SERVIZIO GEOLOGICO SISMICO E DEI SUOLI
REGIONE EMILIA ROMAGNA

VALIDATION OF THE EU SOIL SAMPLING PROTOCOL TO CERTIFY THE CHANGES OF ORGANIC CARBON STOCK IN MINERAL SOILS IN THE EMILIA-ROMAGNA REGION (ITALY)

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Introduction

The data presented in this paper was collected and analyzed[1] as part of a survey carried out for validation of the AFRSS (Area Frame Randomised Soil Sampling) method (Stolbovoy et al, 2005) in two sites on the Emilia-Romagna plain. They were also evaluated in relation to soil data available in the Soils Database of the Geological, Seismic and Soil Survey – Emilia-Romagna Region (ERR) (shared with the Food and Agricultural System Development Service of ERR. In particular, data utilized included that acquired and processed for the Soil Map 1:50.000 of the Emilia-Romagna plain and for the Fertilizer Assistance Service, both set up in the 1980s. In addition, data obtained from the multi-year experimental research project entitled "Restoration and maintenance of soil organic matter through the use of composted soil improvers" coordinated by the Reggio Emilia Research Centre on Animal Production (CRPA), still ongoing, was also utilized.
In adopting the AFRSS method, a new application was developed with a view to automating the process of creating a template to "overlay" on the selected sampling sites. The application is an Extension for Arc View GIS 3.x which creates a GRID of 10x10 cells over the chosen site, selecting and numbering the cells as indicated in the method (see annex B).

Site "MODENA-S.PROSPERO"

The site, to the north of Modena, in polygon 687 of the Soil Map 1:50.000 of the Emilia Romagna plain denominated [PRD1] (Pradoni 1 consociation), is situated on the Modenese plain on alluvial deposits laid down relatively recently (post-Roman) by overflowing of the river Secchia (figure 1). Planted with wheat, in rotation with maize and sugar-beet, it is typical of the dominant crop system in this area. The site lies in an area currently designated as not vulnerable by the Nitrate Vulnerable Zones Map, approved by the Emilia-Romagna regional council deliberation n. 570 of 11th February 1997.

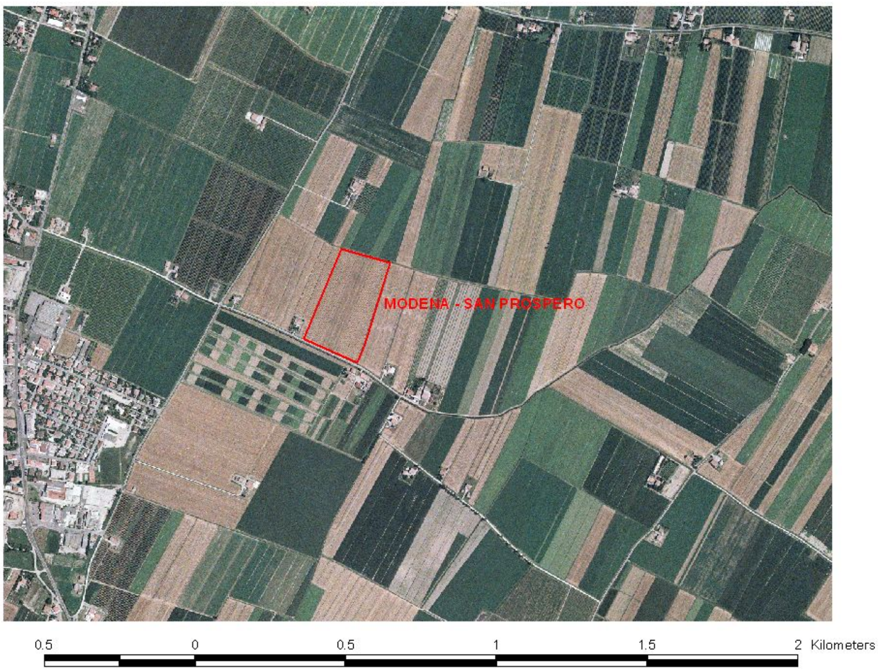


Figure 1. Site location: the direction of the fields is dictated by the drainage channels (open ditches) for surface water, which run predominantly north-south; to the south of the site lie the experimental research fields of the Molza experimental farm (CRA –ISA) and to the west, the town of San Prospero (orthophoto IT-2000).

[1] Analyses carried out according with the official Italian methods of soil analysis by LARIAN Laboratorio Ricerca ed Analisi, via delle Albicocche, 19 Pomezia (Rome), Italy.

The soil of the site, belonging to the regional Soil Tipological Unit (STU) La Boaria *silty-clay* (Archive F5008, RER 2006), is common within the environment of the Emilia-Romagna alluvial plain, in natural distal levees and in interfluvial basins, in particular in small-medium sized depressions lying between the river levees.
The substrate consists of fine to medium textured calcareous sediments.
The land use is recorded as cropland and cropland with trees, with crop rotation with alfa-alfa, quite common in the Emilia section, and tree crops (especially vineyards); field grown vegetable crops are rare.

Soil properties: the soil is very deep, characterised by a fine texture and by vertic properties.

It has a high rooting depth in poorly aerated horizons. The presence of vertic characteristics is partly responsible for restricting rooting depth; oxygen availability is moderate while permeability is low.

> Important subsurface aquifer sites for this STU in the Emilia-Romagna plain are found both in areas with natural drainage and in areas with mixed drainage (natural and mechanical drainage) with a prevalence of mechanical over natural.
> In winter months these soils are saturated and may feature a perched aquifer. It must be stressed that in these soils recharge occurs by surface water and it is believed that even when the ground is wet, monitoring equipment does not always detect unconfined water.
> Water has been detected in those horizons with a relatively coarse soil texture (SILTY CLAY LOAM) from a depth between 120 and 185 cm from the topographical surface, in winter months (January – April inclusive). From May it falls and in 4 months reaches its maximum depth of around 270 cm; from September to November monitoring equipment detects no water and the aquifer is again detected in January (little data is available).

Profile: the plough horizon, dark greyish brown, is silty clay loam and moderately alkaline; the subsoil horizon, olive grey in the matrix and dark grey on the faces of peds, is silty clay and moderately alkaline. The cationic exchange capacity is high. (Annex A)

Soil Typological Unit (*Phase of Soil Series)*: La Boaria silty clay – LBA1

Soil classification:
Soil Taxonomy Classification (KEYS 2003): Vertic Haplustepts fine, mixed, superactive, mesic
WRB Classification, 1998: Calcari Hypovertic Cambisols

Adaptation of the template: MODENA-S.PROSPERO

The geographic coordinates (UTM 32*) of the cropland plot margins are given in Table 1. The Xmax and Xmin, rounded to integer values, are 661367 and 661074. By computation (Xmax - Xmin) is 293.2 m. Applying the same operation to Y coordinates, the difference (Ymax –Ymin) is found to be 383.6 m. The biggest axis value (Maxis) is 383.6 m and defines the size of the template square (Figure 2). Based on the Maxis value, the Gs value would be 383.6/10 = 38.36 m. Consequently, the distance between sampling points (Gs/5) is about 7.6 m, and the position of the soil profile (Gs/2) is about 19.2 m in the grid.

Table 1. Geographical coordinates (UTM32*) of the plot extent (Modena-S.Prospero).

	X	Y
Minimum	661074	961837
Maximum	661367	962220

The plot area is 6.3 ha and the number of sampling sites should be 4 (Figure 1). Following the procedure described in the method, the 11th, 14th, 1st and 7th grids have been selected:
- 11 : x: 661207.91, y: 961894.13
- 14 : x: 661131.19, y: 961970.85
- 1 : x: 661207.91, y: 962009.21
- 7 : x: 661284.63, y: 962162.65

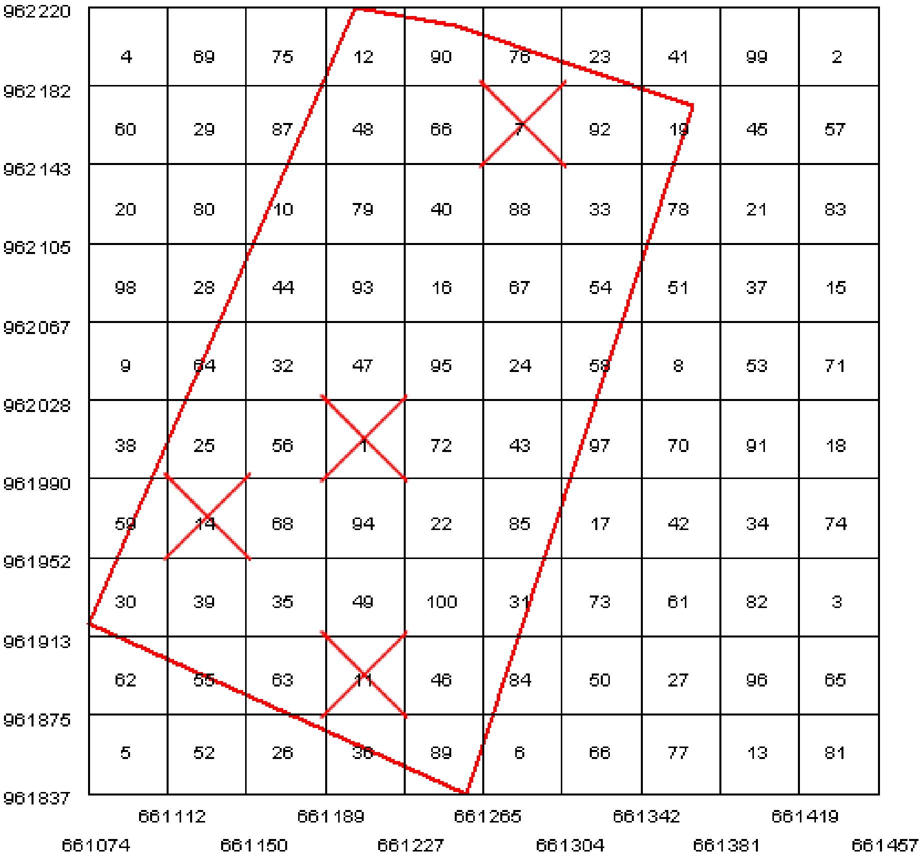


Figure 2. Positioning of the plot (Modena-S.PROSPERO) on the template and detection of the coordinates of the soil profiles (red crosses).

Site "PARMA - EIA"

The site, lying NW of Parma, in polygon 888 of the Soil Map 1:50.000 of the Emilia-Romagna plain denominated [CTL4] (Cataldi 4 consociation), is situated in the upper Parma plain, in alluvial fan zone, on alluvial deposits laid down by the area's main watercourses (Taro, Parma, Baganza). Planted with waxy corn, in rotation with alfa alfa and common wheat, a typical crop system in this area, the site is characterised by the presence of intensive livestock production, which has favoured the development of the Parmigiano-Reggiano cheese making industry (typical production zone). The site lies in an area currently designated as vulnerable by the Nitrate Vulnerable Zones Map, approved by the Emilia-Romagna regional council deliberation n. 570 of 11th February 1997 (figure 3).

Figure 3. Site location: the Roman agrarian irrigation system is clearly visible (grid plan of north-south "*cardi*" and east-west "*decumani*" measuring approx. 700 m per side); on the left bank of the river Taro (orthophoto AGEA-2001).

The soil of the site, belonging to the regional STU Roncole Verdi *silty-clay* (RNV1) (Archive F5008, RER 2006), is common across the entire foothill plain of the region; on the Parma plain, as on that of Reggio it is also found on the alluvial plain, in the near ancient natural levees (pre-Roman), on slightly raised ground, no longer affected by sedimentary deposits accumulated over the course of the last few thousand years. The substrate consists of fine or moderately fine alluvial sediments, rich in carbonates. Gravel is generally present, in the cartographic polygon, from 8 m, locally even at 3 m of depth. The land use is cropland and cropland with trees, in the western part of the region the land use is dominated from a rotation of cropland and alfa alfa and secondly with vineyards.

Soil properties: the soil, which is very deep, is characterised by a fine texture and sometimes by vertic properties.

It has a high rooting depth in horizons with high concentrations of CaCO3. At times the presence of vertic characteristics is partly responsible for restricting rooting depth; soil oxygen availability ranges from good to moderate while permeability is moderately low.

Profile: the plough horizon, dark grey brown, is silty clay loam and moderately alkaline; the subsoil horizon, light olive brown, is silty clay and moderately alkaline. The cationic exchange capacity is high (Annex A).

Soil Typological Unit (*Phase of Soil Series)*:: Roncole Verdi *silty clay loam* - RNV1

Soil classification:
Soil Taxonomy Classification (KEYS 2003): Calcic Udic Haplustepts fine, mixed, superactive, mesic
Only 30% of profiles (15 out of 49) show slickensides within 125 cm. Udertic Haplustepts fine, mixed, superactive, mesic; 50% of soils observed do not present the Bk horizon within 100 cm, 8% present the Bk below the Ap horizon (<70 cm)

WRB Classification, 1998: Bathicalcic Cambisols

Adaptation of the template: PARMA-EIA

The geographic coordinates (UTM 32*) of the cropland plot margins are given in Table 2. The Xmax and Xmin, rounded to integer values, are 599239 and 599125. By computation (Xmax - Xmin) is 113.9 m. Applying the same operation to Y coordinates the difference (Ymax –Ymin) is found to be 228.3 m. The biggest axis value (Maxis) is 228.3 m and defines the size of the template square (Figure 4). Based on the Maxis value, the Gs value would be 228.3/10 = 22.83 m. Consequently, the distance between sampling points (Gs/5) is approx. 4.5 m, and the position of the soil profile (Gs/2) is approx. 11.4 m in the grid.

Table 2. Geographical coordinates (UTM32*) of the plot extent (Parma-EIA).

	X	Y
Minimum	599125	966842
Maximum	599239	967070

The plot area is 1.3 ha and the number of sampling sites should be 3 (Figure 2). Following the procedure described in the method, the 14th, 32nd and 10th grids have been selected:
- 14 : x: 599159.11, y: 966921.66
- 32 : x: 599181.94, y: 966967.32
- 10 : x: 599181.94, y: 967012.99

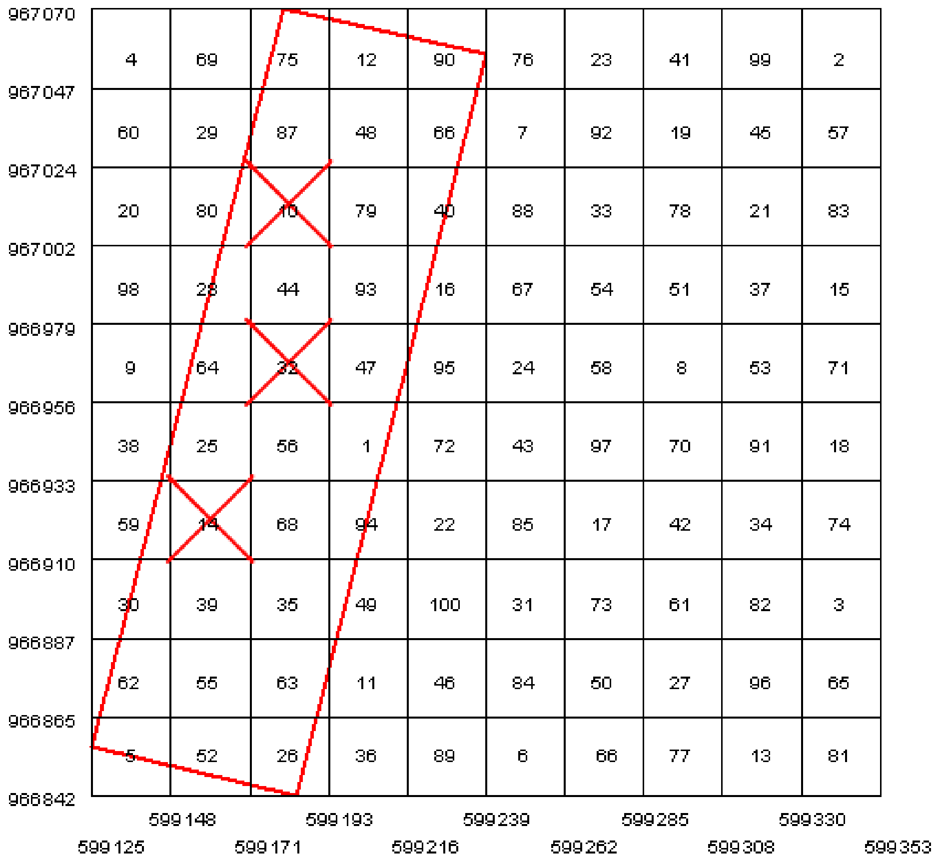


Figure 4. Positioning of the plot (Parma-EIA) on the template and detection of the coordinates of the soil profiles (red crosses).

Results and Discussion

Soil sampling in individual cells, in accordance with the AFRSS method in agricultural fields (Stolbovoy et al, 2005), was conducted with composite soil samples combining 25 sub-samples from a depth of between 10 and 20 cm; with regard to the reference profile, situated in the centre of each cell, the soil was described, characterized and its bulk density recorded using the hand-driven core method (Blake, 1965).
The description of the soil plus analytical findings were used to match it to the Regional Soil Archive of Emilia-Romagna (Archive F5008, RER 2006).

The characterization of the first "Modena - S. Prospero" experimental research site (samples from E9600T0001 to E9600T0004, tab. 3) enabled it to be linked to the La Boaria1 (LBA1) soils of the silty clay *Calcari Hypovertic Cambisols*. The characterization of the second "Parma – Eia" experimental research site (samples from E9600T0005 to E9600T0007) allowed the soil to be linked to the Roncole Verdi1 (RNV1) soils of the silty clay *Bathicalcic Cambisols*.
The organic carbon (CO) content of LBA1 soils ranges from 1.15% to 1.5%. In RNV1 soils it ranges from 1.11% to 1.33%. The CO content within the sample areas studied is fairly uniform and in both soils its variability is around 0.2%.
The bulk density of LBA1 soils was measured at between 1.60 to 1.76 gcm^{-3} and between 1.40 and 1.56 gcm^{-3} in RNV1. The values measured at the first site appear significantly higher than those in the regional database for LBA1 soils (range 1.32-1.57 gcm^{-3}), with an average of 1.46 gcm^{-3}. In the "Parma-EIA" experimental research site, bulk density values appear to be in line with those in the regional database for RNV1 soils.

Table 3. Characteristics of samples and soil carbon calculations in accordance with the AFRSS method (Stolbovoy et al, 2005).

Profile	Depth min	Depth max	OM	C	Bulk density	Soil carbon density	Soil carbon stock (per ha)	Soil carbon stock (plot)	Average soil carbon stock (per ha)	Average soil carbon stock (plot)	Standard deviation soil carbon stock (plot)	Difference in average carbon stocks between samplings	Plot area
	cm	cm	%	%	gcm^{-3}	kgcm^{-3}	tC/ha	tC	tC/ha	tC	tC	%	ha
Cropland, LBA1 soil (La Boaria1, *Calcari Hypovertic Cambisols*), first sampling													
E9600T0001	10	20	2.12	1.24	1.66	2.06	61.74	392.61	62.51	397.49	16.87		6.36
E9600T0002	10	20	2.11	1.23	1.76	2.17	65.15	414.29					
E9600T0003	10	20	2.28	1.33	1.60	2.13	64.00	406.98					
E9600T0004	10	20	1.96	1.15	1.72	1.97	59.14	376.10					
Cropland, LBA1 soil (La Boaria1, *Calcari Hypovertic Cambisols*), second sampling												1.88	
CS_E9600T0001	10	20	2.15	1.26	1.66	2.09	62.61	398.16	63.71	405.12	17.27		6.36
CS_E9600T0002	10	20	2.17	1.27	1.76	2.23	67.00	426.08					
CS_E9600T0003	10	20	2.30	1.35	1.60	2.15	64.56	410.55					
CS_E9600T0004	10	20	2.01	1.18	1.72	2.02	60.65	385.69					
Cropland, RNV1 soil (Roncole Verdi1, *Bathicalcic Cambisols*), first sampling													
E9600T0005	10	20	1.89	1.11	1.40	1.55	46.42	62.03	52.28	69.86	7.83		1.34
E9600T0006	10	20	1.91	1.12	1.56	1.74	52.27	69.86					
E9600T0007	10	20	2.27	1.33	1.46	1.94	58.14	77.70					
Cropland, RNV1 soil (Roncole Verdi1, *Bathicalcic Cambisols*), second sampling												2.63	
CS_E9600T0005	10	20	1.89	1.11	1.40	1.55	46.42	62.03	53.69	71.75	8.51		1.34
CS_E9600T0006	10	20	2.13	1.25	1.56	1.94	58.29	77.90					
CS_E9600T0007	10	20	2.20	1.29	1.46	1.88	56.35	75.30					

Table 4. Average, standard deviation and coefficient of variation of organic carbon in fields studied. Data given in *italics* relates to all samples collected in each field, namely ordinary sampling and resampling with simulation of positioning error.

Site	Number of Sites	Average C %	Standard Deviation	Coefficient of Variation %	*t* Test
T1-T4	4	1.24	0.08	6.2	52.11
SS T1-T4	4	1.26	0.07	5.5	
T1-T4 & SS T1-T4	*8*	1.25	0.07	*5.5*	-
T5-T7	3	1.18	0.13	10.6	29.41
SS T5-T7	3	1.21	0.10	7.8	
T5-T7 & SS T5-T7	*6*	1.20	0.10	*8.4*	-

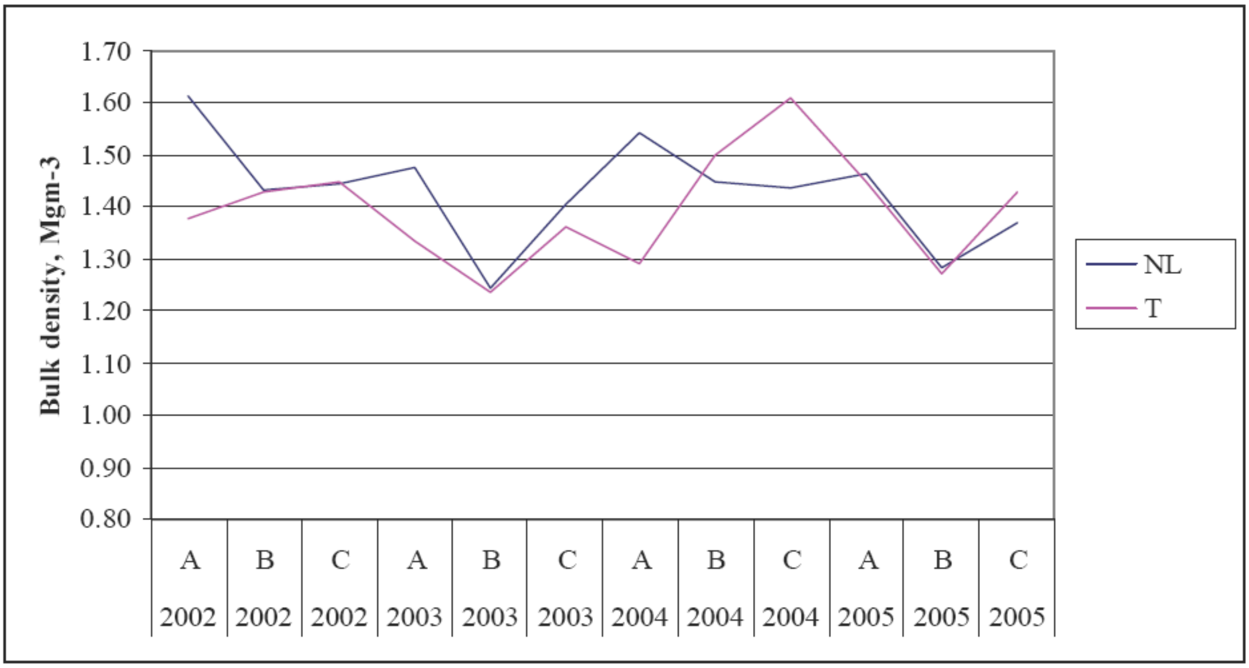
Soil Carbon Density (SCD) values range from 1.93 to 2.23 $kgcm^{-3}$ in the "Modena - S. Prospero" site and from 1.55 to 1.94 $kgcm^{-3}$ in the "Parma – Eia" site. These values in the first site correspond to 62.51 and 63.71 tonnes of Carbon per hectare in the first and second samplings respectively, conducted by moving 1 metre from the sampling grid (simulation of positioning error), namely to 397.49 and 405.12 tC for the entire area. In the second site they correspond to 52.28 and 53.69 tC/ha in the first and second samplings respectively (simulation of positioning error), namely to 69.86 and 71,75 tC for the entire plot.

One of the critical points in the application of the AFRSS procedure, as underlined by Stolbovoy et al, (2006) concerns the heterogeneity of soils within fields where OCS validation is conducted. For this reason, during this experimentation it was decided to note the soil characteristics for each individual sampling point, verifying their attribution to the Regional Soil Typological Archive, with the dual purpose of verifying the pedological characteristics and checking against the existing data in the Emilia-Romagna soils database.

The homogeneity of the pedological characteristics found in the two plots studied is also borne out by the carbon distribution. In the "Modena - S. Prospero" site the coefficient of variation between the various samples is in the region of 5-6% (6.2% for the first sample and 5.5% for the simulation of positioning error); in the "Parma – Eia" site the coefficient of variation between the various samples is in the region of 8% (10.6% for the first sample and 7.8% for the simulation of positioning error). Within a given plot, a carbon variation of less than 10% provides positive indication of good pedological homogeneity and, historically speaking, a uniform land use (tab.4).

Unlike sampling expressly intended for the measurement of organic carbon, which is relatively straightforward in terms of execution, establishing bulk density is more problematic. The use of the hand-driven core method (Blake, 1965), certainly the most widely used, requires that samples taken have a soil water content approaching the field capacity, a situation which occurs just a few times a year, and which, above all, cannot be forecast far enough in advance to plan a data collection survey. Moreover, in all soils and especially in tilled soils, the time of year that samples are collected and the time that elapses between sample collection and soil tillage has a huge effect on bulk density. One ongoing study initiated several years ago in an area near the "Parma – Eia" site on soils similar to those studied here (C.R.P.A. -"Restoration and maintenance of soil organic matter through the use of compost), reports an extremely high variability in bulk density measured both at different times of year and over the course of the years (fig.5).

Fig 3: Bulk density trend over the four-year period 2002-2005 in an experimental research site near the “Parma – Eia” site. NL= Not tilled, T= Tilled sample; A= April, B= July, C= October. Density values in the graph are the result of an average of 6 repetitions for each sampling (F. Ungaro - CNR-IRPI internal report 2005)



By way of example, we can calculate the amount in tonnes of soil carbon stock in the “Parma – Eia” site by using the essential data from the above experiment, namely 1.24 and 1.61 gcm^{-3} (Table 5); we can note how for the same soil carbon stock present, when the bulk density value utilized changes, the amount varies significantly (23%). Such a high level of uncertainty in measurement risks thwarting a meticulous procedure like the AFRSS method.

Table 5. Calculation of the carbon stock in the “Parma – Eia” site using the essential values of bulk density

Profile,	Depth min	Depth max	OM	C	Bulk density	Soil carbon density	Soil carbon stock (per ha)	Soil carbon stock (plot)	Average soil carbon stock (per ha)	Average soil carbon stock (plot)	Standard deviation soil carbon stock (plot)	Difference in average carbon stocks between BD	Plot area
	cm	cm	%	%	gcm^{-3}	kgCm^{-3}	tC	tC	tC	tC	tC	%	ha
E9600T0005 min_BD	10	20	1,89	1,11	1,24	0,14	41,12	54,94	44,02	58,82	6,22	22,98	1,34
E9600T0006 min_BD	10	20	1,91	1,12	1,24	0,14	41,55	55,53					
E9600T0007 min_BD	10	20	2,27	1,33	1,24	0,16	49,38	65,99					
E9600T0005 MAX_BD	10	20	1,89	1,11	1,61	0,18	53,38	71,34	57,15	76,37	8,07		
E9600T0006 MAX_BD	10	20	1,91	1,12	1,61	0,18	53,95	72,09					
E9600T0007 MAX_BD	10	20	2,27	1,33	1,61	0,21	64,12	85,68					

The method involves monitoring changes of carbon stock between time t_0 and time t_1, and then calculating the equivalent change in levels of carbon dioxide. Oddly though it may seem, a change in the region of 20-25% between time t_0 and time t_1 could actually lead to a negative total, despite having shifted agricultural practices towards an increase in soil carbon stock.
A pragmatic if not drastic solution to this problem could be to use the same BD value both times. Given that the difference refers to two samples conducted in the same soil and at the same point, and that the changes in soil carbon stock over several years or a few decades, even with drastic changes in farming practices, could never be of such a magnitude as to bring about a change as major as the above mentioned positioning error.
To monitor changes, it is suffice to use the difference in % of organic carbon (irrespective of bulk density) and then calculate the change in soil carbon stock with a single measurement of the bulk density value.

Using locally validated pedotransfer functions to calculate bulk density can solve the problem of incorrect determination of the changes of organic carbon stock.

ORGANIC CARBON SEQUESTRATION CAPACITY IN “LA BOARIA 1” AND “RONCOLE VERDI 1” SOILS

Soil carbon sequestration capacity, as we know, depends not only on land use, but on its intrinsic characteristics and on various environmental factors which influence soil formation. Soil mapping of the Emilia Romagna plain, surveyed at scale 1:50.000, allows us to differentiate soils, identifying STU at level of *Phase of Serie* (Soil Taxonomy, 1975).
The opportunity to avail of a useful number of observations for a given soil, in an area with largely analogous environmental characteristics, allows us to estimate, albeit inexactly, the minimum and maximum carbon stock values achievable in that given STU in relation also to land use.
Observations in the regional soil database attributed to the two STU sampled, which proved valuable for studying the change in organic carbon stock, total 118 for La Boaria 1 soils and 50 for Roncole Verdi 1 soils.
Across the region, in LBA1 soils carbon stock values range from levels scarcely above 0.6% to over 2%. The average value is approximately 1.2%, with a standard deviation below 0.3. Distribution in the various geographical areas reveals significantly different trends even from a statistical point of view (Fig. 6, and Tab. 6). What becomes immediately apparent is a progressive decrease in average soil carbon stock as one moves from West to East, a trend which goes hand in hand with a progressive fall in the standard deviation.
As regards variations associated with different land uses, there are significant differences between the three types considered (Cropland, Tree crops and Pasture/Uncultivated) (Tab. 7). The values found to be on average lowest are those associated with tree crops (fruit orchards, vineyards, ...), cropland reveals slightly higher values; soils utilized as Pasture/Uncultivated land have decidedly higher values, although the statistic sample on which data is based is relatively small.
It is interesting to note that when an agricultural arable land, after being converted to permanent grassland, after 20 years of non-cultivation (Fig. 6), soil carbon stock is significantly above average, though without reaching extreme levels; indeed, values are comparable to some La Boaria 1 soils utilized as cropland.

In RNV1 soils, carbon stock varies from amounts in the region of 0.7% up to over 2%. The average is approximately 1.4% with a standard deviation of 0.4. From study of the analysis of the variance of territorial distribution of RNV1 soils, it emerges that only one group remains distinct from the others: that situated in the provinces of Parma, Reggio Emilia and Modena (Fig. 7, and Tab. 6). These soils are generally richer in Organic Carbon compared to homologous soils in the rest of the region and this is believed to be attributable to the widespread presence in these provinces of rotational crops and/or permanent grazing. The limited spread of these soils westwards, however, makes it difficult to conduct a reliable statistic analysis of their variability on a regional scale. Similarly, because of the non uniformity of the sample, analysis of variance conducted for these soils in relation to their use reveals no significant differences (Tab.7).
For RNV1 soils, analogously to LBA1 soils, the number of samples analyzed makes it possible to trace a distribution curve of soil carbon stock levels (red line in figure 7). Also in this case, the curve can be interpreted as a fairly reliable representation of the potential of RNV1 soils to accumulate, or spend, organic carbon depending on land use and the agricultural and land management practices pursued.

Fig. 6: Organic carbon trend (%) in La Boaria1 STU. Data is given both for geographic areas (blue curve) and for the entire region (red curve), average value and standard deviation are also indicated (dotted lines and coloured box). Corresponding land use for each sample is also indicated.

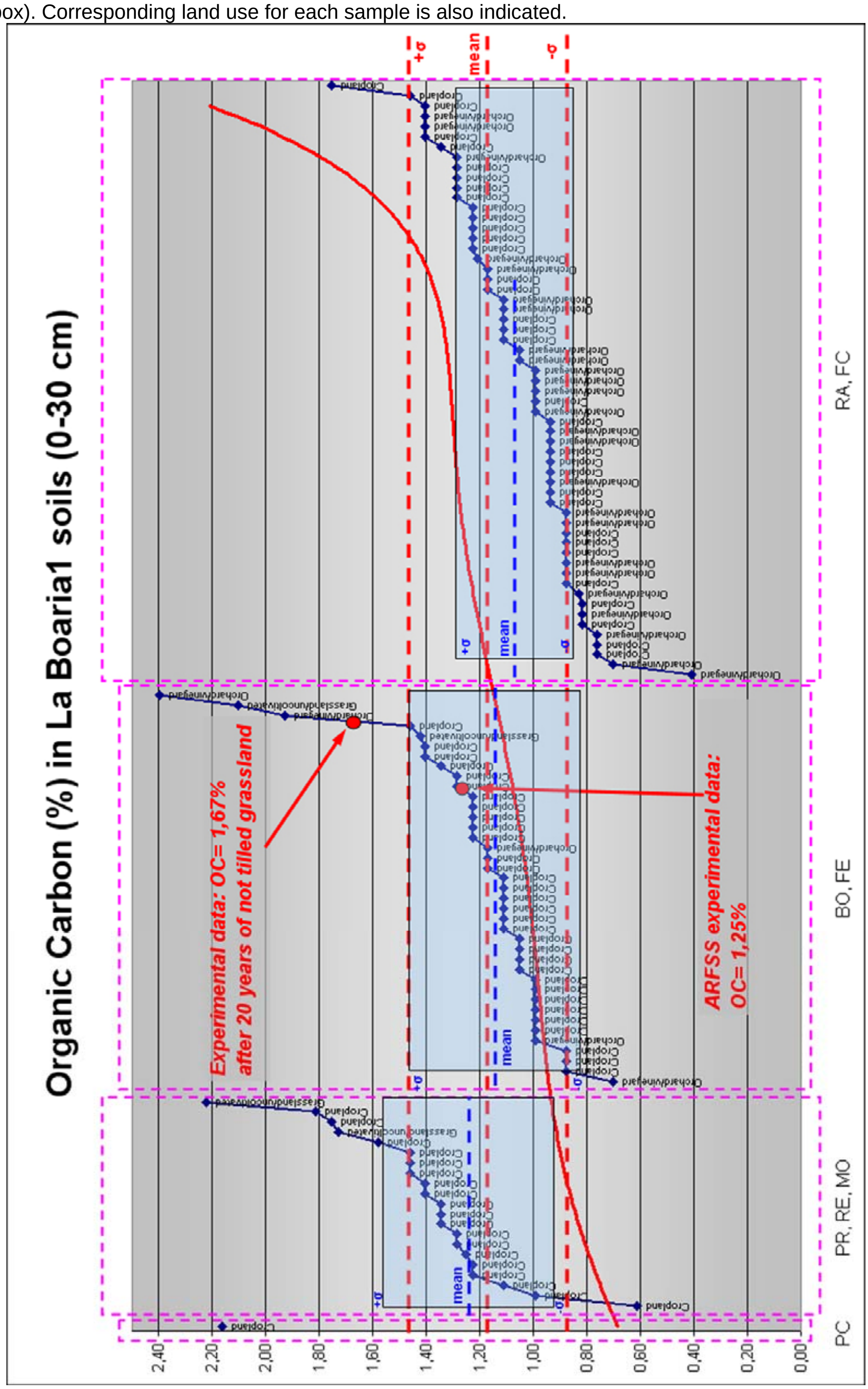


Fig. 7: Organic carbon trend (%) in Roncole Verdi STU. Data is given both for geographic areas (blue curve) and for the entire region (red curve), average value and standard deviation are also indicated (dotted lines and coloured box). Corresponding land use for each sample is also indicated.

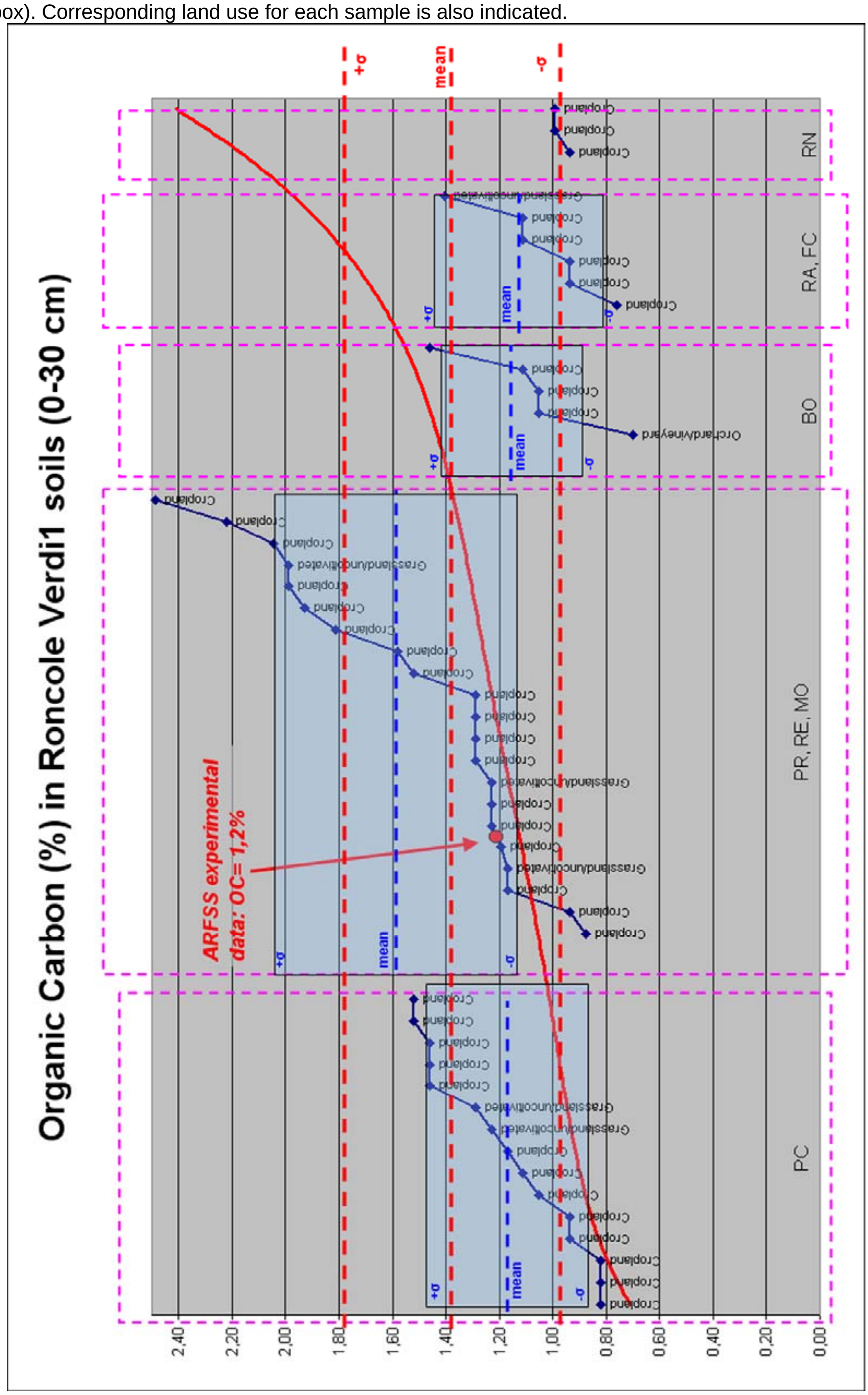


Table 6: Analysis of variance (ANOVA) for organic carbon stock in La Boaria and Roncole Verdi STU in relation to the geographic areas where they are commonly found (grouping of provinces conducted based on agronomic considerations).

RNV1

ANOVA Table for C org

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Zona	4	2,142	,536	4,374	,0045
Residual	45	5,509	,122		

Model II estimate of between component variance: ,047
2 cases were omitted due to missing values.

Means Table for C org
Effect: Zona

	Count	Mean	Std. Dev.	Std. Err.
1-PC	15	1,174	,268	,069
2-PR-RE-MO	21	1,513	,446	,097
3-BO-FE	5	1,074	,270	,121
4-RA-FC	6	1,043	,218	,089
5-RN	3	,973	,029	,017

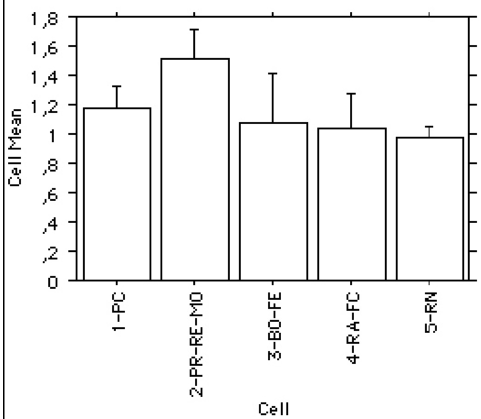
2 cases were omitted due to missing values.

Fisher's PLSD for C org
Effect: Zona
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
1-PC, 2-PR-RE-MO	-,339	,238	,0063	S
1-PC, 3-BO-FE	,100	,364	,5827	
1-PC, 4-RA-FC	,131	,340	,4435	
1-PC, 5-RN	,201	,446	,3694	
2-PR-RE-MO, 3-BO-FE	,439	,351	,0152	S
2-PR-RE-MO, 4-RA-FC	,470	,326	,0057	S
2-PR-RE-MO, 5-RN	,540	,435	,0161	S
3-BO-FE, 4-RA-FC	,031	,427	,8856	
3-BO-FE, 5-RN	,101	,515	,6955	
4-RA-FC, 5-RN	,070	,498	,7785	

2 cases were omitted due to missing values.

Interaction Bar Plot for C org
Effect: Zona
Error Bars: 95% Confidence Interval



2 cases were omitted due to missing values.

LBA1

ANOVA Table for C org

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Zona	3	2,677	,892	13,792	<,0001
Residual	114	7,374	,065		

Model II estimate of between component variance: ,034
2 cases were omitted due to missing values.

Means Table for C org
Effect: Zona

	Count	Mean	Std. Dev.	Std. Err.
1-PC	1	2,160	•	•
2-PR-RE-MO	21	1,396	,324	,071
3-BO-FE	38	1,169	,264	,043
4-RA-FC	58	1,066	,218	,029

2 cases were omitted due to missing values.

Fisher's PLSD for C org
Effect: Zona
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
1-PC, 2-PR-RE-MO	,764	,516	,0040	S
1-PC, 3-BO-FE	,991	,510	,0002	S
1-PC, 4-RA-FC	1,094	,508	<,0001	S
2-PR-RE-MO, 3-BO-FE	,227	,137	,0014	S
2-PR-RE-MO, 4-RA-FC	,330	,128	<,0001	S
3-BO-FE, 4-RA-FC	,103	,105	,0546	

2 cases were omitted due to missing values.

Interaction Bar Plot for C org
Effect: Zona
Error Bars: 95% Confidence Interval

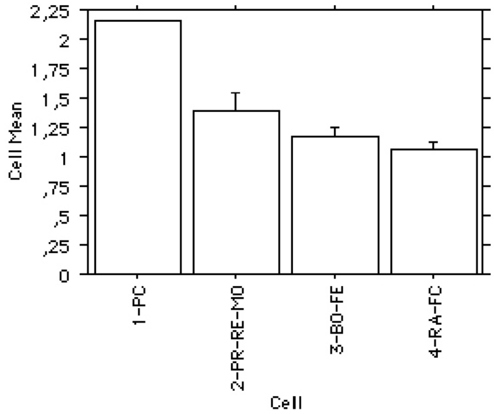


Table 7: Analysis of variance (ANOVA) for organic carbon stock in La Boaria 1 and Roncole Verdi 1 STU in relation to land use.

RNV1

ANOVA Table for C org

	DF	Sum of Squares	Mean Square	F-Val...	P-Val...
Uso Semplificato	2	,403	,202	1,286	,2861
Residual	46	7,215	,157		

Model II estimate of between component variance: ,007
3 cases were omitted due to missing values.

Means Table for C org
Effect: Uso Semplificato

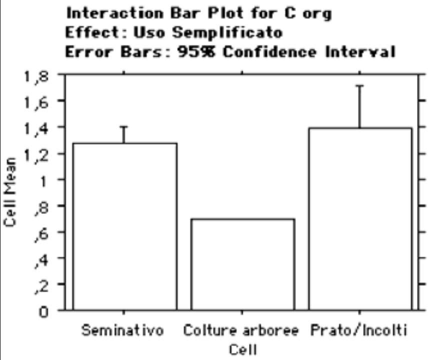
	Count	Mean	Std. Dev.	Std. Err.
Seminativo	42	1,273	,406	,063
Colture arboree	1	,700	•	•
Prato/Incolti	6	1,385	,306	,125

3 cases were omitted due to missing values.

Fisher's PLSD for C org
Effect: Uso Semplificato
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value
Seminativo, Colture arboree	,573	,807	,1594
Seminativo, Prato/Incolti	-,112	,348	,5206
Colture arboree, Prato/Inc...	-,685	,861	,1161

3 cases were omitted due to missing values.



3 cases were omitted due to missing values.

LBA1

ANOVA Table for C org

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Uso Semplificato	2	2,472	1,236	18,757	<,0001
Residual	115	7,579	,066		

Model II estimate of between component variance: ,048
2 cases were omitted due to missing values.

Means Table for C org
Effect: Uso Semplificato

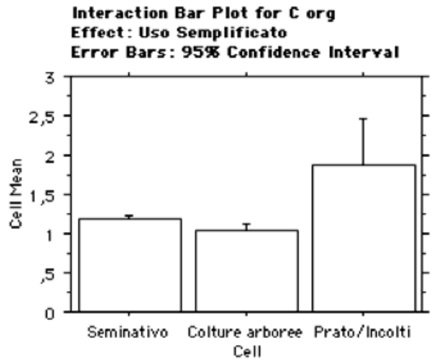
	Count	Mean	Std. Dev.	Std. Err.
Seminativo	86	1,178	,253	,027
Colture arboree	28	1,035	,253	,048
Prato/Incolti	4	1,870	,366	,183

2 cases were omitted due to missing values.

Fisher's PLSD for C org
Effect: Uso Semplificato
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
Seminativo, Colture arboree	,143	,111	,0120	S
Seminativo, Prato/Incolti	-,692	,260	<,0001	S
Colture arboree, Prato/Inc...	-,835	,272	<,0001	S

2 cases were omitted due to missing values.



2 cases were omitted due to missing values.

FINAL CONSIDERATIONS

We can gain a good indication of the temporal dynamics of organic carbon in the soils studied by utilizing the data from the “Modena - S. Prospero” experimental research site and from the experimental farm Molza of the CRA – Agronomical Research Institute. Data on carbon from the Molza farm was collected just a few dozen metres from the plot studied using the AFRSS procedure and the soil STU is the same.
The research experiment being conducted by Molza involves monitoring of the carbon content in a plot which has lain uncultivated for 20 years, where the only activity carried out has been mowing of the grass. In the period prior to the experiment, the plot had been used for crop rotation. The CO measured after twenty years was 1.67%. By comparing this with the 1.25% value of the “Modena - S. Prospero” site, we can estimate, albeit approximately, the potential annual organic carbon accumulation of La Boaria 1 soils in the Emilia plain.
Under current conditions, an average carbon content of 61.74 t(C)ha^{-1} is estimated, if after twenty years of being left as pasture land this soil reached the values recorded on the Molza land, still using the same bulk density value, it would reach 83.17 t(C)ha^{-1}, in other words an increase of 21.43 t(C)ha^{-1} (136.25 t(C) for the entire AFRSS plot) which equates to an annual accumulation rate of 1.07 tonnes of carbon per hectare (6.81 t(C) for the entire plot).

According the Kyoto Protocol, carbon trapped and removed from the environment has a price tag. This price, expressed in Europe in € per tonne of CO_2, has a fluctuating value subject to the trends of a number of “emissions markets” (*International Emissions Trading Association*).

This enables us to evaluate the possibility of economically sustainable carbon capture in the AFRSS site. If we compute the data on soil-stored carbon into carbon dioxide, we see that 21.43 $t(C)ha^{-1}$ corresponds to 78.50 $t(CO_2)ha^{-1}$ and for the entire plot 136.25 t(C) corresponds to 499.21 $t(CO_2)$.

Table 8: Trend of price of CO_2 in Europe and yield per hectare in the simulation at the “Modena - S. Prospero” site.

Date	Price CO_2	Variation in price of CO_2 compared to Jan. 06	Annual yield per hectare for CO_2 quotas	Yield over 20 years per hectare for CO_2 quotas	Annual accumulation rate of CO_2 per hectare
	$€t^{-1}$	€	€	€	tha^{-1}
January 06	23	-	90	1749	78
April 06	30	+30,43	117	2340	78
May 06	10	-56,52	39	780	78
July 06	16	-30,43	62	1248	78
December 06	7	-69,57	27	546	78
January 07	4	-82,61	16	312	78

Table 8 simulates the trend in the economic yield over the last year based on variations in the price per tonne of CO_2.

At the start of January 2007, the price was approximately 4€ per tonne, a price which almost halved in the space of a month and fell by over 80% over the course of the year. At current prices, the approximately 78 tonnes of CO_2 per hectare accumulated in the study plot would yield approximately 312 €/ha over twenty years, in other words 16 € per hectare per annum. At current prices, therefore, the economic sustainability of such a project would be practically non-existent and even supposing accumulation rates were double, the problem of sustainability remains unchanged.

Despite this, soil carbon storage is of huge environmental benefit and, when planned in tandem with other environmental and agricultural improvement measures suitably supported by economic policies that truly recognize its value, it can be a good means of mitigating increasing concentrations of greenhouse gases in the atmosphere.

As regards the *ArcView-GIS extension* (http://arcscripts.esri.com/details.asp?dbid=14781) for calculating the template, several points merit consideration:

1) The tool has a calculation threshold which is equivalent to working surfaces of 5000 m² or greater. During drafting of the last JRC publication, this limit was removed, consequently the Extension update must be implemented, downloadable from the ESRI *download* area.

2) When calculating the size of the cells of the GRID and also at the next selection step, several problems may arise in the case of plots which are particularly elongated in shape (as many plots often are in Emilia-Romagna, among other regions). Typically in this situation, none or only a few cells happen to fall completely within the boundaries of the plot. In this case, there are two possible solutions:

- **a)** the method of calculation can be adapted, naturally in agreement with the authors of the model;
- **b)** the plot can be divided into sub-areas which are more regular in shape and therefore compatible with the software. Care must be taken in verifying the representativeness of the sub-area with regards to certification of the entire plot.

In the case of a) one possibility is to attempt to translate the GRID origin, verifying, for each movement, if and how many cells fall completely within the plot. This would prolong calculation time immensely and may not lead to an entirely satisfactory result, insomuch as there is no guarantee that it will be possible to identify the minimum number of cells based on the surface area of the plot. Another possibility is to select of those cells which, despite not falling entirely within the boundaries of the plot, intersect it, in other words, to adopt the same method applied during rasterization of a vectorial object. This last solution has proven the most interesting and unquestionably the most satisfactory in terms of results, moreover it is relatively straightforward to implement within the current *Extension.*

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Annex A

Description of soils and laboratory data

Site "MODENA – SAN PROSPERO"

Reference profile (outside delineation)

Pedon ID code: **A1403V0117**
Surveyors: Marina Guermandi, Domenico Preti, 22nd August 1988;
Land use: arable;
Soil Taxonomy Classification '92: Vertic Ustochrepts fine, mixed, mesic.

The soil was described in conditions of little surface moisture, up to 70 cm in depth, moist beyond that.

Ap1 0-60 cm; silty clay, dark greyish brown (2.5Y 4/2); moderate medium subangular blocky structure; violent HCI effervescence; moderately alkaline; clear abrupt boundary.

Ap2 60-70 cm; as above, but structure parting to strong coarse angular blocky structure.

Bg 70-110 cm; silty clay, olive grey in the matrix (5Y 4/2), dark grey on the faces of peds (5Y 4/1) with very little olive brown (2.5Y 4/4) mottling; moderate coarse angular blocky structure (barely visible platy, parallel to topographic surface); violent HCI effervescence; moderate alkaline; clear abrupt boundary.

Cg1 110-150 cm; silty clay, grey matrix (5Y 5/1), olive grey (5Y 4/2) faces and abundant dark yellowish brown (10YR 4/6) mottling; strong very coarse angular blocky structure; few slikensides; violent HCI effervescence; moderately alkaline; clear abrupt boundary.

Cg2 150-170 cm; silty clay, grey (5Y 5/1)with abundant yellowish brown (10YR 5/6) mottling; strong coarse angular blocky structure; violent HCI effervescence; moderately alkaline.

N° horiz.	Upper horiz.	Lower horiz.	Total sand	Very fine sand	Total silt	Clay	Textural class	ph (H_2O)	Total lime	Active lime	Organic matter	EC (1:5)
	cm	cm	%	%	%	%			%	%	%	mSm^{-1}
1	0	60	6,00	4,00	50,00	44,00	AL	8,3	16	12	2,50	0,320
3	70	110	4,00	3,00	50,00	46,00	AL	8,3	19	13	1,00	0,180
4	110	150	3,00	2,00	44,00	53,00	AL	8,3	15	12	1,00	0,220
5	150	170	3,00	2,00	53,00	44,00	AL	8,3	20	13	0,90	0,200
6	170	210	5,00	4,00	76,00	19,00	FL	8,3	20	10	0,80	

Profile D1403V0117

site “PARMA - EIA”

Reference profile (outside delineation)

Pedon ID code: **D1301V0028**

Surveyors and description date: Silvia Pelle - Vanna Maria Sale, 28th September 1988

Soil Taxonomy Classification: Fluventic Ustochrepts fine, mixed, mesic

Classification FAO: Haplic Calcisols

Colours refer to moist soil, unless otherwise stated.

Ap 0-60 cm; silty clay loam, olive brown (2.5Y 4/3); moderate coarse subangular blocky structure; few soft, very small concretions of calcium carbonate; slight effervescence; moderately alkaline; abrupt wavy boundary.

Bw 60-95 cm; silty clay, dark greyish brown (2.5Y 4/2); moderate coarse subangular blocky structure; few concretions of calcium carbonate; slight effervescence; moderately alkaline; gradual wavy boundary.

Bk 95-130 cm; silty clay loam, greyish brow (2,5Y 5/2); strong medium angular blocky primary structure, moderate coarse prismatic secondary structure; many concretions and masses of calcium carbonate; strong effervescence; moderately alkaline; gradual wavy boundary.

Ab 130-160 cm; silty clay loam, dark brown (10YR 3/3) in the matrix and very dark brown (2.5Y 3/2) on faces of peds; strong medium angular primary structure, moderate coarse prismatic secondary structure; few masses of calcium carbonate; slight effervescence; moderately alkaline; gradual wavy boundary.

Bgb 160-200 cm; silty clay, light olive brown (2.5Y 5/4) with primary grey mottling (2.5Y 5/1) and secondary brownish yellow mottling (10YR 6/7); strong medium prismatic structure; few concretions of calcium carbonate, strong medium angular blocky primary structure and moderate coarse prismatic secondary structure; strong effervescence; moderately alkaline; lower boundary not seen.

N° horiz.	Upper boundary	Lower boundary	Total sand	Very fine sand	Silt 50-20μ	Silt 20-2μ	Clay	ph (H_2O)	Total lime	Active lime	Organic matter
	cm	cm	%	%	%	%	%		%	%	%
1	0	60	5	8	11	39	37	8.0	2	1	2.3
2	60	95	5	5	7	40	43	8.1	4	2	1.3
3	95	130	4	7	8	46	35	8.3	19	9	1.0
4	130	160	9	11	13	30	37	8.3	4	2	0.8
5	160	200	8	17	17	30	28	8.4	23	6	0.6

Profile D1301V0028

Landscape

Landscape of upper Emilia plain, near the via Emilia (S.S. n.9)

Annex B

AFRSS_Template.avx
Build a template with Area-Frame Randomised Soil Sampling (AFRSS) method

http://arcscripts.esri.com/details.asp?dbid=14781

About

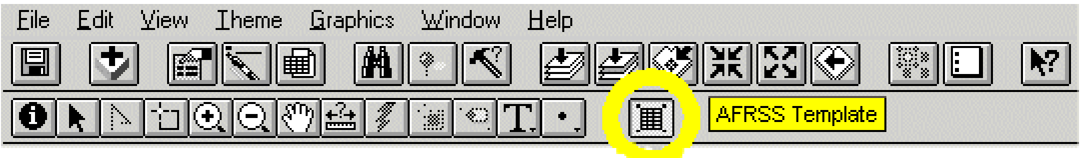
The AFRSS_Template extension was developed to automate the process of building a template over agricultural and forestry plots according to a new method of soil sampling named "Area-Frame Randomised Soil Sampling" (AFRSS) (Stolbovoy et al. 2005) . The Kyoto Protocol (UNFCCC, 1998) considers soils as an essential component to mitigate the increasing concentrations of greenhouse gases in the atmosphere. The objective of the AFRSS is to design a protocol for soil sampling at the Land Use, Land-Use Change, and Forestry (LULUCF) (IPCC, 2000) plot, which is selected field, pasture or forest plot. The results of the analysis should allow national agents to certify changes in organic carbon stock in soils that can be attributed to LULUCF activities.

Installation

If the ArcView GIS software was installed using the standard defaults, the extension should be placed in your "**C:\ESRI\AV_GIS30\ARCVIEW\EXT32**" directory. If the user organization has explicitly set a new pathname for the $USEREXT system variable, the avx file should be placed in the corresponding directory.

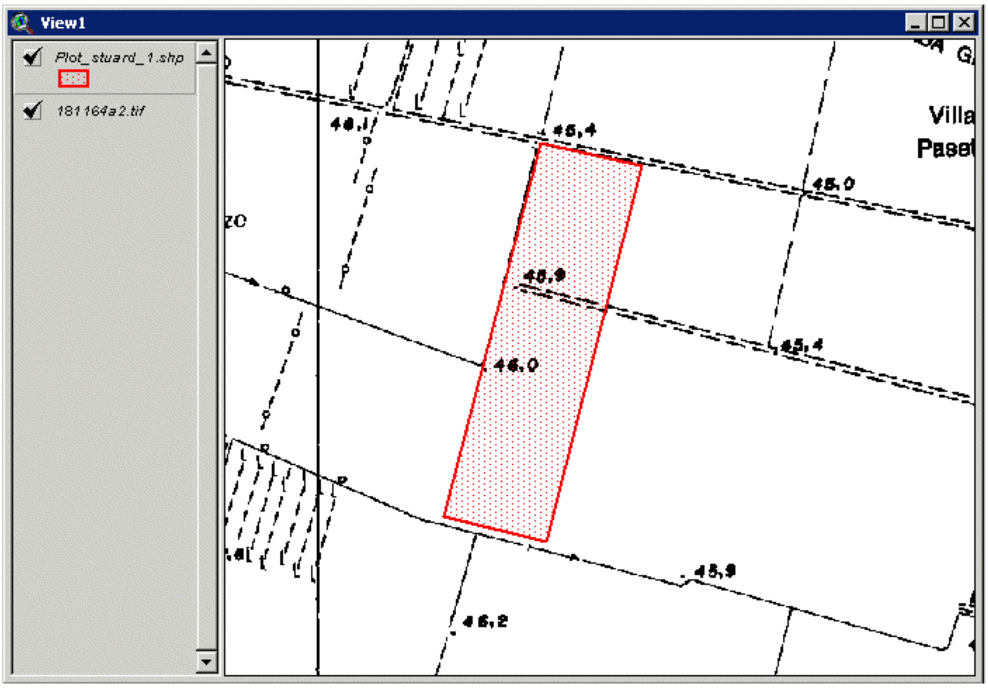
Getting Started

To use the extension, you must first load it into current ArcView project. This is done from the "Extensions" dialog box accessed through the "File" pulldown menu. Look for **AFRSS_Template** in the list of "Available Extensions" and place a check in the box next to the title. This will load the **AFRSS_Template** Extension into ArcView. When you open a view you will see the AFRSS_Template tool.



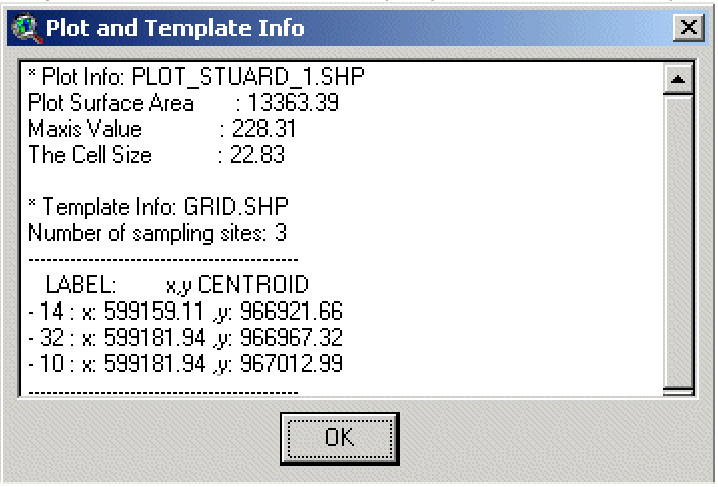
AFRSS_Template tool

Lets you select a polygon feature from the active theme in the view. Before you use this tool, make the theme from which you wish to select features active, by clicking on its name in the view's Table of Contents. If this tool remains dimmed out after you make a theme active, that theme does not contain polygon features. You select features by clicking on them individually. Features that you select are highlighted on the view. After that, if the shape area is greater than or equal to 5000 square meters, you will be prompted to provide a name and location for the new Template shapefile.



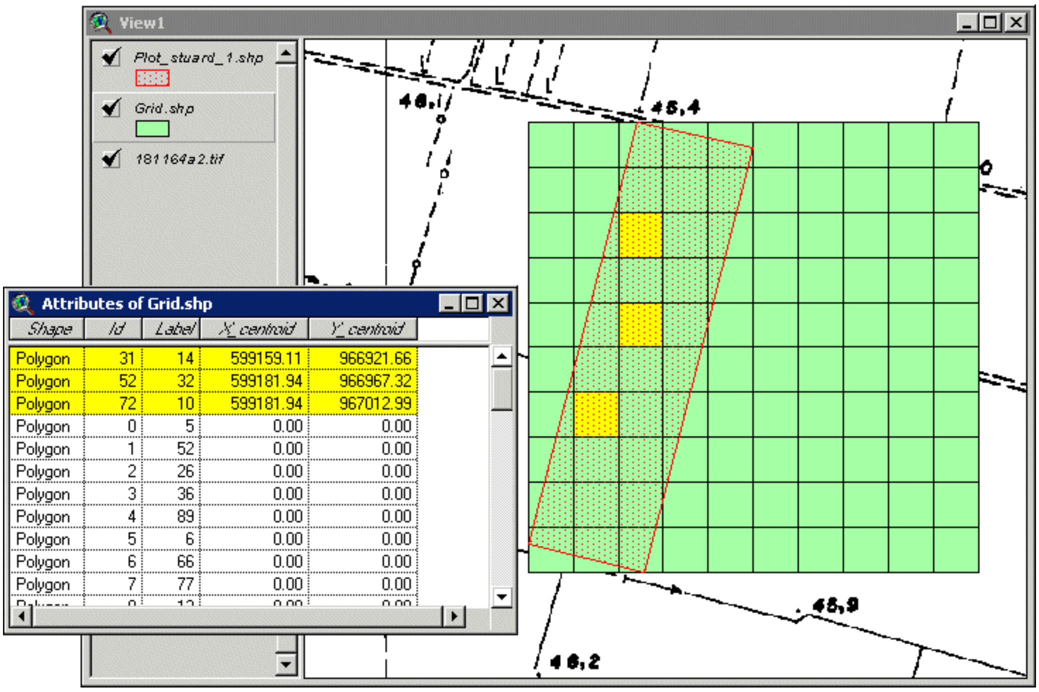
The tool will then generate a Template based on polygon geometric shape. When the building process is completed the shapefile will be added to your view as a new theme and a message box about the selected polygon and Template will be displayed.

Plot and Template Info
As show in the image, the info box supplies some information on the main parameters used to build the template and the number of sampling sites conditioned by the plot area.

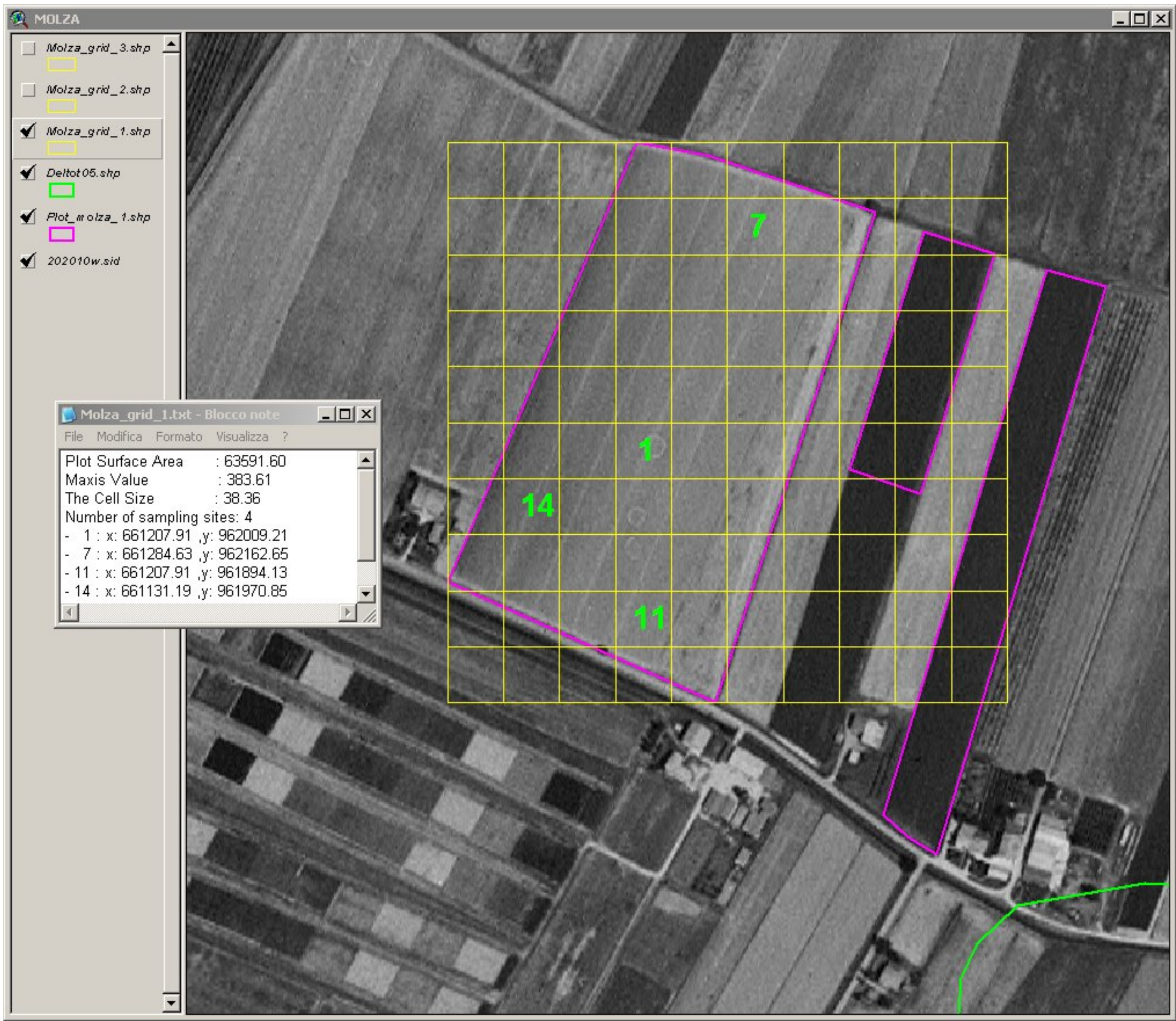


This information is copied to the system clipboard. Open a text editor like Notepad, paste the contents of the clipboard, and save or print them from the text editor.

Template
The sampling sites are selected and identified on the Attributes Table of the Template with the LABEL field. For each selected record the Extension returns the centroid calculation, fields X_CENTROID and Y_CENTROID, to the selected set of records.



Support
We welcome any suggestions on how to improve the tool and make it work even better for you. Currently, technical support for AFRSS_Template.avx is available via email to rbertozzi@regione.emilia-romagna.it



Site “MODENA – SAN PROSPERO”

Site “PARMA - EIA”