Earthworm, mycorrhiza and root interactions: their effects on some chemical, physical and biological soil properties

Roxane Kohler-Milleret[1], Claire Le Bayon[1], Sonia Tarnawski[2], Pascal Boivin[3], Jean-Michel Gobat[1]
[1]University of Neuchâtel, Institute of Biology, Laboratory Soil & Vegetation, CH-2009 Neuchâtel
[2]University of Neuchâtel, Institute of Biology, Laboratory of Microbiology, CH-2009 Neuchâtel
[3]University of applied science of western Switzerland, Laboratory of Soils and Substrates, CH-1254 Jussy

Abstract

The belowground communities include a large variety of soil organisms showing highly complex interactions. Among the great diversity of soil biota, plant roots, earthworms, and arbuscular mycorrhizal fungi (AMF) that form a symbiosis with plant roots, are key components. However, only few studies tried to assess the individual or interactive effects of these soil organisms on soil properties and how they influence plant growth. Two experiments have been performed in order to test the influence of the three organisms on soil chemical, physical and biological (bacterial community structure) properties). The chemical soil properties were mainly influenced by plant roots and AMF (increased phosphorus uptake by the roots), the physical properties by plant roots (greater structural stability) and earthworms (lower structural stability), and bacterial structures by all organisms. Generally, AMF positively affected shoot and/or root biomass whereas earthworms had no significant effect on plant growth.

Keywords: soil structure, plant biomass, phosphorus, soil organisms, interactions

Résumé: Interactions entre vers de terre, mycorhizes et racines: leurs effets sur quelques propriétés chimiques, physiques et biologiques du sol

Les communautés des êtres vivants dans le sol incluent une grande variété d'organismes qui sont liés entre eux par des interactions complexes. Parmi la grande diversité d'organismes du sol, les racines des plantes, les vers de terre et les champignons arbusculaires mycorhiziens (CAM) qui forment une symbiose avec les racines, sont des éléments clés. Cependant, il n'existe que peu d'études visant à estimer leurs effets individuels ou leurs interactions sur les propriétés du sol et leur influence sur la croissance des plantes. Deux expériences ont été menées afin de tester l'influence de ces trois organismes sur les propriétés chimiques, physiques et biologiques (structure des communautés bactériennes) du sol. Les propriétés chimiques ont été principalement influencées par les racines et les CAM (meilleures assimilation du phosphore par les plantes), les propriétés physiques par les racines (meilleure stabilité structurale) et les vers de terre (diminution de la stabilité), et les structure bactériennes par tous les organismes. Généralement, les CAM ont augmenté la biomasse des plantes alors que les vers de terre n'ont eu aucun effet.

1. Introduction

The belowground communities include a large variety of soil organisms showing highly complex interactions across trophic or non-trophic groups (COLEMAN 2008). Soil organisms have been recognized to contribute to a wide range of ecosystem services (BARRIOS 2007). They can modify soil physical structure and water regimes, enhancing the amount and efficiency of nutrient acquisition by the vegetation and improving plant health. Among the great diversity of soil biota, plant roots, earthworms, and arbuscular mycorrhizal fungi (AMF) that form a symbiosis with plant roots, are key components (SIX et al. 2002). However, only few studies tried to assess the individual or interactive effects of earthworms, AMF and roots, on soil properties and how they influence plant growth.

The objectives are consequently to assess separately and in combination the effects of endogeic earthworms (*Allolobophora chlorotica*), AMF (*Glomus intraradices*) and leek plants (*Allium porrum*) on some soil physical (soil macroaggregate stability, shrinkage analysis), chemical (nutrient content, mainly phosphorus) and biological (bacterial community structures) properties. The effects of earthworms and AMF on plant growth were in turn investigated.

2. Materials and methods

To reach these objectives, two experiments were designed. The first experiment was conducted in a climate chamber and used a compartmental design consisting of microcosms separated vertically into two parts with a nylon mesh to prevent the roots to pass through, but not AMF (Figure 1). The soil used was a loamy Anthrosol that was maintained under phosphorus (P) limited conditions in order to promote the AMF-root symbiosis. We measured soil structure through the percentage of water stable macroaggregates in the 1-2 mm size class ($WSA_{1\text{-}2mm}$), shrinkage analysis (e.g. bulk soil density and hydro-structural stability, see Milleret et al. *in press* for details), as well as available phosphorus in the soil, and bacterial genetic (16S rDNA-based DGGE) and functional (Biolog^{TM} Ecoplate) community structures.

The second experiment was performed in order to test whether the effects of the three organisms were different according to the P concentration in the soil. The design was similar to the previous experiment; except that it was conducted in a glasshouse and that P fertilization treatment was performed using 5mM KH_2PO_4. We focussed our measurements on available P. Moreover, in both experiment, biological interactions were assessed by measuring the effect of AMF and earthworms on shoot and root biomass.

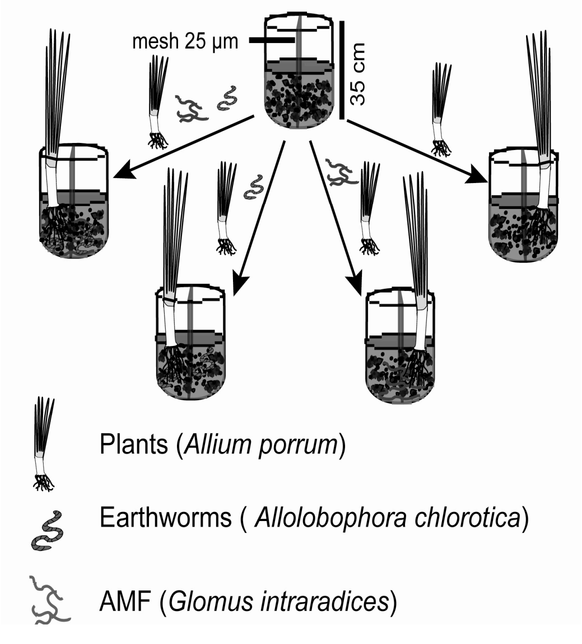

Figure 1 Experimental design of the experiments. Each microcosm received 4,5 kg of air-dried, sieved (2mm) soil (loamy Anthrosol) that was gamma-ray sterilized and re-inoculated with a filtered washings of initial soil before receiving three leek plantlets in one side. AMF and earthworms were then randomly introduced into the microcosms.

3. Results

Overall, the effects of AMF or earthworms on plant performance varied according to the experiments. AMF enhanced shoot and/or root biomass in the first experiment or had no effect in the second experiment, whereas earthworms had no significant effect on plant growth.

The effects of roots, AMF and earthworms on soil chemical, physical and biological properties are presented in Table 1. Chemical soil properties were mainly influenced by plant roots and AMF (MILLERET et al. 2009). Available P decreased in the presence of plant roots in the first experiment, but no difference with unplanted pots was measured in the second experiment. As for plant roots, AMF generally decreased P availability in the soil except in the second experiment. The effect of earthworms on chemical nutrient in the bulk soil was not significant, but drilosphere soil (the fraction of soil influenced by earthworms i.e. casts and burrow-linings) contained higher concentration of P.

Physical soil properties were mainly affected by plant roots and earthworms (MILLERET et al. *in press*). Plant roots improved soil structure by decreasing soil density and increasing soil stability. AMF did not significantly influenced soil structure but positively interacted with plant roots. Plants had therefore the greatest positive impact on soil structure, and AMF seem to have a positive synergistic effect by accentuating the plant root effects. Contrarily to plant roots, earthworms negatively affected soil structure, mainly by decreasing soil stability and increasing the bulk soil density (i.e. they increased soil compaction).

Biological properties, i.e. bacterial community structures, were affected by plant roots, AMF and earthworms, either directly in the bulk soil (AMF and plant roots) or indirectly via the drilosphere soil.

4. Discussion

Overall, results confirmed that earthworms, mycorrhizae and plant roots have various individual and interactive effects on soil properties.

The general effects of soil organisms on soil properties may be summarized as follow:

i. *Glomus intraradices* principally affects soil **chemical** properties by modifying the soil nutrient content, mainly decreasing the amount of available P in the surrounding soil

ii. *Allolobophora chlorotica* greatly influences soil **physical** properties by destabilizing the soil and increasing the bulk soil density *iii.* The roots of *Allium porrum* affect both **chemical and physical** soil properties by reducing the P availability in the bulk soil and by improving the soil structure

iv. The structure of the bacterial communities is affected by the three soil organisms

In conclusion, although we studied the relationships between only three soil organisms, we showed that biotic interactions occurring in the soil are highly complex. Moreover, the two experiments highlighted the importance of measuring physical and chemical soil parameters when studying soil organism interactions and their influence on plant growth. From this point of view, an integrated approach aiming at measuring the effects of biological processes (e.g. interactions between soil living organisms) and physico-chemical ones (e.g. shrinkage analysis) is widely encouraged and seem, according to our results, very useful and promising for future studies.

Table 1 Effects of roots, AMF, earthworms and their interactions on the chemical, physical and biological properties studied in the two experiments. ↑ or ↓: the response variable is significantly increased or decreased ($P < 0.05$) in the presence of the main factors (plant roots, AMF and earthworms). Yes: the response variable is significantly affected ($P < 0.05$) by the explanatory variables, but positive or negative effects cannot be described. Marginal effects ($P < 0.1$) are put into brackets; ns, not significant; -, not available.

Soil properties	Experiment	Response variable	Root	AMF	Worm	Root x AMF	Root x Worm	AMF x Worm
Chemical	1	Available P	↓	↓	ns	yes	ns	ns
	2	Total P	(↓)	(↓)	ns	ns	ns	(yes)
		Organic P	↓	ns	ns	ns	(yes)	ns
		Available P	ns	ns	ns	ns	ns	(yes)
Physical	1	$WSA_{(1-2\ mm)}$	↑	ns	↓	yes	ns	ns
		Bulk soil density	↓	ns	↑	yes	-	-
		hydro-structural stability	↑	ns	↓	-	-	-
Biological	1	DGGE	yes	ns	ns	yes	ns	ns
		Biolog™ Ecoplate	yes	yes	ns	yes	ns	yes

5. References

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