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Effects of bioenergy crop cultivation on earthworm communities—A comparative study of perennial (*Miscanthus*) and annual crops with consideration of graded land-use intensity

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ABSTRACT

Energy crops are of growing importance in agriculture worldwide. This field study aimed to investigate earthworm communities of different intensively cultivated soils during a 2-year period, with special emphasis on annual and perennial energy crops like rapeseed, maize, and *Miscanthus*. These were compared with cereals, grassland, and fallow sites. Distribution patterns of earthworm abundance, species, and ecological categories were analysed by constrained ordination procedures (redundancy analysis; CANOCO) using a set of environmental variables as predictors, such as CN value of harvest residues, SOC and N_t content, soil pH, soil texture, and land-use intensity. The latter was determined by principal component analysis using average soil coverage and intensity of tillage, weed control, and fertilisation as input variables. It was clearly found that land-use intensity was the dominant regressor for earthworm abundance and total number of species. The diversity of earthworm communities was especially enhanced and showed a more balanced species composition in extensively managed soils under grassland, fallow, and *Miscanthus*. For the total number of species, *Miscanthus* (5.1 ± 0.9) took a medium position and neither differed significantly from intensively managed rapeseed (4.0 ± 0.9), cereals (3.7 ± 1.1), and maize sites (3.0 ± 1.4), nor from grassland (6.8 ± 1.5) and fallow (6.4 ± 1.0) sites. Total earthworm abundance ranged between 355 (±132) and 62 (±49) individuals m^{-2} in fallow and maize sites, respectively.

Interestingly, *Miscanthus* had quite positive effects on earthworm communities although the CN value of harvest residues was very high. It is recommended that *Miscanthus* may facilitate a diverse earthworm community even in intensive agricultural landscapes.

1. Introduction

Fossil energy is replaced increasingly by renewable resources, e.g. through the cultivation of energy crops. In particular rapeseed for biofuel production and maize as co-ferment for biogas production have been developed as locally dominant crops in Germany (Kruska and Emmerling, 2008). Perennial crops intended for solid fuels were merely cultivated on less than 0.2% of the total arable land used for the production of renewable resources in Germany (FNR, 2011). At this, C4-grasses of the genus *Miscanthus* with cultivation periods up to 25 years received considerable attention in the past decades due to the high aboveground yield potential and relatively low requirements regarding soil tillage, weed control, and fertilisation (Boelcke et al., 1998; Clifton-Brown et al., 2008; Kahle et al., 2001).

Critical aspects of an enhanced bioenergy crop production are often related to a reduced production of food crops (Muller, 2009). Because food production is indispensible for life, sustainable bioenergy production is claimed to maintain soil quality of arable land, even for future generations (KBU, 2008). This demand has often been related to physical (e.g. soil erosion) and chemical (e.g. C-sequestration) soil properties. Preservation and promotion of ecological soil functions, such as livelihood and habitat for plants, animals and soil organisms, water- and nutrient-cycles and buffer capacity against pollutants, which are strongly related to agrobiodiversity, are also stated objectives (Rowe et al., 2009). Owing to the characteristics of the *Miscanthus* cropping system outlined above, *Miscanthus* seems promising to fulfil several demands in the context of sustainable agricultural land-use.

Earthworms (Lumbricidae) are termed ‘ecosystem engineers’ by reason of their key role in modifying the soil environment (Chan, 2001; Lavelle et al., 1997) and therefore are regularly used as bioindicators. Their contribution, e.g. to the formation of soil macropores, which can modify soil aeration and water infiltration, stable and nutrient-rich soil aggregates, as well as to organic

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matter breakdown is well researched and generally accepted (e.g. Bastardie et al., 2005; Edwards and Bohlen, 1996; Jouquet et al., 2008; Lee, 1985). By this, they crucially affect further soil organisms, e.g. soil micro-flora and related enzyme activities (Ernst et al., 2009b).

Various studies have been focused on the effects of annual crops, such as maize, rapeseed and cereals, on the abundance and species number of earthworms, due to differences within the respective cropping system (e.g. quantity and quality of nutrient-inputs, soil tillage) (e.g. Binet et al., 1997; Ernst and Emmerling, 2009; Pérès et al., 2010; Schmidt et al., 2001; Simonsen et al., 2010). Even earthworm populations of grassland, pasture and fallow sites have been studied (e.g. Curry et al., 2008; Emmerling, 2001; Pižl, 1992; van Vliet et al., 2007). In general, earthworm populations are more abundant and species-rich in undisturbed habitats compared to arable land (Chan, 2001). Besides the studies of Kohli et al. (1999) and Semere and Slater (2007), reports of general effects of perennial *Miscanthus* on biota are scarce and in particular long-term effects on earthworm communities have yet not been described. Additionally, no comparative study, which directly compares several annual and perennial bioenergy crops within an enclosed geographical area, is available.

The aim of the present study was (i) to characterise *Miscanthus* crops by their intensity of land-use compared to fallow, grassland, cereals, maize, and rapeseed sites and (ii) to investigate earthworm biodiversity as indicated by the total number of species, the abundance within ecological categories (according to Bouché, 1977), and the species composition of populations in soils from the different kinds of land-use during a 2-year investigation period in 2009 and 2010. It is hypothesised that soils of more extensively (e.g. in terms of reduced tillage, fertilisation, weed control) cultivated renewable resources may also be characterised by a higher biodiversity of earthworm populations compared to conventional food- and bioenergy-crops, respectively, and therefore seem to be particularly promising to preserve and promote ecological functions in soil.

2. Materials and methods

2.1. Study area

The study area *Kenner Flur* is situated north-eastern of the city of Trier, Rhineland-Palatinate, Germany (49°48′39.46″N, 6°43′12.58″E). It is a predominantly agricultural used lower terrace of the river Moselle, located at 125 m above sea level without appreciable differences in altitude. Relative relief is 3.5 m by a north–south expansion of 1.8 km and east–west expansion of 2.5 km (Weidenfeller, 1990). Mean annual temperatures were 10.7 °C and 9.7 °C with annual precipitations of 800 mm and 690 mm in 2009 and 2010, respectively (long-time means of the years 1997–2010: 10.5 °C, 761 mm; agricultural meteorological station Trier-Riol).

2.2. Investigated crops and land-use history

Wheat (*Triticum aestivum*), rye (*Secale cereale*) and triticale (×*Triticosecale*) represented the most commonly cultivated cereals at the study area. They were summarized as ‘cereals’. While maize (*Zea mays*), rapeseed (*Brassica napus*) and cereals were cultivated by crop rotation, *Miscanthus* is a perennial grass with cultivation periods up to 25 years which is mainly used as solid fuel for combustion. The considered crops of *Miscanthus* × *giganteus* were planted in 1995. Additionally, grassland (used for forage-production; occasionally directly used as pasture) and fallow sites were investigated for comparative purposes. Grassland existed for almost 200 years at the sampling sites (LV, 1968), whereby soils were affected by river training during the early sixties of the last century (Weidenfeller, 1990). The fallow sites were located on former cereal fields and were set aside 20 years before.

2.3. Sampling sites

The earthworm sampling sites for a respective crop were defined as sites, where the crop was cultivated during the past cultivation period, and thus earthworm communities had completed one whole cycle of soil tillage, weed control and fertilisation at each site. In addition, crop residues were tilled into the soil after harvest (cereals, rapeseed, and maize; Table 1) and hence could serve as a main food source. The sampling sites per crop were randomly dispersed and were either located on the same or on different arable fields (Table 1). The minimum distance between close-by sites was 20 m.

2.3.1. Environmental variables of sampling sites

Earthworm communities might be affected by a number of abiotic factors. Besides the management variables *soil tillage*, *weed control*, *fertilisation* and *soil coverage*, that best characterised the differing intensity of land-use, we investigated typical physical and chemical parameters of sampled soils and harvest residues. Each sampling site ($n = 60$) can therefore be characterised by several variables presented in Table 1. A detailed description of management variables and appropriate classifications is presented additionally.

Soil samples (0–15 cm depth; $n = 10$ per crop) for the determination of *pH*, organic carbon (C_{org}) and total nitrogen (N_t) were taken as pooled samples in the range of 1 m around each earthworm sampling site. Plant residues of each crop (pooled sample; consisting of, e.g. leaves, shoots, roots, maize-cobs) were collected subsequent to the harvest from the soil surface to determine the C:N ratio of harvest residues (CN_{hr}). Soil samples were sieved (2 mm mesh size), air-dried, finely grounded and oven-dried at 105 °C. Plant material was dried at 60 °C and ball-milled. Total carbon and nitrogen contents of soil and harvest residues were determined by EuroEA 3000 elemental analyser (HekaTech, Wegberg, Germany). In the case of calciferous soils a total organic carbon analyser (TOC-V_{CPN}, Shimadzu, Duisburg, Germany) was used.

Soil texture and soil types of the sampling sites were withdrawn from the work of Weidenfeller (1990). In general, soils of the study area were characterised by loamy sands and sandy loams. Soil types according to World Reference Base for Soil Resources (IUSS, 2006) were Hortic Anthrosol, Stagnic Luvisol, Fluvic Cambisol, Fluvic Cambisol (Calcaric), Haplic Fluvisol, Haplic Fluvisol (Calcaric), Stagnic Fluvisol, and Haplic Luvisol (Table 1).

At the study area, available field capacity of soils only ranged on a high to very high level (170 to >230 mm). Since no considerable gradient of water supply existed within soils, this variable was not taken into account for further statistical analysis.

2.3.2. Earthworm collecting

Earthworm collecting occurred prior to the first incidence of ground frost in late autumn 2009 and 2010, respectively, to take into account the temporal variability of earthworm populations. Within both single sampling years, each crop was sampled in five-fold replication ($n = 10$ for both years) by a combination of hand-sorting and chemical extraction. A soil monolith of $0.25\ m^2 \times 20$ cm depth was separated from the surrounding soil and carefully searched through for earthworms. Deep living endogeic and anecic species were extracted by use of Allyl isothiocyanate (AITC) as chemical expellant (Zaborski, 2003). As AITC is not readily water-soluble, 800 μl were emulsified with 16 ml methyl alcohol (CH_4O). The dilution was given to 10 litres of water on the verge of sampling and was finally poured into the pit from which