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RESPIRATION ACTIVITY OF FLY ASH MIXED WITH COMPOST

Respiration activity of fly ash mixed with compost is associated with total oxygen demand or the rate of carbon dioxide evolution. It is also affected by temperature, humidity, vegetation cover, organic matter content, pH, as well as the type and rate of fertilizers.

The objective of this study was to determine the respiration activity, measured as carbon dioxide emission from fly ash and mixtures of fly ash with compost, under controlled temperature and humidity conditions. The relationships between respiration activity and the pH and organic carbon content of substrates were also analyzed. It was found that carbon dioxide emission was significantly affected by compost dose, incubation temperature and the moisture content of substrates. The research revealed a negative correlation between CO_2 emission and the organic carbon content of substrates.

1. INTRODUCTION

The rate of the exchange of carbon dioxide, oxygen and other gases between the soil, plants and atmosphere is controlled by atmospheric, physical and biological conditions [1]. A detailed analysis of those relationships allows us to predict the atmospheric concentrations of the above gases over a specified period of time.

Soil respiration activity may vary widely, depending on temperature, moisture and organic matter content, reaction, heavy metal concentration and vegetation cover. The amount of CO_2 in soil air changes dynamically: its maximum concentration is observed under increased humidity and high temperature conditions. Soil respiration occurs as a consequence of the living activity of soil-dwelling creatures. The amount of oxygen taken or carbon dioxide emitted at a specific time by a unit of volume or mass is adopted as a measure of this activity. The level of CO_2 emission taking place during the mineralization of organic matter (contained in or supplied to the soil) is a good indicator of biological processes. In addition, the amount of carbon dioxide being emitted provides us with the information about the rate of biological processes occurring in the soil [1]–[3].

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The objective of this study was to determine the respiration activity, measured as carbon dioxide emission from fly ash and the mixtures of fly ash with compost, under controlled temperature and humidity conditions. The relationships between respiration activity and pH and organic carbon content of substrates were also analyzed.

2. MATERIALS AND METHODS

The material from a 6-year pot experiment, whose aim was to determine changes in the chemical properties of fly ash following the addition of compost, was used in the present study. Fly ash was mixed with compost in different proportions. The experiment included the following treatments:

- fly ash (100%) – control sample,
- fly ash + compost (75+25%),
- fly ash + compost (50+50%).

A grass mixture composed of red fescue (*Festuca rubra* L.), perennial ryegrass (*Lolium perenne* L.) and meadow bluegrass (*Poa pratensis* L.) was grown in pots. Respiration activity, measured as carbon dioxide emission, was determined in the fifth year of the experiment, at the end of the growing season.

Fly ash used in the experiment was obtained from the Municipal Heating Plant (MPEC) in Olsztyn. It consisted of fractions arrested by dust collectors, i.e. multicyclones. Based on soil classification, ash was classified as sandy silt. It contained 652.1 g kg^{-1} d.m. of ash. The carbon content of ash, determined in the first year of the experiment, at the end of the growing season, reached 128.6 g kg^{-1} d.m. at pH_{H_2O} 8.8. The compost used in the experiment was obtained from the Waste Treatment Plant in Olsztyn. It consisted of stabilized sewage sludge, leaves, grass, sawdust and organic wastes. The organic carbon content of compost was 53 g kg^{-1} d.m. at pH_{KCl} 7.7.

Carbon dioxide emission was determined by the absorption method, with the use of 0.05 mol NaOH. The samples taken from pots were brought to a moisture content of 40, 60 and 80% of maximum water capacity, put into 1 dm^3 jars and placed in a controlled environment chamber (Microclima 1000, Snijder Scientific B.V.). Carbon dioxide emission was measured at 10, 20 and 30 °C. The amount of emitted carbon dioxide was determined as described by ISERMEYER [4]. Incubation in a phytotron was carried out at a specified temperature, after the substrates were brought to the desired moisture content. It lasted for 3 days. Carbon dioxide emission was measured every 24 h. The jars were aired out each time and the NaOH solution was replaced.

The amount of CO_2 emitted during the experiment was calculated using the following formula:

$$CO_2 = \frac{(V_0 - V)\cdot 1.1}{dwt} \quad \text{(mg)},$$

where:

V_0 – the amount of HCl used for control (blank) sample titration (cm^3),

V – the amount of HCl used for titration of samples taken from particular substrates (cm^3),

dwt – the dry weight per g of the material taken from substrates,

1.1 – the conversion factor (1 cm^3 0.05 mol · dm^{-3} NaOH equals 1.1 mg CO_2).

Organic carbon content and pH were determined in all treatments.

The results obtained were verified by an analysis of variance ANOVA (the *F*-test) for multi-factorial designs. The analysis of variance (the *F*-test) was performed based on mean values of all measurements, as well as on interactions between the experimental factors. The experimental factors were as follows: the dose of compost, moisture content of substrate and incubation temperature. Significant differences were determined by the Newman–Keuls test at a significance level of $p = 0.01$. The results of post-hoc tests are presented as homogeneous groups, denoted by respective letters in tables. The relationships between the parameters tested were found with the use of the Pearson linear correlation between two variables. The significance of correlation coefficients r was estimated at a significance level of $p < 0.01$. Significant correlations were described and interpreted based on a scale indicating the strength of relationships between variables, proposed by STANISZ [5]. The statistical analysis was performed using STATISTICA 7.1 PL software (StatSoft Inc. 2005).

The term *substrate* used in the paper refers to both fly ash alone and the mixtures of fly ash with compost.

3. RESULTS AND DISCUSSION

Experimental results are presented in tables 1–5 and in the figure.

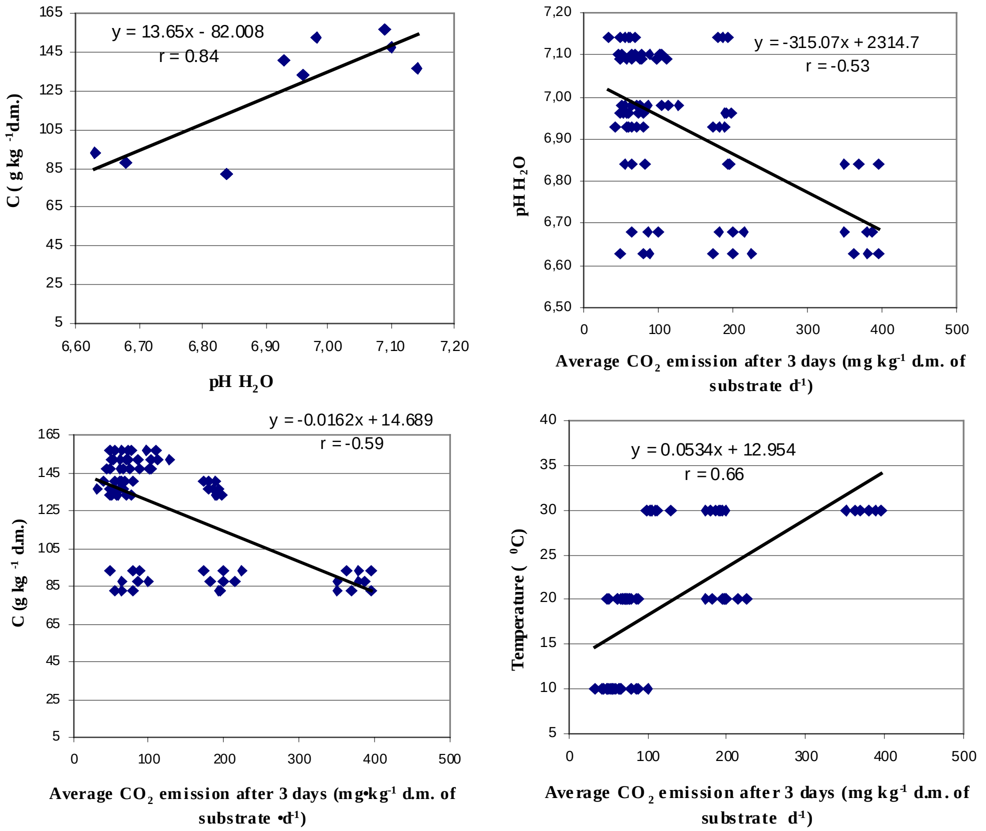
Table 1 shows the coefficients of the analysis of variance (the *F*-test) of CO_2 emission from fly ash and fly ash–compost mixtures. The impact of experimental factors on carbon dioxide emission was estimated for the values recorded on the 1st, 2nd and 3rd day, and for mean values. It was found that in all cases the respiration activity depended on the compost dose and incubation temperature. The effect of the moisture content in substrates on carbon dioxide emission was statistically non-significant only on the first day. Interactions between the compost dose and moisture content as well as between the compost dose and temperature were statistically significant in the majority of cases. The relationships between the moisture content in substrates and incubation temperature as well as between all the factors analyzed were statistically non-significant. The analysis of variance showed that temperature, followed by the compost dose, had the greatest influence on CO_2 emission.

Table 1

Analysis of variance (F-test) of CO_2 emission from fly ash and fly ash–compost mixtures

Factors and interactions	Incubation time (d)			
	1st	2nd	3rd	Means
	$F_{emp.}$			
D	843.94*	743.36*	429.99*	1677.99*
W	0.43	6.60*	5.89*	8.19*
T	1939.68*	756.18*	264.55*	2150.76*
D×*W*	2.15	6.28*	6.40*	9.62*
D×*T*	371.50*	168.91*	62.47*	435.08*
W×*T*	1.03	0.33	1.80	0.33
D×*W*×*T*	0.95	1.49	1.87	1.28

D – dose of compost, *W* – moisture, *T* – incubation temperature, *D*×*W*, *D*×*T*, *W*×*T*, *D*×*W*×*T* – interactions between experimental factors, * – relationship significant at p = 0.01, $F_{emp.}$ – coefficients of analysis of variance



Interactions between experimental factors

The effect of particular experimental factors on the respiration activity of substrates is discussed below.

3.1. DOSE OF COMPOST

Average CO_2 emission from all the samples ranged between 78.51 and 215.51 mg CO_2 kg^{-1} d.m. of substrate·d^{-1} (table 2). The compost added to fly ash substantially increased its respiration activity. Carbon dioxide emission from fly ash mixed with 25% and 50% of compost increased by 274% and 130%, respectively. The same trend was observed when each day of measurements was analyzed separately. As was already mentioned, the analysis of variance indicated that the compost dose had a significant effect on carbon dioxide evolution. The interaction between the compost dose and incubation temperature was also significant. The highest rate of carbon dioxide emission was recorded in fly ash mixed with 25% of compost incubated at 30 °C under all humidity conditions analyzed (table 3). Average CO_2 emission from those samples reached 374.58 mg CO_2 kg^{-1} d.m. of substrate d^{-1}.

Table 2

Carbon dioxide emission (mg CO_2 kg^{-1} d.m. substrate d^{-1}), depending on compost dose, incubation temperature and the moisture content of substrates (for all treatments)

Factors		CO_2 emission			
		Incubation time (day)			
		1st	2nd	3rd	Means
Compost dose (%)	0	121.54 b	66.88 a	47.12 a	78.51 a
	25	253.54 c	224.31 c	168.70 c	215.51 c
	50	110.63 a	109.28 b	85.72 b	101.88 b
Incubation temperature (°C)	10	73.25 a	53.60 a	53.40 a	60.08 a
	20	113.24 b	129.13 b	96.80 b	113.05 b
	30	299.22 c	217.74 c	151.34 c	222.77 c
Moisture content of substrates (%)	40	162.56 a	125.72 a	92.87 a	127.05 a
	60	159.88 a	133.68 ab	101.20 ab	131.59 ab
	80	163.27 a	141.07 b	107.46 b	137.27 b
Means		161.90	133.49	100.51	131.97

Values with differing superscripts are significantly different at p = 0.01; to compare the relationships analyzed, the values are marked with a, b, c; these values represents different homogeneous groups (based on post-hoc tests).

Table 3

Carbon dioxide emission (mg $CO_2 \cdot kg^{-1}$ d.m. substrate$\cdot d^{-1}$) from fly ash, depending on compost dose, incubation temperature and moisture content of substrates

Factors		CO2 emission								
		Substrates								
		Fly ash			Fly ash + compost (75+25%)			Fly ash + compost (50+50%)		
Incubation time (day)	Moisture (%)	Temperature (°C)								
		10	20	30	10	20	30	10	20	30
1st	40	77.18	110.07	178.85	78.06	164.24	500.67	78.46	51.87	223.61
	60	72.70	113.06	161.65	81.08	181.63	500.67	55.66	38.19	234.25
	80	84.66	121.29	174.36	84.11	190.70	500.67	47.31	48.07	218.29
2nd	40	45.79	57.00	89.14	46.31	223.21	332.84	46.55	87.58	203.09
	60	47.28	64.48	89.14	75.79	233.04	372.15	41.99	93.66	185.61
	80	47.28	65.97	95.87	74.28	258.75	402.39	57.18	78.46	189.41
3rd	40	42.80	48.78	63.73	43.28	163.49	230.77	43.51	76.94	122.54
	60	35.32	54.01	53.26	89.40	182.39	254.97	33.63	60.22	147.62
	80	25.60	45.04	55.50	93.18	184.66	276.13	73.90	55.66	157.50
Means for incubation time	40	55.26	71.95	110.57	55.88	183.65	354.76	56.17	72.13	183.08
	60	51.77	77.18	101.35	82.09	199.02	375.93	43.76	64.02	189.16
	80	52.51	77.43	108.58	83.86	211.37	393.06	59.46	60.73	188.40
Means for temperature		53.18	75.52	106.83	73.94	198.01	374.58	53.13	61.32	186.88
Means for substrate		78.51			215.51			101.88		

3.2. TEMPERATURE OF INCUBATION

The highest and the lowest levels of carbon dioxide emission were recorded when the samples were incubated at 30 °C and 10 °C, respectively. The analysis of mean values of measurements (table 2) revealed that a rise in temperature by 10 °C (from 10 to 20 °C) and by 20 °C (from 10 to 30 °C) caused an increase in carbon dioxide emission by 188% and 370%, respectively. The same relationships were observed for each treatment analyzed separately. KLIMEK [6] demonstrates that a rise in ambient temperature causes a rapid increase in CO_2 emission, which then continues at a slower rate. This process lasts until the optimum temperature is reached and exceeded. Subsequently carbon dioxide emission gradually decreases. The optimum temperature may vary depending on soil type. In the case of the ash–compost mixtures analyzed in this study, the rate of CO_2 emission was found to increase with temperature, but the optimum temperature was not determined – this would require further investigations.

3.3. MOISTURE CONTENT OF SUBSTRATES

The effect of the moisture content of substrates on carbon dioxide emission, although statistically significant, was lesser that that of incubation temperature or compost dose. The interaction between the compost dose and the moisture content of substrates was also statistically significant. The highest respiration activity recorded in the samples with a moisture content of 80% of maximum water capacity proved that CO_2 emission was directly proportional to moisture content (table 2). Average carbon dioxide emission proved to be on a comparable level within all the moisture ranges analyzed. YOUSTE et al. [7], FANG and MONCRIEFF [8], RADECKI-PAWLIK and BOROŃ [9], XU and QI [10], and CONANT et al. [11] also observed the impact of moisture content on soil respiration activity. Those authors demonstrated that an increase in moisture content resulted in a faster rate of carbon dioxide emission, which was also confirmed in the current experiment, involving different types of substrates. However, when particular treatments were examined separately it was found that not always an increase in the moisture content of substrates caused an increase in CO_2 emission.

3.4. ORGANIC CARBON CONTENT AND pH OF SUBSTRATES

The estimation of respiration activity was preceded by the determination of the organic carbon content and pH of substrates during all treatments. Those parameters were not determined on the completion of the experiment, because the incubation of samples at specified temperature and humidity lasted for 3 days. According to professional literature pertaining to carbon dioxide emission from soils, the content of organic carbon decreases during prolonged incubation [6], [12].

The control sample (100% fly ash) comprised the highest content of organic carbon (table 4). The addition of compost, in the amount of 25 and 50%, caused a decrease in organic carbon content by 42 and 10%, compared with the control treatment, respectively. The carbon content of fly ash used in the experiment was 152.2 g kg^{-1} d.m. According to many autors [13]–[15] the carbon content of fly ash may vary from 2.9 to 249 g kg^{-1} d.m. PATI and SAHU [16] reported that mixing fly ash with soil reduces the biological activity of the mixture if the ash contains a small quantity of organic carbon. MCCARTY et al. [15] found that the addition of ash with a high (up to 25%) carbon content to light soils enabled their biological activity to be enhanced. In the present study, both fly ash and compost had a high carbon content. When mixed, those components contributed to an increase in the respiration activity of substrates, in comparison with the control treatment. However, greater respiration activity was observed for the lower dose of compost (25%). The 75+25% mixture of fly ash and compost was also characterized by the lowest organic carbon content. pH of all the substrates analyzed ranged from 6.7 to 7.1. The compost added to fly ash in the amount of 25 and 50% decreased the pH from 7.1 (fly ash) to 6.7 (fly ash and compost 75+25%) and 7.0 (fly ash and compost 50+50%).

Table 4

Organic carbon content (g kg^{-1} d.m.) and pH of substrates

Treatments	$C_{org.}$	pH_{H_2O}
Fly ash	152.2 c	7.1 b
Fly ash + compost (75+25%)	87.6 a	6.7 a
Fly ash + compost (50+50%)	136.8 b	7 b
Means	109.6	6.9

in table 2

3.5. ANALYSIS OF CORRELATION

The analysis of the Pearson correlation, performed for all the treatments, confirmed that respiration activity depended significantly on the temperature, the organic carbon content and pH of substrates (table 5). Neither the moisture content of substrates nor the dose of compost were correlated with carbon dioxide emission. The correlation between carbon dioxide evolution and incubation temperature was high (r = 0.66). Organic carbon content and pH of substrates were found to be significantly, but negatively, correlated with carbon dioxide emission: r = –0.59 and r = –0.53, respectively (the figure). Substrates with the lowest pH were characterized by

Table 5

Matrix of correlation between the factors analyzed

Factors			*D*	*T*	*W*	CO_2 emission				$C_{org.}$	pH_{H_2O}
						Days			Means		
						1st	2nd	3rd			
D			1.00	0.00	0.00	–0.03	0.16	0.22	0.09	–0.23	–0.11
T			0.00	1.00	0.00	**0.69**	**0.63**	**0.55**	**0.66**	0.00	0.00
W			0.00	0.00	1.00	0.00	0.06	0.08	0.04	0.00	0.00
CO_2 emission	Days	1	–0.03	**0.69**	0.00	1.00	**0.90**	**0.86**	**0.96**	**–0.46**	**–0.41**
		2	0,16	**0.63**	0.06	**0.90**	1.00	**0.96**	**0.98**	**–0.62**	**–0.56**
		3	0.22	**0.55**	0.08	**0.86**	**0.96**	1.00	**0.96**	**–0.69**	**–0.64**
	Means		0.09	**0.66**	0.04	**0.96**	**0.98**	**0.96**	1.00	**–0.59**	**–0.53**
$C_{org.}$			–0.23	0.00	0.00	**–0.46**	**–0.62**	**–0.69**	**–0.59**	1.00	**0.84**
pH_{H_2O}			–0.11	0.00	0.00	**–0.41**	**–0.56**	**–0.64**	**–0.53**	**0.84**	1.00

D – comost dose, *T* – temperature, *W* – moisture, d – day.
Values significant at $p < 0.01$ in bold print.

the highest carbon dioxide emission. This is consistent with the findings of McCARTY et al. [15], who reported that CO_2 emission from soils containing fly ash with a high pH level is lower, compared with that from soils with a lower pH level. In the current study, the largest amount of carbon dioxide was emitted from the substrates with the lowest organic carbon content, i.e. from fly ash mixed with compost at the ratio of 75% + 25%.

4. CONCLUSIONS

1. The study confirmed the significant effect of compost on the respiration activity of fly ash. The respiration activity of fly ash amended with compost (in the amount of 25%) increased by more than 2.5 times.

2. A rise in incubation temperature enhanced the rate of carbon dioxide emission from ash–compost mixtures. A 10 °C increase in temperature caused an almost 200% increase in CO_2 emission.

3. Carbon dioxide emission was significantly affected by substrate humidity. The highest level of CO_2 emission was found in the substrates with a 80% moisture content.

4. The analysis of correlation showed that respiration activity significantly depended on incubation temperature, organic carbon content and pH of substrates. The correlation between carbon dioxide evolution and incubation temperature was high (r = 0.66). Organic carbon content and pH of substrates were negatively correlated with carbon dioxide emission.

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