Effect of heavy metals on soil respiration during decomposition of sugarcane (*Saccharum officinarum* L.) trash in different soils

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ABSTRACT

An experiment was conducted to study the effect of heavy metals (Cd, Cr and Pb), soil texture (sandy, loam and clay) and incubation periods (7, 15, 30, 60, 90 and 120 days) on soil respiration (CO_2 evolution) during sugarcane trash decomposition in laboratory conditions of the Indian Institute of Sugarcane Research, Lucknow, India. Surface soils (0–15 cm) were collected from agricultural fields and crop residue of sugarcane trash (*Saccharum officinarum* L.) was taken in the institute farm. Crop residue (10 t/ha) and heavy metals (10, 50, 100, 1000 μg/g) were mixed and incubated at 30°C ± 2°C in an incubator. The rate of soil respiration (CO_2 evolution) decreased with increasing heavy metals concentration. During the 120 days, the toxicity decreased but still remained significant. Maximum soil respiration was recorded at 7 days of incubation period; further, it decreased with increasing incubation period. The highest drop of soil respiration rate was caused by addition of 1000 μg/g Cd, Cr and Pb levels. Clay soils evolved maximum CO_2 followed by loam and sandy soil.

Keywords: soil respiration; sugarcane trash; CO_2 evolution; heavy metals

Soil respiration, measured as CO_2 evolution or O_2 consumption, is one of the easiest, most general and most frequently used parameters for measuring the decomposition of organic compounds in soil. It depends on many biotic and abiotic factors, which prevents comparison of the degree of soil microflora functioning on its respiration level. Therefore the effect of heavy metals on soil respiration in various soils may only be assessed based on the principle of proportional change in activity in comparison with the control, i.e. with no treatment (Doelman and Haanstra 1984).

Decomposition of crop resides is a key process in the cycling of essential elements within ecosystems. Low decomposition, resulting from harsh climate, soil reactions, limited supply of essential nutrients and presence of recalcitrant organic compounds, can lead to accumulation of organic matter in soil and to immobilization of essential nutrients (Cotrufo et al. 1995).

Due to various anthropogenic activities, potentially toxic metals are accumulated in soils, with a risk of biota and ground water contamination. Among various reactive soil constituents, soil organic matter has a large sorption capacity towards metal ions (Yin et al. 2002, Dumat et al. 2006) and therefore metals often accumulate in the organic topsoils. Metals influence the soil biota in its diversity, abundance and activity (Barajas-Aceves et al. 1999). But nevertheless, their impact on the crop residues turnover is not well documented. Soil organic matter is composed of various organic constituents chemically heterogeneous (materials in various stages of decomposition for instance) with a large range of reactivity and turnover time in soil (Mhater and Pankhurst 1997).

Plant residues added to the soil are transformed into CO_2, microbial material and relatively stable humus components (Sajjad et al. 2002). The rapidity with which these transformations occur depends on the soil physico-chemical properties, environmental conditions and the chemistry of the residues. Decomposition of plant residues results in the production of CO_2, microbial biomass and metabolites, and stable humus compounds. It has been recognized that high concentrations of heavy metals can have deleterious effects on organic matter decomposition and soil biological processes (Chaney et al. 1978).

The aim of this study was to determine whether present levels of heavy metals pollution could affect crop residues decomposition. The crop residue of sugarcane (*Saccharum officinarum* L.) trash is very common in agricultural production system of India. In this paper the rate (CO_2 evolution) of decomposition of crop residue, with different metals contamination in soils and incubation periods were compared.

MATERIAL AND METHODS

Soils. Incubation studies were conducted at the Indian Institute of Sugarcane Research, Lucknow, India in 2001–2002 on agricultural soils of different texture (sandy, loam and clay). It was obtained by digging surface soil to a depth of 0–15 cm. The soil sample was passed through a 2-mm sieve, air dried and kept in sealed containers at 4°C before analysis and incubation experiments. The physico-chemical characteristics of the soils are given in Table 1.

Plant residue. Sugarcane trash was sampled after harvest of the crop in the month of February. Plant residue was washed with running water, rinsed three times with distilled water, then dried at 60°C and chapped (< 2 cm) and kept in sealed container until analysis or incubation experiment. Sub-samples of plant material were analysed for total carbon (43.4%), total nitrogen (0.40%), phosphorus (0.70), potassium (0.97) and C:N ratio (108.7).

Incubation experiment. Sieved soil samples (250 g) were placed in 500 ml plastic bottles of (7 cm dia. × 16 cm ht.) and mixed with salts of Cd as cadmium chloride ($CdCl_2$), Pb as lead acetate [$(CH_3COO)_2Pb \cdot 3H_2O$] and Cr as potassium dichromate ($K_2Cr_2O_7$) separately, to provide the concentrations of 0, 10, 50, 100 and 1000 μg/g dry soil. Chapped sugarcane trash (10 t/ha) was mixed in the treated soils. Each treatment was replicated three times and water content in the each soil was adjusted to 60% of the maximum water holding capacity (WHC) and maintained through out the incubation period. Bottles were placed in an incubator and the temperature was maintained at 30°C ± 0.5°C in completely sealed container containing 10 ml of 1M NaOH and 10 ml of H_2O in a separate small vials (2 cm dia. × 5.7 cm ht.) to prevent drying. Two empty jars containing only NaOH and H_2O were used to establish blank values. The CO_2 trapped in the NaOH solution was determined by titration with 1M HCl, at different incubation periods. Incubated soils as above were sampled at 7, 15, 30, 60, 90 and 120 days after initiating.

Table 1. Characteristics of sandy, loam and clay soils

Characteristics	Sandy soil	Loam soil	Clay soil
pH (1:2.5)	8.0	7.8	7.5
EC (dS/m(1:2.5))	0.45	0.53	1.12
Organic carbon (%)	0.30	0.65	0.95
Sand (%)	82.50	71.40	10.20
Silt (%)	8.50	15.00	13.20
Clay (%)	9.0	13.60	76.60
NH_4^+-N mg/kg	8.0	15.00	25.00
NO_3^- N mg/kg	7.50	19.20	32.50
Available P/kg	7.00	15.00	22.00
Available K/kg	110	170	210
Cd mg/kg	1.00	1.50	2.00
Cr mg/kg	0.50	1.00	2.00
Pb mg/kg	0.50	1.00	2.00

Analytical methods. Soil pH and electrical conductivity (EC) were determined in 1:2.5 soils: water suspension, while sand, silt and clay percentage were measured by the International Pipette Method (Page et al. 1982). Organic carbon was analysed by dichromate oxidation and titration with ferrous ammonium sulphate (Walkley and Black 1934). Total N, NH_4^+-N and NO_3^--N were determined by the micro-Kjeldahl method (Page et al. 1982). The total contents of heavy metals in soils were determined following digestion with nitric and perchloric acids and then analysed in atomic absorption spectrophotometer (Perkin Elmer HGA500). Sub-samples of dried sugarcane trash were analysed for total nitrogen, phosphorus and potassium by acid digestion methods (Page et al. 1982).

Statistical analysis. Analysis of variance (ANOVA) for completely randomised design was used to compare the effect of heavy metals on CO_2 evolution in three soils at different incubation periods. Treatments effects were considered significant at $P < 0.05$ (Snedecor and Cochran 1967).

RESULTS

The effects of cadmium, chromium and lead on CO_2 release on sandy, loam and clay soil at different periods of incubation were presented in Tables 2–4. Soil respiration (CO_2 evolution) is the most general and most frequently used parameters for measuring the rate of decomposition of organic compounds in soils.

The soil respiration (CO_2 evolution) significantly decreased in Cd contaminated soils compared to uncontaminated soils (Table 2). The CO_2 evolution

Table 2. Effect of cadmium, soil texture and incubation period on CO_2 evolution (μg/g soil) during decomposition of sugarcane trash

Cadmium levels (μg/g)	Incubation periods (days)						
	7	15	30	60	90	120	mean
Sandy							
0	35.30	29.67	19.93	15.23	14.30	10.40	20.81
10	32.07	27.47	23.73	19.80	12.07	10.07	20.87
50	27.00	19.67	19.00	14.87	13.00	12.47	17.67
100	21.20	17.40	17.33	14.47	12.67	11.27	15.72
1000	13.30	10.30	9.20	7.40	7.17	6.67	9.01
Mean	25.78	20.90	17.84	14.35	11.84	10.17	16.82
Loam							
0	55.33	50.00	40.00	34.93	24.83	19.87	37.49
10	53.17	47.67	39.87	32.53	24.33	19.67	36.21
50	50.33	43.33	40.53	29.73	19.53	19.87	33.89
100	40.80	29.40	29.13	24.80	20.07	18.20	27.07
1000	30.43	24.47	24.13	19.47	14.76	14.50	21.29
Mean	46.01	38.97	34.73	28.29	20.70	18.42	31.19
Clay							
0	75.13	70.27	62.30	55.17	40.00	22.00	54.14
10	74.87	69.20	62.07	55.07	39.70	20.37	53.54
50	70.07	65.23	54.67	49.40	34.67	19.40	48.91
100	64.50	60.13	49.67	45.93	30.80	17.20	44.57
1000	39.53	20.50	15.20	15.40	15.13	14.27	20.01
Mean	64.82	57.07	48.78	44.19	31.90	18.65	44.23
CD (0.05)	Soil texture – 0.12, metal concentrations – 0.16, incubation days – 0.17, Interactions Soil texture × incubation days – 0.53, soil texture × metal concentrations – 0.59, incubation days × metal concentrations – 0.31, Soil texture × metal – concentrations × incubation days – 0.67						

of sugarcane trash ranged from 6.6 to 75.1 μg/g soils. The lowest and the highest CO_2 evolution were observed in 1000 μg/g Cd and 0 Cd levels (control) after 120 and 7 days of incubation periods in sandy and clay soils, respectively. Increasing levels of Cd decreased the amount of CO_2 evolution in all soils. Our results indicated that CO_2 evolution decreased by 56.7, 43.2 and 63.0% in sandy, loam and clay soils, respectively at higher levels of Cd (1000 μg/g soil). Maximum CO_2 evolution was observed in clay followed by loam and sandy soils. The overall CO_2 evolution decreased with increasing incubation periods. After 120 days of incubation periods CO_2 evolution decreases were 49.8, 52.3 and 63.9% in sandy, loam and clay soils, respectively at 1000 μg/g Cd levels.

The CO_2 evolution of Cr contaminated soil with sugarcane trash ranged from 6.8 to 74.6 μg/g soils. After addition of Cr at the amount of 1000 μg/g soils, CO_2 evolution decrease was 57.3, 39.5 and 58.7% in sandy, loam and clay soils, respectively, compared with control (Table 3). The lowest and the highest CO_2 evolution was observed in 1000 μg/g Cr and 0 Cr levels (control) after 120 and 7 days of incubation periods in sandy and clay soils, respectively. Overall means of CO_2 evolution were not affected with addition of Cr up to 10 μg/g in sandy and loam soils, but further addition of Cr significantly reduced the CO_2 evolution. In clay soils, however, the addition of Cr at 10 μg/g or more decreased CO_2 evolution over control. Maximum CO_2 evolved at 7 days of incubation periods. After 120 days of incubation periods CO_2 evolution decrease by 46.6, 48.7 and 71.4% in sandy, loam and clay soils, respectively, at Cr levels of 1000 μg/g soil.

The CO_2 evolution of lead contaminated soils with sugarcane trash ranged from 7.3 to 75.0 μg/g soil (Table 4). Evolution of CO_2, irrespective of concentrations and incubation periods, reached 16.9, 33.0 and 46.2 μg/g CO_2 in sandy, loam and clay soils, respectively. In contrast, the CO_2 evolution decreased by 51.0, 35.3 and 56.9%

Table 3. Effect of chromium, soil texture and incubation period on CO_2 (μg/g soil) evolution during decomposition of sugarcane trash

Chromium levels (μg/g)	Incubation periods (days)						
	7	15	30	60	90	120	mean
Sandy							
0	35.00	29.73	20.73	14.47	13.27	10.17	20.56
10	30.20	27.67	23.37	20.53	12.87	10.33	20.83
50	24.47	19.73	19.13	14.20	12.20	10.27	16.67
100	19.40	16.13	16.13	13.93	11.47	11.73	14.80
1000	12.80	10.00	8.87	7.07	7.00	6.83	8.76
Mean	24.37	20.65	17.65	14.04	11.36	9.87	16.32
Loam							
0	56.47	49.47	40.53	34.13	24.93	19.87	37.57
10	54.60	48.20	41.00	33.00	25.40	19.80	37.00
50	50.67	44.60	39.40	29.60	20.27	19.53	34.01
100	41.53	40.07	32.60	24.47	19.67	17.40	29.29
1000	31.80	26.20	25.20	20.13	16.63	16.30	22.71
Mean	47.01	41.71	35.75	28.27	21.38	18.58	32.12
Clay							
0	74.67	70.33	65.20	54.93	40.17	21.53	54.47
10	73.67	67.67	60.07	50.20	40.13	19.67	51.90
50	71.33	66.00	55.73	51.27	36.60	20.37	50.22
100	65.33	60.20	50.33	50.93	29.67	19.93	46.07
1000	44.73	25.03	18.20	17.20	17.00	12.77	22.49
Mean	65.95	57.87	49.91	44.91	32.71	18.85	45.03
CD (0.05)	Soil texture – 0.11, metal concentrations – 0.14, incubation days – 0.16 Interactions Soil texture × incubation days – 0.48, Soil texture × metal concentrations – 0.54, incubation days × metal concentrations – 0.34, soil texture × metal – concentrations × incubation days – 0.60						

over control in sandy, loam and clay soils respectively at 1000 μg/g Pb level. Addition of Pb up to 10 μg/g in loam and clay soils increases CO_2 evolution, whereas its further addition over these doses significantly decreases the CO_2 evolution. Maximum CO_2 evolved at 7 days of incubation periods. Further, CO_2 evolution decreased with increased incubation periods. After 120 days of incubation periods CO_2 evolution decreased by 48.8, 47.9 and 64.5% in sandy, loam and clay soils, respectively, at Pb levels of 1000 μg/g soil.

DISCUSSION

Soil respiration is influenced by several environmental conditions, soils and plant composition and *ex situ* studies are difficult and differences in soil respiration may reflect many different environmental conditions. To avid such scenarios of variations, we chose to measure soil respiration in soils incorporated with crop residue from the control (unpolluted) and polluted soils under controlled conditions.

Several environmental conditions affect the mineralization of added organic materials. The time of oxidization of a given substrate depends upon its chemical composition and the physical and chemical conditions of the surrounding environment. Temperature, microorganisms, O_2 supply, moisture, pH, available minerals, heavy metals and the C:N ratio of the plant residue are the main environmental factors. Soil respiration rate, which can be considered an index of general soil microbial activity, also significantly decreases in the polluted soils (Lighthart et al. 1983, Laskowski et al. 1994, Cotrufo et.al. 1995, Dumat et al. 2006). Early studies on the effects of heavy metals on soil respiration show the inhibitory effects of Pb, Zn, Cd or Cu (Williams et al. 1977, Coughtrey et al. 1979). Our data indicate

Table 4. Effect of lead, soil texture and incubation period on CO_2 (μg/g soil) evolution during decomposition of sugarcane trash

Lead levels (μg/g)	Incubation periods (days)						
	7	15	30	60	90	120	mean
Sandy							
0	36.00	29.47	20.07	15.13	13.33	10.53	20.76
10	34.00	29.20	18.90	14.67	14.03	10.27	20.18
50	29.00	24.80	15.00	14.20	12.57	10.87	17.74
100	21.47	18.53	17.80	14.87	12.20	9.27	15.69
1000	14.27	13.17	8.93	9.23	8.07	7.30	10.16
Mean	26.95	23.03	16.14	13.62	12.04	9.65	16.91
Loam							
0	56.00	49.87	37.47	32.60	26.33	17.73	36.65
10	54.93	50.00	42.00	30.60	24.83	18.20	36.76
50	52.07	47.80	42.10	35.07	24.80	20.00	36.97
100	44.03	40.67	35.27	29.93	20.20	17.97	31.34
1000	33.47	26.97	25.77	20.63	17.43	17.43	23.62
Mean	48.10	43.06	36.52	29.77	22.70	18.27	33.07
Clay							
0	75.00	70.07	61.00	54.67	39.93	20.40	53.51
10	75.00	68.67	61.67	57.00	42.80	25.20	55.06
50	71.00	66.67	62.00	54.67	40.83	23.20	53.06
100	65.00	60.00	51.67	49.67	35.20	17.27	46.47
1000	46.00	21.17	19.20	18.07	17.37	16.33	23.02
Mean	66.40	57.31	51.11	46.81	35.23	20.48	46.22
CD (0.05)	Soil texture – 0.16, metal concentrations – 0.21, incubation days – 0.23 Interactions Soil texture × incubation days – 0.71, soil texture × metal concentrations – 0.80, incubation days × metal concentrations – 0.50, soil texture × metal – concentrations × incubation days – 0.89						

that the differences in CO_2 evolution on heavy metal polluted and control (unpolluted) soil decline with increase in concentration and incubation periods. Therefore, in the conditions of our experiment, with no limits of water availability and temperature, the influence of heavy metals on soil respiration seems to be important. An alternative scenario would be that differences in the soil respiration were due to the effect of heavy metals pollution on the soil physico-chemical properties (sandy, loam and clay) and residue composition. Unfortunately, we did not examine the weight loss of the residue and change in soil and crop residue composition during decomposition.

A decreased rate of soil respiration related to increased incubation period may be attributed partly to the concentration of heavy metals, which would bring down the soil microbial activity. A soil respiration expresses the rate of aerobic catabolism of soil heterotrophs and was found to be correlated with crop residue-mass loss in different types of residues (Heal et al. 1978). Inhibition of residue respiration by heavy metals was reported previously (Chaney et al. 1978, Freedman and Hutchinson 1980, Kuperman and Carreiro 1997) and it reflects the harmful effect of heavy metals on residue decomposer communities.

During the 120 days, the toxicity decreased but was still significant. Inhibition was greatest in the clay soils and lowest in the sandy soil. In a loam soil, inhibiting effects were intermediate, but distinct. The biotic and abiotic factors were responsible for these different degrees of inhibition (Doelman and Haanstra 1984).

In this study soil respiration was 2 and 2.5 fold higher in loam and clay soils, respectively, compared to sandy soil. According to Oades (1995), a high amount of clay decreases the biodegradation of soil organic matter and therefore increases the stock of carbon. Mullar and Hoper (2004) reported that the capacity of soil against microbial decomposition depends on its clay content. Therefore the soil respiration could be lower in sandy soil in comparison with loam and clay.

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