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Original Research

Carbon Dioxide Emission to the Atmosphere from Overburden under Controlled Temperature Conditions

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Abstract

Being a component of atmospheric air, carbon dioxide is widely distributed in nature and constantly exchanged between the atmosphere and ecosystems. It also serves as an indicator of the rate of processes taking place in the soil environment and reflects the rate of organic matter decomposition during industrial waste management and degraded land reclamation. Human activity may increase CO_2 emission to the atmosphere, thus contributing to its higher concentration in atmospheric air. CO_2 content of soil air is modified by a variety of factors, including temperature, humidity, porosity, root respiration, etc. CO_2 emitted to the atmosphere is the product of numerous chemical processes, primarily organic matter decomposition under aerobic and anaerobic conditions, and urea decomposition.

This paper presents experimental results concerning CO_2 emission from light soil deposit in the form of overburden, before and after fertilization with sewage sludge. CO_2 emission was determined in a controlled environment chamber at a temperature of 10, 20 and 30°C and a constant water capacity of 60%. It was found that both higher temperatures and the addition of sludge increased CO_2 emission to the atmosphere. The observed relationships were confirmed by an analysis of variance, and correlations between the tested variables and CO_2 emission were determined.

Keywords: carbon dioxide, emission, overburden, sewage sludge, temperature

Introduction

Carbon dioxide is the product of mineralization of organic carbon compounds in the soil. The oxidation of organic substance contained in the soil is the source of energy for soil-dwelling organisms, and the product of their respiration – carbon dioxide – is emitted to the atmosphere [1, 2]. Carbon dioxide is mostly associated with respiration (CO_2 emission to the air) and photosynthesis (CO_2 absorption from the air) [3, 4]. Carbon dioxide emission is an indicator of the rate of processes taking place in the soil environment, and reflects the rate of reclamation of land degraded due to mining, including opencast mining [5].

Soil carbon dioxide emissions may vary widely depending on the type of soil, its moisture content, temperature, reaction, management system, application of mineral and organic fertilizers or pesticides, as well as on other factors. CO_2 emission from the soil is also considerably affected by agricultural practices. For instance, fertilization and liming promote mineralization, thus increasing carbon dioxide emission [6-8].

The aim of the present study was to estimate the levels of carbon dioxide emission from light soil in the form

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of overburden, depending on the doses of sewage sludge. The effect of temperature changes on CO_2 emission, and correlations between the tested variables were also determined.

Experimental Procedures

CO_2 emission to the atmosphere was studied during a long-term pot experiment conducted in a greenhouse. Carbon dioxide emission was determined in the fourth year of the experiment, in the middle of the growing season, in the following experimental systems:
- overburden (100%),
- overburden + sewage sludge (75 + 25%),
- overburden + sewage sludge (50 + 50%).

Samples of overburden were taken from a dumping ground at a gravel-pit in Żabi Róg (Province of Warmia and Mazury). The overburden, whose granulometric composition resembled that of light loamy sand, contained 5.87 g · kg^{-1} $C_{org.}$, and its pH was equal to 7.5. The sludge used in the experiment was obtained from the Municipal Wastewater Treatment Plant in Olsztyn. It had a sticky-greasy consistency and contained 74.8 g · kg^{-1} $C_{org.}$, and its pH was at a level of 7.9.

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.

Carbon dioxide emission was determined by the absorption method, with the use of 0.05 mol·dm^{-3} NaOH, on three consecutive days. Such a methodology was adopted for all experimental systems, since it provided the most reliable results. Other authors, i.e. Pinzari et al. [7], Dziejowski et al. [9], Wang et al. [10], and Bae et al. [11], also employed the absorption method to estimate carbon dioxide emission. However, those measurements were not carried out under conditions of precisely controlled soil moisture content and incubation temperature. In the current experiment samples taken from pots were brought to a moisture content of 60% of maximum water capacity, put into 1 l jars and placed in a controlled environment chamber (Microclima 1000, Snijders Scientific B.V.). Carbon dioxide emission was measured at three temperatures: 10, 20 and 30°C. A detailed description of methodology can be found in a previous work of Rogalski and Bęś [12].

The obtained results were verified by an analysis of variance ANOVA (F test) for two-factorial designs. The experimental factors were as follows:
- dose of sewage sludge: 0, 25 and 50%,
- temperature during measurement: 10, 20 and 30°C.

Significant differences were determined by Duncan's test at a significance level of p=0.01. The results of post-hoc tests are presented as homogenous groups, denoted by respective letters in Tables. Relationships between the tested parameters were determined with the use of 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 [13]. The statistical analysis was performed using STATISTICA 7.1 PL software (StatSoft Inc. 2005).

Results and Discussion

Experimental results are presented in Tables 1 and 2, and in Figures 1 and 2.

The analysis of variance (F test) showed that carbon dioxide emission was significantly affected by both sludge dose (factor I) and temperature (factor II), regardless of the time of measurement (Table 1). The interaction between the experimental factors was also significant. The values of coefficient F indicate that temperature had a higher effect on carbon dioxide emission than sludge dose.

Table 2 presents the results of the current experiment. Two systems were analyzed, namely overburden with the addition of sewage sludge in the amount of 25 and 50%. Overburden without sludge served as a control system. It was found that carbon dioxide emissions depended on sludge dose, temperature and time of measurement.

Table 1. Analysis of variance (test F) carbon dioxide emission from overburden and overburden mixed with sewage sludge.

Factors	CO_2 emission on day 1 of measurement		CO_2 emission on day 2 of measurement		CO_2 emission on day 3 of measurement		Average CO_2 emission	
	$F_{emp.}$	p	$F_{emp.}$	p	$F_{emp.}$	p	$F_{emp.}$	p
D	83.715*	0.00000	5.518*	0.013519	9.979*	0.001213	11.738*	0.000546
T	306.117*	0.00000	219.723*	0.00000	29.658*	0.000002	307.194*	0.00000
DxT	12.809*	0.000042	23.927*	0.000001	6.682*	0.001766	25.675*	0.00000

D – sewage sludge dose: 0, 25, 50%, T –incubation temperature: 10, 20, 30 °C, DxT – interaction between experimental factors, $F_{emp.}$ – F empirical, p – significance level, *$F_{emp.}$> $F_{tab.}$ – relationship significant at p=0.01

Table 2. Carbon dioxide emission (mg $CO_2 \cdot kg^{-1}$ dry mass (d.m.) soil$\cdot d^{-1}$) from overburden and overburden mixed with sewage sludge.

Time of measurement (day – d)	CO_2 emission (mg $CO_2 \cdot kg^{-1}$ d.m. soil$\cdot d^{-1}$)			
	Experimental system			Means
	Overburden	Overburden + sewage sludge (75+25%)	Overburden + sewage sludge (50+50%)	
10 °C				
1 d	22.77 ab	64.75 d	54.74 cd	**47.42 y**
2 d	36.90 bc	25.41 ab	14.93 ab	**25.75 x**
3 d	13.07 a	14.75 ab	15.76 ab	**14.53 x**
Means	**24.25 A**	**34.97 C**	**28.48 B**	**29.23**
20 °C				
1 d	64.77 c	140.0 d	153.08 e	**119.28 z**
2 d	23.13 a	63.93 c	73.35 c	**53.47 y**
3 d	24.68 a	38.03 b	49.43 b	**37.38 x**
Means	**37.53 A**	**80.65 B**	**91.95 C**	**70.04**
30 °C				
1 d	147.28 bc	170.75 c	242.37 d	**186.80 y**
2 d	138.80 b	85.78 a	132.35 b	**118.98 x**
3 d	131.09 b	77.69 a	99.66 a	**102.81 x**
Means	**139.06 B**	**111.41 A**	**158.13 C**	**136.20**

Values followed by different letters differ statistically at p=0.01; values followed by: a, b,…, A, B, C and x, y, z – comparison of factors; these values belong to different homogenous groups (based on post-hoc tests)

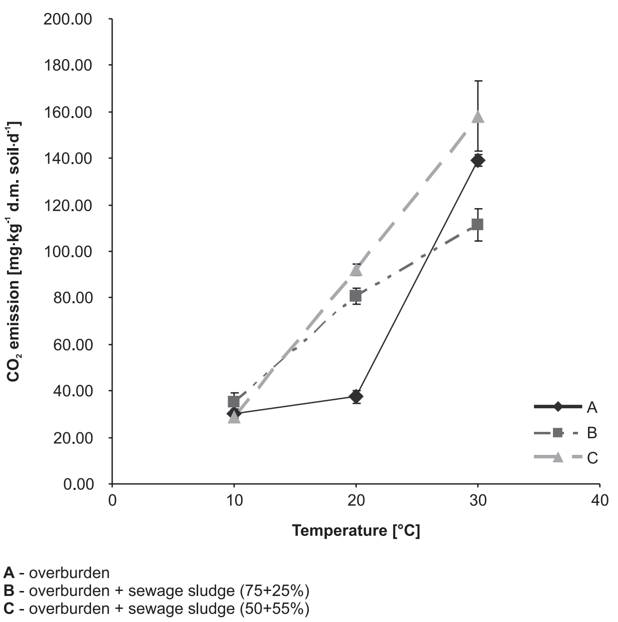

Fig. 1. CO_2 emission (mg $CO_2 \cdot kg^{-1}$ d.m. soil$\cdot d^{-1}$) in particular systems as a function of temperatures (means after three days of incubation).

Effect of Sludge Dose on CO_2 Emission

Laboratory analysis revealed that in the majority of systems carbon dioxide emission increased following the addition of sewage sludge (25% or 50%). This trend is easily noticeable when all measurement results are considered. Only at a temperature of 30°C were carbon dioxide emissions higher in overburden samples containing no sludge than in those containing 25% sludge. At this temperature average CO_2 emissions determined in the control system on three consecutive days was 25% higher, compared to the values obtained for the 75+25% mixture of overburden and sewage sludge, and reached 139.06 mg $CO_2 \cdot kg^{-1}$ dry mass (d.m.) soil$\cdot d^{-1}$. Total average CO_2 emission to the atmosphere determined after three days ranged from 24.25 mg $CO_2 \cdot kg^{-1}$ d.m. soil$\cdot d^{-1}$ in overburden without sludge (measured at 10°C) to 158.13 mg $CO_2 \cdot kg^{-1}$ d.m. soil$\cdot d^{-1}$ in overburden containing 50% sludge (measured at 30°C). An increase in carbon dioxide emission from the soil containing organic substance in the form of unconventional fertilizers was also observed by Wolna-Maruwka et al. [14], Quemada and Menacho [15], and Rogalski et al. [16]. Those authors demonstrated that soils amended with high doses of sewage sludge were

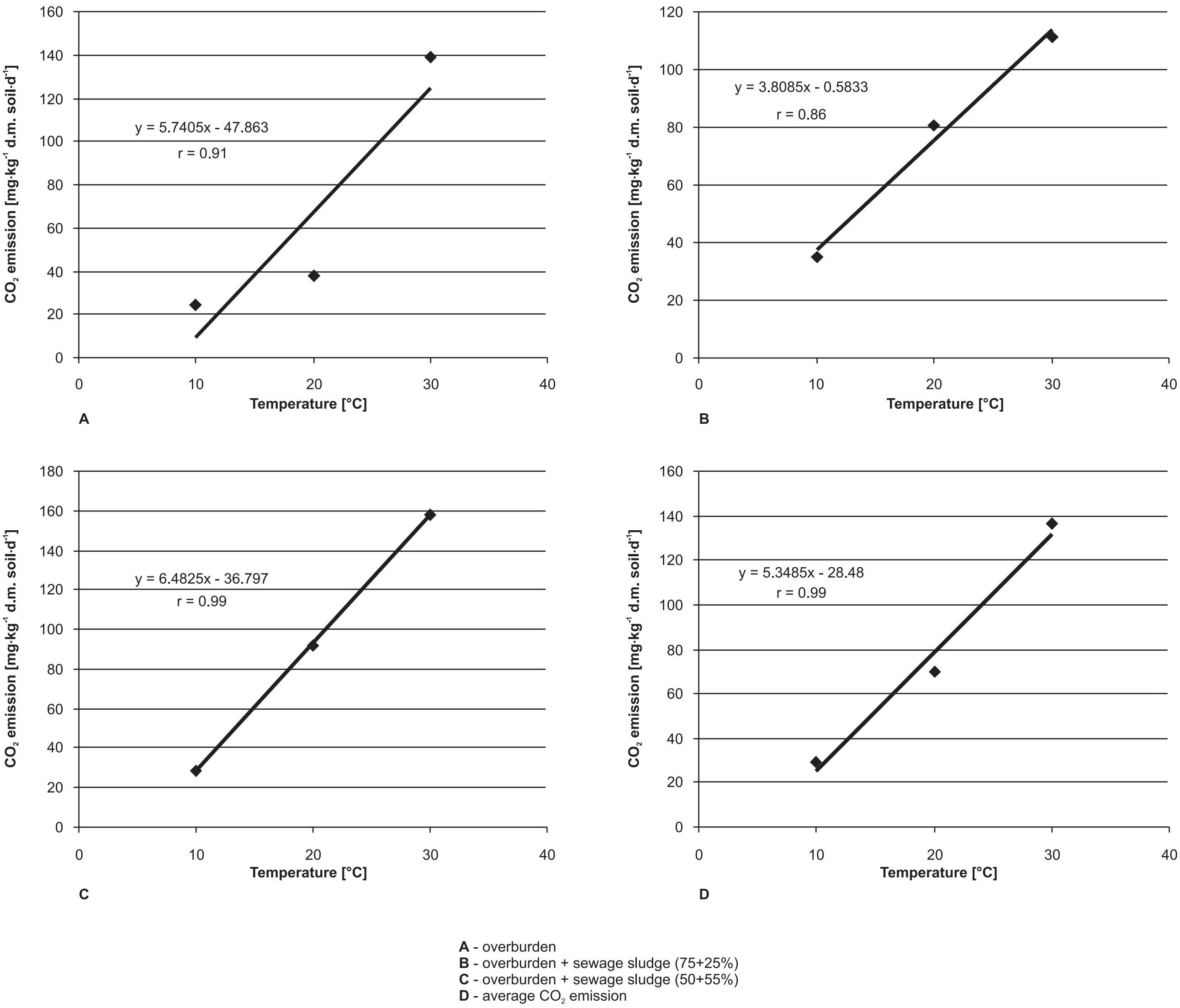

Fig. 2. Relationship between CO_2 emission and incubation temperature.

characterized by higher rates of carbon dioxide evolution. Gostkowska et al. [17], Kopeć and Noworolnik [18] and Rogalski et al. [16] reported that soils fertilized with different mineral and organic fertilizers (municipal wastewater, sewage sludge, manure, animal slurry) emitted 11 to 651 mg $CO_2 \cdot kg^{-1}$ d.m. soil d^{-1}. The results of this study remain within the above ranges. The values obtained at different temperatures do not indicate clearly which dose of sludge (25 or 50%) caused a significant increase in carbon dioxide emission. The analysis of mean values obtained at all temperatures showed that the 25% and 50% addition of sewage sludge increased CO_2 emission by 13% and 38%, respectively.

Effect of Temperature on CO_2 Emission

The results of the present experiment suggest that a rise in temperature was followed by a faster rate of carbon dioxide emission. Average CO_2 emission over the experimental period increased along with temperature, reaching 29.23 mg $CO_2 \cdot kg^{-1}$ d.m. soil$\cdot d^{-1}$, 70.04 mg $CO_2 \cdot kg^{-1}$ d.m. soil$\cdot d^{-1}$ and 136.2 mg $CO_2 \cdot kg^{-1}$ d.m. soil d^{-1} at 10, 20 and 30°C, respectively. A rise in the temperature of incubation from 10 to 30°C caused an over fourfold increase in CO_2 emission. Włodarczyk et al. [6] reported that the respiratory activity of brown soil and loess chernozem increased fourfold under the influence of higher temperatures (10 and 20°C). In the current experiment the highest level of CO_2 emission was observed in samples incubated at 30°C. This is consistent with the findings of O'Connel [19], Grundmann et al. [20], and Thierron and Laudelout [21], who demonstrated that the temperature range of 20 to 30°C is the most favorable to carbon dioxide emission. According to O'Connel [19], the maximum temperature for measuring CO_2 evolution from the soil is 30°C, since the rate of organic matter decomposition decreases at higher temperatures. However, the author provided no information on the water capacity of soil for which this relationship is valid.

Figure 1 illustrates carbon dioxide emissions in the analyzed systems, as a function of temperature. Average CO_2 emission at 10°C from overburden without sludge and with 25 or 50% of sludge was comparable, ranging from 24 to 35 mg $CO_2 \cdot kg^{-1}$ d.m. $soil \cdot d^{-1}$. At higher incubation temperatures (20 and 30°C) carbon dioxide evolution varied widely. After three days of measurement, the highest average carbon dioxide emission (158.13 mg $CO_2 \cdot kg^{-1}$ d.m. $soil \cdot d^{-1}$) was recorded in samples composed of overburden and sewage sludge (50%+50%), incubated at 30°C. The analysis of individual systems revealed that in the case of overburden samples a rise in incubation temperature from 10 to 30°C increased carbon dioxide emission by 573%. In overburden samples containing 25% and 50% of sludge this increase reached 318% and 555%, respectively.

Effect of the Time of Measurement on CO_2 Emission

The amount of carbon dioxide emission to the atmosphere was different on particular days of measurement. The highest rate of CO_2 evolution was observed on day 1 – 117.76 mg $CO_2 \cdot kg^{-1}$ d.m. $soil \cdot d^{-1}$ on average. With the passage of time carbon dioxide emission decreased by 44%, to 51.57 mg $CO_2 \cdot kg^{-1}$ d.m. $soil \cdot d^{-1}$ on day 3. A similar trend was noted by Włodarczyk [22], who reported that CO_2 emission decreased substantially after one day. The analysis of particular temperatures of incubation applied in the study indicated that between day 1 and 3 carbon dioxide emission decreased threefold at 10 and 20°C, and almost twofold at 30°C.

Analysis of Correlation

The analysis of Pearson simple correlation confirmed that there was a significant and almost full correlation between the temperature of incubation and the rate of carbon dioxide evolution (r=0.99) (means for all experimental systems). Significant correlations between temperature and CO_2 emission were also noted when each system was examined separately. The coefficients of correlation and regression equations are shown in Fig. 2. The correlation between sludge dose and CO_2 emission was found to be low and statistically non-significant (r=0.44).

Conclusions

1. Average CO_2 emission from overburden to the atmosphere, determined for all temperature ranges analyzed in the study, increased by 13% and 38% following the 25% and 50% addition of sewage sludge, respectively, compared to the control system.
2. A rise in incubation temperature increased CO_2 emission, irrespective of sludge dose, by 240 and 466% at 20 and 30°C respectively, in comparison with 10°C.
3. The analysis of correlation confirmed an almost full correlation between the temperature of incubation and the rate of carbon dioxide emission (r=0.99). The correlation between sludge dose and CO_2 emission was found to be statistically non-significant.

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