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MICROBIAL ACTIVITY CHANGES IN SOIL AMENDED WITH RAW AND COMPOSTED SEWAGE SLUDGE

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ABSTRACT

The changing of soil biological characteristics due to the addition of raw and composted sewage sludge (at 0, 1.5 and 3.0%) were evaluated during a 165-day incubation experiment. Generally, increasing the addition rate of sewage sludge and its compost up to 3%, total organic C content (TOC), cumulative organic C decomposition (COCD), biomass C and basal respiration in soil were significantly increased. The increase in biomass C and basal respiration were significantly higher in sewage sludge-treated soil as compared with compost-treated soil. By extending the incubation period, TOC content biomass C and basal respiration were significantly decreased and COCD was significantly increased

The differences in biomass C/TOC ratio at the beginning and end of the incubation experiment were significantly higher in waste-amended soil as compared with the untreated soil. Such differences were much higher when the soil treated with sewage sludge as compared to the soil treated with compost.

At the beginning of the experiment, all values of metabolic quotient (qCO_2) in the waste-amended soil were significantly higher as compared with the untreated one. Sewage sludge-amended soil had usually greater qCO_2 values compared with compost-treated soil at the used two application rates.

High positive correlations were observed between biomass C, basal respiration and the biomass C/TOC ratio. Any of these may be used as a bio-indicator of a soil biological activity after amendment by organic materials.

Keyword: Microbial biomass C, basal repiration, qCO_2, biomass C/TOC, sewage sludge, compost.

INTRODUCTION

The soils of semiarid zones are usually low in organic carbon content and need organic amendments to improve their physicochemical and biological properties and thus their productiveness and natural fertility (Pascual *et al*., 1997). Intensive work has been conducted on the influence of such amendments on the soil's physical and chemical parameters (Pagliai and Vittori Antisari 1993). However, little is known about the effect on microbial activity of such soils. Such knowledge is required to detect any of possible toxicities resulting from the use of urban organic materials (Perucci 1992), and as a marker of the soil rehabilitation (Garcia *et al*., 1994). Although at first sight it might seem relatively easy to find parameters to measure soil biological activity, the study of microorganisms in a soil and their reactions at a microhabitat level is not straightforward.

Meanwhile, greater attention had recently led to a recognition of the need to improve soil quality and to support plant growth in a sustainable way, which takes into account environmental concerns. One method of reversing the degradation and improving the quality of soils involves the addition of several kinds of wastes such as solid organic waste, sewage sludge, agricultural and industrial wastes, and animal manure (Lalande *et al*., 1998; Mamo *et al*., 1999; Pascual *et al*., 1999b; Albiach *et al*., 2000; Lalande *et al*., 2000; Masciandaro *et al*., 2000). In this way, the additional benefit of reducing waste disposal costs is also obtained. Some of these wastes can be added to the soil without any risk (Lerch *et al*., 1992), whereas some others can produce toxic and depressant effects on plants and the microbial community (Ayuso *et al*., 1996). The use of municipal solid waste (MSW) compost is increasing in many European countries (Allievi *et al*., 1993; Gigliotti *et al*., 1997; Convertini *et al*., 1998; Mamo *et al*., 1999; Pascual *et al*., 1999a).

Chemical and physical soil parameters have been used to measure soil quality. A range of soil processes have been considered to be the most suitable rapid indicators of changes in the soil quality (Visser and Parkinsson, 1992) or to be measured in long-term experiments (Parr and Papendick, 1997). While the chemical characteristics of a soil can define its quality (Hassink, 1997), the microbiological and biochemical components of soil are more sensitive to the changes in the soil quality. A single soil parameter such as total C content or microbial biomass C (Brookes, 1995) or ratios between two parameters, such as the metabolic quotient (Anderson and Domsch, 1993), as well as enzyme activities (Nannipieri *et al*., 1990) could be proposed as indicators.

Biological processes have been studied using a wide variety of parameters including the direct methods, which make it possible to measure microbial biomass microscopically (Jenkinson, 1976), and the indirect methods which are based on analysis of the constituents of microorganisms, basically carbon and nitrogen (Jenkinson and Ladd, 1981). Paul and Voroney (1989) concluded that basic knowledge of a soil's microbial biomass could help toward understanding how various ecosystems work. Brookes *et al*. (1987) suggested that it is impossible to evaluate the ecological significance of a microorganism in a given environment simply by knowing the number present, and that it is more important to obtain information regarding their activity. For these reasons, other biological parameters must be investigated: basal respiration, biomass C/total organic carbon (TOC) ratio and metabolic quotient (qCO2). Basal respiration has been used as an indicator of microbiological activity in burnt soils (Carballas *et al*., 1979). Garcia *et al*. (1994) suggested that this parameter was related to the fraction of biomass carbon that is truly active. Biomass/TOC has also been used effectively to follow the organic matter content of the soil to which organic materials have been added (Hart *et al*., 1989). The metabolic quotient (qCO2) has been proposed as a useful parameter for studying the respiratory activity of a soil (Santruskova and Straskraba, 1991).

In most cases sewage sludge applications had a promoting effect on the size of the soil microbial biomass, compared to the unsludged soil (Balzer and Ahrens, 1992). Pascual *et al*. (1997) found that the addition of organic materials (municipal solid waste, sewage sludge and compost) to the soil increased the values of biomass carbon, basal respiration, biomass C/total organic C ratio and metabolic quotient (qCO2), indicating the activation of soil microorganisms. These biological parameters showed a decreasing tendency with time. This favorable effect on soil biological activity was more noticeable with the addition of fresh wastes (municipal solid waste or sewage sludge) than with compost.

Soil amendment with municipal solid waste (MSW) compost increased the organic C and total N contents, and dehydrogenase and nitrate reductase activities of soil. In cropped plots amended with MSW compost, dehydrogenase activity was positively correlated with -glucosidase activity, and both enzyme activities with organic C content (Crecchio *et al*., 2001). Three months after MSW compost addition to burnt soils, the number of viable fungal propagules increased in all the amended soils. This positive effect lasted until the end of the experiment. From 30 days onwards, all the amended soils showed a greater total number of bacterial cell forming units than the unamended burnt soil (Guerrero *et al*., 2000).

The aim of this work was to evaluate soil microbial activity changes as affected by the addition of sewage sludge and its compost to the soil at rates of 1.5 and 3.0% by using the parameters of total organic C content, cumulative C decomposition, biomass C, biomass C/TOC ratio, basal and specific respiration.

MATERIALS AND METHODS

An incubation experiment was conducted to study the effect of the raw and composted sewage sludge on soil microbial activity. Sandy soil sample from the upper surface (0-30 cm) was obtained from Saba Abar, Ismailia (the sample consisted of sand 92.9, silt 2.8, clay 4.3%, $CaCO_3$ 1.65%, pH 7.25 and EC 1.5 dSm^{-1}), and was characterized by its low organic matter (2.7 g kg^{-1}) and nutrient content (total N 0.14 g kg^{-1} soil, P 0.10 g kg^{-1} and K0.12 g kg^{-1}). Soil sample was air-dried, ground, sieved using a 2-mm sieve and stored at room temperature (25 ^{o}C).

One hundred gram soil samples were transferred to plastic containers (4.5 cm in diameter and 4 cm deep). Dry sewage sludge collected from the Wastewater Treatment Plant at Serabium, Ismailia, and its compost (sewage sludge was co-composted with rice straw at rate 1:1 w :w for 8 weeks) were added at rates of 1.5 and 3.0% to the soil samples and an unamended soil was used as control. Moisture was kept at 60% from soil water holding capacity. Soil samples were incubated at 30 ^{0}C. The characteristics of both sewage sludge and its compost are presented in Table (1).

Table (1). Characteristics of the sewage sludge and its compost.

Parameter	Sewage sludge	Sewage sludge compost
pH	7.11	7.19
EC, dSm^{-1}	3.75	3.97
Total N, g kg^{-1}	17.5	13.4
Total P, g kg^{-1}	2.4	1.3
Total K, g kg^{-1}	12.0	12.1
Total organic C , g kg^{-1}	227	195
C/N ratio	13.0	14.5
Fe, mg kg^{-1}	450	141
Mn, mg kg^{-1}	190	94
Zn, mg kg^{-1}	250	57
Cu, mg kg^{-1}	55	33
Ni, mg kg^{-1}	25	13

Samples were taken after 0, 7, 14, 30, 45, 75, 105, 135 and 165 days of incubation and kept at 4 ^{0}C. The total organic carbon (TOC) content was determined by oxidation with potassium dichromate in a sulfuric medium and evaluated using the excess of dichromate with Mohr's salt (Yeomans and Bremner, 1989). Microbial biomass C was determined by fumigation of the sample with ethanol free $CHCl_3$ and 50 mM K_2SO_4 extraction method (Vance *et al*., 1987). For the respiration rate determination, 50 g dry soil samples were placed in hermetically sealed flasks, moistened and incubated in the dark at 28 ^{0}C; at appropriate times carbonate was measured by tritation with 0.1 M HCl; the value of the CO_2 emitted in a glass flask without soil (control) was subtracted from the value for CO_2 emitted from the soil sample (Parr and Smith, 1969). The cumulative C decomposition, microbial biomass to total organic carbon ratio (biomass C/TOC) (Hart *et al*., 1989) and metabolic quotient (qCO2), which was calculated by dividing the C-CO_2 released from the sample in 1 h by the biomass C content (Santruskova and Straskraba, 1991; Pascual *et al*., 1997), were also obtained. Complete randomized block design was used and all measurements were the average of three replicates.

The objective of the study was to use total organic C content (TOC), cumulative C decomposition, biomass C, biomass C/TOC ratio, basal and specific (respiration/biomass C (qCO_2)) respiration for the evaluation of the effect of both raw and composted sewage sludge on the soil microbial behavior.

RESULTS AND DISCUSSION

Periodical changes in total organic carbon content (TOC) in soil treated with sewage sludge and its compost at rates of 1.5 and 3.0% during 165 day incubation period are presented in Figure (1). Generally, increasing the addition rate of sewage sludge and its compost up to 3%, TOC content in soil was significantly increased as compared with the untreated soil. By extending the incubation period, TOC content was significantly decreased due to the consequence C mineralization depending on the waste type. During the first 20 days, TOC content in soil amended with raw sewage sludge was much higher as compared with that in compost-amended sample at both application rates. Then, it became much greater in compost-treated soil as compared with sewage sludge-treated soil till the end of the experiment. Data presented in Figure (2) on the cumulative organic C decomposition support the results obtained on TOC content. Since, the highly significant cumulative organic C decomposition values were usually related to the raw sewage sludge treatments. Cumulative organic C decomposition was significantly increased by increasing the waste application rate and by the extending duration of incubation.

The obtained results were in a good agreement with those obtained by Pascual *et al*. (1997). They found that the decrease in TOC content was greater during the first 30 days when fresh wastes (municipal solid wastes and sewage sludge) were incorporated in the soil as compared with composted wastes.

Fig1,2

During this stage, the most biodegradable C fractions incorporated with the organic materials are degraded by microorganisms (Beloso *et al*., 1993). The compost-treated soil showed lower C mineralization rates than the soil treated with fresh wastes since the organic matter contained in a compost is more stable than that in fresh wastes (Mabrouk, 2000).

Periodical changes in soil biomass C as a result of applying 1.5 and 3.0% sewage sludge and its compost during 165 day incubation period are shown in Figure (3). The incorporation of both sewage sludge and compost in the soil significantly increased the biomass C level as compared with the untreated soil, which reflects the corresponding number of microorganisms and coincides with the observations obtained by Perucci (1992), Goyal *et al*. (1993) and Pascual *et al*. (1997). Generally, the soil biomass C was significantly increased by increasing waste application rate up to 3%. The increase in biomass C was significantly higher in sewage sludge-treated soil as compared with compost-treated soil. Biomass C mean values were 98.4, 229.9, 278.0, 211.0 and 354.8 μg g^{-1} soil in control, 1.5% compost, 1.5% sewage sludge, 3.0% compost and 3.0% sewage sludge treatments, respectively. The general increase in biomass C obtained can be attributed to the incorporation of easily biodegradable organic wastes, which stimulates the autochthonous microbial activity of the soil, or the incorporation of exogenous microorganisms (Perucci, 1992). The greatest increase in biomass C occurred in the soil amended with sewage sludge, may be due to that materials being produced by the microbial activity; once this process has terminated, part of the microorganisms are retained in the sludge.
In addition, the sewage sludge has a higher content of water soluble C (Table 1), which acts as energy source for the micoorganisms, thus contributing to an increase in their activity and biomass.

By increasing incubation period, soil biomass C was significantly decreased till the end of the experiment, since its mean values were ranged between 99.2 – 502.5 μg g^{-1} soil at 165 day and the beginning, respectively. However, in the waste-amended soil, the biomass C levels were still significantly higher than those in unamended soil, which indicates that the soil quality has recovered due to the organic additions. This results were in a good agreement with those obtained with by Pascual *et al*. (1997). The soil amended with compost showed lower biomass C levels as compared with sewage sludge amended one because of the stability of the added material. This stability as probably due to the microbial C being partially protected within the compost`s humic substances.

Microbial biomass carbon as an indicator of the changing soil quality is better than TOC since it is more sensitive to such changes. Variations in TOC are slower to be detected because it contains high percentages of stable fractions. The C of microbial biomass, on the other hand, responded rapidly and with a greater degree of sensitivity to incorporate organic materials even at low doses. The biomass C parameter can provide useful information when different treatments are compared (Smith *et al*., 1993).

Fig3,4

Basal respiration was defined as a useful parameter in measuring the soil biological activity (Anderson, 1982). Periodical changes in soil basal respiration as result of applying 1.5 and 3.0% sewage sludge and its compost during 165 day incubation period are shown in Figure (4). Applying both sewage sludge and its significantly increased soil basal respiration compost as compared with the untreated soil. Also, increasing organic waste application rates significantly increased basal respiration. It was much greater in sewage sludge-treated soil as compared to compost-treated soil at both application rates.

Periodical changes in calculated biomass C/TOC ratio as result of applying 1.5 and 3.0% sewage sludge and its compost during 165 day incubation period are shown in Table (2). The values were significantly higher in waste-amended soil as compared with the untreated soil. The differences in biomass C/TOC ratio between the beginning and end of the incubation experiment were much higher when the soil treated with sewage sludge as compared with the soil treated with compost. This would indicate the greater availability of mineralized materials at the beginning and the stabilization of the organic matter at the end of experiment. By increasing waste application rate, the differences in biomass C/TOC ratio between the beginning and the end of the experiment were increased. Similar trend in biomass C/TOC ratio as a result of increasing application rate of sewage sludge and its compost as was obtained by Pascual *et al*. (1997).

The biomass C/TOC ratio has been proposed as a sensitive indicator of changes in organic matter and it has also been used effectively to follow the state of soil organic matter content after the addition of organic materials (Hart *et al*., 1989). Pascual *et al*. (1997) suggested that this ratio is a reflection of the potential of organic matter mineralization and not of the stability of the organic matter.

Table (2). Periodical changes in the biomass C/TOC ratio of the soil treated with sewage sludge and its compost at rates 1.5 and 3.0% during 165-day incubation period.

Treatment	Incubation time, days									Mean
	0	7	14	30	45	75	105	135	165	
Control	8.39	8.10	7.75	7.73	7.69	7.64	8.80	6.02	5.57	7.30
1.5% SS	9.83	10.19	11.61	9.59	11.97	5.33	4.85	4.33	3.52	7.91
3% SS	10.92	7.53	8.20	7.22	6.06	4.87	4.00	3.13	2.62	6.06
1.5% comp.	8.86	9.61	9.83	8.47	5.55	4.61	4.03	3.72	3.08	6.42
3% comp.	9.50	7.69	7.61	6.55	5.26	4.21	3.43	2.62	2.22	5.45
Mean	9.49	8.62	9.00	7.91	7.31	5.33	4.62	3.96	3.40	6.63

SS= sewage sludge **Comp. = compost**

$LSD_{0.05}$

Treatment	**0.09**
Time	**0.12**
Treatment x time	**0.28**

Periodical changes in metabolic quotient (qCO_2) as a result of applying 1.5 and 3.0% sewage sludge and its compost during 165 day incubation period are shown in Table (3). At the beginning of the experiment, all values of qCO_2 in the waste-amended soil were significantly higher as compared with those of the untreated sample. Sewage sludge-amended soil has usually greater qCO_2 values compared with compost-treated soil at the two application rates. This may be due to the addition of relatively high proportion of easily biodegradable compounds when sewage sludge was added. By extending the incubation period, qCO_2 values were gradually decreased to reach the value of the control at the end of the experiment, due to the protective and buffering capacity of the soil (Pascual *et al*., 1997).

Table (3). Periodical changes in metabolic quotient (qCO2) of the soil treated with sewage sludge and its compost at rates of 1.5 and 3.0% during 165 day incubation period.

Treatment	Incubation time, days									Mean
	0	7	14	30	45	75	105	135	165	
Control	2.49	2.34	2.49	2.35	2.32	2.23	2.27	2.30	2.47	2.38
1.5% SS	3.07	2.82	2.72	2.57	2.62	2.52	2.83	2.75	2.50	2.63
3% SS	3.89	3.59	3.11	2.62	3.00	2.98	2.97	2.92	2.54	3.05
1.5% comp.	2.59	2.72	2.68	2.48	2.50	2.40	2.38	2.40	2.48	2.53
3% comp.	2.80	2.98	2.92	2.56	2.78	2.64	2.85	2.55	2.52	2.67
Mean	2.97	2.85	2.78	2.52	2.38	2.60	2.72	2.58	2.50	2.66

$LSD_{0.05}$

Treatment	**0.04**
Time	**0.05**
Treatment x time	**0.12**

The metabolic quotient (qCO_2) is known to be related with the hypothesis of energy optimization and it can be used as an indicator of environmental stress since it is calculated from parameters which are very sensitive to environmental changes (Anderson and Domsch, 1993). The evolution of CO_2 shows that the addition of fresh wastes put the microbial population under stress. These, in order to survive in such a hostile environment, put up defense mechanisms by increasing their respiration per unit of biomass (Anderson and Domsch, 1993). The compost-amended soil, in addition to having the smallest percentage of carbon biomass compared with total organic carbon (Table 2); showed the least activity and least altered the ecosystem, probably because of the added material's stability, which is reflected or the qCO_2 values (Table 3).

The correlation coefficients and regression equation constants between total organic carbon (TOC) content and the different biological parameters are presented in Table (4). Generally, in all treatments, there are high correlations between TOC, biomass C, basal respiration and biomass C/TOC ratio. Similar high correlations were found between cumulative organic carbon decomposition (COCD), biomass C, basal respiration and biomass C/TOC ratio. Generally, these correlations were greater in the soils amended with raw sewage sludge (at the rate of 3.0%) than in those amended with compost and in the control, and they were also greater in the high-dose treatments. There are no correlations between TOC and biomass C/TOC ratio and between COCD and biomass C/TOC ratio when soil treated with 1.5% sewage sludge.

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Significant correlations were recorded between TOC and qCO_2 and between COCD and qCO_2 at 0.05 level in soil treated with sewage sludge at rate 1.5%. Also, significant correlations were found between biomass C and qCO_2 in soil treated with 3.0% sewage sludge (0.05 level) and in soil treated with 1.5% compost (0.01 level). A positive correlation was found between biomass C/TOC ratio and qCO_2 in 1.5% sewage sludge treatment.

According to the foregoing results, it can be concluded that the stronger the initial reactivation after the incorporation of organic wastes in a soil (as with the high dose of fresh wastes) the greater the correlation will be between the different parameters, since the variations will be so great that they can only be attributed to the evolution of the microorganisms generated by the amendment.

Correlation coefficients and regression equations between the time mean values of TOC, COCD, biomass C, basal respiration, biomass C/TOC ratio and qCO_2 are presented in Table (5). These data show high positive correlation between biomass C, basal respiration and the biomass C/TOC ratio. Any of these may be used as a bio-indicator of a soil biological activity after amendment by organic materials. The same finding was obtained by Pascual *et al*. (1997).

Table (5). Correlation coefficients (r) and regression equations between the time mean values of the different parameters.

Parameter	r	Regression equation
	Total organic C content	
COCD	-0.999a	Y = 90.584 – 17.786X
Biomass C	0.938a	Y = -562.877 + 213.959X
Basal respiration	0.973a	Y = -49.729 + 17.513X
Biomass C/ TOC	0.787b	Y = -5.064 + 3.080X
qCO_2	0.829a	Y = 1.632 + 0.269X
	Total organic C decomposition	
Biomass C	-0.947a	Y = 529.37 – 12.142X
Basal respiration	-0.979a	Y = 39.591 – 0.990X
Biomass C/ TOC	-0.804a	Y = 10.604 – 0.176X
qCO_2	-0.825a	Y = 3.001 – 0.015X
	Biomass C	
Basal respiration	0.990a	Y = -2.712 + 0.078X
Biomass C/ TOC	0.950a	Y = 2.507 + 0.016X
qCO_2	0.711b	Y = 2.403 + 0.001X
	Basal respiration	
Biomass C/ TOC	0.901a	Y = 3.285 + 0.195X
qCO_2	0.790b	Y = 2.415 + 0.014X
	Biomass C/ TOC	
qCO_2	Ns	

TOC = Total organic carbon COCD = cumulative organic carbon decomposition
a= correlation is significant at the 0.01 level. b= correlation is significant at the 0.05 level.
Ns= not significant.

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التغيرات في النشاط الميكروبي في الأرض المعاملة بمخلفات الصرف الصحي الخام والمكمورة

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أجريت تجربة تحضين لمدة 165 يوم بغرض دراسة التغيرات في الخواص البيولوجية للتربة نتيجة معاملتها بكل من مخلفات الصرف الصحي الخام والمكمورة بمعدلات صفر ، 1.5 ، 3.0%. تم أخذ عينات تربة على فترات صفر ، 7 ، 14 ، 30 ، 45 ، 75 ، 105 ، 135 ، 165 يوم لتقدير المحتوي الكلي من الكربون العضوي TOC والكربون الحيوي biomass C والتنفس basal respiration وتم حساب كلا من النسبة التراكمية لتحلل الكربون العضوي COCD ونسبة الكربون الحيوي إلي الكربون العضوي الكلى biomass C/TOC ونسبة التنفس إلى الكربون الحيوي metabolic quotient (qCO_2). أجريت التحليلات الإحصائية للنتائج كما تم دراسة علاقات الارتباط بين الثوابت المختلفة.

وقد أشارت النتائج إلى الآتي:

1- عموما أدي زيادة معدل إضافة مخلفات الصرف الصحي ومكمورتها للتربة إلي زيادة معنوية في محتواها من الكربون العضوي الكلي وزيادة النسبة التراكمية لتحلل هذا الكربون كما أدي أيضا إلي زيادة معنوية في كل من الكربون الحيوي والتنفس. وكانت الزيادة في الكربون الحيوي والتنفس أعلي في الأرض المعاملة بمخلفات الصرف الصحي الخام بالمقارنة بالأرض المعاملة بالمكمورة.

2- حدث نقصا معنويا فى كل من محتوي الكربون العضوي الكلى و الكربون الحيوي والتنفس بينما زادت النسبة التراكمية لتحلل الكربون العضوي معنويا بزيادة فترة التحضين.

3- كانت الاختلافات بين قيم نسبة biomass C/TOC وكذلك قيم qCO_2 عند بداية التجربة ونهاية فترة التحضين كبيرة في الأرض المعاملة بالمخلفات بالمقارنة بالأرض الغير معاملة. كما كانت تلك الاختلافات كبيرة في الأرض المعاملة بمخلفات الصرف الصحي الخام بالمقارنة بالمكمورة.

4- وجود علاقات ارتباط إيجابية بين كل من biomass C و basal respiration و biomass C/TOC مما يشير إلي إمكانية استخدام أي من تلك الثوابت كمؤشرات للنشاط البيولوجي في التربة عقب معاملتها بالمواد العضوية.

Table (4). Correlation coefficients (r) and regression equation constants between different parameter values and total organic carbon content (TOC) of the soil treated with sewage sludge and its compost during 165-day incubation period.

Parameter	Control			Sewage sludge, %						Sewage sludge compost, %					
				1.5			3.0			1.5			3.0		
	r	a	b	r	a	b	r	a	b	r	a	b	r	a	b
							TOC								
Biomass C	0.945c	-128.5	1695	0.872c	-378.7	190.7	0.964c	-673.9	189.2	0.851c	-690.8	264.8	0.942c	-1090	256.3
Basal respiration	0.971c	-9.51	10.55	0.920c	-31.41	14.52	0.978c	-74.00	18.75	0.844c	-46.53	17.45	0.935c	-79.08	18.21
Biomass C/TOC	0.826c	-2.27	7.14	Ns			0.874c	-4.464	1.936	0.735c	-12.59	5.462	0.857c	-12.33	3.254
QCO_2	Ns			0.780d	1.964	0.221	Ns			Ns			Ns		
							COCD								
Biomass C	-0.946c	129.13	-2.58	-0.872c	523.5	-9.02	-0.964c	839.3	-15.13	-0.847c	449.6	-11.44	-0.940c	707.4	-18.13
Basal respiration	-0.971c	7.532	-0.160	-0.920c	37.20	-0.686	-0.978c	76.01	-1.500	-0.839c	28.59	-0.753	-0.933c	48.58	-1.287
Biomass C/TOC	-0.826c	8.589	-0.109	Ns			-0.874c	11.02	-0.155	-0.730d	10.93	-0.235	-0.855c	10.48	-0.230
QCO_2	Ns			-0.780d	3.008	-0.010	Ns			Ns			Ns		
							Biomass c								
Basal respiration	0.983c	-0.250	0.060	0.993c	-1.427	0.072	0.985c	-6.150	0.096	0.998c	-1.111	0.066	0.992c	-1.648	0.071
Biomass C/TOC	0.964c	2.717	0.047	0.846c	2.536	0.020	0.964c	2.205	0.011	0.981c	1.012	0.023	0.980c	1.201	0.014
QCO_2	Ns			Ns			0.692d	2.540	0.001	0.849c	2.304	0.001	Ns		
							Basal respiration								
Biomass C/TOC	0.915c	3.204	0.728	Ns			0.911c	3.120	0.105	0.979c	1.423	0.352	0.973c	1.574	0.190
QCO_2	Ns			Ns			0.727d	2.603	0.013	0.879c	2.312	0.014	Ns		
							Biomass C/TOC								
QCO_2	Ns			Ns			Ns			0.848c	2.269	0.038	Ns		

TOC = Total organic carbon COCD = cumulative organic carbon decomposition a= intercept b= slope
c= correlation is significant at the 0.01 level. d= correlation is significant at the 0.05 level. Ns= not significant.