Microbial properties and carbon dynamics in a heterogeneous soil landscape under different cropping systems and fertilizer regimes

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Abstract

In order to reveal impacts of different cropping systems and fertilizer regimes on soil microbial properties and carbon dynamics, plots with 10 years of mono-cropping maize and rye were compared in a traditional field trial. Additionally, a more complex long-term field experiment was initiated, resembling typical periglacial landscape features with different soils, cropping systems and fertilizer regimes, and were firstly characterized for soil ecological conditions. After 10 years of mono-cropping, evidence was provided for unchanged soil organic matter and nitrogen contents but differences of organic matter content in several soil fractions. Carbon turn-over of different substrates in the mono-culture rye system was more intense compared to the maize system. Soil microbial properties did not differ significantly after ten years of mono-culture, however, evidence for differences in bacterial community composition were revealed. Further studies will be conducted to reveal interrelations between cropping systems, organic matter application to soil, soil organic matter fractions, microbial activities, and carbon turn-over.

Key Words

Microbial biomass, CO_2 respiration, microbial communities, rye, maize, fermentation slurry

Introduction

Crop management practices are known to determine the quantity and quality, as well as seasonal and spatial distribution of plant residues entering soil. Consequently, several scenarios of land use change are well studied in this respect, e.g., carbon fluxes after land use change from cropland to grassland (Alberti *et al*., 2006). Especially for systems of cropping energy plants, which are fast-growing crops planted for the specific purpose of producing energy from all or parts of the resulting plant, rarely any studies do exist about the impacts on soil carbon dynamics (Ma *et al*., 2000). Therefore, combined studies of soil microbial properties (biomass, activity, structure) and pools of soil organic matter (SOM) are performed in systematic field trials, comparing different cropping systems and fertilizer regimes. Our study is intended to contribute knowledge for understanding the impact of land use management on soil carbon dynamics by detailed soil microbiological and chemical analyses.

Methods

First exploratory studies were conducted on traditional field trials located at ZALF Research Station Dedelow, NE Germany, providing 10-years of mono-cultures of maize and rye considered to decrease or sustain SOM content in the long-term, respectively. Subsequently, a long-term field experiment (CarboZALF-D, Dedelow) was initiated in 2009, resembling typical periglacial landscape features and a range of different soil types and soil properties, and were firstly characterized for soil ecological "starting conditions" (2009: completely under maize). At the beginning of the 2010 vegetation period, 14 experimental field plots will be analysed providing variants of soils (Luvisol, Kolluvisol), cropping systems (wheat *vs*. energy maize), and fertilizer regimes (100% mineral fertilizer, 50% to 50% mineral fertilizer and biofermentation slurry, 100% slurry).

Soil microbial biomass (C_{mic}) was determined by a substrate-induced respiration method (Anderson and Domsch, 1978) at 20°C using an automated infrared gas analysis system (Heinemeyer *et al*., 1989). Soil *basal* CO_2 *respiration* was measured hourly under continuous aeration of the samples, using the automated infrared gas analysis system over a period of at least 8 up to 18 h at 20°C. The *ecophysiological quotients* qCO_2 and C_{mic} / C_{org} ratio were calculated. *Bacterial, fungal and actinomycetal contributions to soil microbial biomass* were determined by phospholipid fatty acid analysis (Frostegard *et al*., 1993; Maassen *et al*., 2006). The *bacterial community composition* was analyzed using terminal restriction fragment length polymorphism of 16S rRNA genes (Ulrich and Becker, 2006).

The *content and the composition of soil organic matter* were analysed in two steps: firstly, coarse organic particles were separated from soil samples in four replications by using electrostatic attraction of a charged glass surface (Kaiser *et al*., 2009). Subsequently, dry weight per kg soil was estimated. In the second step, physically unbounded, macro-aggregate and micro-aggregate occluded organic particles, as well as water-soluble OM fractions were sequentially separated by a combination of ultrasonic treatment, density separation, sieving, and water extraction. *Carbon mineralization dynamics* were investigated under laboratory conditions in soil samples from the maize and rye cropping systems using ^{14}C-labelled maize and rye root substrates. For this purpose a continuous-flow incubation device (microcosm) was constructed, as described by Chen *et al*. (2009).

Results

Studies on field trials at ZALF Research Station revealed soil carbon and nitrogen contents that were not different after 10-years monoculturing maize and rye. Correspondingly, the content of soil microbial biomass under mono-cultures of maize and rye (97 and 100 µg C_{mic} g^{-1} soil, respectively) did not differ. Furthermore, soil basal respiration was 0.11 and 0.13 µg CO_2-C g^{-1} h^{-1} under maize and rye, respectively, also without a significant difference. However, the mineralization rates of ^{14}C-plant residues *in vitro* were two times higher in soil from the rye system compared to soil from the maize system (Figure 1). During 26 days of incubation, 22% and 44% of added ^{14}C-substrates were mineralized in soils from maize and rye systems, respectively.

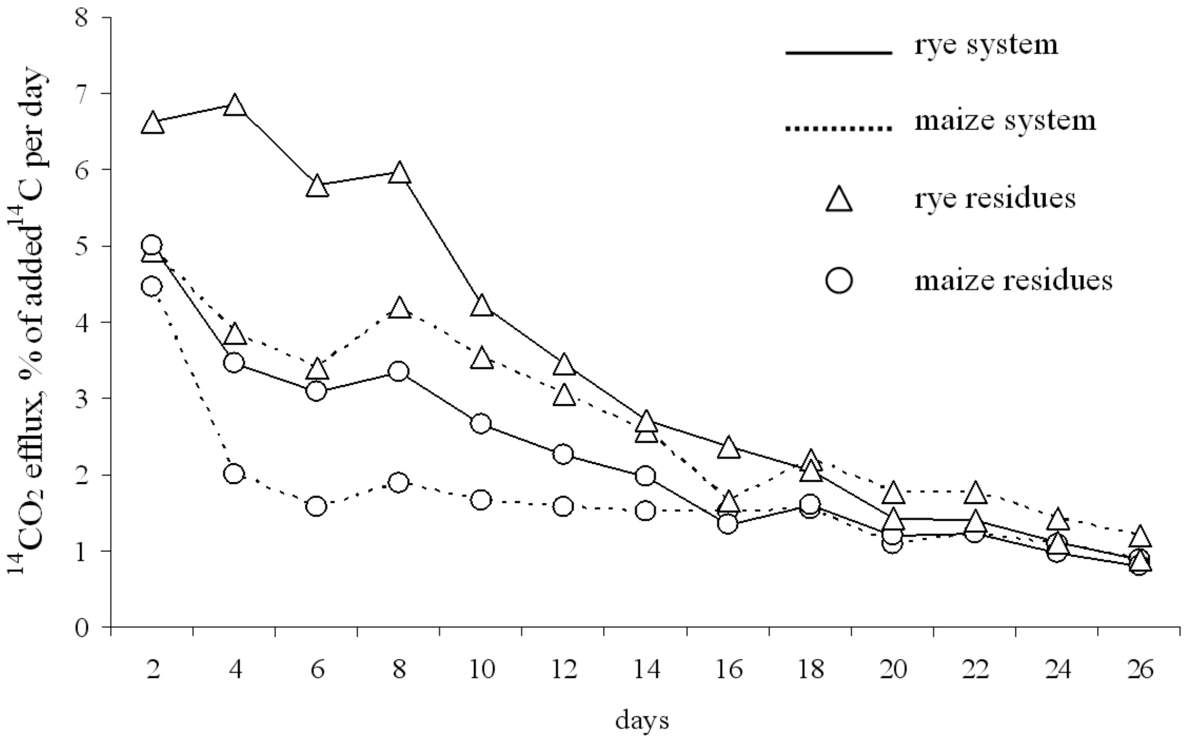

Figure 1. Mineralization rates of ^{14}C-labelled, rye and maize roots residues in soils from rye and maize mono-cropping systems.

Particulate organic matter content derived after water extraction was about by two times higher in soil under mono-culture rye compared to soil under maize. The highest amount of SOM was extracted from soil micro-aggregates in the maize cropping system, while the amounts of SOM extracted from macro-aggregates as well as water-soluble fractions were similar in soils under maize and rye cropping systems. Overall, the highest significant differences in organic matter content in soils under maize and rye cropping systems were found in fractions obtained by ultrasonic dispersion of soil micro-aggregates. Concerning microbial community composition (fungi, bacteria, actinomycetes), results from bacterial community analyses revealed differences in variants, most clearly for the maize versus the rye and rotation systems – but mixed clusters were also present.

Conclusion

From our studies on traditional field trials we can conclude, I) soil organic matter contents did not differ after 10 years of mono-cropping maize and rye, but differences of SOM contents in soil fractions were detected. II) Carbon turn-over of different substrates in the mono-culture rye system was more intense compared to the maize system. III) Soil microbial properties did not differ significantly after ten years of mono-culture, however, evidence for differences in bacterial community composition was detected. Further studies are required to reveal interrelations between land use, soil organic matter fractions, microbial activities and carbon turn-over. For this reason, a new long-term field experiment (CarboZALF-D, Dedelow, NE Germany) was initiated, resembling typical periglacial landscape features and a range of different soil types and soil properties. Different cropping systems and fertilizer regimes will be established in 2010 and consecutively studied.

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