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Dynamic of nematode communities in energy plant cropping systems

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ABSTRACT

The perennial cropping system of the cup plant (*Silphium perfoliatum*) might counteract major drawbacks of intensively managed annual biomass production systems due to a long-term reduction of agricultural management. In this context, the ecological value of the cup plant was assessed for free-living soil nematodes to reveal changes in soil biodiversity and functions associated with cultivation period length. For this purpose, cup plant fields from a chronosequence were sampled in two consecutive years and compared to energy maize production systems. Nematodes were identified on a family level and assigned to feeding guilds. General and nematode-specific diversity indices, as well as multivariate redundancy analysis were used to assess changes in community structure. General mixed-effects modeling and multi model averaging were applied to reveal the influence of cultivation period length and environmental factors on nematode assemblages. Major changes were found in almost all trophic groups. In the long-term, abundances of herbivores, fungivores and carnivores increased along with total nematode abundance. Bacterivores remained almost unchanged, but decreased in dominance. Old cup plant fields (8+ years) showed mass occurrences of *Helicotylenchus* spp.. In cup plant fields, facilitation of fungal decomposer channels and top-down regulation within the nematode food web could improve soil fertility and soil quality. However, long-term dynamic of the nematode community was not indicative of succession and remained characteristic for agroecosystems, hence positive effects are presumably restricted to conversion of farmed land.

1. Introduction

Perennial energy crops are on the way to become a keystone in environmentally friendly production of biomass. Since the rapidly growing sector of biomass production for energy purposes has expanded traditional food, feed and fiber production, the importance of land use will increasingly change for future generations [1]. Balancing the trade-offs between productivity and sustainability is probably one of the biggest challenges in light of climate and demographic change [2,3]. Agriculture has to provide food security as well as tap its full potential in sparing of natural capital, i.e., protection of biodiversity and ecosystem services [1]. However, to account for a considerable amount of the world's primary energy demand, biomass production must expand and/or take over a major share of existing cropland [4]. Competition with food and fiber production seems to give rise to a major drawback in the issue of climate change mitigation as well as biodiversity conservation: conversion of semi-natural land and agricultural intensification [4]. The question of where and to what extent energy crops should be cultivated depends not least on crop type [5].

Today an alarming large share of land used for bioenergy production is cropped with maize (*Zea mays*) [6,7]. Germany is a pioneer in the sector of renewable energy generation. Since the German renewable energy law came into force, the area of annual silage maize for biomass production reached 900 × 10^3 ha, accounting for 35% of the total maize acreage in 2014 [8]. Also, productivity of maize can easily be enhanced through intensification of the management regime. However, from an ecological perspective, large areas cropped with maize bear high risks for a decline in ecosystem services and respective biodiversity [9,10]. All agriculture depends on fertile soils and the ecosystem services provided by the biological processes therein. Hence, consideration of soil biodiversity is an inevitable part in the long lasting challenge for a sustainable energy supply from bioenergy crops [11].

The cup plant (*Silphium perfoliatum* L.) is a promising candidate among perennial energy crops to counteract the negative effects of large scale biomass production from maize. The cup plant

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implicates several ecological and agronomical advantages like a late flowering period, permanent ground cover and a long productive lifetime of at least 10 years. The management regime is reduced after the first two years, then weed management is abandoned since the cup plant is able to suppress competing plants. No tillage takes place throughout the cultivation period. It has been suggested that the cup plant will yield biomass and biomethane at amounts competitive to maize, if breeding and optimization of the cultivation process are done [12,13]. Positive implications for agrobiodiversity have already been observed [14,15]. Earthworm communities increased in deep burrowing, anecic species in the long-term, improving water infiltration and erosion-resistance. Furthermore, an increase has been discovered in earthworm functional- and species-diversity [14].

Nematodes offer outstanding properties in their use as indicators of soil condition and soil functions [16,17]. They are abundant as well as functionally and taxonomically diverse in almost every habitat of the world. They typically comprise eight trophic groups [18], of which five are frequently found and can easily be identified: bacterivores, fungivores, obligatory plant parasites, predators (= carnivores) and omnivores. These groups belong to three positions in the soil food chain [19]. Herbivores constitute primary consumers that feed on living plants. Bacterivores and fungivores consume primary decomposers and are involved in decomposition and nitrogen mineralization by regulating growth and activity of their food sources [20], their ratio (Nematode Channel Ratio) [21], gives good information about the dominant underlying decomposition pathway. Predacious nematodes feed on nematodes and carry out top-down control of other soil biota [19]. The role of omnivores cannot be clearly classified; due to their variability in resource utilization they add “connectedness” to the food web [22].

Based on their reproductive strategies, nematodes can be assigned to a colonizer-persister (c-p) scale, taking values from 1 to 5, on a range from extreme r- to extreme K-strategists [23]. Due to the c-p scaling, the concept of maturity indices can be applied to nematode assemblages, even at the family level [16,23]. The Maturity Index family (MI, MI2-5, ΣMI, ΣMI2-5, PPI) provides measures of environmental disturbance and its consequent enrichment effects, hence they indicate ecological succession [17]. Evolution of the c-p concept leads to indices of ecosystem function: the weighted faunal analysis concept is constructed to indicate whether the soil community is basal (and inferred stressed), enriched, or structured and stable [24]. It uses the Structure Index SI and Enrichment Index EI to assess food web location along structure and enrichment trajectories [25]. Additionally, the Channel Index CI weights decomposer nematodes by their fecundity and life course characteristics to determine soil fertility levels and nutrient availability. Nematodes have been successfully used for investigation of long-term patterns of succession involved in conversion of arable land [26–29] as well as in the assessment of ecological condition of soils in annual vs. perennial cropping systems [22]. Furthermore, assessment of nematode communities in soils after abandonment of agriculture revealed positive effects on nematode diversity [28].

Here we present the results of an assessment of the nematode communities in fields of *S. perfoliatum*. The objectives of the study were (i) to elucidate patterns in the dynamic of nematode communities during long-term cropping of *S. perfoliatum* and (ii) to evaluate this dynamic in light of biodiversity conservation and soil ecosystem functions with reference to conventional energy maize cropping. For this purpose, fields belonging to a chronosequence were sampled to substitute cultivation periods of 1–10 years. General and nematode specific diversity indices as well as trophic guild analysis were used to reveal the influence of cultivation period length and other environmental parameters on nematode community dynamic. The data are used for ecological considerations of improvements towards more sustainable biomass production by the use of *S. perfoliatum*.

2. Materials and methods

2.1. Study sites and study design

Sites (n = 18) cropped with the cup plant (*Silphium perfoliatum*) and maize (*Zea mays*) for bioenergy production were sampled. All sites were used for agricultural purposes at commercial farms or business-related research farms. Geographically the sites were situated at seven locations in Lower Saxony and Thuringia, Germany. The number of sites at a particular location varied between one and five. The locations were Erfurt (50.98132°N, 11.00591°E, 215 m a.s.l.), Niederdorla (51.13602°N, 10.40000°E, 289 m a.s.l.), Dornburg (51.00365°N, 11.65741°E, 242 m a.s.l.), Pahren (50.65273°N, 11.89898°E, 417 m a.s.l.) and Hessberg (50.42461°N°, 10.78183°E, 380 m a.s.l.) in Thuringia; and Burgstemmen (52.14602°N, 9.78059°E, 88 m a.s.l.) and Gehrden (52.29513°N, 9.60931°E, 90 m a.s.l.; WGS84) in Lower Saxony. Sampling took place in two consecutive years in Autumn 2012 and Autumn 2013. Sites cropped with the cup plant (n = 12) were part of a chronosequence of four different age classes (*S.p.*_Y, *S.p.*_I1, *S.p.*_I2, *S.p.*_O) with n = 3 replicates (Table 1).

The reference fields cropped with *Z. mays* had to be switched in the second year of sampling due to crop rotations. Six sites featured replicates for maize. Since maize is an annual crop, it was assigned to an own age class and treated as age 0. The soil was characterized by high silt and low sand fractions at all sites. Soil types consisted mainly of Luvisols and Mollic Leptosols, exceptions were the locations Erfurt and Hessberg, where soil types were Terra Fusca and Chernozem, respectively (Table 1).

The management practices differed in intensity according to the age class of the sites. The management intensity decreased gradually with increasing age. Maize fields were associated with intensive soil management. Ploughing, seedbed preparation and frequent use of machinery for pesticide and fertilizer application caused high disturbance of the soil system. Cup plant fields received mechanical weed control up to the second year. Later on, machinery only had access to the fields for fertilizer application and harvest.

2.2. Environmental parameters

The following environmental variables were assessed: pH, gravimetric water content (GWC), total C and N content of soil, grain size fractions and climatic conditions, temperature, humidity and precipitation. Climatic conditions were averaged over the 30-day period before sampling. Information about management practices was obtained from the farmers via questionnaires. Five soil cores were taken (d = 4 cm, h = 10 cm) for the determination of physico-chemical properties. GWC was determined from 25 g of soil dried in the oven at 105 °C for at least 24 h. pH was measured using an electrode and a pH meter (Five Easy™, Mettler Toledo, Gießen, Germany) with 10 g of air-dried soil samples, cleaned for organic matter and solved in 0.02 M $CaCl_2$ solution (gravimetrical ratio 1:1.25). C and N contents were determined in a gas chromatograph (TruMac, Leco, Mönchengladbach, Germany) with 3 g of air-dried soil, ball-milled to fine powder (MM 400, Retsch, Haan, Germany). Grain size fractions were analyzed by the Agricultural Analytic and Research Institute North-West (LUFA Nord-West, Oldenburg, Germany). Climatic parameters were taken from weather stations close to the sampling locations. Temperature was