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Contrasted effect of biochar and earthworms on rice growth and resource allocation in different soils

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ABSTRACT

Adding biochar to soils and maintaining high earthworm biomasses are potential ways to increase the fertility of tropical soils and the sustainability of crop production in the spirit of agroecology and ecological engineering. However, a thorough functional assessment of biochar effect on plant growth and resource allocations is so far missing. Moreover, earthworms and biochar increase mineral nutrient availability through an increase in mineralization and nutrient retention respectively and are likely to interact through various other mechanisms. They could thus increase plant growth synergistically. This hypothesis was tested for rice in a greenhouse experiment. Besides, the relative effects of biochar and earthworms were compared in three different soil treatments (a nutrient rich soil, a nutrient poor soil, a nutrient poor soil supplemented with fertilization). Biochar and earthworm effects on rice growth and resource allocation highly depended on soil type and were generally additive (no synergy). In the rich soil, there were both clear positive biochar and earthworm effects, while there were generally only positive earthworm effects in the poor soil, and neither earthworm nor biochar effect in the poor soil with fertilization. The analysis of earthworm and biochar effects on different plant traits and soil mineral nitrogen content, confirmed that they act through an increase in nutrient availability. However it also suggested that another mechanism, such as the release in the soil of molecules recognized as phytohormones by plants, is also involved in earthworm action. This mechanism could for example help explaining how earthworms increase rice resource allocation to roots and influence the allocation to grains.

1. Introduction

Managing soil fauna (especially earthworms Lavelle et al., 2001) and biochar applications (Lehmann et al., 2003c; Glaser, 2007) are often proposed as appealing ways to increase the fertility of tropical soils in a sustainable way. Indeed, tropical soils are often poor in organic matter (Tiessen et al., 1994) and tend to have low cation exchange capacitites (Glaser, 2007) and both earthworms and biochar influence soil organic matter dynamics, the release of mineral nutriments and their retention. While studying the effect of biochar on plant growth is a fairly new field of researches (Lehmann and Rondon, 2006; Steiner et al., 2008; Blackwell et al., 2009), effects of earthworms on plant growth is an old field. Nevertheless, this issue has mostly been addressed in terms of biomass accumulation and more seldomly in term of resource allocation (Scheu, 2003; Laossi et al., 2009). Our study aims at meeting this need and particularly at determining the effect of biochar and earthworms on plant resource allocation and at infering the underlying mechanisms. Moreover, comparing biochar and earthworm effects that influence soil properties and plant growth partially (and only partially) through the same mechanisms, should throw new lights on this broad subject.

The application of biochar, i.e. incompletely combusted organic matter, (Glaser et al., 2002; Lehmann et al., 2003c) is historically not a new practice. It has re-emerged after the study of the Terra Preta do Indio, which are highly fertile soils (Lehmann et al., 2003c). These soils were created by Amerindian populations in

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pre-Columbian times (Glaser et al., 2002). Apart from high SOM contents, the most striking feature of Terra Preta, is their high nutrient content (Glaser, 2007). This suggests that creating modern Terra Preta could be a way to increase tropical soil fertility and to maintain higher soil carbon stocks, thus mitigating the current rise in atmospheric CO_2 (Marris, 2006). Biochar can enhance long-term soil fertility through several mechanisms. The polycyclic aromatic structure of biochar makes it chemically and biologically stable, allowing it to persist in the environment for centuries (DeLuca et al., 2006). Besides this remarkable chemical structure, biochar has a porous physical structure which leads to very large surface area (Lehmann and Rondon, 2006). This increases the soil cation exchange capacity as well as its capacity to retain dissolved organic matter (Lehmann and Rondon, 2006). Moreover, biochar modifies the community of soil microorganisms as well as their activity, probably because it provides a suitable habitat for them (Pietikäinen and Fritze, 2000). This is likely to improve directly and indirectly plant growth (Reynolds et al., 2003; Marris, 2006).

Maintaining high biomasses of earthworms would be another sustainable way to increase tropical soil fertility (Lavelle et al., 2001). Two reviews about the effect of earthworms on plant growth (Brown et al., 1999; Scheu, 2003) showed that plant shoot biomass is higher in the presence of earthworms (70–80% of the reviewed experiments). Five mechanisms have been shown to be involved in these positive effects (Brown et al., 2004a): (1) increased mineralization of soil organic matter therefore increasing nutrient availability; (2) production of plant growth substances via the stimulation of microbial activity; (3) biocontrol of pests and parasites; (4) stimulation of symbionts and (5) modification of soil porosity and aggregation which induces changes in water and oxygen availability to plants.

Manipulating earthworms and soil content in biochar are two ways to manipulate soil fertility in the spirit of agroecology and ecological engineering. Indeed, in the two cases, soil physico-chemical and biotic characteristics are modified interactively through ecological processes, which could allow a more parsimonious use of industrially produced fertilizers. Biochar and earthworms influence plant growth through mechanisms that are partially the same: they both change soil structure and soil microbial community (Pietikäinen and Fritze, 2000; Brown et al., 2004a) and influence nutrient cycling. While, earthworms increase organic matter mineralization on the short term (Scheu, 2003; Brown et al., 2004a), biochar increases the retention of mineral nutrients (Lehmann and Rondon, 2006) which decreases lixiviation and is likely to increase nutrient availability on the long term (Lehmann and Rondon, 2006; Lehmann et al., 2006). Finally, biochar and earthworms have been shown to directly interact: earthworms ingest biochar particles and reject them in their casts, which is likely to influence biochar distribution in the soil profile (Topoliantz and Ponge, 2003; Topoliantz et al., 2005, Van Zwieten et al., 2009). Therefore, we hypothesize that earthworms and biochar interact in the ways they influence plant growth. To test this hypothesis and to compare the respective effect of earthworms and biochar we investigated, in a greenhouse microcosm experiment, the effects of earthworms (*Pontoscolex corethrurus*) and biochar on rice growth (*Oryza sativa*).

It has already been shown that earthworm effects on plant growth change with soil type (Doube et al., 1997; Wurst and Jones, 2003; Brown et al., 2004a; Laossi et al., 2010) but the effect of biochar on plant growth across different soil types has never been directly studied. Therefore, in the present work, each treatment (eathworm and biochar) was implemented in three different soil treatments: two unfertilized soils of contrasted fertility, and the lower-fertility soil supplemented with mineral fertilizer. Assessing the responsiveness of crops to biochar and earthworms in different soils and according to agricultural practices is indeed required to determine where and when using biochar and earthworms improves crop sustainability. This should also help infering the underlying mechanisms (Blouin et al., 2006; Laossi et al., 2010).

Finally, the effect of earthworms and biochar on total plant biomass production has been studied much more than their effects on plant resource allocation. We thus also analyzed the way earthworms and biochar influence the allocation to seeds, roots and shoots, root system architecture and allocation of nitrogen. This is for example useful to determine whether earthworms and biochar increase crop yield (here, the total grain biomass) or only increase the accumulation of vegetative biomasses. This should also give insights on the mechanisms through which earthworms and biochar influence plants. Altogether, the following questions were specifically addressed: (1) What is the relative impact of biochar and earthworms on rice growth? (2) Do soil types and tretaments cause changes in rice responsiveness to earthworm and biochar? (3) Do earthworms and biochar interact in the way they influence rice growth? (4) In which way earthworms and biochar modify resource allocation in rice plants?

2. Materials and methods

2.1. Experimental design

The experiment was conducted at CIAT (Centro Internacional de Agricultura Tropical) greenhouses in Cali, Colombia. Plants were submitted to the four possible combinations of two factors, each one determined by the presence/absence respectively of earthworms and biochar. All the following treatments combinations were implemented in three soils treatments (see below): biochar x earthworms (BE), biochar (B), earthworms (E) and control (C) and five replicates were implemented for each treatment combination, resulting in 60 microcosms. Rice was grown in greenhouses for three months under controlled conditions: relative humidity = 65–95%, temperature = 27–29 °C, light intensity = 600 μmol $m^{-2}\,s^{-1}$ and a 12 h photoperiod.

2.2. Microcosms

Containers (microcosms) consisted of PVC pots (diameter 10 cm and 15 cm height). They were filled with 900 g of sieved (2 mm) dry soil. Drains at the bottom of pots were covered with 1 mm plastic mesh to prevent earthworms from escaping. Soil was maintained at 80% soil field capacity (checked through regular weighing of the pots).

Microcosms were arranged in a completely randomized design. The soil was collected in July 2006, during the rainy season, from two long-term field experiments that aimed at comparing plant production in plots with and without the addition of biochar: (1) an experiment on coffee that was established in 2004, in the Andean hillsides of the Cauca Department, south-western Colombia (Pescador, 2° 48′N 76° 33′ W), (2) an experiment on grass and corn production that was established in 2002 (Matazul, 4°19′N, 72°39′W in the Colombian Eastern Plains, Llanos). Soil was collected in the control treatments of these experiments for our microcosm treatments without biochar, and from their biochar treatments for our microcosm treatments with biochar. The rate of biochar application was respectively 25.5 and 45.5 g of biochar per dry kg of soil for "Pescador" and "Matazul" in the 0–10 layer. Since we collected the soil from the same layer, these rates also correspond to the rates of biochar application in our microcosms. In the two cases, biochar was ground mechanically to pass through a 5 mm mesh. For Pescador, biochar was produced from logs of *Eucalyptus deglupta*: temperature was maintained at 350 °C and the oxygen level at 15%,