RegioneEmiliaRomagna Servizio Geologico Sismico e dei Suoli
irpi Istituto di Ricerca per la Protezione Idrogeologica
Consiglio Nazionale delle Ricerche

A parametric simulation approach conditional on soil map delineations to map soil carbon stock at regional scale (Emilia Romagna, Italy)

F. Ungaro[1], F. Staffilani[2], M. Guermandi[2], P. Tarocco[2]

CNR IRPI Sede di Firenze Pedologia Applicata- Via Madonna del Piano 10. 5019 Sesto F.no (FI)

Servizio Geologico, Sismico e dei Suoli, Regione Emilia Romagna, Viale Silvani 4/3 40122 Bologna

Soils store more than twice as much carbon than vegetation or atmosphere (Bellamy et. Al, 2005) and sustainable land management practices need to be implemented in order to reduce soil carbon losses and mitigate climate changes (Dawson and Smith, 2007).

Accurate estimates of soil organic carbon (SOC) at regional scale are important to estimate the potential of soils as C reservoir and different approaches can be used resulting in different degree of uncertainty associated to the estimates (Ungaro et al, 2005). Among the major source of uncertainty, land use, soil map and bulk density for the reference depth are those with the greater influence on the final SOC stock estimation (Meersman, 2007).

In order to reduce the uncertainty associated to SOC stock estimates, an integrated approach combining the properties of 1:50.000 soil map delineation with geostatistical sequential Gaussian simulation has been developed to estimate SOC stock (0-30 cm) of the soils the Emilia Romagna plain (11,595 km^2) in Northern Italy. Soil data (19,000 observations) , collected and made available by the Regional agricultural extension (SACT Data base) and by the soil survey services (SGSS data base), from 199 soil typological units, have been referred to 13 soil functional great groups (A-R), dived in 42 functional subgroups (Table 1). Soil functional groups are defined in terms of top-soil textural family, oxygen availability, slope, presence of organic materials (Op horizons), and flooding occurrence; the criteria for the subgroups are: origin of the soil material, amount of limestone, oxygen availability. The box and whisker plot in Fig. 1 shows the mean values (and the standard errors) of topsoil organic C for the 13 soil functional groups. The observations within each functional groups have been further divided in 9 subgroups referring to the nine agricultural districts of the plain characterized by different dominant land use which results in distinct levels of soil organic C (Fig. 2).

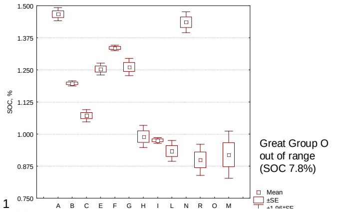


Fig. 1

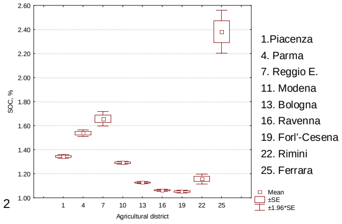


Fig. 2

Functional Great Groups	Num. Functional Sub-groups	Criteria for Functional Great Groups	Criteria for Functional Sub-groups
A	**6**	Ap texture FINE (C, CL, SC)	Origin of parent material, O_2 availability, limestone
B	**2**	Ap texture MEDIUM (SiL, Si), good O_2 availability,	Origin of parent material, limestone
C	**1**	Ap texture MEDIUM (SiL, Si), moderate O_2 availability	Origin of parent material, limestone
E	**5**	Ap texture MEDIUM-FINE (SiCL, CL, SCL with clay <35%), O_2 availability moderate to poor	Origin of parent material, limestone
F	**4**	Ap texture MEDIUM-FINE (SiCL, CL, SCL with clay <35%), good O_2 availability	Origin of parent material, limestone
G	**2**	Ap texture MOD.FINE (SiCL, CL, with clay > 35%) – FINE (C, CL, SC), moderate O_2 availability	Limestone
H	**3**	Frequent flooding	Ap texture, origin of parent material, limestone, O_2 availability
I	**3**	Ap texture MOD.COARSE (SL,L) to COARSE (S, LS), good O_2 availability	Origin of parent material, limestone
L	**2**	Ap texture MOD.COARSE (SL, L), moderate O_2 availability	Origin of parent material, limestone
M	**3**	Ap texture COARSE (S, LS)	Origin of parent material, O_2 availability
N	**2**	SKELETAL textural family	Limestone
O	**5**	High SOC %	Texture A/Op, O_2 availability, limestone
R	**4**	Slope > 6%	Texture, O_2 availability, limestone

Table 1. Criteria for the definition of soil functional groups.

The average SOC values (%) of each soil functional great group or sub-group of each district were used to assign a SOC value to each delineation of the 1:50.000 map (Fig. 3); the mean value of the delineation was than subtracted to each data point within the delineation in order to calculate the SOC residuals. Once normalized with a normal score transformation (NS, Goovaerts, 1997), the residuals experimental semivariogram was calculated with a lag of 1500 m (Fig.4) and fitted with a double nested spherical model (Table 2). Sequential Gaussian simulations (N = 100) of the normalized residuals were implemented on a 1 km regular grid, adopting a multiple grid search strategy. Once back-transformed, the estimated C residuals were added to the locally varying delineation dependent SOC means in order to derive a distribution of 100 values for each grid cell whose median was retained for the calculation of the topsoil SOC stock. The calculation of the SOC stock (Mg ha^{-1}) required a bulk density value (Mg m^{-3}): this was estimated using a set of locally calibrated pedotransfer functions (Ungaro, 2007) whose inputs beside organic C, namely sand, silt, and clay fractions (%), were estimated for each grid cell following the same procedure described for SOC (Figs. 6-8). The parameters of the omnidirectional semivariograms of the NS residuals are shown in Table 2.

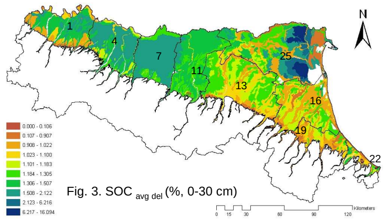


Fig. 3. SOC $_{avg\ del}$ (%, 0-30 cm)

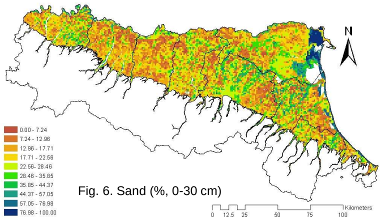


Fig. 6. Sand (%, 0-30 cm)

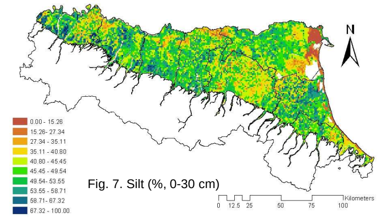
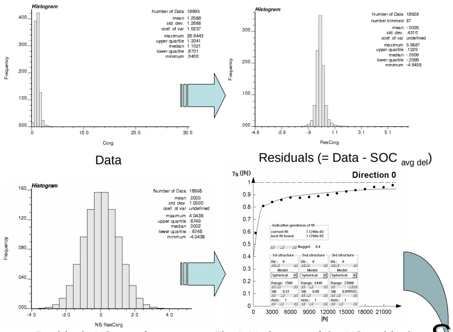


Fig. 7. Silt (%, 0-30 cm)



Data

Residuals (= Data - SOC $_{avg\ del}$)

Residuals NS transform

Fig 4. Variogram of the NS residuals

Variable	Nugget	Sill 1	Sill 2	Range 1 (m)	Range 2 (m)
SOC %	0.40	0.37	0.08	1500	6440
Sand %	0.48	0.40	0.12	1800	8000
Silt %	0.40	0.48	0.12	2000	8680
Clay %	0.40	0.46	0.14	2100	18270

Table 2. NS residual variograms parameters (Lag 1500 m).

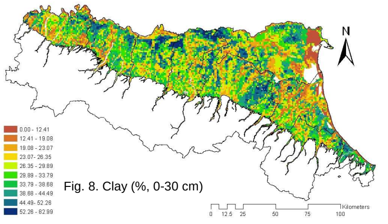


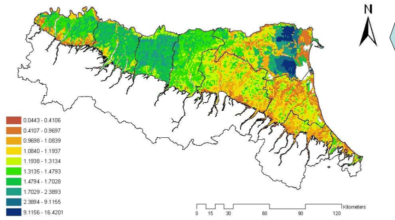
Fig. 8. Clay (%, 0-30 cm)

Variable	Support	MPE	RMSPE	R²	Delta %
Clay %	Cell	-1.454	9.697	0.45	9.1
	Del	-1.846	10.664	0.36	
Sand %	Cell	0.112	12.683	0.44	8.4
	Del	-1.855	13.851	0.35	
Silt %	Cell	-0.475	8.616	0.48	17.5
	Del	-1.022	10.443	0.17	
SOC %	Cell	0.072	0.703	0.79	2.1
	Del	0.078	0.718	0.79	

Table 3. SGS results validation (N = 2000; MPE: mean prediction error; RMSPE: rooted mean squared prediction error; Delta% = 100 * (RMSPE $_{del}$ – RMSPE $_{cell}$)/ (RMSPE $_{del}$).

SGS

BD = *PTFs* (SOC, Sand, Silt, Clay)



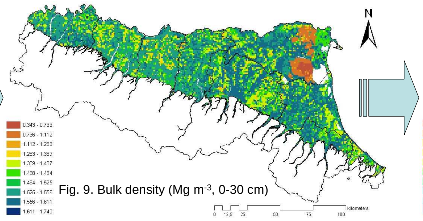


Fig. 9. Bulk density (Mg m^{-3}, 0-30 cm)

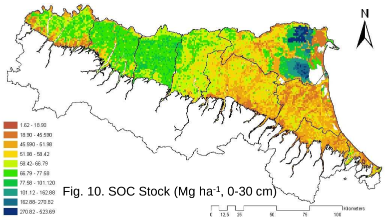


Fig. 10. SOC Stock (Mg ha^{-1}, 0-30 cm)

Fig. 5. Sequential Gaussian Simulation of the NS residuals, followed by back-transformation and sum of the local SOC $_{avg\ del}$: SOC %, median value (N = 100).

SOC (Mg ha^{-1}) = SOC % * 10 * Bulk density * 0.30 * 10000/1000

The PTF estimated bulk density is shown in Fig. 9. The resulting SOC stock at the reference depth of 30 cm is illustrated in Fig. 10. The application of the parametric simulation approach for the residuals of combined soil map and land use delineation (*Cell*) resulted in lower standard errors for all the variables used for SOC stock assessment, with improvement in accuracy over the traditional delination mean approach (*Del*) ranging from 2% (C org. %) to 18% (silt %) assessed on a subset of 2000 independent observations (Table 3).

References: Bellamy P., Loveland P., Bradley I., Lark M., & Kirk G. (2005) – *Carbon losses from all soils across England and Wales 1978-2003.* Nature, **437** (8), 245-248. Dawson J., & Smith P. (2007) – *Carbon losses from soil and its consequences for land-use management*. Science of the Total Environment, **382**, 165-190. Goovaerts P. (1997). *Geostatistics for Natural Resources Evaluation.* Oxford University Press, New York, NY, 483 pp. Meersmans J., De Ridder F., Canters F., De Baets S., & Van Molle M. (2007) – *A multiple regression approach to assess the spatial distribution of Soil Organic Carbon (SOC) at the regional scale (Flanders, Belgium).* Geoderma, **143**, 1-13. Ungaro F., Calzolari C., Tarocco P., Giapponesi A., & Sarno G. (2005) - *Quantifying spatial uncertainty of soil organic matter indicators using conditional sequential simulations: a case study in Emilia Romagna plain (Northern Italy)*. Canadian Journal of Soil Science, **85**, 499-510. Ungaro F. (2007) - *Metodi indiretti per la stima delle proprietà idrologiche dei suoli: definizioni di nuove pedofunzioni per la stima della densità apparente dei suoli della pianura emiliano-romagnola.* Rapporto, CNR IRPI Firenze, 68 pp.

84° Congresso Nazionale
Sassari, 15-17 Settembre 2008

Sessione S29 Matematica e statistica per le scienze della terra.

Società Geologica Italiana