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Spatial Variability of Soil Microbial Respiration in Eastern Hyranian Forests

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ABSTRACT: Soil spatial variability has explained as soil quality. Spatial variability could be interpreted by variography analysing. In eastern Hyrcanian forest, we examined soil microbial respiration variability in two different bed rocks and forest types to understand what controls spatial variability. For this purpose, 398 sample points specified by random transect method were selected and soil microbial respiration determined by closed bottle test. Samples were classified in two different bed rocks and forest types, and then variogram model fit to each other. Spatial structure was defined by nugget to sill ratio and cross validation done by MBE, RMSE and MSDR indices. Results do not show significant difference between bed rocks or forest types. So we test different hypothesis. Spatial structure and cross validation in virgin forest compared with managed forest. 81% of structural variance of SMR defined in virgin forest that have more spatial dependence than managed. We conclude virginity is cause of controlling soil microbial respiration variability.

Keywords: Soil microbial respiration, Variability, Variogram, Virgin forest

INTRODUCTION

Forest soil respirations are the result of heterotrophic respiration by microorganisms and soil fauna and autotrophic respiration by roots associated with mycorrhizae. The contribution of each element needs to be understood to evaluate implications of environmental change on soil carbon cycling and sequestration. Published data indicated that root/rhizosphere respiration can account for as little as 10 percent to greater than 90 percent of total soil respiration depending on vegetation type and season of the year (Hanson *et al.,* 2000). In the other hand, studies which have integrated percent microbial contribution to total soil respiration show mean values of 54.2 percent for forest soil. Also the contribution rate of soil microbial respiration (SMR) to the total soil respiration reported between 41.3% and 70.3%, indicating that SMR is a major component of soil respiration (Bowden *et al.,* 1993). Anyway in natural Oak forest SMR consisted 20% of soil respiration (Kelting *et al.,* 1997).

Soil respiration correlated with temperature (Wiant, 1967) and moisture that reported in several studied (Rey *et al.,* 2002; Epron *et al.,* 2004; Yuste *et al.,* 2005; Araujo *et al.,* 2010) although Yim *et al.* (2003) indicated two mentioned parameter did not contribute to the spatial variability of soil respiration and suggesting that these two factors have a greater influence on the temporal variability of soil respiration. Raich and Tufekcioglu (2000) represented soil respiration were differenced between forest biomes that affected by forest type and stand structure.

SMR consisting largely of a consortium of bacteria and fungi is important in regulating ecosystem processes such as decomposition, energy flow, carbon (C) storage, and trace gas fluxes (Swift *et al.,*1979; Paul and Clark, 1997; Schlesinger, 1997).SMR is responsible for the transformation of soil organic matter and the associated mineralization of important nutrients that strongly regulate plant productivity or ecosystem net primary production.

Spatial variability of soil respiration within larch plantation determined among 50 sampling point within 30m × 30m plot by coefficient of variation (CV). The average of CV was 28% also temperature and moisture content did not contribute to the spatial variability of soil respiration. Finally authors suggested these two factors have a greater influence on the temporal variability than on the spatial variability of soil respiration (Yim *et al.,* 2003).

Nael *et al.* (2004) study spatial variability of organic C and microbial respiration in undisturbed and disturbed sites including an oak forest and a semiarid rangeland in central Iran. They reported 0.41 and 0.19 mg CO_2/g day in protected and disturbed forest. Spatial variability of the two variables in forest sites demonstrated pure nugget and spherical pattern in protected and disturbed sites, respectively. As for the rangeland ecosystem, pure nugget pattern was observed for both sites.

The spatial heterogeneity of soil respiration rates determined using the coefficient of variation (CV). Results showed CV ranged from 40 to 45% across the study sites and was not significantly different between them on culture plantations and forest (Adachi *et al.*, 2005).

The spatial variability of heterotrophic, rhizospheric and total soil respiration determined in wheat stand.61 sample point within a 50 m × 50 m plot were measured. The highest spatial variability was detected for the rhizospheric respiration during the period of massive plant growth. Compared to the heterotrophic contribution the coefficient of variation in space was constantly higher for the rhizospheric contribution. Variogram analyses revealed an almost completely random spatial distribution of heterotrophic respiration, whereas the rhizospheric respiration showed a clear spatial autocorrelation and by an average spatial correlation length of 18 m (Prolingheuer *et al.*, 2014).

Habashi showed bed rock, forest type and forest floor thickness have significant effects on SMR rate while distance to nearest tree and its DBH have not effect. In small scale, 3 mentioned variables controlled 77 percent of SMR variances change. There is a paucity of information about spatial variability of SMR in Hyrcanian forest ecosystems so in this study our objective was investigated spatial variability of SMR and its dependency in two different bedrock and forest type in a mixed eastern Hyrcanian forest (Habashi *et al.*, 2015).

MATERIAL AND METHODS

A. Description of the study site

This research was conducted in compartment 1Shastkalate forest station, at the Gorgan University of Agricultural Sciences and Natural Resources. The forest is mixed deciduous, with an average annual precipitation of about 650 mm. It is located in northern Iran (36° 41' to 36° 45' northern latitudes and 54° 20' to 54° 24' eastern longitudes) with an area of about 3716 ha and an altitude ranging from 100 to 1000 m above sea level. All compartment is covered mostly with *Fagus orientalis* Lipsky (Oriental Beech), mixed with *Carpinus betulus* L. (Common Hornbeam), and *Parrotia persica* (DC.) C.A. Mey (Persian Ironwood Tree). This site is characterized by brown forest soils, with a mostly limestone and loess bedrock (Ghanbari *et al.*, 2011). We select two forest type (include beech-hornbeam and beech- Persian ironwood) and bedrock (include limestone and loess).

B. Laboratory and field analysis

Randomness- Transect sampling were used then 398 soil samples (0-20 cm depth as shallow soil and 20-40 cm as deep soil) were collected from transect in non-uniform at 0.5, 1, 2, 4, 8, 16, 32, 64 m interval at different azimuth. The position of first sample determined using global position system (GPS) then other samples coordinates specified by trigonometric equations. Soil microbial respiration rate (SMR) was measured by the closed bottle method (Anderson, 1982) and expressed on mg CO_2/g day.

C. Statistical analysis

Primary statistical analyses such as frequency distribution, normality tests were conducted using SPSS (SPSS, 1998). Geostatistics were used as the technique of variography to measure the spatial variability of SMR (Webster and Oliver, 2001). Variography was done for identify overall autocorrelation structure, optimal lag classes, anisotropy and data outliers. It relates the semi-variance, half the expected squared difference between paired data values Z(x) and Z (xi +h), to the lag distance h, by which locations are separated. For discrete sampling sites, such as soil samples, the function is estimated as: $\gamma(h) = \frac{1}{2N(h)}\sum_{i=1}^{n(h)}(z_{(xi)} - z_{(xi+h)})^2$

Where Z (xi) is the value of the SMR at location of xi, and N(h) is the number of pairs of sample points separated by the lag distance h. Paying attention to irregular sampling in this paper, it is rare for the distance between the sample pairs to be exactly equal to h, therefore, the lag distance h is of ten represented by a distance band. We used cross-validation and jack-knifing (these terms are used according to Deutsch and Journel, 1998). In cross-validation the data are dropped one at a time and re-estimated by interpolation from the remaining data. Jack-knifing refers to the comparison of predictions with observations for this purpose. Three indices were computed include MBE, RMSE and MSDR as $MBE = \frac{1}{n}\sum_{x=1}^{n}\left[\hat{z}_{(x)} - z_{(x)}\right]$, $RMSE = \frac{1}{n}\sqrt{\sum_{x=1}^{n}\left[\hat{z}_{(x)} - z_{(x)}\right]^2}$ and $MSDR = \frac{1}{n}\sum_{x=1}^{n}\left[\frac{\hat{z}_{(x)} - z_{(x)}}{\sigma_{(x)}}\right]^2$ where $\hat{z}_{(x)}$ is predicted SMR, $z_{(x)}$ is measured SMR and $\sigma_{(x)}$ is standard deviation $\sigma(x) = \sqrt{\frac{1}{n}\sum_{x=1}^{n}\left[\hat{z}_{(x)} - z_{(x)}\right]^2}$. Calculation of experimental variograms and modeling of spatial variability SMR were carried out by the GS+ (Gamma Design; Plainwell, Michigan, Version 5.3) and Variowin programs (Pannatier, 1993).

RESULTS

A. Descriptive parameters and probability distribution of SMR data set

To evaluate the SMR data, the representative percentiles were calculated (Table 1). The SMR minimum, median, maximum, mean, skewness and kurtosis values in shallow soil layer were 0.00, 0.11, 0.2, 0.105, -0.1 and -0.38mg CO_2.g. Day-1respectively revealing normal distribution. The mentioned statistical parameters in deep soil were 0.00, 0.05, 0.19, 0.051, 0.75 and 1.03 mg CO_2. g. Day-1 respectively. Average SMR value decreased with increased soil depth. The lowest CV revealed in loess bed rock in shallow soil and highest find out in limestone bed rock in deep soil that were 33.94 and 77.5 percent, respectively (Table 1).

Table 1: Percentiles and descriptive of SMR rate in (mg CO_2/g day).

Soil Layer	N	Forest type, Utilize status or bedrock	percentile					Mean	Standard Deviation	Skewness	Kurtosis	CV
			Min	25%	Median	75%	max					
Shallow	96	Beech- Hornbeam	0.00	0.08	0.11	0.13	0.2	0.107	0.037	-0.07	-0.18	34.58
	102	Persian Ironwood-Hornbeam	0.01	0.07	0.11	0.13	0.2	0.103	0.039	-0.12	-0.55	37.86
	101	Limestone	0.00	0.08	0.11	0.13	0.2	0.101	0.038	0.10	-0.02	37.62
	97	Loess	0.01	0.08	0.11	0.14	0.19	0.109	0.037	-0.32	-0.61	33.94
	50	Virgin	0.00	0.08	0.09	0.11	0.2	0.099	0.035	0.17	0.93	35.35
	148	Managed	0.01	0.08	0.11	0.14	0.2	0.108	0.038	-0.21	-0.59	35.18
	198	Average	0.00	0.08	0.11	0.13	0.2	0.105	0.037	-0.10	-0.35	35.24
Deep	101	Beech- Hornbeam	0.00	0.03	0.05	0.06	0.19	0.052	0.036	1.03	1.79	69.23
	97	Persian Ironwood-Hornbeam	0.00	0.03	0.05	0.07	0.14	0.05	0.033	0.35	-0.34	66
	99	Limestone	0.00	0.02	0.03	0.05	0.14	0.04	0.031	0.7	0.34	77.5
	99	Loess	0.00	0.04	0.06	0.08	0.19	0.063	0.033	0.95	1.57	52.38
	50	Virgin	0.00	0.02	0.03	0.05	0.09	0.038	0.024	0.16	-0.55	63.16
	148	Managed	0.00	0.03	0.05	0.08	0.19	0.056	0.036	0.68	0.81	64.28
	198	Average	0.00	0.03	0.05	0.07	0.19	0.051	0.034	0.77	1.11	66.67

Anyway komlogorov-smirinov normality test were perform and the histogram have exhibited normal distribution.

B. Variography and Cross-Validation

Experimental variograms were calculated upon the SMR data. Anisotropy did not appear and the best isotropic variogram models were fitted by the cross validation method. Except for deep soil introduces in limestone has spherical model, for other soil an exponential model provide best fit with the highest structural variance and squared value to SMR variogram.

Table 2: Variograms characteristics of shallow and deep soil in two forest types and bed rocks.

Soil layer	Forest type or bedrock	Variogram Model	Nugget	Sill	Range (m)	Nugget/Sill ratio (percent)	R
Shallow soil	Beech- Hornbeam	Exponential	0.0018	0.0034	861	53	0.555
	Persian Ironwood-Hornbeam	Exponential	0.0007	0.0016	26	44	0.971
	Limestone	Exponential	0.0009	0.0018	170	50	0.933
	Loess	Exponential	0.0006	0.0015	72	40	0.847
Deep Soil	Beech- Hornbeam	Exponential	0.0007	0.0014	287.8	50	0.928
	Persian Ironwood-Hornbeam	Exponential	0.0009	0.0018	975	50	0.549
	Limestone	Spherical	0.0008	0.0017	2110	47	0.52
	Loess	Exponential	0.0006	0.0013	65	46	0.886

Table 3: Variograms characteristics of virgin and managed forest.

Soil layer	Forest status	Variogram Model	Nugget	Sill	Range (m)	Nugget/Sill ratio (percent)	R
Shallow soil	Virgin	Exponential	0.0003	0.0016	87	19	0.931
	managed	Exponential	0.0008	0.0017	88	47	0.898
Deep Soil	Virgin	Exponential	0.0006	0.0011	810.8	54	0.640
	managed	Exponential	0.0008	0.0018	282	50	0.841

Table 4: Cross validation indices.

Soil layer	Forest type, statusor bedrock	Variogram Model	MBE	RMSE	RMSDR
Shallow soil	Beech- Hornbeam	Exponential	-0.0001	0.030	0.989
	Persian Ironwood-Hornbeam	Exponential	-0.0004	0.036	0.990
	Limestone	Exponential	-0.0006	0.034	0.990
	Loess	Exponential	-0.0003	0.033	0.990
	Virgin	Exponential	0.0002	0.027	0.98
	managed	Exponential	0.0009	0.025	0.98
Deep Soil	Beech- Hornbeam	Exponential	-0.0009	0.028	1.003
	Persian Ironwood-Hornbeam	Exponential	0.0004	0.030	0.989
	Limestone	Spherical	0.0009	0.030	0.991
	Loess	Exponential	-0.0006	0.027	1.000
	Virgin	Exponential	-0.0003	0.036	1.05
	managed	Exponential	0.0002	0.029	0.99

In study area, SMR were auto correlated over distances of 26-2110 m, respectively. Nugget to sill ratio, which indicates spatial structure was describes about 40-50% of variation of SMR. Table 2 revealed variogram characteristics of shallow and deep soil in two forest types and bed rocks.

So the last step, we examine other classification. Study area were classified into two section include virgin forest and managed forest. Best variogram model were fitted again in virgin and managed forest by cross validation method.

Variogram characteristics were calculated again and showed in Table 3. Range of spatial autocorrelation of SMR was the same in virgin and managed forest shallow soil with value about 88 m but followed the order of managed and virgin forest in deep soil between 282-811m respectively (Table 3).

The last tabled (Table 4) showed cross validation indices in 3 different classification based upon bedrock, forest type and forest status.

DISCUSSION

Average of SMR rate in study area were 0.1 and 0.05 mg CO_2/g day in shallow and deep soil respectively. SMR rate indicated micro-organisms activity; therefore, it is expected to decrease micro-organisms nutrients with increasing depth simultaneously reduced microbial respiration. There is more organic material in shallow forest soil with good vegetation cover is the reason for increased microbial activity. The labile pool of SOC provides important substrate for microbial respiration. Therefore, the change of SOC content, especially in the top soil, affects soil microbial activities (Atkin *et al.*, 2000). More activity of micro-organisms in grassland and forest are due to plant roots, plant residues and more organic matter (Yousefifard *et al.*, 2007). Nael reported 0.41 and 0.19 mgCO_2/g day in protected and disturbed forest that could be comprised with shallow soil in this research (Nael *et al.*, 2004). Rangeland destroyed and land use changes in different slope position cause decrease of soil microbial respiration (SMR) content. This is in line with the findings of Yousefifard *et al*. (2007) and Khormali *et al.* (2009). In our finding SMR rate was similar in virgin and managed forest (0.099 and 0.108 in shallow soil and 0.038 and 0.056 in deep soil respectively) that showed tree cutting based on group selection silvicultural method does not negative effect on microbial respiratory and activity.

Spatial heterogeneity of SMR was investigated by CV and results showed shallow soil has less than deep soil that was reflected the last mentioned cause. Range of CV was 34-78% while in other research soil respiration CV range reported 28% and 40-50% respectively (Yim *et al.,* 2003; Adachi *et al.,* 2005).

The spatial scale, the number of the samples and the sampling layout (spatial resolution of the sampling) of our measurements seemed to be adequate for studying small scale variability and heterogeneity of SMR in Hyrcanian forest ecosystem. The forest structure, type and stands may be relevant in SMR by influencing litter deposition (Epron *et al.,* 2004), root respiration (Habashi and Rafiee, 2014) or stand canopy microclimate (Kelting, 1998). Because in the last finding, temperature and moisture have not influence in spatial variability of SMR (Yim *et al.,* 2003) while bedrock, forest type and forest floor thickness have significant effect on SMR (Habashi*et al.,* 2015) we measure spatial variability of SMR based on bedrock and forest type site classification.SMR in different classification present a weak to moderate spatial structure. Results showed similar spatial structure (Nugget/Sill ratio) in two classification method while structural variance was between 40 and 50%. The same spatial structure of SMR in different bedrock and forest type reflected same spatial distribution of various microbial groups. Results also showed range was between 27- 2110 m indicating the homogeneity conditions in forest soils studied. So as to increase the effective range we can be expected in the longer distances can be predicted. Prolingheuer using variography analyses revealed clear spatial autocorrelation by an average spatial correlation length of 18 m in rhizospheric respiration (Prolingheuer *et al.*, 2014).

The best spatial structure of SMR was found in virgin forest, shallow soil. 81% of structural variance (Nugget/Sill ration was 19%) showed that SMR in virgin forest is more spatial dependence than managed forest or that of SMR is sensitive index affected not only by inherent but also by management factors.

The current study emphasized that SMR is the important biological indices that spatial variability of it's affected by silvi cultural practices so can vary greatly at the small scale.

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