Soil & Tillage Research 173 (2017) 53–63

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Indicators of earthworm bioturbation to improve visual assessment of soil structure

Denis Piron[a,*], Hubert Boizard[b], Djilali Heddadj[c], Guénola Pérès[d,e], Vincent Hallaire[d], Daniel Cluzeau[a]

[a] UMR 6553 EcoBio, Univ. Rennes 1, CNRS, Station Biologique, F-35380 Paimpont, France
[b] INRA, UPR1158 AgroImpact, 80200 Estrées-Mons, France
[c] Chambres d'Agriculture de Bretagne, Avenue du Général Borgnis Desbordes, BP 398, F-56009 Vannes, France
[d] INRA, AGROCAMPUS OUEST, UMR 1069 SAS, F-35000 Rennes, France
[e] Forensic and Applied Sciences, University of Central Lancashire, PR1 2HE, Preston, UK

ARTICLE INFO

Article history:
Received 30 March 2016
Received in revised form 26 October 2016
Accepted 27 October 2016
Available online 4 November 2016

Keywords:
Earthworm bioturbation
Soil structure
Soil visual examination
Soil profile description
Burrows
Cast production

ABSTRACT

Earthworm bioturbation, a biological process that strongly influences soil structure dynamics, is attracting more interest with the development of no-tillage farming. However, while methods for Visual Soil Structure Assessment (VSSA) are of great use to agronomists working to improve crop management and preserve soil structure, few methods have indicators that consider earthworm biostructures. One reason is that VSSA methods were initially created for conventional tillage systems, where tillage and compaction are the main drivers of soil structure over time, while bioturbation is a secondary driver. However, bioturbation is now recognised as an important process for soil functioning under no-tillage and reduced tillage systems. Among biostructures, the presence of burrows is one frequently-used indicator, but casts are rarely studied in the field, except in the "Soil-Structure Patterns" method (SSP), which provides a typology of soil structure that includes earthworm features. However the SSP typology appears complex (11 patterns), and implementing the method is time consuming. To improve VSSA methods, we identified patterns to define new indicators of earthworm bioturbation. We first assessed whether the patterns identified were useful for highlighting the real impact of bioturbation on the distribution of soil structures and the impact of tillage on earthworm activity. We then applied the pattern descriptions to the "profil cultural" method, which provides a detailed assessment of soil structure in the soil profile. This study was performed at two experimental sites in France experiencing different types of soil impacts (i.e. tillage, compaction). Identifying patterns in soil morphological units helped us to define four types of bioturbation: (1) type 0: no visible bioturbation; (2) type 1: presence of burrows; (3) type 2: presence of a few fresh cast aggregates; and (4) type 3: high presence of casts in different welded states. This new typology seemed relevant and complementary to typical indicators. When applied to the "profil cultural" method, these bioturbation indicators can improve the assessment of the soil structure usually provided by VSSA methods and provide more accurate information to agronomists and farmers about soil functioning, including biological activities.

1. Introduction

Soil structure is a major soil property since it regulates soil functions such as water movement, water content, oxygenation and temperature (Dexter, 1988; Letey, 1991; Neira et al., 2015). Soil structure also greatly influences plant germination and root growth (Braunack and Dexter, 1989; Dürr and Aubertot, 2000; Schneider and Gupta, 1985; Tormena et al., 2016). Therefore, assessing soil structure is an important issue in determining soil quality (Ball and Munkholm, 2015). Methods for visual soil structure assessment (VSSA), used directly in the field, are useful to agronomists and agricultural advisers when making soil management decisions related to soil structure. These methods are based on visual indicators such as visual porosity, arrangement of clods or the ease with which clods break up (Gautronneau and Manichon, 1987; Guimarães et al., 2011; Richard et al., 1999; Shepherd, 2009; Weill and Munkholm, 2015) but do not consider criteria related directly to bioturbation.

* Corresponding author.
E-mail address: pirondenis@orange.fr (D. Piron).

http://dx.doi.org/10.1016/j.still.2016.10.013
0167-1987/

Bioturbation is defined as biological reworking of soils or sediments by organisms, including microbes, rooting plants and burrowing animals (Meysman et al., 2006). Bioturbation is recognised for its influence on ecosystem regulation (e.g. nutrient cycling, water flux) (Wilkinson et al., 2009). Bioturbation by earthworms contributes to soil regulation and evolution, notably in temperate ecosystems (Lavelle et al., 2006). Earthworms are considered "soil ecosystem engineers" because bioturbation changes soil resources and creates habitats for other soil organisms at the scale of the soil profile (Blouin et al., 2013; Eisenhauer, 2010; Jones et al., 1994).

Earthworm bioturbation produces two kinds of soil structures (i.e. biostructures): burrows and casts (Lee and Foster, 1991). Burrows are produced by excavation (i.e. ingestion and casting of soil material) or by pushing the soil aside (Jégou et al., 2000). The degree of verticality and branching of burrow architecture depends on the earthworm species (Blouin et al., 2013). Casts are produced by ingestion of soil and organic matter, later excreted on the soil surface or below-ground. They look like ovoid or spherical pellets. Both biostructures have effects on soil porosity and hydraulic properties. Burrows increase water infiltration when they connect to the soil surface and constitute preferential flow paths in the soil (Capowiez et al., 2015; Blouin et al., 2013; Joschko et al., 1992; Trojan and Linden, 1992). Packing voids within casts influence soil mesoporosity and increase water retention (Bottinelli et al., 2010; Castellanos-Navarrete et al., 2012; Lamandé et al., 2003; Oades, 1993). Moreover, biostructures are hotspots for microbial activity by providing favourable oxygen and pH conditions, as well as organic matter enriched in plant nutrients (Brown et al., 2000; Bundt et al., 2001; Monard et al., 2008; Stroud et al., 2016).

Intensive agricultural management rarely considers the ecosystem services that soil fauna can supply. Conventional farming tills the soil to obtain a favourable soil structure, which limits the contribution of uncontrolled biological processes and tends to inhibit formation of habitats for other soil organisms (Giller et al., 1997; Young et al., 2001). In such systems, tillage and compaction are the main drivers of fragmentation of soil structure over time (Boizard et al., 2002; Bronick and Lal, 2005; Díaz-Zorita et al., 2002; Mueller et al., 2009). Simulation models support this assertion; the model Sisol, considering only soil tillage and compaction, reproduced much of the dynamics of soil structure over time (Roger-Estrade et al., 2000). Repetitive and intensive soil tillage kills earthworms and therefore decreases evolution of soil structures due to bioturbation (Drees et al., 1994). In contrast, more attention should be paid to soil biodiversity and its effects on soil structure when designing more integrated agricultural management, including reduced or no-tillage (Bardgett and Cook, 1998; Brussaard et al., 2007; Mueller et al., 2009). Thus, earthworms are increasingly studied since their bioturbation influences soil structure more naturally and is one way to restore degraded soil structure and preserve soil functions such as root penetration and water infiltration (Capowiez et al., 2009b; Fonte et al., 2010; Lipiec et al., 2015; Syers and Springett, 1984).

Earthworm activity is commonly assessed by studying earthworm communities. Characteristics of earthworm communities (e.g. abundance, biomass, species richness, diversity, ecological group structure) are suitable indicators of agricultural practices and provide information about their potential impacts on soil quality (Paoletti, 1999; Ponge et al., 2013; Pérès et al., 2011). Nevertheless, these descriptors do not provide robust information about impacts of earthworms on soil physical properties, since relationships between earthworm community characteristics and the quantity of biostructures remain difficult to predict (Pérès et al., 2010; Blouin et al., 2013). This is because earthworm community characteristics represent only potential bioturbation at a given moment but not over time. Moreover, earthworm foraging and casting behaviours depend of intrinsic soil parameters (e.g. texture, moisture), climate conditions and soil organic matter availability or palatability (Butt et al., 2005; Jeanson, 1968; Lowe and Butt, 2002; Pérès et al., 1998). Therefore, it seems necessary to assess earthworm bioturbation using direct field estimates.

Until recently, only field methods were used to describe burrows or the deposit of casts at the soil surface (Mueller et al., 2009; Peigné et al., 2013; Pérès et al., 1998). Casts at the soil surface are an interesting indicator of earthworm activities; however, their presence varies strongly over time as they result from seasonal biological activities and are altered by seedbed preparation. Moreover, surface casts are limited to the activity of anecic species, which form only a part of earthworm communities. Therefore surface casts depict only a small part of the drilosphere (i.e. the sphere of influence of earthworms) compared to the high quantity of cast aggregates deposited in the soil (Lamandé et al., 2003; Whalen et al., 2004). For these reasons, Piron et al. (2012) investigated all recognisable features of earthworm bioturbation in the soil profile, thus distinguishing different types of burrows and casts according to the apparent age and welded state of cast aggregates, and developed a typology of seven Soil-Structure Patterns (SSP). The SSP method was developed to assess the real contribution of earthworm bioturbation to soil quality at the soil profile scale. Although relevant for research approaches, this method appeared unsuitable due to its complexity (11 patterns) and the time required to implement the method for routine assessment of bioturbation by agronomists when providing soil management advice (Piron et al., 2012). Currently, assessment methods based on soil profiles or on soil samples extracted with a spade lack rapid and objective biological criteria to complement VSSA (Ball et al., 2007; Roger-Estrade et al., 2000; Mueller et al., 2009). The assessment can be shortened, as in the "profil cultural" method, whose description of soil structure focuses on the type of porosity within soil fragments (porosity visible to the naked eye) and generates three types of porosity (type Δ, with high bulk density; type Γ, resulting from agglomeration of small soil aggregates; and type Φ, which are Δ clods in which cracks have appeared due to weathering) without considering biological activity (Roger-Estrade et al., 2004). Consequently, although earthworms are important in restoring soil macroporosity by digging macropores after a soil compaction event (Capowiez et al., 2012), this method does not differentiate between the two Δ states with or without burrows. This results in an excessively severe assessment of soil structure under no-tillage, in which vertical pores have a major influence on the dynamics of soil structure and play an important role in soil functioning and root access to the subsoil (Ehlers et al., 1983; McKenzie et al., 2009; Peigné et al., 2013). Integrating a bioturbation indicator into VSSA appears necessary to describe the influence of earthworm bioturbation on soil-structure dynamics and to better predict consequences of earthworm activity on soil structure, plant growth, and hydric properties.

This study developed field indicators of earthworm bioturbation to improve visual assessment of soil structure. To this end, we described patterns using the SSP method. First, we applied the SSP method to three soil tillage treatments to assess the suitability of its typology to classify soil structure at the soil-profile scale. Second, we observed patterns within morphological units (MU), which are zones with a homogeneous soil structure according the "profil cultural" method. From these observations, different "types of bioturbation" were differentiated and used to assess different MUs of several agricultural management practices at two French experimental sites. We discuss the relevance of these "types of bioturbation" to form bioindicators of earthworm activities and to improve assessment of soil structure.