USE OF MICROARTHROPODS AS BIOLOGICAL INDICATORS OF SOIL QUALITY: THE BSQ SINTHETIC INDICATOR

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Abstract

The introduction of sustainable development principle has lead to an increasing attention towards concepts such as soil quality and soil health. Soil quality is the ability of soil to function effectively as a component of a healthy ecosystem.

Traditional approach to soil quality evaluation was based on the use of physical, chemical and microbiological indicators. Different authors proposed recently new methods for soil quality evaluation, based on soil microarthropods. Soil microarthropods demonstrated to respond sensitively to land management practices and to be correlated with beneficial soil functions. This paper presents two biological indicators of soil quality based on microarthropods and collembola.

Introduction

Modern agriculture has led to deep changes in the agroecosystems and to severe impacts on the environment. Among these impacts reduction of biodiversity and degradation of soil quality are often viewed as major threat for the future (Solbrig, 1991).

Although soil quality represent a value-based concept, related to the objectives of ecosystem management (Schoenholtz *et al*, 2000) it is possible to achieve a general definition of it. In synthesis, the concepts expressed by the Soil Science Society of America (Karlen *et al*, 1997) and by the International Soil Science Society during the International Congress in Montpellier, define soil quality as "the functionality of a soil in its own environment, the capability to sustain plants and animal productivity, and to maintain or improve the air and water quality". Soil quality can be evaluated by using a large number of indicators (chemical, physical, biological) depending on the scale and the objective of the evaluation; the importance of some of these parameters is generally accepted.

A review of soil quality indicators showed that few of them are largely dominant. Soil organic matter among chemical indicators (Bowman *et al*, 2000, Brejda *et al* 2000, Gilley *et al*, 2001, Kettler *et al*, 2000, Li *et al*, 2001, Liebig and Doran, 1999), bulk density (Gilley *et al*, 2001, Kettler *et al*, 2000, Li *et al*, 2001, Liebig and Doran, 1999) and aggregate stability (Bowman *et al*, 2000, Six *et al*, 2000) among physical indicators, were the most represented, while few researches deals with biological indicators of soil quality (Gilley *et al*, 2001, Liebig and Doran, 1999).

Different authors proposed recently new methods for soil quality assessment, based on soil microfauna. Some of these methods are based on the global evaluation of microarthropods (Parisi, 2001), while other are based on the evaluation of single taxa (Paoletti, 1999, Paoletti *et al*, 1999, Parisi 2001). The applications of these bioindicators are often limited by the difficulty of microarthropods classification, that quite often they require very specialised work. The introduction of simplified ecomorphological index, that does not require the classification of organism at species level, allowed to a wider application of these methodologies.

In this paper two biological indicators of soil quality are presented: the BSQ-ar (Biological Soil Quality- arthropods) and BSQ-c (Biological Soil Quality- collembola).

Biological Soil Quality index

The biological soil quality was evaluated by using the BSQ (Biological Soil Quality) index, proposed by Parisi (2001). The BSQ is based on the following concept: the higher is soil quality, the higher will be the numbers of microarthropods groups adapted to the soil habitat. Among edaphic microarthropods morphological characters of their body (Figure 1) show the adaptation level to soil environment.

The BSQ-i is based on the life-form approach (Sacchi and Testard, 1971) applied to edaphic microarthropods with a double objective of: 1) evaluating the microarthropods adaptation level to soil habitat; 2) overcoming the difficult taxonomic analysis of species. In fact BSQ-i do not requires of species present in the sample.

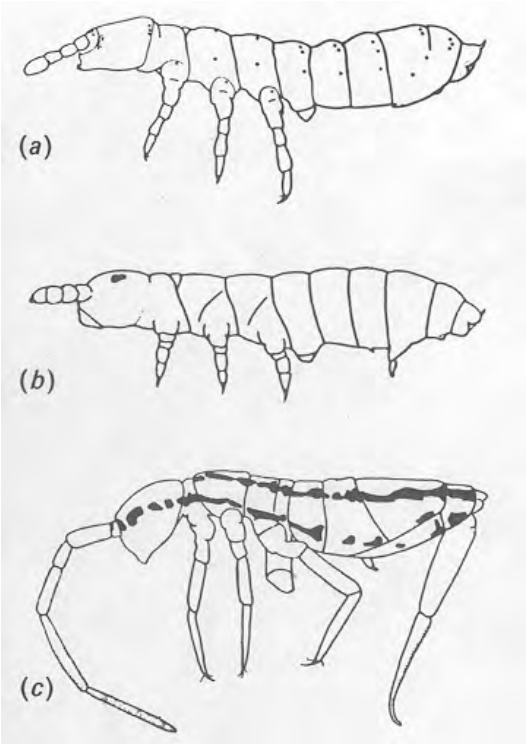

Figure 1. Morphological characters showing different levels of adaptation to soil environment in collembola species (from Gisin)

BSQ index is applied by separating the organism extracted from soil samples into groups having homogeneous morphological characters. This is done on the base of the Ecomorphological Indexes (EMI) (Parisi, 2001), that allow to associate a score to each microarthropod group and to calculate the BSQ index by adding the score of each group.

Two different types of BSQ are proposed, one based on microarthropods (BSQ-ar) and a second one based only on Collembola species (BSQ-c). In table 1 are reported the scores (Ecomorfologic Index: EMI) associated to each microarthropod group (for instance Diplura EMI=20) for BSQ-ar calculation. Some groups reported a single EMI value (for example Protura EMI=20, figure 2a) because all species belonging to this group were euedaphic; others groups reported a range of EMI values (for instance: coleoptera 1-20, figure 2b) because in these groups there were species with different soil adaptation levels (higher EMI values were assigned to species more adapted to soil habitat).

Table 1. Ecomorfologic Index (EMI)

GroupE1MI	**GroupEMI**		
Protura	20	Other holometabolous (larvae)	10
Diplura	20	(adults)	1
Collembola	1-20	Pseudoscorpionida	20
Microcoryphia	10	Palpigradi	20
Zygentoma	10	Opiliones	10
Dermaptera	1	Araneae	1-5
Orthoptera	1	Acari	10-20
Embioptera	10	Isopoda	10
Blattaria	5	Diplopoda	5-20
Psocoptera	1	Pauropoda	20
Hemiptera	1	Symphyla	20
Thysanoptera	1	Chilopoda	10-20
Coleoptera (adults)	1-20	Hymenoptera	1-5
Diptera (larvae)	10		

Explanatory notes:

Collembola: evident epigeic forms, with long appendices, developed eyes, complex livery EMI1; epigeic forms not present on plants, with developed appendices and bristle or calypter, developed eyes EMI 2; small size forms, middle size appendices, eyes developed, modest livery EMI 4; emiedaphic forms, with developed eyes, reduced appendices, uniform livery EMI 6; emiedaphic forms, limited ocellus number, reduced appendices, reduced or absented furca, pigmentation present EMI 8; euedaphic forms, pigmentation absent, reduced or absented ocellus, presented but reduced furca EMI 10; tipically euedaphic forms, pigmentation and furca absent, with apomorphic sensorial structures.

Coleoptera: epigeic form, EMI value 1; size shorther 2 mm: points 4; thin tegument: points 5; microapterism or apterism: points 5; microphthalmy or anophthalmy: points 5: EMI was a summation of points related to every present character.

Hymenoptera: generally, EMI 1; formicidae EMI 5.

Araneae: small and depigmentation form EMI 5; forms greater of 5 mm EMI 1.

Acari: Oribatida EMI 20; others EMI 10.

Diplopoda: forms larger than 5 mm EMI 5; forms smaller than 5 mm EMI 20.

Chilopoda: forms larger than 5 mm with developed legs EMI 10; other forms EMI 20.

Collembola are among the most abundant soil microarthropods and are very sensitive to variations in soil environment. Do to this reasons the BSQ-c, a specific index for Collembola group, was also proposed. Application of BSQ-c original version [12] was difficult because it was necessary to classify the organisms at genus level. In this paper a simplified version of BSQ-c, proposed by Parisi, is presented.

The latest BSQ-c requires only the classification of "large groups", corresponding to "Gisiniane family" (homogeneous groups of organism, wider than the actual Collembola families). After soil extration Collembola were separated into six groups: Podurid, Onichiurid, Isotomid, Entomobrid, Neelid (group not autonomous in "Gisinian's key") and Sminturid. In each group the biological form with higher EMI value is recorded. BSQ-c was a summation of six higher EMI-values.

BSQ-c is not always correlated with BSQ-ar; however some study showed that high BSQ-ar value corresponded to high or medium BSQ-c value; above all, low BSQ-ar value corresponded to low BSQ-c index.

CASE STUDY: PERMANENT GRASSLANDS OF NORTHERN ITALY

Materials and Methods

The study area is located in the Po valley (Northern Italy), north-east of Modena (lat. 44° 39' N, long. 10° 56' W); the mean elevation is 28 m a.s.l. Soils were developed on recent alluvial deposits, aged between middle-age and modern-age; from geomorphologic point of view, these deposits are considered to be built by the secondary hydrographic network. Inside this area 5 different sites were investigated:

Balugola (BA): it is the oldest permanent grassland. It was established since 1736 and it was irrigated using the traditional method (flood irrigation) since many years.

Botti (BO): it is a permanent grassland, irrigated (flood irrigation), and it was established more than 100 years ago.

Galli (GA): it is a permanent grassland, having the same age of Botti, but it isn't irrigated any more since 20 years.

Medica (ME): it is a vineyard (30 years ago). At the time of sampling it was cultivated with alfalfa since 2 years.

Troni (TR): it is a former permanent grassland (same age as Botti), plowed for the first time 20 years ago. At the time of sampling it was cultivated with sugarbeet.
Soils of the investigated sites were classified according to USDA Soil Taxonomy (1998) and World Reference Base for Soil Resources (WRB) (1998), on the base of the existing pedological map 1:50,000 (Regione Emilia-Romagnia 1993) and describing a soil profile for each investigated site. Sampling methods of soil were differentiated for chemical and physical analyses and for the evaluation of BSQ-index.

Soil samples for chemical analyses consisted in composites samples (3 subsamples) and were taken in triplicate from 5 depth (0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, 50-60 cm, 60-80 cm) in each investigated site. Samples were air dried, sieved to pass a 2 mm mesh and kept in a plastic container in the laboratory before analyses.

Organic carbon was determined by wet oxidation (potassium dichromate-sulphuric acid) and back titration with iron ammonium sulphate, according to Walkley-Black method (1934). Particle size distribution of the 2 mm fractions were measured by the hydrometer method. Soil pH was measured in 1:2.5 soil:water dilution (w:w) using a glass electrode.

Total calcium carbonate was measured using a volumetric calcimeter. Bulk density and aggregate stability were made in triplicate on samples taken from 0-10 cm depth. Aggregate Stability Index (ASI) was determined using wet sieving with vertical oscillation (30 oscillations per minute), according to the method described by Cavazza (1981).

The analysis was realised using 10 g of 1-2 mm aggregates (A); the aggregates were wetted by capillarity and then sieved (0.2 mm sieve) in water for 30 minutes. After this treatment aggregates >0.2 mm were dried at 105° C and weighted (B); then the stable aggregates were dispersed with sodium hexametaphosphate, sieved with distilled water, dried and weighted (C). The index is given by the following ratio:

$$ASI = (B\ \ C) / (A\ \ C)$$

Land use effect on aggregate stability index was determined by Duncan test for comparison of means by using the SPSS software (SPSS, 1993). Soil sample collection and microarthropods extraction is realised according to the standard methodology applied in soil biology: soil core samples (10x10x5 cm) and extraction by using the modified Berlese-Tullgren funnel (Phillipson, 1971).

Results and Discussions

According to Soil Taxonomy, soils of the investigated area can be classified as Fluventic Ustochrepts fine, mixed, mesic, while according to WRB classification these soils belong to Fluvic Cambisol. A general description of soil parameters is reported in Table 2.

Aggregate stability index showed significant differences ($P<0.01$) between grasslands and cultivated soils (Table 3). It is clear the influence of organic carbon content on aggregate stability, as evidenced by Unger (1997).

Table 2. Soil physical and chemical parameters of the investigated sites. The indicated values represent the average of three analyses

		CULTIVATED		PERMANENT GRASSLANDS		
Soil parameters	**Depth (cm)**	**TR**	**ME**	**BA**	**BO**	**GA**
Textural class	0-10	Silty clay	Silty clay	Clay	Clay	Clay
Sand	0-10	4.8	2.2	3.70	4.90	3.50
Silt	0-10	41.5	42.2	39.40	37.70	34.40
Clay	0-10	53.7	55.6	56.90	57.40	62.10
Bulk density (g cm $^{-3}$)	0-5	1.25	1.32	1.03	1.12	1.05
Organic carbon (mg g $^{-1}$)	0-10	23.87	19.04	62.59	74.09	69.64
	10-20	24.49	18.89	43.73	48.94	46.54
	20-30	25.88	20.21	35.19	30.30	41.88
	30-40	26.84	19.86	26.92	17.08	32.11
	40-50	21.91	19.06	18.26	12.54	16.75
	50-60	21.68	15.06	13.77	10.64	13.02
	60-80	16.50	10.08	9.19	8.77	16.45
pH	0-10	7.83	7.73	7.32	7.13	7.22
	10-20	7.79	7.77	7.38	7.26	7.46
	20-30	7.78	7.87	7.42	7.48	7.57
	30-40	7.78	7.83	7.62	7.64	7.68
	40-50	7.77	7.93	7.84	7.73	7.78
	50-60	7.75	7.94	7.95	7.80	7.58
	60-80	7.85	8.01	8.15	7.90	7.58
Calcium carbonate (%)	0-10	16.95	9.97	9.97	12.46	5.48
	10-20	12.96	9.97	11.96	14.96	7.98
	20-30	11.96	10.97	13.96	15.45	7.48
	30-40	10.47	10.47	13.46	14.96	8.97
	40-50	18.94	9.97	14.96	13.96	7.98
	50-60	13.46	9.97	16.45	14.26	8.97
	60-80	13.46	17.95	16.95	14.46	8.97

Table 3. Aggregate Stability Index (ASI) variation according to land use type

Aggregate Stability Index		
Study sites	Average*	Std. Dev.
GA	73.74 Aa	1.75
BA	69.68 ABb	1.35
BO	68.47Bb	1.47
TR	22.73 Cc	2.13
ME	13.84 Dd	2.24

** The Average values followed by the same letter
do not have significant differences at 0.01 and 0.05
(capital and small letters) probability, based on Duncan test

The BSQ-c values (table 4) were particularly high in the irrigated permanent grassland (Botti), owing to the high occurrence of species well adapted to edaphic life and submersion (*Folsomides parvulus*). The soils of Botti and Medica were very similar in species richness, but quite different as far as BSQ-c is concerned. The BSQ-c values were, in fact, 154 in Botti and 71 in Medica.

The soils of Troni were the poorest in Collembola species (only 3), while the other soils evidenced homogeneous species richness. The BSQ-ar values showed the same trend of BSQ-c, with the exception of Botti. In this unit in fact, the waterlogging evidenced a marked influence in favour of Collembola, while other edaphic microarthropods were disadvantaged. According to the increasing values of BSQ-ar and BSQ-c, the soils of the study sites can be ordered along the following sequence Troni-Medica-Balugola-Galli.

Table 4. Biological Soil Quality index for michroartropods and for collembola

Study sites	BSQ-ar	BSQ-c
GA	116	105
BA	97	94
BO	71	144
TR	70	13
ME	87	68

Conclusions

The combined use of chemical, physical and biological indicators allowed to attribute a high soil quality to the permanent grasslands of the investigated area and to validate the BSQ index.

The BSQ appear to be sensitive to short term variations in the agronomic management, such as the crop cultivated in the arable land parcels, while is less sensitive towards large variation of important soil parameters such as the organic carbon content. Values of BSQ-c seems to be more related to the organic carbon content and soil aggregate stability with respect to BSQ-ar. Animal biodiversity, expressed as both as number of species or number of taxa, was markedly higher in the permanent grasslands.

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