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Indicators of change in the organic matter in arid soils

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Abstract

Soil organic matter is a key component in ecosystems, as it is the essential part of a set of relevant processes and constitutes an important carbon pool contributing to Global Change. The design of environmental monitoring programmes should include indicators of the current status of ecosystems, alerting to incipient changes in them. In this context, a sampling scheme has been designed taking into account the main processes and soil uses affecting the dynamics of soil organic matter. Well-tested parameters were determined in order to assess which of them are most useful as indicators of soil organic matter evolution in arid soil, such as that in the “Cabo de Gata-Níjar” Natural Park (SE Spain).

The parameters characterising the lability of the different fractions indicate changes in soil organic matter triggered by changes in soil use and soil dynamics. Changes in soil use, when drastic, are best reflected by those fractions comprising a high percentage of the total soil carbon, while the processes having slower dynamics are best demonstrated by the labile fractions. As a result of the sensitivity analysis of parameters *versus* changes, and taking into account the operational difficulties for determining them, the following indicators are proposed for a monitoring programme: total organic carbon, active fraction of the organic carbon and ratios of this fraction *versus* total organic carbon (%) (as given by the lability index proposed).

Keywords: Degradation; Global Change; Vegetation; Land use; Monitoring programmes

1. Introduction

The carbon cycle is in the centre of the processes (physical, chemical and biological) that are particularly relevant for ecosystem functioning, and in the context of global climate change it takes on great importance as it is one of the main reservoirs that may help to regulate the greenhouse effect. The changes in the use of soils or the state of vegetation may alter the processes for the accumulation or loss of organic matter in soils in a short period of time, thereby affecting the total amount of carbon stored. The need to detect these changes is a challenge at present and should be essential in the design of environmental monitoring programmes.

Many articles have been published on the search for tools to attain this target and they have not always taken into account the spatial and temporal heterogeneity of the properties of the soil, the general environmental conditions and the historical handling of the soil (Post et al., 2001). However, it is necessary for the indicators of change in the organic fractions to take into account a double temporal scale: the anthropic disruptions (fast processes) and the ecosystems' own dynamics (slow processes). The “pool” of carbon in the soil is a complex

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entity that has this dual temporal scale, with some carbon linked to the inorganic components that are stable over time ("recalcitrant fraction"), and other more dynamic compounds associated to the biological activity with fast turnover ("labile fraction") (McLauchlan and Hobbie, 2004). The parameters that characterise the latter fraction are the most useful as indicators within a monitoring programme for detecting an "early alert" of the changes.

The aim of this paper, which comes under the environmental monitoring programme for the Cabo de Gata-Níjar Natural Park (Almería, Spain), is to find indicators of change in the carbon of soils that represent the main historical uses of the territory, and in the most common processes that affect the dynamics of the organic matter. To do so, different fractions of the organic carbon were measured and their capacity for detecting differences in use of the soils from arid ecosystems was analysed.

2. Materials and methods

2.1. Site selection and field sampling

The study was performed in an arid zone in the south-east of the Iberian Peninsula (Cabo de Gata-Níjar Natural Park) (Fig. 1) with mean annual rainfall of 200 mm and mean annual temperature of 18 °C. The two main geomorphologic units are the mountainous range, with shrublands and soils of type Luvic Phaeozems or Eutric Leptosols on volcanic substrata and Rendzic or Calcaric Leptosols on limestone; and the piedmont geomorphologic unit, with extensive crops in dry farming, often abandoned and in different stages of vegetative succession, and soils of type Luvic or Haplic Calcisols (FAO-ISRIC_ISSS, 1998).

Representative plots from two different soilscapes were selected, each containing the varying and representative land uses of the Natural Park. Processes that affect the carbon dynamics in arid zones were considered in each soilscape/land use: vegetation succession in piedmont/crops and cover changes in mountain/shrublands:

- Dryland farming systems (DF), vegetation succession effect: *Dryland farming* (*Dr*) recent cultivation (3 plots); *Wetland* (*Wl*), initial phase of abandonment, pasture (3 plots); *scrublands* (*Sl*), abandonment with vegetation succession, woody vegetation with low coverage (3 plots).
- Shrublands (SH): vegetation cover effect: *Conserved* (*Co*), vegetation cover around 75% (3 plots);

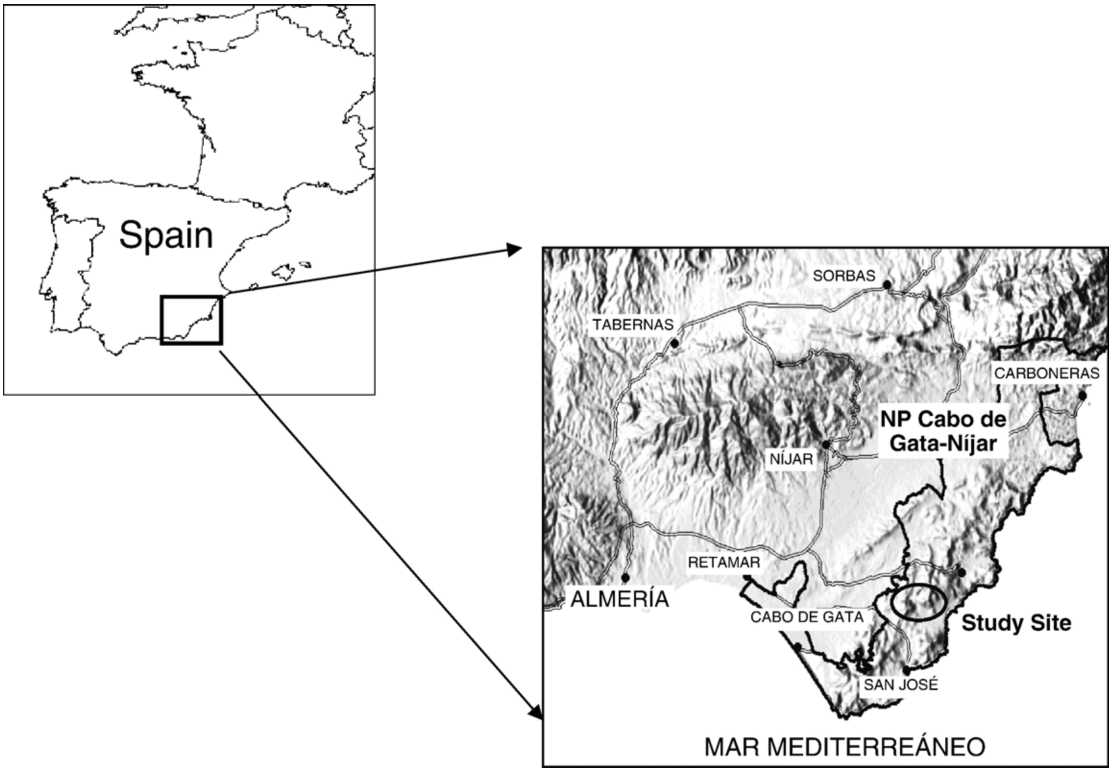

Fig. 1. Map of the study site. Cabo de Gata-Níjar Natural Park, Andalusia, Spain.

Degraded (*Dg*), vegetation cover between 30 and 50% (3 plots). We considered distribution in "patches" of the organic fraction, and samples were taken in each plot, in *vegetated-patches* (*Vp*) and in *inter-patches* (*Ip*) (total plots in shrublands: 6, total samples: 12).

The size of the plots was 10 × 10 m in which five subsamples were taken from the upper layer (0–15 cm) selected at random and these were mixed in order to obtain the final sample.

2.2. Chemical analysis of the soil samples

Soil samples were air dried, passed through a 2-mm sieve and stored at room temperature until chemical analysis was carried out. The procedures used in analysis are outlined by SSSA (Klute, 1986): particle-size distribution was determined by the pipette method; the free iron oxides were extracted with citrate–dithionite by the Holmgrem method; $CaCO_3$ equivalent by Bernard's calcimeter.

Four fractions of organic carbon were analysed: 1) *total organic carbon content* (OCt), oxidation with dichromate, with a correction factor of 1.3 (Walkley and Black, 1947); 2) *stabilised fraction* (OC_pyro), extraction with pyrophosphate + NaOH (Kononova, 1982) and subsequent determination of the carbon using the same method as for the OCt; 3) *particulate organic fraction* (OC_POM), dispersion and sieving of the organic matter (Cambardella and Elliot, 1992) over 0.05 mm and subsequent determination of the carbon using the same method as for the OCt; 4) *active organic carbon* (OC_act), chemical fractioning based on the degree of oxidation of the organic matter with potassium permanganate (Weil et al., 2003).

2.3. Data analysis

The relation between the fractions was calculated using a modification of the lability index proposed by Blair et al. (1995),

$$\text{Lability of the } C \text{ (per fraction)} = \text{OCfraction}/\text{OCt}-\text{OCfraction}$$

The variability of the determination of the different fractions of *C* was measured as the relative standard deviation (r.s.d.). Statistical data analysis was carried out using SPSS v.12.0 (SPSS Inc., Illinois, USA, 2005).

3. Results and discussion

The organic carbon content corresponding to each of the fractions considered is shown on Fig. 2. The mean value of OCt and OC_pyro in soils with shrublands are almost twice than those in the cultivated soil ($P < 0.001$). The direct provision of vegetation remains causes large differences in vegetated-patches as compared to inter-patches, although in this case the most noticeable ones arise in the OC_POM fraction, with it being relatively lower in OCt, OC_pyro and OC_act. In the sequence for the states of abandonment of the crops there are no significant differences in the OCt ($P > 0.05$). There is a slight drop in the OCt in the shrublands with less coverage (degraded), as well as in the fraction OC_POM; on the contrary, a slight increase was noted in OC_act and OC_pyro.

The evolution of the particulate fraction (OC_POM) confirms the relationship between the increase in the lability of the carbon and the rise in the productivity, or a

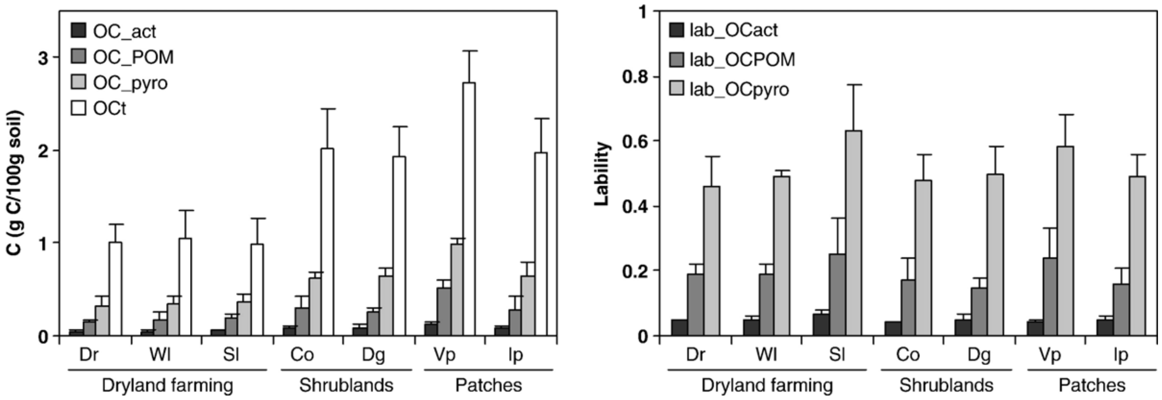

Fig. 2. Mean values and standard deviations of organic carbon content and lability index in fractions measured. The values were grouped according to the considerate land uses and processes. The short words show correspondence to: OCt: total organic carbon content; OC_pyro: stabilised fraction; OC_POM: particulate organic fraction; OC_act: active organic carbon. Dr: Dryland farming; Wl: wetland; Sl: scrublands; Vp: vegetated-patches Ip: inter-patches; Co: conserved; Dg: degraded.

Table 1
Mean parameters (slope and r-square) of the linear regression analysis between total organic carbon (OC$_t$) and organic fractions measured by land uses

Y	Dryland farming		Shrublands		Overall	
	Slope	r^2	Slope	r^2	Slope	r^2
OC_pyro[a]	0.310	0.769	0.356	0.766	0.350	0.923
OC_POM	0.109	n.s.[b]	0.246	0.530	0.186	0.697
OC_act	0.033	0.507	0.052	0.727	0.039	0.826

[a] OC_pyro: stabilised fraction; OC_POM: particulate organic fraction; OC_act: active organic carbon.

[b] n.s. There is no significant ($P > 0.05$) relationship between X and Y.

greater return of vegetation remains of the ecosystem; assuming that more advanced stages in succession or greater coverage imply more productivity (Chan et al., 2002). The OC_act fraction is also directly related to the productivity in the succession of crops, in shrublands however it seems to be an inverse relation and the drop in the vegetation cover (lower productivity) turns into an increase in the lability. This behaviour might be explained by the nature of these compounds, not related exclusively to the provision of vegetation remains but also to products from the biological activity (Weil et al., 2003). This demonstrates that compounds with a highly diverse nature are included under a common denomination (labile fraction), responding to the action of different processes without a clear definition, which makes it difficult to interpret the changes.

The variability of the results (r.s.d.), which is inversely proportional to the capacity of a variable to discriminate trends, ranges between 10 and 45%. The highest variability is shown in all cases by the OC_POM fraction, due in part to the methodological complexity of the analytical measurement of the parameter.

The linear regression analysis (Table 1) between OCt and the other fractions estimated shows that the OC_pyro fraction represents 35% of the total carbon, OC_POM 18.6% and OC_act 3.9%, confirming the scant link between the two labile fractions measured. The lability, expressed as the sum of all the fractions of C measured, is higher in shrublands (66%) than in the cultivated areas (45%), responding to a lower productivity and higher rate of mineralization in the cultivated areas. The fraction with a greater difference between these two systems is OC_ POM, rising from 11% in cultivated areas to 25% in shrublands, thus confirming its link to the productivity or provision of remains (Table 1).

The relationship between fractions of organic C and some soil properties, which contribute to the establishment of humic compounds in soil, such as granulometric composition, carbonate and free iron oxide contents, were analysed. The OC_POM fraction does not have any relationship with any of the analysed properties, thus confirming the idea that it involves vegetation remains with scant incorporation in the soil. In contrast, the OC_act fraction, theoretically linked to the biological activity, is significantly related with the silt (r: 0.962), the total carbonates (r: 0.942) and the iron oxides (r: −0.882). It shows that this fraction might include compounds produced by the biological metabolization but they are found in an initial phase of stabilisation with the soil components.

The sensitivity of the parameters to the considered changes was analysed using an ANOVA test (Table 2). Drastic changes in the ecosystems (crops *versus* shrublands, or vegetation-patches *versus* inter-patches) can be discriminated with any of the fractions of organic matter measured ($P < 0.05$). The value of F indicates that the most sensitive parameters to this change are OC_pyro

Table 2
Comparative sensitivity of organic fractions to detect changes produced by processes that affect the carbon dynamics

		OCt[a]	OC_pyro	OC_POM	OC_act
Effect: DF/SH[b]	OC content	42.27 (0.0000)	54.39 (0.0000)	9.46 (0.0089)	13.84 (0.0026)
	Lability		0.43 (0.5252)	2.04 (0.1769)	4.08 (0.0644)
Effect: Dr/Wl/Sl	OC content	0.05 (0.9500)	0.30 (0.7497)	0.26 (0.7764)	0.81 (0.2422)
	Lability		2.71 (0.1447)	0.86 (0.4683)	7.76 (0.0223)
Effect: Vp/Ip	OC content	13.61 (0.042)	28.41 (0.0003)	11.38 (0.0071)	3.65 (0.0850)
	Lability		2.85 (0.1222)	3.34 (0.0977)	0.07 (0.7906)
Effect: Co/Dg	OC content	0.02 (0.8854)	0.10 (0.7572)	0.35 (0.5684)	0.68 (0.4287)
	Lability		0.07 (07923)	0.75 (0.4055)	1.75 (0.2156)

The F-ratio values of ANOVA test are shown, the P-value for each value is shown in parenthesis.

[a] OCt: total organic carbon content; OC_pyro: stabilised fraction; OC_POM: particulate organic fraction; OC_act: active organic carbon.

[b] DF: Dryland farming systems; SH: shrublands; Dr: dryland farming; Wl: wetland; Sl: scrublands; Vp: vegetated-patches Ip: inter-patches; Co: conserved; Dg: degraded.

and OCt, whilst the labile fractions are somewhat less. Amongst the relative lability of the indices measured, what might be expected from a greater sensitivity, only the lab_OCact allows detect differences between populations ($P=0.013$).

Changes introduced by more subtle processes in which the total organic carbon content does not change or it changes slowly, such as the evolution of cultivated soil that has been abandoned or the process of coverage loss of shrubs, are more difficult to detect. None of the parameters measured directly establishes significant differences, only the OC_act seems to show some trend, and the lability indices are more sensitive and sometimes detect significant differences, as lab_OCact in the cultivations sequence ($P=0.022$).

4. Conclusions

The carbon fractions reflect the changes caused by the alterations in use and the dynamics of the soils, but the parameters that are sensitive to these processes differ: profound changes are better discriminated by fractions that represent a high percentage of the total organic carbon, whilst slow dynamics are better reflected in the labile fractions. From the latter, the particulate is related with the productivity of the ecosystems and is independent of the edaphic features, whereas in the active one we noted a greater link to soil properties.

Due to the sensitivity to the changes analysed, and bearing in mind their methodological complexity, we propose the following as the indicators of the organic fraction in the environmental monitoring programmes for arid environments: the total organic carbon content, the active fraction of the carbon, and the relative percentage of this fraction estimated by the lability index proposed.

References

Blair GJ, Lefroy RD, Lisle L. Soil carbon fractions based on their degree of oxidation, and development of a carbon management index for agricultural systems. Aust J Agric Res 1995;46:1459–66.

Cambardella A, Elliot ET. Particulate soil organic matter changes across a grassland cultivation sequence. Soil Sci Soc Am J 1992;56: 777–83.

Chan KY, Heenan DP, Oates A. Soil carbon and relationship to soil quality under different tillage and stubble management. Soil Tillage Res 2002;63:133–9.

FAO-ISRIC_ISSS. World reference base for soil resources. FAO. World Soil Resources Reports, vol. 84. 1998. Rome, 88 pp.

Kononova MM. Materia orgánica del suelo. Su naturaleza, propiedades y métodos de investigación. Oikos-Tau, Barcelona; 1982. p. 268–83.

Klute A. Methods of soil analysis. Part 1. Physical and mineralogical methods. SSSA Book Series, vol. 5. Madison (WI): ASA and SSSA Publisher; 1986. 1188 pp.

McLauchlan K, Hobbie SH. Comparison of labile soil organic matter fractionation techniques. Soil Sci Soc Am J 2004;68:1616–25.

Post WM, Izaurralde RC, Mann LK, Bliss N. Monitoring and verifying changes of organic carbon in soil. Clim Change 2001;51:73–99.

Walkley AL, Black A. A critical examination of a rapid method for determining organic carbon in soils: effect of variations in digestion conditions and of inorganic soil constituents. Soil Sci 1947;63: 251–63.

Weil RR, Islam KR, Stine MA, Gruver JB, Samson-Liebig SE. Estimating active carbon for soil quality assessment: a simplified method for laboratory and field use. Am J Altern Agric 2003;18: 3–17.