The Spatial Variability of Soil Dehydrogenase Activity: A Survey in Urban Soils

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Summary

Information on soil microorganisms and their activity used to determine microbiological characteristics are very important for soil quality and productivity. Studies of enzyme activities provide information on the biochemical processes occurring in soil. There is growing evidence that soil biological parameters may be potential and sensitive indicators of soil ecological conditions and soil management. Soil microbiological parameters may be evaluated statistically due to application of geostatistical methods to soil science. Measurement of soil dehydrogenase activity (DHA) has been used to establish indices of soil microbiological activity. The objective of this study was to assess the spatial variability of the DHA using the geostatistics in the topsoils of an urban area. DHA along a transect in an urban area was determined using 39 soil samples from the upper 20 cm of soil varied from 10.7-258.4 μg TPF g^{-1} soil respectively. The spherical model fits the best semivariogram model for DHA and exhibited spatial dependence with range of influence of approximately 48.2 km.

Key words

spatial variability; dehydrogenase activity; kriging; urban soils

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Received: June 14, 2006 | Accepted: October 5, 2006

Introduction

Studies on enzyme activities provide information on the biochemical processes occurring in soil. Enzyme activities are very sensitive to both natural and anthropogenic disturbances, and show a quick response to the induced changes in soil ecosystems (Dick, 1997). Soil biological parameters may be effective indicators of environmental stress, management practices (Dick and Tabatabai, 1992) and management-induced changes in soil quality (Dick, 1992; Kennedy and Papendick, 1995). Soil enzymes assays have been used monitoring of microbial activity related to specific macronutrient transformations (Sinsabaugh, 1994). These sensitive enzyme activities are affected by some environmental factors (temperature, moisture etc.), agricultural practices such as soil tillage, usage of pesticides and fertilizers, soil amendment with organic residues (Dick, 1992; Bergstrom et al., 1998) and, pollution with heavy metals (Bååth, 1989; Giller, 1998; Kızılkaya et al., 2004; Kızılkaya and Bayraklı, 2005).

The activity of the dehydrogenase (DHA) is considered an indicator of the oxidative metabolism in soils and thus of the microbiological activity (Skujins 1973) because it is linked to viable cells. Soil DHA reflects the total range of oxidative activity of soil microflora and, consequently it may be a good indicator of microbiological activity in the soil (Skujins, 1976). The measurement of the DHA in soils and sediments has been used extensively as dehydrogenases are intracellular to the microbial biomass, common throughout microbial species and are rapidly degraded following cell death (Rossel and Tarradellas, 1991). However, the relationship between an individual biochemical property and the total microbial activity is not always obvious, especially in the case of complex systems like soils, where the microorganisms and processes involved in the degradation of the organic compounds are highly diverse (Nannipieri et al., 1990).

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 the spatial structure of soil properties. The spatial variability of soil enzyme activities has been examined by using classical statistical approaches (Bonmati et al., 1991). However, geostatistics, which had its origins in the mining industry, is becoming increasingly popular among soil scientists for assessing spatial variability, and there are several excellent reviews of the process (Trangmar et al.,1985; Goovaerts, 1998; Aşkın et al., 2004; Aşkın and Kızılkaya, 2005, 2006; Kızılkaya and Aşkın, 2004, 2005). The objective of the present study was to determine the spatial variability of DHA and the number of sampling requirements to get representative value of DHA using semivariogram analysis within an urban area.

Material and methods

Study area and soil sampling

The study area was located in the urban area in Gümüşhacıköy, Amasya (40^0 53' N; 35^0 13' W) in the northwest Turkey (Figure 1). Annual mean of precipitation was 400 mm and temperature was ranged from -10^0C to 38 ^{0}C in sampling area.

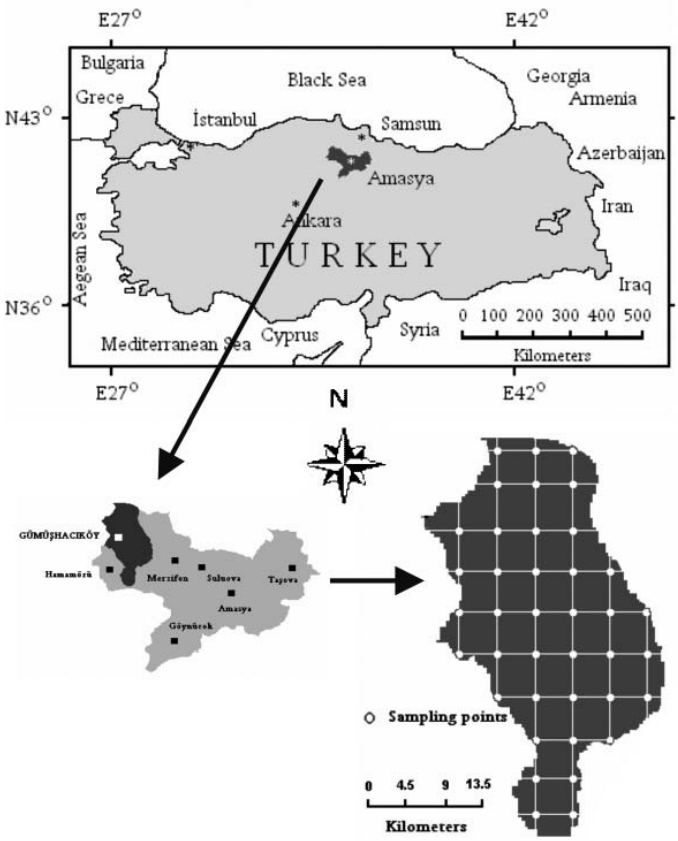

Figure 1.
Location of the study area showing the sampling design

Samples from the upper 20 cm of soil were systematically collected from 39 sampling points in the urban area (Figure 1). The primary grid consisted of 39 points spaced 4500 by 4500 m. After removing residues and roots, samples were 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. Dehydrogenase activity reported is means of three replicates and is expressed on a moisture-free basis. Moisture content was determined by drying the soil samples at 105 °C for 24 h.

Table 1. Summary statistics on the soil pysico-chemical properties and DHA (n = 39)

Soil Properties	Mean	Min.	Max.	S_d†	S_e‡
Sand, %	46.0	29.0	68.6	11.66	1.87
Silt, %	24.1	14.6	33.3	4.96	0.79
Clay, %	29.9	12.8	43.2	8.27	1.32
pH (1:2.5 soil: water suspension)	8.06	7.30	8.60	0.34	0.06
Electrical conductivity, dS m^{-1}	0.24	0.13	1.75	0.26	0.04
Lime content, %	5.38	0.20	15.86	4.40	0.70
Organic matter content, %	2.23	0.38	5.02	1.10	0.18
Cation exchange capacity, cmol kg^{-1}	41.98	23.48	60.02	9.49	1.52
Dehydrogenase activity (DHA), µg TPF g^{-1} soil	104.7	10.7	258.4	54.03	8.65

† Standard deviation; ‡ Standard error

Table 2. Anisotropic model fitted to variogram of DHA

	Nugget, Co	Sill, Co+C	Range (Ao), m	C/Co+C, %	Co/Co+C, %	r^2	Model	SD
DHA	1665	7533	48200	77.9	22.1	0.53	Sph	S

SD-Spatial Dependence; Sph-Spherical; S-Strong

Soil physicochemical properties and dehydrogenase activity (DHA)

Physico-chemical analyses were conducted on air-dried samples stored at room temperature and from which crop residues, root fragments and rock larger than 2 mm in diameter had been removed. Selected soil physico-chemical properties were determined by the following methods: soil particle size distribution by the hydrometer method (Bouyoucos, 1951), pH by pH-meter (Peech, 1965) in 1:2.5 (w/v) soil:water suspension, cation exchange capacity (CEC) by the Bower method (Rowell, 1996), and $CaCO_3$ content by Scheibler calsimeter (Allison and Moodie, 1965). All soil samples were sieved through a 150 µm mesh before determining the total organic carbon content by the wet oxidation method (Walkley– Black) with $K_2Cr_2O_7$ (Rowell, 1996).

Dehydrogenase activity (DHA) was determined using the classical TTC method suggested by Pepper et al. (1995). To 6 g of sieved soil 30 mg glucose, 1 ml of 3% TTC (2,3,5-triphenyltetrazoliumchlorid) solution and 2.5 ml pure water were added. The samples were incubated for 24 h at 27 ^{0}C in the dark. The formation of TPF (1,3,5 triphenylformazan) was determined spectrophotometrically at 485 nm and results were expressed as µg TPF g^{-1} dry soil.

Geostatistical analysis

The degree of spatial dependence of a random variable Z(xi) 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 γ(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

Soil physico-chemical properties and dehydrogenase activity

Some statistical results for selected soil physico-chemical properties are given in Table 1. Soil samples were mostly: with moderate coarse texture; with alkaline pH; moderate in organic matter content (average of 2.23 %); moderate in lime content (average of 5.38 %), and free of alkaline problem (ESP<15 %).

Dehydrogenase activities (DHA) of surface soils are presented in Table 1. After a 24h incubation at 27 ^{0}C, the DHA contents, as determined by using the reduction of 2,3,5-triphenyltetrazolium chloride (TTC) to triphenylformazan (TPF) method, were 10.7 – 258.4 µg TPF g^{-1} dry soil (mean 104.7 µg TPF g^{-1} dry soil).

Spatial variability of DHA

Semivariance values were calculated using the GS+ package program. The spherical model was selected for spatial variability of DHA by the GS+ (GS+, 1998). The model parameters and the experimental variogram for DHA are presented in Table 2 and illustrated by Figure 2.

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

DHA was block-kriged based on the exponential anisotropic model on a 1 × 1 km grid (1008 locations). The descriptive statistics are given in Table 3 for observed and kriged DHA values.

The range of kriged DHA values was 66.4–260.8 μg TPF g^{-1} soil, and the mean was 102.2 μg TPF g^{-1} soil, somewhat narrower than the range and lower than the mean of measured DHA values (10.7–258.4 and 104.7 μg TPF g^{-1} soil). The standard deviation of the kriged DHA values was lower than of the measured selected model (Öztaş, 1996; Trangmar et. al., 1985). The zone of influence for DHA was approximately 48.2 km (Table 3). Figure 3 shows a block-kriged map of DHA illustrated using the same 1008 points used to krige DHA.

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

Descriptive statistic	Dehydrogenase activity, μg TPF g^{-1} soil	
	Observed	Predicted
Number of samples (n)	39	1008
Minimum	10.7	66.4
Maximum	258.4	260.8
Mean	104.7	102.2
Standard deviation	54.03	18.61

Creating map from block-kriged data can aid understanding of the spatial distribution of soil microbial properties in this urban area. As with other interpolation techniques, the contour lines predicted values for a particular location. However, the values predicted by Kriging were determined by using a semivariogram, which allows associated with each prediction to be determined (Killham and Staddon, 2002).

Discussion

In this study, spherical anisotropic model was the best semivariogram model for DHA. The ratio of nugget to total variation of DHA indicated strong spatial dependence of this microbiological property of topsoil's in urban area. 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 weak spatial dependence of the physico-chemical soil properties whereas microbial biomass and their activities showed strongl spatial dependence. Powlson (1994) also concluded that microbial biomass is not as reproducible as chemical measurements because it is affected by several factors and shows a high spatial variability. Mummey et al. (2002) suggested that plant cover plays a central role in establishing heterogeneity and regulating ecological processes. Indeed, plants contribute to soil heterogeneity

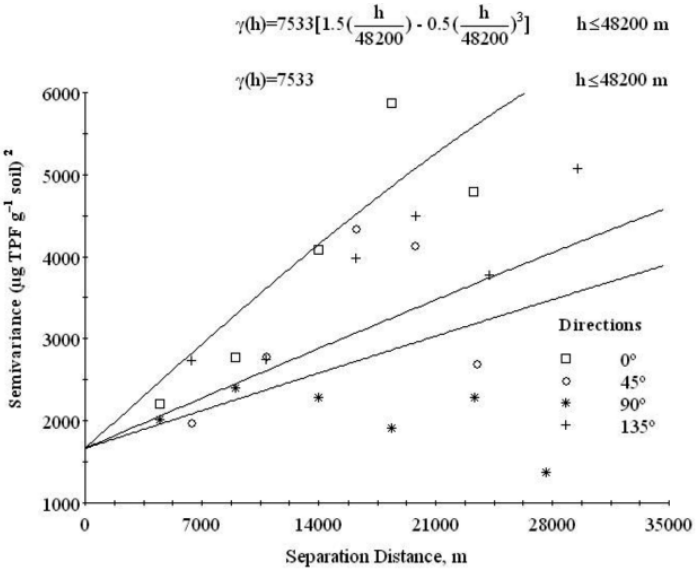

Figure 2. Experimental semivariogram for DHA

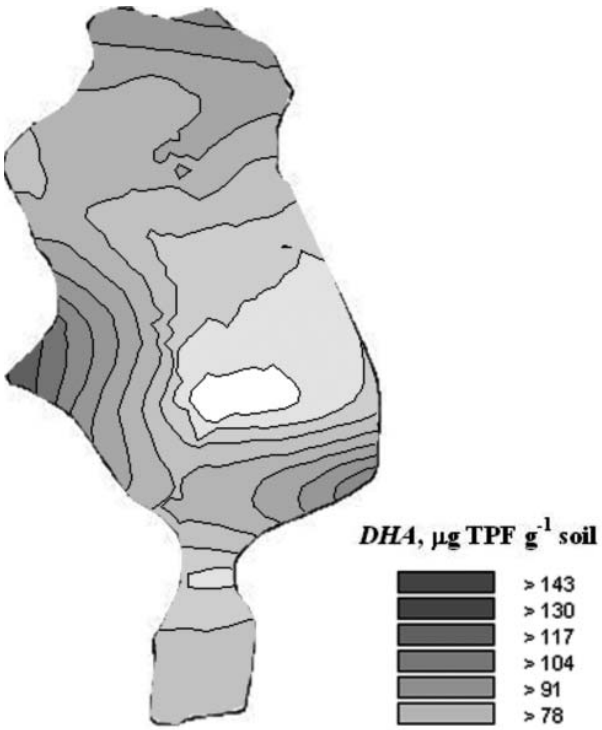

Figure 3. Block-kriged map of DHA, μg TPF g^{-1} soil

by their effects on soil moisture, aeration, pH etc., and by the litter distribution. All these factors can affect enzyme synthesis in microbes and enzyme survival outside the microbial cells.

We used the semivariogram analysis to estimate the magnitude of the spatial variation of DHA. The DHA may

be a good indicator of microbiological activity in the soil and therefore measuring DHA correctly is essential for evaluating a soil microbiological fertility budget. Because DHA has a strong spatial dependence, a large number of sampling points is required to estimate a representative value of DHA within the study area. However, this is practically difficult when using classical survey methods that are commonly employed under field conditions. Many studies have estimated DHA for selected area using most of sampling points. Moreover, these studies have usually not used any specific plan for determining distribution of DHA within the area. Consequently, these estimates may have an error. The variability of DHA within a soil ecosystem can be described by the coefficient of variation (CV). The number of sampling points required estimating a statistically significant means DHA rate can be obtained using the CV value. However it is difficult to compare the magnitude of the spatial variability of DHA among different studies due to differences in the size of experiment plots and the number of sampling points (Fang et al., 1998; Yim et al., 2003). Also, when the number of sampling points required is predicted from DHA data obtained from a few sampling points, the statistical significance of the estimate will be weak.

Conclusion

Spherical anisotropic model was the best semivariogram model for DHA. The ratio of nugget to total variation of DHA was 22.1 %, indicating strong spatial dependence of this microbiological property of topsoils in urban area. The range for this enzyme was 48.2 km. This information can be used to gain a better understanding of the spatial distribution of dehydrogenase activity. Kriging should decrease the required sampling density in the urban area.

In order to compare the spatial variability of soil DHA among different studies, more research on the effects of the employed methods is needed (e.g. chamber method). Additional studies are needed to determine more clearly the effects of seasonal change, other environmental factors and agricultural practices, such as fertilizer and pesticide treatments, organic matter management and cultivation on the spatial variability of dehydrogenase activity.

These assessments of dehydrogenase activities are generalized and should only be used for regional planning purposes. Spatial analysis of soil microbiological properties could be useful for assessing soil quality and health, as well as for developing appropriate sampling strategies.

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