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Functional role of microarthropods in soil aggregation

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ABSTRACT

Soil aggregation has received a lot of attention in the last years; however, the focus was mostly on soil microorganisms or larger soil fauna, especially earthworms. The impact of the large group of microarthropods, e.g. Collembola and Acari, is nearly unknown and hence underrepresented in the literature. Here we propose and discuss potential direct and indirect mechanisms of how microarthropods could influence this process with the focus on collembolans, which are in general a relatively well studied taxon. Indirect mechanisms are likely to have larger impacts on soil aggregation than direct effects. The variety of indirect mechanisms based on the provision of organic material like fecal pellets, molts and necromass as food source for microorganisms is high and given available evidence we propose that these mechanisms are the most influential. We highlight the need for overcoming the challenges of culturing and handling of these animals in order to be able to design small scale experiments and field studies which would enable us to understand the role of the different functional groups, their interaction with other soil fauna and the impact of land use practices on soil aggregation.

Introduction

Soil structure plays a critical ecosystemic role in biogeochemical processes (e.g. Jastrow, 1996), water infiltration, gas exchange efficacy, and resistance against erosional loss, and influences the performance of soil biota, including roots (Oades, 1984; Miller and Jastrow, 1992; Hartge and Stewart, 1995; Rillig and Mummey, 2006). Soil structure is often referred to as the arrangement of different macro- and microaggregate size fractions (organic/mineral complexes of >250 μm or <250 μm, respectively) and the corresponding pore spaces (Hartge and Stewart, 1995; Rillig and Mummey, 2006). In hierarchically structured soils, organic matter serves as the main binding agent to form and stabilize aggregates (Tisdall and Oades, 1982), but additionally, soil texture, soil microorganisms, roots, inorganic binding agents, the predominant environmental conditions, and the soil fauna are important for this process (Dexter and Horn, 1988; Rillig et al., 2015).

While soil fauna is generally acknowledged as being important for soil aggregation, direct empirical evidence is scarce for microarthropods, including mites and collembolans, the two most abundant and diverse groups. This is surprising given that these animals can occur at high densities, and given their role in the processing of organic matter via chemical, physical and biological mechanisms (Lee and Foster, 1991; Wolters, 2000). We are only aware of two studies that have experimentally quantified the impact of Collembola on soil structure (Siddiky et al., 2012a,b); these experimental data, however, revealed an effect size comparable to that of much more thoroughly studied soil biota, such as fungi. These experiments should be extended to the field as this might also be of agricultural interest.

Among the various groups of soil biota, especially the effects of mycorrhizal fungi, bacteria, earthworms, and termites have been studied intensely (e.g.; Lee and Foster, 1991; Oades and Water, 1991; Bossuyt et al., 2005; Pulleman et al., 2005; Rillig and Mummey, 2006; Velasquez et al., 2007). It is known that the excretion of e.g. polysaccharides by bacteria and the physical enmeshment of soil particles by fungal mycelia have a positive effect (see e.g. Lynch and Bragg, 1985; Oades, 1993; Tisdall, 1994b; Degens, 1997; Rillig and Mummey, 2006). Larger soil animals like earthworms and termites directly affect soil structure by their burrowing activities and by the digestion and excretion of relatively large amounts of organic material and soil particles, which might also lead to increased soil aggregation (e.g. Lee, 1985; Lee and Foster, 1991; Lavelle, 1998; or see review by Tisdall, 1994a,b; Six et al., 2004).

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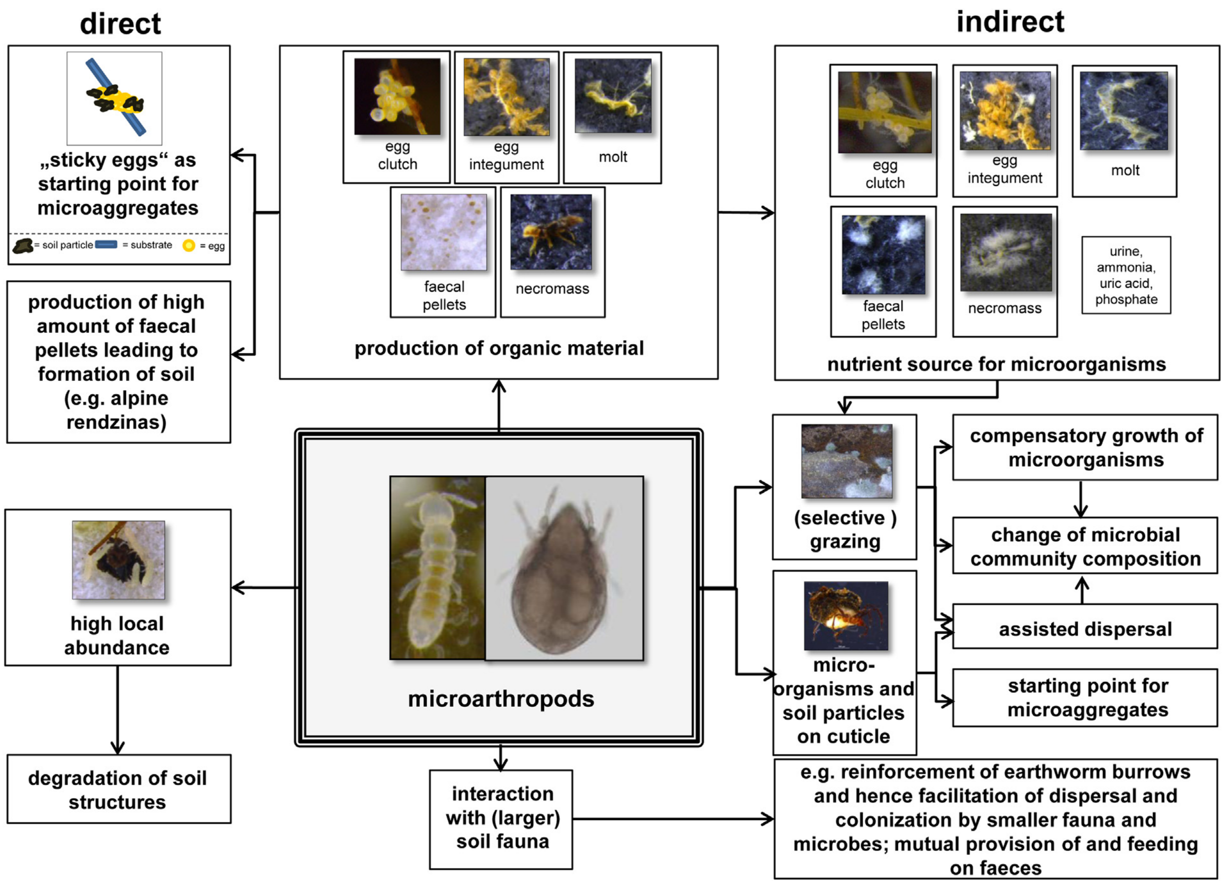

Fig. 1. Overview of potential mechanisms used by microarthropods for the formation of soil aggregates. Mechanisms are divided into direct and indirect processes and based on Collembola and oribatid mites as most abundant soil microarthropod representatives.

Given this striking asymmetry in our understanding of biotic contributions to soil aggregation, we here propose and discuss potential mechanisms for Collembola, which are also likely applicable to other soil microarthropods. We distinguish between direct and indirect effects (Fig. 1); however all the mechanisms we discuss would in reality take place simultaneously and in interaction with each other. As the collembolan *Folsomia candida* is very well studied, especially with regard to properties that might be involved in mechanisms of soil aggregation, we base our discussion mostly on this species, but we believe without much loss of generality.

Direct mechanisms

Direct effects of collembolans on soil structure can be categorized in terms of input of organic material, which positively contributes to soil structure, and degradation of aggregates, which is a negative effect.

Organic matter inputs

Possible positive, direct effects of collembolans on soil structure include the production, modification and movement of organic matter, which can then serve as binding agents, nuclei or building blocks for aggregates. Assimilated nutrients can either be contained in animal tissue or be excreted as metabolic waste. Especially because microarthropods can occur in high numbers, they might produce a large amount of fecal pellets. It has to be assumed that many soils contain millions of fecal pellets per square meter (Hopkin, 2007). In this context, Kubiena (1953) reports about the so-called ‘alpine pitch rendzinas’ on limestone which are nearly completely composed of collembolan feces forming a 15–20 cm deep black humus layer.

Collembolan eggs are deposited in clutches and need a couple of days to weeks to develop (Hopkin, 2007). Eggs of the collembolan family Sminthuridae might be covered by a mixture of soil and collembolan waste to protect them from mold and dehydration (Betsch-Pinot, 1976, 1977; Dallai et al., 2008). After hatching, the remaining egg integuments might serve as source of fresh organic material to microorganisms (which will be discussed in the paragraph about indirect mechanisms) or, due to the attached soil particles and organic material, as nuclei for microaggregate formation. Collembolans go through several instars, which might mean molting at fairly high rates. Most species molt throughout their whole life (up to 45 times). Specimens of *Folsomia candida* may live up to six months; however, for other species shorter or far longer (one year and longer) life-spans have been reported (Hopkin, 2007), which means that their production of molts could be significant. Interestingly, some oribatid mites can even survive for up to three years (Capinera, 2008). Their molts are hard-bodied due to chitin and other components in the cuticle (see Weigmann, 2006) and hence their breakdown should be slower, and thus they could serve as more long-lived building blocks of aggregates. Finally, the production of necromass especially in short-lived species besides fecal pellets, molts and eggs, can potentially influence soil aggregation. Unfortunately, there is no study dealing explicitly with the input of these types of organic material. Given the potentially high local abundances, this should clearly be a target of future research.