Investigation on spatial variability of soil chemical and biochemical properties using independent sampling of pairs of locations

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Abstract
The spatial variability of chemical and biochemical soil variables is often unknown in advance and it is usually investigated with nested sampling designs. Such designs do not prevent the chance of drawing variograms with a high nugget effect, in particular when variables with short-range spatial variability – like biochemical ones – are investigated. In the present research, we alternatively tested the sampling approach for non-ergodic variograms proposed by Brus and de Gruijter (1994), which is based on the independent selection of pairs of locations separated by increasing lag distances. The investigation was carried out in a 23-years old Sauvignon vineyard collecting 120 soil samples in 10 pairs of locations for each of the 6 selected lag distances. Samples were analysed for SOM, pH and K_2SO_4-extractable C, N, alkaline phosphatase and β-glucosidase. The sampling design we tested was effective in detecting soil variability at the vineyard scale. The shape of variograms also suggested that no spatial structure would have been obtained if we would alternatively adopt a systematic sampling design. Combined with easily measurable biochemical parameters, this sampling approach can be very useful in managing soil fertility according to a precision farming approach. In the end, all the investigated parameters but C_{extr} looked sensitive to the variation of soil thickness originated by machine levelling, showing that soil surface modifications made with heavy machinery can negatively affect soil fertility for decades.

Key Words
Spatial variability, biochemical indexes, chemical parameters, sampling design.

Introduction
The spatial variability of chemical and biochemical soil variables is often unknown in advance. It is usually investigated with nested sampling designs that do not prevent to draw variograms with a high nugget effect, in particular when variables with short-range spatial variability – like the biochemical ones – are investigated. In the present research, we alternatively tested the sampling approach for non-ergodic variograms proposed by Brus and de Gruijter (1994), which is based on the independent selection of pairs of locations separated by increasing lag distances. Our purpose was to assess the feasibility of this approach when applied to single sampling campaigns for the determination of seasonally variable biochemical parameters that, like extractable N and enzime assays, can be very useful in soil fertility management.

Methods
The investigation was carried out in a 23-years old Sauvignon vineyard of about 1 hectare located in the Friuli Venezia Giulia region, far northeast of Italy. This area has been originated by the outcrop of Eocene turbidites that display alternated layers of marls and sandstones. The soil of the surveyed vineyard, in particular, was an Aric Regosol (FAO 1998) on a topslope area that was levelled before plantation.
A total of 120 sampling locations was selected according to the design-based procedure for non-ergodic variograms proposed by Brus and de Gruijter (1994). In practice, we selected 6 lag distances – 2, 5, 10, 20, 30 and 40 m – in order to include all possible scales of variability within the size of the vineyard. Ten pairs of locations per lag were then selected on the basis of a simple random sampling design.
Soil samples were collected in August 2007 in the 2-20 cm soil layer and split in two subsamples. The first one was kept moist to determine biochemical parameters. Extractable organic C (C_{extr}) and N (N_{extr}) were determined with a Shimadzu TOC-V CSN analyser equipped with a TNC module, after extraction with 0.5 M K_2SO_4 for 30 minutes. β-glucosidase and alkaline phospatase were determined using p-nitrophenyl derivatives. The second subsample was air-dried and sieved at 2 mm for pH (potentiometric measurements in a 10 mM $CaCl_2$ solution) and soil organic matter (loss on ignition) determination.
The sampling design adopted produced an uneven distribution of observations. We then used the residual maximum likelihood (REML) approach to model variograms (Marchant and Lark 2007). Since REML modelling needs Gaussian-distributed, we transformed data with the Gaussian anamorphosis transformation

implemented in the ISATIS package (Geovariances 2000). Gaussian-transformed data were analysed and interpolated with the *geoR* library of the R statistical package (Ribeiro and Diggle 2001). Predicted data were in the end back-transformed to draw up maps in the original units of measure.

Results

Table 1 summarizes the statistics of the data. The coefficient of variation ranged between 1% on pH and 54% of N_{extr} and, apart from alkaline phosphatase and pH, variables displayed a non-Gaussian distribution.

Table 1. Summary statistics (*n* = 120)

	Min	Mean	Max	Std. Dev.	Skewness	Kurtosis
SOM (g/kg)	6.9	36.4	55.4	7.8	-0.390	4.197
C_{extr} (mg/kg)	1.02	2.05	4.34	0.59	0.857	4.515
N_{extr} (mg/kg)	0.14	1.00	2.53	0.54	0.416	2.671
pH	7.18	7.33	7.50	0.06	0.077	2.907
Phosphatase (μM p-NP/g)	16.2	77.0	130.9	25.7	-0.102	2.336
β-glucosidase (μM p-NP/g)	5.5	18.2	50.9	8.9	1.392	5.239

Table 2 reports the parameters of the models fitted to variograms of Gaussian-transformed variables. Despite the very detailed scale adopted, only N_{extr} and phosphatase showed a nugget effect lower than 50% of the total variance. As far as the scale of the spatial variability is concerned, the lowest range concerned C_{extr}, whereas SOM and N_{extr}, and phosphatase and β-glucosidase showed comparable scales of variability.

Table 2. Variogram models fitted with the REML approach.

	Nugget variance	Range (m)	Sill variance
SOM	0.609	45	0.413
C_{extr}	0.599	8	0.380
N_{extr}	0.252	57	0.895
PH	0.746	17	0.242
Phosphatase	0.525	79	0.548
β-glucosidase	0.694	91	0.385

Figure 1, in the end, shows the spatial pattern of four variables and the orthophoto of the vineyard took in 2003. The aerial photograph taken about 20 years from vineyard plantation is related to soil levelling. According to the photograph taken in the previous flight of 1975, the light-coloured areas located in the upper and in the lower-right part of the picture correspond to slightly raised field portions whose soil was partly removed by levelling. The spatial pattern of the four interpolation maps is comparable to that of the photograph. Higher pH values indicate a higher content of carbonated materials near the surface, hence the presence of a thinner soil. The other parameters display almost the same pattern of pH, suggesting a long-term effect of machine levelling on SOM and other parameters related to soil microbiological activity. This kind of information is very useful in soil fertility management, helping to modulate fertilization at a very detailed scale to decrease production variability in vineyards.

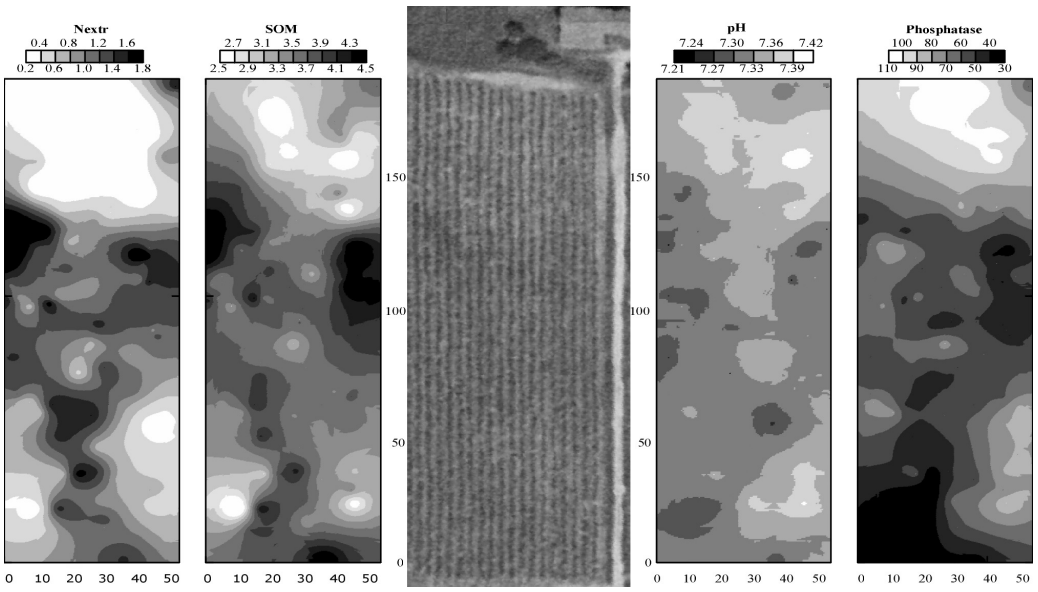

Figure 1. The 2003 orthophoto of the vineyard (in the centre) and kriging maps (left to right) of N_{extr}, SOM, pH and alkaline phosphatase.

Conclusion

The sampling design we tested was effective in detecting soil variability at the field scale of a single vineyard. The shape of variograms also suggests that no spatial structure would have been obtained with sampling distances larger than 15-20 m, i.e. those that we should have adopted to survey the same area by means of a systematic sampling design. Combined with easily measurable biochemical parameters, this sampling approach can be very useful in managing soil fertility according to a precision farming approach. In the end, all the investigated parameters but C_{extr} looked sensitive to the variation of soil thickness originated by machine levelling, showing that soil surface modifications make with heavy machinery can negatively affect soil fertility for decades.

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