Spatial Distribution Patterns of Soil Microbial Biomass Carbon within the Pasture

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Summary

Soil microbial biomass (*Cmic*) is the indicator of ecosystem productivity. Although *Cmic* represents big part of a temperate pasture ecosystem the biomass of the vegetation of the vegetation represents even bigger part, yet most of the carbon-energy balance and nutrient mobility happens through the *Cmic*. The purpose of this study was to assess the spatial variability of the soil *Cmic* using geostatistics in surface soil of pasture. *Cmic* was determined using 77 soil samples from the upper 20 cm of soil along a transect in a pasture of 1.35 ha. The results varied from 547.7 to 1223.8 µg CO_2-C g^{-1} soil. The exponential model fits the best semivariogram model for *Cmic* and exhibited spatial dependence with a range of influence of approximately 294.1 m.

Key words

spatial variability; soil microbial biomass carbon; kriging; pasture

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Introduction

Soil is a complex system wherein physico-chemical and biochemical factors are held in dynamic equilibrium (Arunachalam et al., 1999). Nowadays, particular attention is given to soil functionality, largely related to microorganisms and their activity. Soils may be considered as biological compounds with complex biochemical and microbiological reactions. Under suitable environmental conditions, the extent of soil organic matter turnover is mainly controlled by microorganisms, their activity and microbial biomass (*Cmic)* (Martens, 1995). The *Cmic* is the entire soil microbial population treated as an entity. The soil *Cmic* is a source of nutrients and changes in the *Cmic* can be used to predict the effects of ecosystem perturbations. This is why microbial indicators have been used as reliable tools to characterize soil quality with respect to land use and soil management (Turco et al., 1994; Doran and Parkin, 1994). Also, soil biological properties should be used as a soil erodibility indicator (Kızılkaya et al., 2003).

Soil *Cmic* is a soil microbiological property of great agronomic value because it shows organic compounds and various inorganic nutrient forms (mineral N, PO_4^{2-}, SO_4^{2-} etc) are available to plants. Variations in *Cmic*, apart from indicating changes in the quantity and quality of a soil's carbon, are also good indicators of the biological status of soils (Pascual et al., 1998). The *Cmic*, containing only 1 to 3% of total soil organic C is an important component of soil organic matter. The *Cmic* depends on many factors including texture, organic matter content, soil nutrient status, soil depth, environmental conditions such as temperature and humidity, pollutants (heavy metals, exhaust emissions etc) and agricultural practices such as fertilizer and pesticide treatments (Bååth, 1989; Flieβbach et al., 1994; Giller 1998; Kızılkaya, 1998; Kızılkaya et al., 2004; Aşkın and Kızılkaya, 2006).

Classic statistics assume that variation is randomly distributed within sampling units. Geostatistics are useful in predicting the spatial distribution of soil properties in the field with a limited number of samples (Bonmati et al., 1991; Chien et al., 1997). Semivariograms and autocorrelograms are typically used to study of the spatial structure of soil properties. Spatial variability is critical to our understanding of soil quality status and the development of methods for soil quality and healthy assessment (Aşkın et al., 2004; Aşkın and Kızılkaya, 2005a,b; Kızılkaya and Aşkın, 2004, 2005). However, there are few published studies on the spatial patterns of *Cmic* in soils. The objective of the present study was to assess the spatial variability of *Cmic* in a pasture using semivariogram analysis.

Material and methods

Study site and design

The study area was located in a pasture on the Karaköy State Farm in the Black Sea region (41°21'N, 36°15'W) of northern Turkey (Figure 1). The study site was located on the Bafra plain in Samsun. The climate is semi-humid with temperatures ranging from 6.6°C to 23.0°C. The annual mean temperature is 14.2°C and the annual mean precipitation is 670.4 mm.

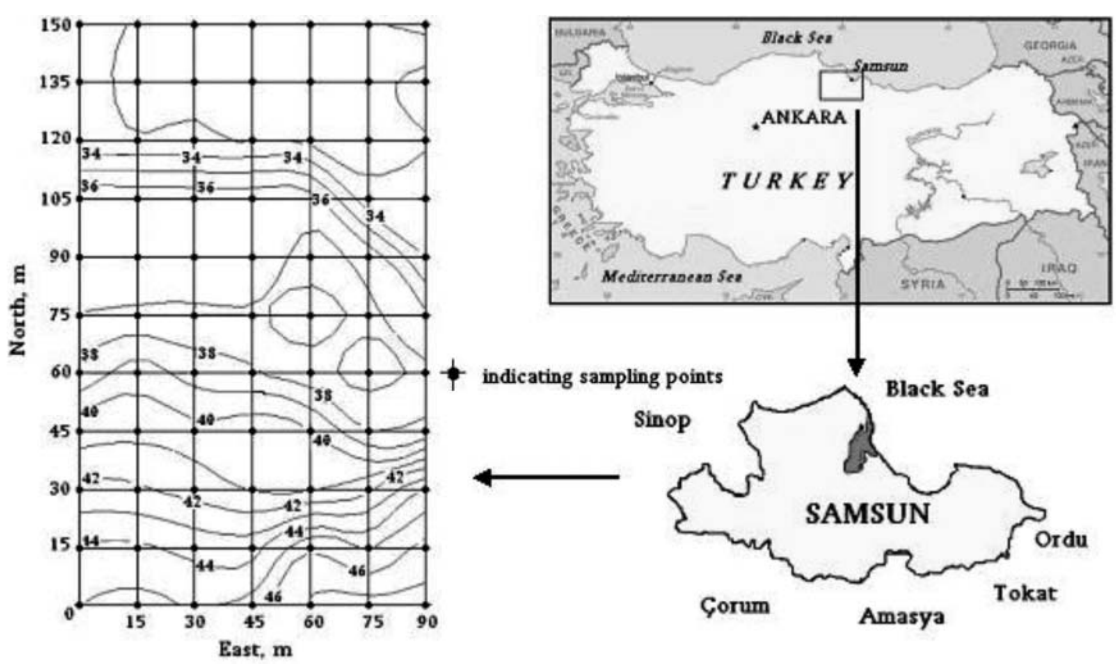

Figure 1. Location map of the Ondokuz Mayıs, contour map of the study area showing the sampling design

Soil sampling

Samples from the upper 20 cm of soil were collected from 77 sampling points at 15-m intervals in the 1.35 hectares (150 x 90 m) pasture (Figure 1). After removing residues and roots the soil was sieved through a 2-mm grid and transferred to cool boxes. Samples were kept at 4°C in a plastic box for 2 days to stabilize microbial activity and then analyzed within the same week. Reported data on the soil microbial biomass carbon are means of three replicates and are expressed on a moisture-free basis. Moisture content was determined by drying the soil samples at 105 °C for 24 h.

Soil physico-chemical properties

Bulk soil samples were air-dried at room temperature, sieved through 2-mm grids, and saved for analysis. Soil organic matter content was measured by a modified Walkley–Black method (Nelson and Sommers, 1982). The soil texture was determined by the hydrometer method (Gee and Bauder, 1979). Soil pH was measured based on a 1:2.5 (w/v) soil–water ratio using a pH meter (Peech, 1965) and cation exchange capacity (CEC) was measured by the Bower method (Rowell, 1996).

Cmic analysis

Cmic was determined according to the substrate-induced respiration method (Anderson and Domsch, 1978). A field moist kept soil sample equivalent to 50 g oven-dry soil (stored at 22 °C for 1 week) was amended with a powder mixture containing 150 mg glucose and 500 mg talcum. The CO_2 evolution rate was measured hourly as it was described by Anderson (1982). Cmic was calculated from the maximum initial respiratory response in terms of mg C g^{-1} soil as 40.04 mg CO_2 g^{-1} + 3.75. Data are expressed as μg CO_2-C g^{-1}1 dry soil.

Geostatistical analysis

The degree of spatial dependence of a random variable $Z(x_i)$ over a certain distance can be described by the following semivariogram function:

$$\gamma(h) = \frac{1}{2N(h)} \Sigma \left[Z(x_i) - Z(x_i + h) \right]^2$$

where $\gamma(h)$ is the semivariance for the interval distance class h, N(h) is the number of pairs of the lag interval, $Z(x_i)$ is the measured sample value at point i, and $Z(x_i+h)$ is the measured sample value at position (i+h) (McBratney and Webster, 1983).

Results and discussion

Soil physico-chemical properties and *Cmic*

Some descriptive statistical values on physico-chemical properties and *Cmic* of the pasture soils are presented in Table 1. The soils were mostly fine in texture, neutral in soil reaction, and high in organic matter content. After a 4h incubation at 22 ^{0}C, the *Cmic* contents, as determined by the using substrate induced respiration (SIR) method were 547.7 – 1223.8 μg CO_2-C g^{-1} dry soil (average 780.3 μg CO_2-C g^{-1} dry soil).

Spatial variability of *Cmic*

The exponential isotropic model was selected for spatial variability of *Cmic* by the GS^+ package program (GS^+, 1998). The model parameters and the experimental variogram for *Cmic* are illustrated in Figure 2.

The ratio of nugget variance to sill expressed in percentages can be regarded as a criterion for classifying the

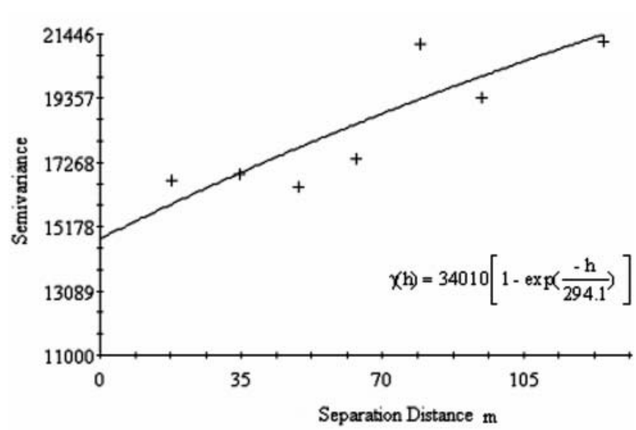

Figure 2. Experimental semivariogram for *Cmic*

Table 1. Summary statistics on the soil physico-chemical properties and *Cmic* (n = 77)

Soil Properties	Mean	Min.	Max.	S_d†	S_e‡
Sand, %	25.7	14.8	45.0	5.59	0.64
Silt, %	27.4	22.1	32.7	1.96	0.22
Clay, %	46.9	32.0	55.9	4.69	0.53
pH (1:2.5 soil: water suspension)	7.10	6.10	7.70	0.44	0.05
Organic matter content, %	4.65	2.67	7.27	0.86	0.10
Cation exchange capacity, cmol kg^{-1}	33.55	27.5	41.1	2.61	0.30
Microbial biomass carbon (*Cmic*), μg CO_2-C g^{-1} dry soil.	780.3	547.7	1223.8	137.42	15.66

† Standard deviation; ‡ Standard error

Table 2. Isotropic model fitted to variogram of *Cmic*

	Nugget, Co	Sill, Co+C	Range (Ao), m	C/Co+C, %	Co/Co+C, %	r^2	Model	SD
Cmic	14780	34010	294.1	56.5	43.5	0.77	E	M

SD-Spatial Dependence; E-Exponential; M-Moderate

spatial dependence of soil properties. If this ratio is less than 25%, then the variable has strong spatial dependence; if the ratio is between 25 and 75%, the variable has moderate dependence; otherwise, the variable has weak dependence (Chien et al., 1997).The range for *Cmic* was approximately 294.1 m (Table 2).

Table 3. Descriptive statistics on the observed and kriged values of *Cmic*

Descriptive statistic	Microbial biomass carbon, µg CO_2-C g^{-1} dry soil	
	Observed	Predicted
Number of samples (n)	77	1581
Minimum	547.7	506.5
Maximum	1223.8	1019.5
Mean	780.3	772.9
Standard deviation	137.42	17.39

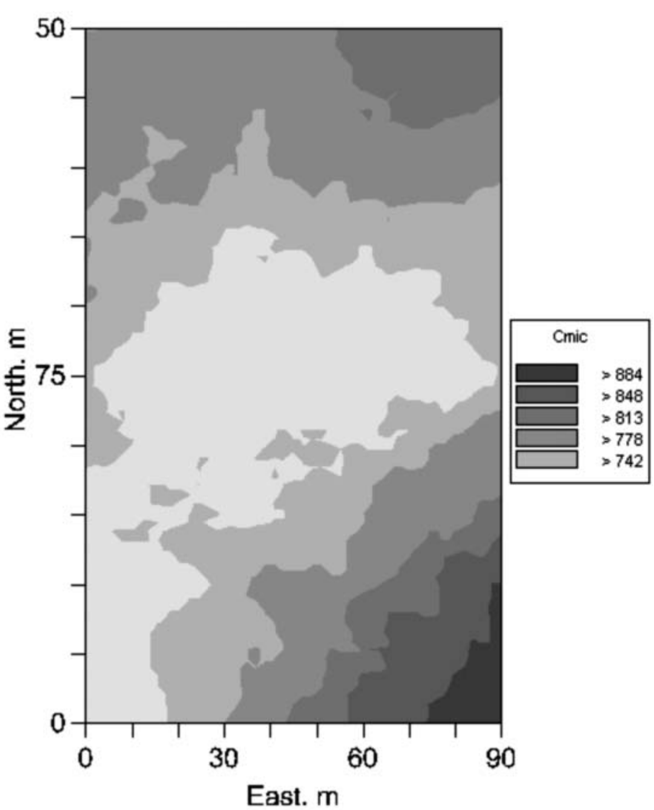

Figure 3. Block-kriged map of *Cmic*, µg CO_2-C g^{-1} dry soil

Cmic was block-kriged based on the exponential isotropic model on a 3 × 3 m grid (1581 locations). The descriptive statistics are given in Table 3 for observed and kriged *Cmic values.*

The range of kriged *Cmic* values was 506.5–1019.5 5 µg CO_2-C g^{-1} dry soil, and the mean was 772.9 µg CO_2-C g^{-1} dry soil, somewhat narrower than the range and lower than the mean of measured *Cmic* values (547.7–1223.8 µg CO_2-C g^{-1} dry soil and 780.3 µg CO_2-C g^{-1} dry soil). The standard deviation of the kriged *Cmic* values was lower than of the measured selected model (Öztaþ, 1996; Trangmar et. al., 1985).

Figure 3 shows a block-kriged map of *Cmic* illustrated using the same 1581 points used to krige *Cmic*.

Creating map from block-kriged data could be used to gain a better understanding of the spatial distribution of the *Cmic* in this pasture. Classical techniques of interpolation of the contour lines predicted values for a particular location. However, the values predicted by Kriging, as a geostatistical technique, were determined by using a semivariogram, which allows associated with each prediction to be determined (Killham and Staddon, 2002).

We found that the exponential isotropic model was the best semivariogram model for *Cmic* in this pasture. Also the ratio of nugget to total variation of *Cmic* was moderate spatial dependence of this microbiological parameter. Bonmati et al. (1991) and Röver and Kaiser (1999) pointed out that the variability of microbiological parameters is higher than that of chemical parameters. Morris (1999) reported that the weak spatial dependence of the physicochemical soil properties whereas microbial biomass and their activities showed strong spatial dependence.

Conclusion

An exponential isotropic model was the best semivariogram model for *Cmic*. The ratio of nugget to total variation of *Cmic* was 43.5%, indicating moderate spatial dependence of this microbiological property. The range for this enzyme was 294.1 m. This information can be used to gain a better understanding of the spatial distribution of microbial biomass carbon in pasture topsoil. Kriging should decrease the required sampling density in the pasture.

These assessments of soil microbial activity are generalized and should only be used for regional planning purposes and site specific management in pasture. Spatial analysis of microbial biomass carbon could be useful for assessing monitoring of soil quality and healthy status, as well as developing appropriate sampling strategies.

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