in the Mars 5 Operation Manual (2001). Soil samples were digested and analyzed using the same reagents. Double deionized water (Milli-Q Millipore 0.055 µS·cm^{-1} resistivity) was used for all dilutions.

Before establishing the experiment, the following parameters were determined in the collected soil samples: pH_{KCl} by potentiometry in a 1 mol·dm^{-3} potassium chloride solution (ISO 10390 2005), HAC using Kappen's method [Klute 1996], total exchangeable bases (TEB - K^+, Na^+, Ca^{2+}, and Mg^{2+}) using Kappen's method [Klute 1996], cation exchange capacity (CEC) from the formula: CEC=HAC+TEB, and percentage base saturation (V) from the formula: BS=100·TEB CEC^{-1}. The organic carbon (Corg.) content was measured using Triuin's method in potassium dichromate with diluted sulfuric (VI) acid [Kawada 1957], phosphorus (P) and potassium (K) contents – using Egner-Riehm's method [Egner et al. 1960], and the magnesium (Mg) content – using atomic absorption spectroscopy (AAS) through extraction with Schachtschabel's method [Schlichting et al. 1995]. Total nitrogen (N-total) was determined using Kjedahl's method after mineralization in concentrated sulfuric (VI) acid using hydrogen peroxide as a catalyst [Bremner 1965], $N\text{-}NH_4^+$ was determined using Nessler's reagent [Ostrowska et al. 1991], and $N\text{-}NO_3^-$ using phenoldisulfonic acid [Ostrowska et al. 1991].

The results were subjected to statistical calculations using the Statistica 10 software package (StatSoft Inc. 2010), with results of each series subjected to statistical analysis using Tukey's analysis of variance. The series were compared with the t-test for dependent variables, assessing differences between the average results. The correlation coefficients (*r*) between the contents of particular heavy metals in the plants were also calculated.

RESULTS AND DISCUSSION

The crop yield of maize (*Zea mays* L.) indicated a clear differentiation and was influenced by the type of compost (C_1–C_6) as well as mineral fertilization (Figure 1). The average crop yield of the overground parts of maize in the series without additional mineral N fertilization was 51.77% higher, and in the mineral N series – 51.42% higher when compared to the control objects. These observations are in accordance with the results reported by Sikora [1998] and Sikora and Enkiri [2000]. These authors have noted that when an N fertilizer was present in a blend with the compost, the compost provided a higher crop yield. N-availability of the compost is generally low and the uptake efficiency of the N fertilizer is also limited due to nitrogen (N) loss and the mineralization-immobilization turnover [Wen et al. 1995]. The influence of variable organic fertilization on the crop yield of maize has been confirmed by the studies of Leroy et al. [2007], Basso and Ritchie [2005] and Doan et al. [2013]. By improving the physical, chemical, and biological properties of the soil, composts may stimulate crop yields [Wyszkowski and Radziemska 2010]. For example, a tomato yield increase of more than 50% was noted in the case when the soil was covered by a layer of solid waste compost [Manios and Kapetanios 1992]. Composts applied in the experiment have resulted in different crop yields of the overground parts of maize. In the control treatments (without and with manure fertilization), the yield of the tested plant was lower than in the treatments in pots with compost (C_1–C_6). The highest crop yield of maize (*Zea mays* L.) was noted in the case of compost containing straw with the addition of lignite. Compost (C_6) with bark and lignite also produced a positive although weaker effect. The addition of lignite (composts C_4–C_6) significantly influenced the crop yield of the overground parts of maize as compared to composts without lignite (C_1–C_3). This yield increase seems to be caused mainly by improved soil structure and enhanced nutritional status of the plants. Mineral fertilization generally increased the crop yield of maize in the control objects.

The applied fertilization resulted in various contents of the microelements in the dry mass of the overground parts of maize (*Zea mays* L.) (Table 3). These factors variably influenced the quantitative changes of the individual elements. Copper is very strongly bound to organic matter. Most probably, more available copper was pre-

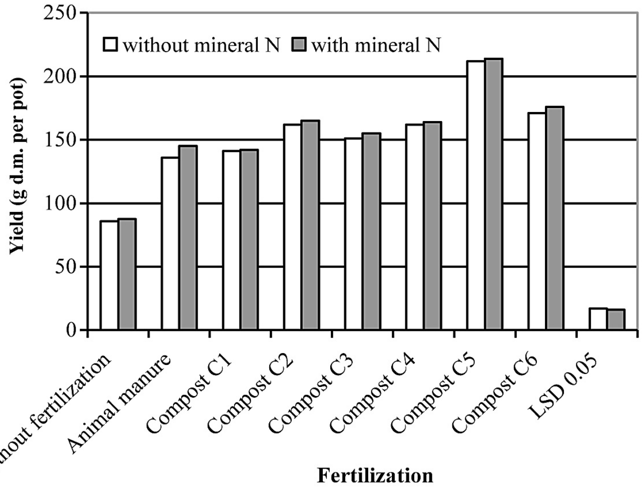

Figure 1. Effect of fertilizer application on the yield of maize (*Zea mays* L.), g d.m. per pot

sent in the soil during the mineralization process. The average content of copper in the overground parts of maize in the series without additional mineral fertilization was 12.89% lower, and in the mineral N series – 6.51% lower in comparison to the control objects. Mineral fertilization with nitrogen and NPK modified the content of microelements in the plants [Wołoszyk et al. 2009]. The overground parts of maize grown on compost comprising a mixture of fish waste and sawdust (compost C_1) without additional mineral fertilization were characterized by the lowest content of copper at 8.92 $mg \cdot kg^{-1}$ dry mass. Zhang et al. [2000] reported that MSW compost application increased the concentrations of copper and zinc in the crop. The highest value of Cu (10.75 $mg \times kg^{-1}$ dry mass) occurred in series with compost produced from fish waste and straw with the addition of lignite.

The obtained results indicate that the content of cadmium in maize (*Zea mays* L.) was variable and affected by the type of the used compost (C_1-C_6) (Table 3). The application of organic material such as compost has been reported to reduce cadmium extractability from soil [Pinto et al. 2004, Li et al. 2006]. In the series without mineral N fertilizer, cadmium content (1.29 $mg \cdot kg^{-1}$ dry mass) in the overground parts of the analyzed plants was most affected by the addition of compost containing fish waste, bark and lignite. In the same series, the lowest content of cadmium at 0.95 $mg \cdot kg^{-1}$ dry mass was observed in plants grown on soil containing compost with sawdust (C_1). Urea fertilization increased the accumulation of cadmium in the overground parts of the tested plants. In the series with mineral fertilization, the cadmium content in maize ranged from 1.01 $mg \times kg^{-1}$ in pots containing compost with sawdust up to 1.27 $mg \times kg^{-1}$ dry mass in pots containing compost with fish waste, bark and lignite (C_6). Complexation of Cd with soil organic matter may not be the main reason for the reduction of Cd toxicity in plants because the complexing abilities of soil organic matter with cadmium are lower than those revealed by other heavy metal ions, such as Zn^{2+}, Cu^{2+} and Pb^{2+} [Plavšic et al. 1991].

Compost and urea fertilization used in the experiments had a significant effect on the content of chromium in maize versus the treatments without mineral N fertilization (Table 3). The average content of chromium in maize (*Zea mays* L.) in the series with additional mineral fertilization was higher than in the series with pure composts. The lowest content of chromium at 0.86 $mg \cdot kg^{-1}$ dry mass in the series with mineral N fertilization was observed in plants grown on soil containing compost with bark (compost C_3). However, in the series without the mineral N fertilizer, the lowest content (0.80 $mg \cdot kg^{-1}$ dry mass) was noted in the case of compost containing fish waste and straw. The highest chromium content in the overground parts of maize (1.09 $mg \cdot kg^{-1}$ dry mass) was noted in the second series of the experiment, in which compost produced from fish waste and bark with the addition of lignite was used (compost C_6).

The type of compost as well as the application of a mineral fertilizer significantly modified the content of nickel in the overground parts of maize (*Zea mays* L.) (Table 3). Organic matter strongly inhibits the uptake of trace elements by plants because composts improve the base saturation of the sorption complex, which limits the uptake

Table 3. Effect of composts on the microelements content in maize (*Zea mays* L.), $mg \cdot kg^{-1}$ dry mass

Fertilization	Series without mineral N					Series with mineral N				
	Cu	Cd	Cr	Ni	Zn	Cu	Cd	Cr	Ni	Zn
Without fertilization	11.25	1.18	0.96	4.00	112.4	11.22	1.23	1.04	4.09	115.4
Animal manure	9.34	0.91	0.75	3.50	101.7	8.54	0.96	0.87	3.68	98.5
Compost C_1	8.92	0.95	0.80	3.65	99.6	9.43	1.01	0.88	3.77	97.1
Compost C_2	10.50	1.04	0.88	3.51	89.9	11.61	1.07	0.92	3.49	90.1
Compost C_3	9.53	1.17	0.83	3.67	104.6	10.42	1.23	0.86	3.59	99.2
Compost C_4	9.16	1.20	0.96	4.50	106.1	9.99	1.15	1.08	4.52	100.1
Compost C_5	10.75	1.26	1.03	4.12	102.5	10.94	1.24	1.11	4.09	95.9
Compost C_6	9.80	1.29	1.04	4.67	106.9	10.52	1.27	1.09	4.76	102.4
Mean C_1-C_6	9.77[a]	1.12[b]	0.92[c]	4.02[d]	101.6[e]	10.49[a]	1.14[b]	0.99[c]	4.04[d]	97.47[e]
$LSD_{0.05}$	0.99	0.14	0.12	0.48	9.04	1.01	0.12	0.15	0.47	10.20

[a-a] – insignificant differences, [b-b, d-d] – significant differences at $p<0.05$, [c-c] – significant differences at $p<0.001$, [e-e] – significant differences at $p<0.01$

of trace metals [Weber et al. 2003]. The average nickel content in maize (*Zea mays* L.) was the lowest in the series without mineral N fertilization. The overground parts of maize grown on compost comprising fish waste and straw with additional mineral N fertilization were characterized by the lowest content of nickel at 3.49 $mg·kg^{-1}$ dry mass. The group of plants grown on compost made of fish waste and bark with the addition of lignite was characterized by the highest concentration of nickel (4.76 $mg·kg^{-1}$ dry mass) in maize planted in pots with additional mineral N fertilization. Addition of lignite (composts C_4–C_6) significantly influenced the nickel content of the overground parts of maize when compared to composts without lignite (C_1–C_3).

In the presented study, the zinc content in the overground parts of maize (*Zea mays* L.) depended on the type of fertilization as well as the applied composts (C_1–C_6) (Table 3). Fertilization with municipal waste compost leads to a higher concentration of zinc in plants [Shuman et al. 2001]. Mazur and Sienkiewicz [2009] claimed that urea used in combination with composts had very strongly increased the concentration of zinc and copper in the vegetative parts of maize (stems and leaves). Copper availability was higher than Zn, although plants uptake zinc rather than copper because of antagonisms between these elements [Kabata-Pendias and Pendias 1992]. In the presented experiment, zinc content was higher in the control object (without fertilization). The lowest content of zinc (3.49 $mg·kg^{-1}$ dry mass) in the overground parts of maize in the series with mineral N fertilization was obtained after application of compost comprising fish waste and straw. The addition of the latter component was also shown to have some effect in the variants without mineral N fertilization.

The correlation coefficients between the content of heavy metals in the overground parts of maize (*Zea mays* L.) in series without mineral N and those with mineral N fertilization have been presented in Table 4. Statistical analysis revealed a significant correlation between the content of the individual microelements in the test plants and the type of compost (C_1–C_6) incorporated into the soil. In the series without mineral N fertilization, a positive high correlation was confirmed between cadmium and chromium (r=0.91) and between nickel and chromium (r=0.84). Moreover, significant correlation was also noted between the contents of chromium and nickel (r=0.84) in the overground parts of the tested plants in the series with mineral N fertilization.

Table 4. Linear correlation coefficients between the heavy metal content in maize (*Zea mays* L.) in series without mineral N-fertilization and series with mineral N-fertilization

Series without mineral N				
	Cu	Cd	Cr	Ni
Cd	0.41*			
Cr	0.41*	0.91***		
Ni	0.52*	0.81**	0.84***	
Zn	0.05	0.52*	0.39	0.57*
Series with mineral N				
	Cu	Cd	Cr	Ni
Cd	0.63*			
Cr	0.42*	0.67*		
Ni	0.06	0.55*	0.84***	
Zn	0.08	0.43*	0.33	0.41*

Significant at *** $p<0.001$, ** $p<0.01$, * $p<0.05$.

CONCLUSIONS

The yield of maize (*Zea mays* L.) depended on mineral N fertilization as well as the type of composts incorporated into the soil. In the series without mineral N fertilization, composts C_1–C_6 had a negative effect on the growth and development of the overground parts of maize. The average crop yield of the overground parts of maize in the series without mineral fertilization and series with mineral N fertilization was higher compared to the control objects. The highest crop yield of maize (*Zea mays* L.) was noted in the case of applying compost containing fish waste and straw with the addition of lignite and with bark and lignite. The content of microelements in maize (*Zea mays* L.) depended on the type of compost as well as mineral fertilization. The most distinct changes were confirmed in the case of copper and zinc, for which mineral N fertilization resulted in the decrease of their content in the analyzed plants. The average accumulation of microelements in maize (*Zea mays* L.) grown in composts C_1–C_6 applied into the soil followed the decreasing order Zn>Cu>Cd>Ni>Cr, respectively. Addition of lignite to the compost mass in the series with mineral N fertilization had a stronger influence on the content of cadmium, chromium, nickel, and zinc in the overground parts of maize.

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