Soil & Tillage Research 109 (2010) 169–173

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Short communication

Consequences of soil sampling depth during the assessment of the effects of tillage and fertilization on soil quality: a common oversight

Iker Mijangos, Carlos Garbisu *

NEIKER-Tecnalia, Basque Institute of Agricultural R&D, Berreaga 1, E-48160 Derio, Spain

ARTICLE INFO

Article history:
Received 26 October 2009
Received in revised form 10 May 2010
Accepted 10 May 2010

Keywords:
Enzyme activities
plow layer
tillage
soil quality

ABSTRACT

The objective of this work is to discuss the consequences of soil sampling depth during the assessment of the effects of tillage and fertilization on soil quality, within the context of a well-known recommendation: the imperative need to consider soil depths covering the entire plow layer during such assessment. It is necessary to (i) warn that this recommendation is most often forgotten and (ii) illustrate with real data the consequences of this common oversight. We carried out two field experiments in Derio (Spain): the first (2004) on a Dystric Cambisol and the second (2005-2007) on an Epidystric Cambisol. We hypothesized that conflicting conclusions regarding the effects of tillage and fertilization on soil quality can be drawn depending on the soil depth subjected to analysis. With respect to soil enzymes, it was found that inconsistencies in values with soil depth can be reduced when the results are expressed as specific activities.

1. Introduction

In an agricultural context, soil quality can be defined as "the soil's capacity to support crop growth without resulting in soil degradation or otherwise harming the environment" (Acton and Gregorich, 1995). Given that soil quality depends on the physical, chemical and biological properties of the soil, preferably, these three types of properties must be considered when assessing changes in the soil condition. In the last years, compared to physical and chemical variables, biological properties are becoming increasingly used as indicators of soil quality, due to their rapid response, higher sensitivity, and capacity to provide information that integrates many environmental factors (Mijangos et al., 2006; Paz-Ferreiro et al., 2009).

Reports in the literature on the effects of agricultural practices on soil quality are often inconsistent and even contradictory. For instance, some authors have reported that plowing may cause an increase in soil microbial activity (Gupta and Germida, 1988), while others observed a decrease in such activity owing to a reduction in organic matter content as a result of the mixing of horizons caused by plowing (Carter, 1986). In addition, it is recurrently stated that organic fertilizers increase soil biochemical activity, due to the associated input of organic substrates and microorganisms (Kandeler et al., 1999), but contradictory results can be found in the literature regarding this aspect (Schipper and Sparling, 2000).

Regarding the response of soil biological properties (enzyme activities) to agricultural practices, there are different possible explanations for the lack of consistent patterns: (i) the number of analyzed samples is insufficient to compensate for the well-known extremely high spatial and temporal variability usually displayed by soil biological properties; (ii) different soil biological properties do not necessarily respond in the same way to changes introduced in the soil ecosystem (Paz-Ferreiro et al., 2009); and (iii) there is a lack of standardized protocols for both soil sampling and the determination of soil biological properties.

The objective of this work is to discuss the consequences of soil sampling depth during the assessment of the effects of tillage and fertilization on soil quality. With this objective in mind, we first discuss some results from one of our previous field experiments (partly published in Mijangos et al., 2006) and compare them with those obtained in a subsequent field experiment, in order to verify the conclusions reached during the reinterpretation of data from the first experiment. Data are discussed within the context of a well-known recommendation: the imperative need *to consider soil depths covering the entire plow layer* during the assessment of the effects of tillage and fertilization on soil quality, so that comparisons among different studies are valid. The ultimate goal of this paper is to warn that this recommendation is still most often forgotten and to illustrate with real data the consequences of this common oversight. We hypothesized that conflicting conclusions regarding the effects of tillage and fertilization on soil quality can be drawn depending on the soil depth considered.

* Corresponding author. NEIKER - Tecnalia, Basque Institute of Agricultural Research and Development, c/Berreaga 1, E-48160 Derio, Spain.
Tel.: +34 94 403 43 00; fax: +34 94 403 43 10.
E-mail address: cgarbisu@neiker.net (C. Garbisu).

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doi:10.1016/j.still.2010.05.001

2. Materials and methods

2.1. Field experiments

Both field experiments were carried out in Derio, Basque Country (northern Spain), an area characterized by a temperate and humid climate (annual mean: 13.5 °C of temperature and 1,200 mm of rainfall). As aforementioned, part of the first field experiment has already been published (Mijangos et al., 2006). Briefly, in 2004, forage corn was sown after organic (O; 10% DM cow slurry) *vs.* inorganic (I; 33.5% NH_4NO_3, 18% P_2O_5 and 60% KCl) fertilization, at the same doses (150 kg N ha^{-1}, 50 kg P ha^{-1}, and 180 kg K^+ ha^{-1}) combined with conventional tillage (CT) *vs.* no-tillage (NT), on a clay loam soil classified as Dystric Cambisol (FAO, 1998). A randomized complete block design with four replicates was established with each experimental plot measuring 5 × 3.5 m. Both organic and inorganic fertilizers were applied manually to the soil surface prior to CT, which consisted of 0-16 cm plowing *plus* rotary tilling. Direct sowing for the NT treatment was carried out with a Semeato machine.

The second field experiment started in 2005 and consisted of growing two different forage crop rotations (corn in summer - Italian ryegrass in winter *vs.* corn in summer - "triticale + pea" mixture in winter) under similar treatments of tillage (0-20 cm plowing) and fertilization as described above (treatments were conducted prior to the establishment of each crop). A randomized complete block design with three replicates was established on a silty clay loam soil classified as Epidystric Cambisol (FAO, 1998), with each experimental plot also measuring 5 × 3.5 m.

2.2. Soil sampling

Before the establishment of the experiments, soil was sampled to verify homogeneity among experimental plots. Likewise, in the first field experiment, soil was sampled one month after sowing, that is to say, 35 days after fertilization and tillage treatments. In the second field experiment, two years after the beginning of the experiment, soil was sampled at the end of the winter crop (at harvest), approximately 6 months after the last treatment application.

In both experiments, soil composite samples from each experimental plot were taken: samples consisted of 15 subsamples per plot that were randomly collected using a probe (3 cm diameter core); core soil samples were divided into two segments (*i.e.*, two soil depths that together covered the entire plow layer): 0-10 and 10-16 cm for the first experiment; and 0-10 and 10-20 for the second experiment.

2.3. Soil chemical and biological properties

For chemical analysis, soils were air-dried at 30 °C for 48 h, sieved to <2 mm, and stored at room temperature (Hernández-Allica et al., 2006). For analysis of biological parameters, excluding dehydrogenase activity, soils were air-dried at 30 °C for 48 h, sieved to <2 mm and stored at 4 °C. For dehydrogenase activity, soils were sieved to <2 mm in fresh and then stored at 4 °C, according to Tabatabai (1994) and Dick et al. (1996). Soil chemical properties (pH, OM content, total N, Olsen P, K^+ and Mg^{2+}) were determined following standard methods (MAPA, 1994). Enzyme activities (dehydrogenase, acid phosphatase, arylsulfatase, β-glucosidase, urease) were determined according to a modification of Tabatabai (1994) as previously described (Rodríguez-Loinaz et al., 2008). For potentially mineralizable N (N_{min}), we followed the method described by Powers (1980).

All laboratory analyses were carried out in duplicate. Differences among treatments were performed as one-way analysis of variance (ANOVA) and Fisher's PLSD-test was used to establish the significance of the differences among means.

3. Results and discussion

From the soil analyses carried out prior to the beginning of the experiments, it was concluded that both experimental fields were highly homogeneous and thus suitable for a study of these characteristics. In fact, no significant differences ($P < 0.05$) were observed among treatment plots for any of the chemical or biological parameters here studied (data not shown).

Table 1 shows the effect of treatments (tillage and fertilization) on soil biological and chemical properties corresponding to the first experiment. Regarding 0-10 cm soil samples, no significant differences were observed among treated plots (O + NT, O + CT, I + NT, I + CT) with respect to chemical properties, except for pH and Mg^{2+} (higher values were observed under organic *versus* inorganic fertilization). At this very same soil depth, O + NT plots showed significantly higher values of dehydrogenase, acid phosphatase, β-glucosidase, urease and N_{min} than I + CT plots. Within each tillage system (CT, NT), organic fertilization led to significantly higher values of dehydrogenase activity in NT plots, and of dehydrogenase, acid phosphatase and β-glucosidase activity in CT plots. Within each fertilization category (O, I), NT led to significantly higher values of dehydrogenase activity in organically-fertilized plots, and of acid phosphatase, β-glucosidase and urease activity in inorganically-fertilized plots. Different results were obtained at a soil depth of 10-16 cm: I + CT plots had significantly higher values of β-glucosidase and urease activity than I + NT or O + NT plots, and O + CT plots showed significantly higher values of β-glucosidase, urease and N_{min} than O + NT plots (Table 1). This was most likely due to higher oxygen availability and the incorporation of organic matter from the topsoil surface layer to this deeper 10-16 cm layer, as a result of CT. When data from both soil sample depths (0-10 and 10-16 cm) were averaged (see columns for 0-16 cm in Table 1), within each fertilization category, NT only led to significantly higher values of β-glucosidase in inorganically-fertilized plots, as compared to CT. In this respect, Carter (1986) reported that NT significantly increased microbial biomass in the top 0-5 cm of the soil, but this increase was gradually offset by a decline at deeper soil depths.

Results from this first experiment help illustrate the conflicting conclusions that might be drawn depending on the soil depth considered. In consequence, if we are to properly compare the effects of tillage and fertilization on soil quality among different studies, comparisons should be done among soil depths covering the entire plow layer. However, as abovementioned, this recommendation is currently not followed in many studies. As an example, Salinas-García et al. (2002) compared the effect of NT *vs.* CT on soil properties using 0-15 cm soil samples, while the depth of plowing was 0-30 cm (from their data, they concluded that the lower soil microbial biomass C and N observed with plowing suggested that CT was not sustainable in the studied area). Roldán et al. (2007) reported that NT was more effective in improving soil physical and biochemical quality than the mouldboard system, with the beneficial effects being more noticeable in the top 0-5 cm of the soil than at deeper layers. However, soil was sampled at 0-5 and 5-15 cm while the mouldboard plow turned the top 20 cm of the soil. Similarly, Jin et al. (2009) compared the effect of different tillage systems, such as subsoiling (SS) with mulch (to a depth of 30-35 cm), reduced tillage (25-30 cm), no-till with mulch, and conventional control (20 cm), on soil quality as reflected by the values of enzyme activities at a 0-10 cm depth. In SS plots, higher values of enzyme activities were accompanied by higher values of crop productivity. Accordingly, the authors (Jin et al., 2009) concluded that enzyme activities might be good indicators of overall changes in soil quality. In other studies (Agbede et al., 2009; Riffaldi et al., 2002; Roldán et al., 2005), a 0-15 cm soil depth was used to compare the effects of NT *vs.* different plowing systems on