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Impact of Alkaline Dust Pollution on Soil Microbial Biomass Carbon

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Abstract: The effect of alkaline dust pollution emitted from Bartın cement plant on the soil microbial biomass carbon was investigated using the chloroform fumigation-extraction (CFE) method. Microbial biomass C (C_{mic}) values ranged from 157.82 to 1201.51 µg g^{-1} soils in the polluted area and from 726.70 to 1529.14 µg g^{-1} soils in the control area. Soils polluted with alkaline cement dust resulted in significant reductions in C_{mic} levels compared to control soils. Microbial biomass C correlated negatively with $CaCO_3$ content ($r = -0.52$, $P < 0.05$) and positively with soil organic C ($r = 0.67$, $P < 0.01$). C_{mic}:C_{org} ratio proved to be a reliable soil microbial parameter for describing the change in the man-made ecosystem. Mean C_{mic}:C_{org} ratio was 2.55 and 3.09 in the polluted soils and control soils, respectively. The decrease in this ratio was an indication of soil degradation in the polluted soils. A significant decline in the C_{mic}:C_{org} ratio in cement dust-polluted soils also indicated that this parameter can serve as a good indicator of soil health.

Key Words: Microbial biomass C, cement dust pollution, C_{mic}:C_{org} ratio, soil health

Alkalen Partikül Kirliliğinin Toprak Mikrobiyal Biomas Karbon İçeriğine Etkisi

Özet: Bu çalışmada, kloroform fumigasyon-ekstraksiyon yöntemi (CFE) kullanılarak Bartın çimento fabrikasından yayılan alkalen partiküllerin toprak mikrobiyal biomas karbon içeriğine etkisi araştırılmıştır. Mikrobiyal biomas C (C_{mic}) değerleri; kirli alanda 157.82-1201.51 µg g^{-1}, kontrol alanında 726.70-1529.14 µg g^{-1} arasında değişim göstermektedir. Kirli alandaki topraklar kontrole göre istatistiksel olarak daha düşük C_{mic} içeriğine sahiptir. Toprakların mikrobiyal biomas C içeriği; $CaCO_3$ miktarı ile negatif ($r = -0.52$, $P < 0.05$), toprak organik C (C_{org}) içeriği ile pozitif ($r = 0.67$, $P < 0.01$) ve anlamlı bir ilişki göstermektedir. İnsan etkisine açık ekosistemlerin değerlendirilmesinde kullanılan ve güvenilir bir gösterge olan C_{mic}:C_{org} oranı; kirli alanda 2.55, kontrol alanında 3.09 olarak bulunmuştur. Bu oranının kirliliğe açık topraklarda daha düşük çıkması toprak kalitesinin bozulduğuna işaret etmektedir. Çimento partikülleri tarafından kirletilen topraklarda, mikrobiyal biomas C : organik C oranında (C_{mic}:C_{org}) belirlenen anlamlı azalma bu oranın toprak sağlığının izlenmesinde iyi bir gösterge olabileceğini göstermektedir.

Anahtar Sözcükler: Mikrobiyal biomas C, çimento partikül kirliliği, C_{mic}:C_{org} oranı, toprak sağlığı

Introduction

The soil microbial biomass is an essential component of most terrestrial ecosystems because it is responsible for regulating nutrient cycling, and acts as a highly labile source of plant-available nutrients. Despite their small volume in soil, microorganisms are key players in the cycling of C, N, S, and P (Jenkinson and Ladd, 1981; Dick, 1992).

Microorganisms respond quickly to environmental stress compared to higher organisms, as they have intimate relations with their surroundings due to their high surface to volume ratio. In some instances, changes in microbial populations or activity can precede detectable changes in soil physical and chemical properties, thereby providing an early sign of soil improvement or an early warning of soil degradation (Doran and Parkin, 1994; Sparling, 1997).

Microbial indicators are implemented in some soil monitoring programs in European countries. The most commonly used microbial indicators for soil health monitoring are microbial biomass, microbial quotient (C_{mic}:C_{org}), and soil respiration (Nielsen and Winding, 2002).

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The C_{mic}:C_{org} ratio, standing for the quantitative correlation between soil organic matter and microbial biomass, should be constant if the system is stable. Any deviation from the established constant would indicate a state of increasing or decreasing organic matter stability. Higher values of the ratio usually indicate the establishment of equilibrium between the inputs of organic matter and the mineralizing activity of the microbial biomass (Anderson and Domsch, 1986).

In general, a high amount of microbial biomass is beneficial to soil fertility and quality, because the microbial biomass reflects the total organic matter content and represents its dynamic part (Sparling, 1997). Decreasing values are an indication of soil degradation and can predict longer term trends in total organic matter content (Powlson et al., 1987). Pollutants can either directly kill microorganisms or decrease substrate availability, resulting in a decrease in microbial biomass (Brookes, 1995).

Air pollutants generated by the cement manufacturing process consist primarily of alkaline particulates from the raw and finished material. Other air pollutants emitted include such materials as sulfur oxides and nitrogen oxides generated from the kiln and drying processes (İncecik, 1994). The pollution of the environment with alkaline dust from cement plants affects all components of nature: plants, animals, soil etc. The pH value of the cement dust (42.5% CaO) from electric filters equals 12.3-12.6, and is strongly alkaline. Alkalization of the ecosystem and changing of the chemical composition of soils are expressed as changes in the species composition, the growth and bioproduction of trees and plant communities, considering the direct effect of cement dust (Mandre, 1995).

The activity of the microbial biomass is commonly used to characterize the microbiological status of soil (Nannipieri et al., 1990), and to determine the effects of cultivation (Beyer at al., 1991), field management (Perott et al., 1992), or contamination (Chander and Brookes, 1993). In addition, it is known that cement dust has essentially affected air pollution and soil (Stern, 1976), which may result in a marked decrease in the soil microbial biomass.

Several studies have shown that the high dust load and its long-term impact on ecosystems may bring about alkalization of precipitation, soil, and subsoil water (Farmer, 1993; Mandre, 1995). Depending on the chemical composition of the alkaline emissions, their deposition in ecosystems may alter soil pH levels, base saturation, contents of carbon, soluble salts, and major elements (Klose and Makeschin, 2004). As a consequence, decreased microbial biomass C and C_{mic}:C_{org} ratios were observed in emission areas (Bååth et al., 1992; Wolters et al., 1995). Several short-term laboratory incubation studies found that the addition of fly ash to sandy soils severely inhibited microbial biomass (Wong and Wong, 1986; Pitchel and Hayes, 1990).

Our primary objective was to determine how cement dust alters soil microbial biomass carbon (C_{mic}). We tested the hypothesis that cement dust changes soil chemical properties (pH and $CaCO_3$ content), which in turn decreases soil microbial biomass. This hypothesis was tested by comparing how soil microbial biomass carbon varied between the polluted area and the control area. A secondary objective was to assess the validity of the microbial indices as bioindicators of microbial processes induced by cement dust pollution.

Materials and Methods

Site description

The research area is Bartın province (41°38′ N, 32°20′ E), situated in the western Black Sea region in Turkey. The climate of this region is humid mesothermal type characterized by warm summers. According to the climatological data for the past 20 years, the annual mean temperature in this province is 12.6 °C. The mean temperature of the hottest month (July) is 22.4 °C and the mean temperature of the coldest month (January) is 4.0 °C. Annual mean precipitation in the region is 1087.0 mm and annual relative humidity is 81.6%. The prevailing wind direction is the NW. Soil is covered by annual herbaceous and dwarf shrubs species. Characteristics of the sampling sites around Bartın cement plant are given in Table 1.

Sampling

Ten individual samples from top soil (0-10 cm) were collected from each site (polluted and control) in the summer of 2006. Stones, and plant and root debris were removed. The 20 soil samples were passed through 2-mm sieves and stored at +4 °C before microbial analysis. Subsamples of the soils were air-dried and ground to pass through a 2-mm sieve for physical and chemical analysis.

Table 1. Characteristics of sampling sites around the Bartın cement plant.

Site characteristics	Polluted area	Control
Distance (m)	100-500	4000-4500
Slope (%)	10-20	25-40
Altitude (m)	50-70	80-100
Exposure	N	NW
Bedrock	Limestone	Limestone
Plant species	*Bellis perennis* L., *Dactylis glomerata* L., *Geranium* sp., *Rosa canina* L., *Rubus* sp.	*Bellis perennis* L., *Geranium* sp., *Euphorbia* sp., *Pteridium aquilinium* L., *Rosa canina* L., *Rubus* sp., *Vicia sativa* L.

Physical and chemical analysis

Particle-size fractions were determined with a hydrometer (Bouyoucos, 1962). pH was determined with a glass electrode in saturated soil (soil/water 1:2.5) on air-dried soil. Electrical conductivity (EC) was determined with an electrical conductivity meter in a 1:5 soil/water suspension. Organic carbon was determined by Walkley-Black wet oxidation (Black, 1965). Total nitrogen was measured by the Kjeldahl method. The total carbonate contents were measured by a Scheibler calcimeter (Rowell, 1994).

Microbial analysis

Soil microbial biomass C was estimated by extracting 30-g oven-dry equivalents of field-moist mineral soil samples in 0.5 M K_2SO_4 (1:4 w/v), by the chloroform-fumigation-extraction method described by Brookes et al. (1985) and Vance et al. (1987). Duplicate subsamples from each soil were placed inside 50-ml glass beakers. Samples designated for fumigation were placed in a vacuum desiccator. Ethanol-free $CHCl_3$ containing boiling chips was placed in a 50-ml beaker in the center of the desiccator. Paper towels moistened with deionized water were also placed in each desiccator to help maintain the water content of the soils during fumigation. The desiccator was sealed, placed in a laboratory hood, and evacuated, allowing the chloroform to boil for approximately 30 s. Samples were fumigated for 24 h at 25 °C in the dark. After chloroform removal, the soils were transferred to a 250-ml bottle and 120 ml of 0.5 M K_2SO_4 was added. At the same time, unfumigated soil samples were placed in the bottles and treated in the same fashion, serving as controls. Bottles were shaken for 30 min on a reciprocating shaker and supernatants were filtered through a Whatman no. 42 filter. Filtrates were kept at 4 °C for up to 1 week.

Microbial biomass C was measured in 8-ml aliquots of K_2SO_4 extracts after oxidation with 0.4 N $K_2Cr_2O_7$ at 150 °C for 30 min and back-titration with ferrous ammonium sulfate. Microbial biomass C was calculated from the difference in extractable organic C between the fumigated and unfumigated soil as follows: Biomass C = 2.64 E_C, where E_C refers to the difference in extractable organic C between the fumigated and unfumigated treatments; 2.64 is the proportionality factor biomass C released by fumigation extraction (Vance et al., 1987).

Statistical analysis

An independent-samples t-test was used to compare the mean characteristics of the polluted soils and the control soils. Correlation coefficients were calculated to evaluate the association between the different soil properties measured. SPSS 11.01 was used to process the data.

Results and Discussion

Soil microbial biomass carbon values are presented in Table 2. Microbial biomass C (C_{mic}) values ranged from 157.82 to 1201.51 µg g^{-1} soils in the polluted area and from 726.70 to 1529.14 µg g^{-1} soils in the control area. Soils polluted with alkaline cement dust resulted in significant reductions in C_{mic} levels compared to control soils ($P < 0.05$). Liblik et al. (2001) reported that cement dust essentially affected the air pollution situation and the soil's chemical characteristics. In that study, the area was polluted with a very high calcium content in the top soil and a value of soil pH about 7.8 was typical. Lime increased (Wolters et al., 1995) or decreased soil microbial biomass (Lorenz et al., 2001).

Table 2. Physical, chemical and biological properties of soils. Values are means of 2 repeated samplings. Asterisks refer to significant differences between polluted and control soil; *, $P < 0.05$; **, $P < 0.01$

Sampling site		Soil properties									
		Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	EC (dS m^{-1})	pH (H_2O)	Total N (mg g^{-1})	[1]C_{org} (mg g^{-1})	[2]C_{mic} (μg g^{-1})	[3]C_{mic}:C_{org} (%)
Polluted	1	16.00	25.40	58.60	9.10	0.24	7.69	1.71	9.80	454.23	4.95
	2	20.32	25.30	54.38	45.50	0.18	7.86	0.79	15.40	157.82	1.02
	3	30.15	27.38	42.47	17.96	0.43	7.66	3.03	66.90	1150.63	1.98
	4	26.30	27.32	46.38	41.74	0.27	7.77	1.57	21.10	547.82	2.62
	5	40.22	23.35	36.43	28.14	0.33	7.78	0.79	54.80	1201.51	2.19
	Mean	26.59	25.76	47.65	28.48	0.29	7.75	1.57	33.60	702.40	2.55
Control	1	17.84	19.41	62.75	0.00	0.16	6.52	4.33	53.10	1033.51	1.91
	2	13.67	19.44	66.88	0.00	0.14	6.51	4.30	43.60	882.20	2.02
	3	15.86	25.44	58.70	11.79	0.33	7.56	2.49	28.10	1529.14	5.44
	4	19.88	23.43	56.69	10.87	0.28	7.62	2.23	21.10	726.70	3.40
	5	25.78	25.50	48.72	4.22	0.25	7.78	1.05	32.60	887.97	2.71
	Mean	18.60**	22.64	58.74**	5.37**	0.23	7.19**	2.93*	35.70	1011.90*	3.09*

[1]C_{org} = soil organic carbon, [2]C_{mic} = soil microbial biomass carbon, [3]C_{mic}:C_{org} = (soil microbial biomass carbon:soil organic carbon) x 100

In the present study, mean soil $CaCO_3$ content was 28.48% and 5.37% in polluted and control soils, respectively. The $CaCO_3$ content of soils in the polluted area was significantly higher than that of soils in the control area ($P < 0.01$). The pH of soils in the polluted area (pH 7.75) was significantly different from that of soils in the control area (pH 7.19, $P < 0.05$) (Table 2). Electrical conductivity of the soil samples ranged from 0.18 to 0.43 dS m^{-1} in the polluted site and 0.14 to 0.33 dS m^{-1} in the control site. There was no obviously difference in soil electrical conductivity between the sites studied (Table 2). These results suggest that the alkaline dust accumulation resulted in significant increases in soil pH and $CaCO_3$ content of polluted soils. Microbial biomass C was inversely correlated with soil $CaCO_3$ content ($r = -0.52$, $P < 0.05$) (Table 3). Differences in microbial biomass C between the polluted soils and controls appeared to be due to the higher concentrations of $CaCO_3$. Besides the soil pH, water, temperature, substrate quantity and availability have been shown to affect the biological response to lime content of soil (Lorenz et al., 2001).

In our study, the textural range of samples was comparatively narrow and the soils, classified mostly as clay, contained almost no coarse fragments. However, the clay content of soils was significantly higher in the control soils than in the polluted soils ($P < 0.05$) (Table 2). By modifying soil microclimatic conditions and soil organic C content, soil texture is known to play a role in determining microbial biomass (Scott et al., 1996). Soils with high clay content lead to more stabilization of soil organic C and higher microbial biomass (Schimel et al., 1994). We did not explore the relationship between soil clay content and soil microbial biomass C. This result suggests that the influence of clay content within the narrow range of soil textures considered in this work was not well understood. Alternatively, alterations in soil chemical properties, such as changes in the $CaCO_3$ content and pH, may have masked the impact of clay content on soil microbial biomass C.

There was the strongest relationship with soil organic carbon content observed in soils: the correlation of microbial biomass C (C_{mic}) with soil organic carbon content (C_{org}) was 0.67 (Table 3). A linear relationship was determined between soil microbial biomass and soil organic carbon. The association between biomass and soil organic C has been described previously by Anderson and Domsch, (1989), who concluded that the microbial

Table 3. Pearson correlation coefficients (r) among measured variables in the study area. Asterisks refer to the level of significance; *, P < 0.05; **, P < 0.01.

Variables	Clay (%)	$CaCO_3$ (%)	pH (H_2O)	EC (dS m^{-1})	N_{tot} (mg g^{-1})	C_{org} (mg g^{-1})	C_{mic} (μg g^{-1})	C_{mic}:C_{org} (%)
Clay	1.00	-0.54*	-0.68**	-0.70**	0.63**	-0.32	-0.08	0.29
$CaCO_3$		1.00	0.62**	0.19	-0.64**	-0.26	-0.52*	-0.32
pH			1.00	0.59**	-0.91**	-0.38	-0.30	0.18
EC				1.00	-0.29	0.32	0.42	0.14
N_{tot}					1.00	0.45*	0.43	-0.08
C_{org}						1.00	0.67**	-0.54*
C_{mic}							1.00	0.14
C_{mic}:C_{org}								1.00

biomass C increases were linear up to about 2.5% soil carbon. However, soil organic C was not significantly different between polluted soils (33.60 mg g^{-1}) and control soils (35.70 mg g^{-1}), which suggests that the availability of soil organic C for soil microorganisms is identical in the 2 areas.

Organic C content of soil did not differ significantly between the 2 sites, whereas total N (N_{tot}) was significantly lower in the polluted site compared with the control site (Table 2). The reason for the low N_{tot} values in the polluted soils was probably the dust pollution, which reduced microbial abundance and activity. Similarly, Klose et al. (2004) reported that alkaline fly ash reduced N concentration, which was attributed to decreases in the decomposition of organic matter by influencing specific microbial and enzymatic processes in soils.

Mean C_{mic}:C_{org} ratio was 2.55 and 3.09 in the polluted soil and control soil, respectively (Table 2). C_{mic}:C_{org} of soils in the polluted area was significantly lower than that of soils in the control area (P < 0.05). This ratio could be useful as a soil quality indicator of conversion efficiency of organic C into microbial C and losses of soil C during decomposition (Sparling, 1992). Generally, if a soil is being degraded, the microbial C pools will decline at a faster rate than the organic carbon, and the C_{mic}:C_{org} ratio will decrease as well (Pinzari et al., 1999; Anderson, 2003).

Microbial biomass as a percentage of soil organic matter is one of the important parameters that can be used to assess the alteration of natural ecosystem caused by the pollutants (Brookes, 1995). C_{mic}:C_{org} ratio proved to be a reliable soil microbial parameter for describing the change in the man-made ecosystem (Insam and Domsch, 1988). In this study, C_{mic}:C_{org} ratio was negatively correlated (r = -0.54, P < 0.01) with soil organic C (Figure 1). The decline in C_{mic}:C_{org} in polluted soils may occur due to a reduction in the rate of carbon mineralization, which in turn results in the accumulation of organic matter in the soil. Generally, there is a reasonably close, linear, and positive relationship between

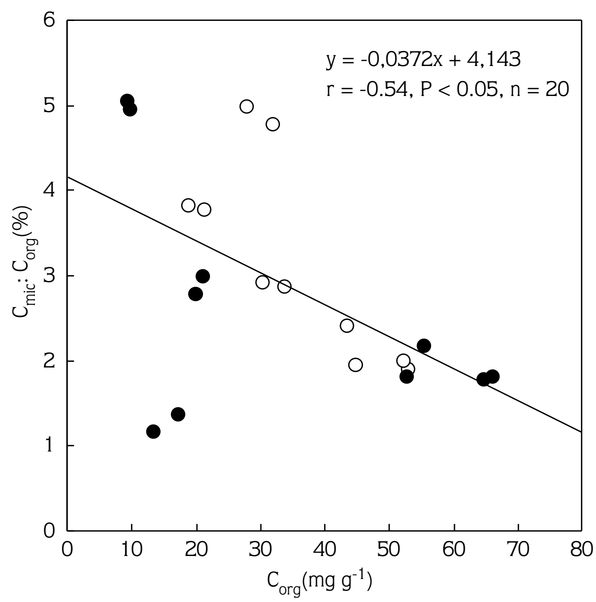

Figure 1. Relationship between soil organic carbon (C_{org}) and C_{mic}:C_{org} ratio in polluted soils (●) and control soils (❍).

organic carbon and the biomass carbon contents in uncontaminated soils (Jenkinson and Ladd, 1981), but no such relationship was found in contaminated soils (Brookes et al., 1984).

Jenkinson and Ladd (1981) proposed that a 2.2 C_{mic}:C_{org} ratio is an equilibrium threshold for cultivated soil. Mean ratios in our study were above this threshold. However, it must be emphasized that this property has varied widely in the literature from 0.27 to 7.0 across different soil management systems, sampling times, and analytical methods (Anderson and Domscsh, 1989).

Conclusions

As far as the aim of this paper is concerned, microbial biomass C proved to be sensitive to changes that occurred in soil chemical properties under pollution. Cement dust pollution of soils caused a significant reduction in the size of soil microbial biomass. However, the critical level of C_{mic}:C_{org} ratio for polluted soil is difficult to assess because of the range of values found in the literature. Due to the alkaline dust accumulation in soil, increasing soil pH values in future will decrease microbial biomass and, as a consequence, will reduce organic matter decomposition and element cycling in cement dust-affected areas in Bartın province.

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