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Impact of cropping sequences and production strategies on soil suppressiveness against cereal cyst nematodes

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ABSTRACT

Cereal cyst nematodes (CCN) cause severe crop damage in many cereal-producing areas. Effects of cropping sequence and production system on soil suppressiveness against CCN were investigated. In a first approach, it was tested if a soil transfer of long-term oat monoculture soil (MOMS) facilitated the development of soil suppressiveness under monoculture of susceptible hosts. At Münster, Germany, microplots with no nematode infestation, *Heterodera avenae* or *Heterodera filipjevi* were amended with non-treated or heat-treated portions of 5% (volume of the upper 15 cm of soil) of MOMS and nematode population dynamics were monitored. Plots were planted either to cyst nematode susceptible cereal or to the non-host sugar beet in the first year, and then to susceptible cereals for three years. In a repetition of the experiment at Braunschweig, Germany, populations of *H. avenae* were monitored for two years. In these experiments, no acute increase of suppressiveness after soil amendment was observed. At Münster in *H. avenae*, final numbers of cysts and number of eggs did not increase in plots after initial oat. In plots with sugar-beet in the first year, cysts and egg populations did not increase, only cysts of *H. filipjevi* initially increased to then decline. In oat and in sugar beet plots at Münster, percentage of diseased eggs of *H. avenae* and *H. filipjevi* significantly increased between 2.4- and 6.5-fold under the third cropping season. Similar results were obtained at Braunschweig. In a second approach in environmental growth chamber experiments, the suppressive potential against *H. avenae* of MOMS sandy loam soil and two loam soils from intensive cereal cropping systems (OSCR: organic production, CSCR: conventional farming) was compared. Microbial communities of these soils and *H. avenae* females were characterized by PCR-DGGE. In the environmental growth chamber experiment, non-heated MOMS soil had fewer than 1/3 of females compared with heated soil equivalents in contrast to 1/2 in OSCR and CSCR both in such comparison. All three soils had higher suppressiveness than soil from infrequent cereal cropping (BNCC). The fingerprinting with PCR-DGGE illustrated high diversity in the different soil origins but did not allow to determine potential contributors in the suppressiveness. Findings of the studies suggested the presence of CCN-suppressive factors under monoculture, and demonstrated a stronger influence of the cropping rather than the farming system on populations of CCN and on soil microbial communities that may lead to soil suppressiveness.

1. Introduction

Soil-borne pathogens and pests persist in complex soil environments constituted by abiotic and biotic parameters. Among the biotic parameters, various microbial activities reduce pests and pathogens, and their functions in suppressive soils are greatly enhanced compared to conducive soils (Baker and Cook, 1974). While great efforts are being made in understanding the processes in specifically suppressive soils (Borneman and Becker, 2007; Weller et al., 2002), strategies for establishing soil suppressiveness to exploit beneficial natural control are lacking. A current hypothesis is that monoculture of susceptible hosts of the target pathogen can lead to the development of suppressive soil (Kerry, 1987). This surmises that copious reproduction of the primary parasite leads to increases of hyperparasites that eventually reduce the primary parasite to low levels, and thus leads to a suppressive

soil (Kerry, 1987). Implementing this concept into production practice recommendations is challenging, because the first years of such monoculture typically are associated with severe yield penalties. In contrast, if a suppressive agent is known, establishing such microorganisms in a new environment is difficult, and inundative biocontrol strategies often are not reproducibly successful (Stirling, 2014). This creates limitations in enabling the establishment and activity of candidate organisms to new soils (Sayre and Walter, 1991).

Cereal cyst nematodes (CCN) are distributed worldwide and are responsible for important yield losses (Nicol et al., 2003). In Central Europe, CCN are major concerns in the production of cereals (Rivoal and Cook, 1993). Recent studies in the Pacific Northwest of the US have shown damaging effects in more wide-spread regions than in the previously known occurrences in the Mediterraneans (Smiley, 2009). In temperate climate zones, Heterodera avenae is the most widely distributed and damaging species (Nicol and Rivoal, 2008). In a dated CCN survey of agricultural soils in Germany, this species was considered more common than any other Heterodera or Globodera species, and constituted 93% of all CCN species sampled from agricultural soils (Sturhan, 1982). Recognition of Heterodera filipjevi as the true identity of several strains of CCN including the "Gotland strain" (Subbotin et al., 2003) has resulted in increased recognition of the damage potential of CCN. This species was frequently distributed in primarily continental climates (Nicol and Rivoal, 2008), and identified as a constraint to cereal production (Öztürk et al., 2000; Nicol et al., 2003; Hajihasani et al., 2010). In a survey of five regions of Germany, H. filipjevi occurred in 20–30% of CCN-infested fields (Grosse, 2006).

In Central Europe, CCN damage is primarily observed in spring cereals. Based on a required winter cold incubation period for overcoming nematode dormancy and initiating infectivity, nematode populations become active during rising soil temperatures in the spring (Rivoal, 1986) when spring cereals germinate and emerge. The exposure of the most sensitive young cereal seedlings to nematode infections results in root deformations and reductions in root functions. For example, excessive root proliferations at the infection sites result in typical knot-like symptoms (Smiley, 2016). CCN are a serious problem in Scandinavia where cropping of spring cereals is more common (Holgado et al., 2004) than in Central Europe. CCN has been partially ignored owed to the exciting finding in the UK that CCN are naturally suppressed by antagonistic fungi in an average summer with copious precipitation (Kerry et al., 1980). In many parts of Germany, problems with CCN may go unnoticed even when conditions are conducive for the nematode's activity.

Studies have addressed the occurrence and microbial communities of nematode suppressive soils (Kerry et al., 1982; Yin et al., 2003; Borneman and Becker, 2007), but it is still poorly understood how a soil becomes suppressive, and furthermore how agronomic practices with the exception of monoculture of susceptible hosts support the development of suppressive soil (Ohnesorge et al., 1974; Westphal and Becker, 2001; Noel and Wax, 2003). Contributors to soil suppressiveness have been identified but many suppressive soils are probably more complex than being solely based on parasitism of the nematode by one species. Specific soil suppressiveness is transferable with small portions of soil (Westphal, 2005). Experimentally, this was repeatedly used to demonstrate specific suppressiveness when untreated suppressive soil was added to fumigated or otherwise microbially perturbed soil (Kluepfel et al., 1993; Westphal and Becker, 2000). Higher soil amendment amounts were necessary for successful transfer of suppressiveness if the receiving conducive soil was left untreated (Stirling and Kerry, 1983; Westphal and Becker, 2000). General soil suppressiveness is eliminated by biocidal treatments.

It was shown for different suppressive soil systems that susceptible host plants were necessary for the development and maintenance of soil suppressiveness (Gair et al., 1969; Kerry et al., 1982; Kerry and Anderson, 1984; Westphal and Becker, 1999; Chen, 2007; Westphal and Xing, 2011). A repeated cultivation of the resistant hosts oilseed radish or sugar beet did not eliminate suppressiveness against H. schachtii whereas a double crop of the non-host wheat reduced suppressiveness (Westphal and Becker, 2001). This provided some evidence that resistant plants can maintain soil suppressiveness while a non-host may be detrimental.

Hypothetically, cropping a susceptible host combined with a soil transfer may support the establishment of soil suppressiveness more than such transfer coupled with cropping a non-host. It is not known how non-hosts would interfere with the establishment of soil suppressiveness. Soil transfer introduces the beneficial organisms perhaps along with supportive components of the already suppressive soil to the nematode-conducive soil environment but could also unintentionally introduce plant pathogens. The nematode antagonists may then increase on the primary parasite more effectively than in traditional inundation of single microbes. This hypothesis was tested in the current study where population density dynamics of H. avenae and H. filipjevi were compared when a soil transfer event was followed by a host crop or non-host plant and thereafter by a sequence of highly susceptible hosts. The soil used for this transfer project was further characterized and compared to soils of different cropping origins.

The specific objectives of the project were (A) to determine if soil of a long-term oat monoculture at Münster, Germany (MOMS) was specifically suppressive, (B) to examine if susceptible crops were crucial for the success of suppressiveness transfer, and (C) to compare the suppressive potential and microbial communities of oat monoculture soil to two soils from intensive cereal cropping systems from conventional (CSCR) or organic farming (OSCR) backgrounds.

2. Material and methods

2.1. Microplot studies

Microplots of $1 \, m^2$ surface area at JKI Münster, Germany contained sandy soil (90.2% sand, 6.1% silt, 6.1% clay, 2.2% O.M., pH 6.1) and either (I) non-infested, (II) naturally infested with H. avenae ($1,478 \pm 280$ eggs per 100 g soil before planting in 2010) or (III) infested with H. filipjevi (240 ± 61 eggs per 100 g soil before planting in 2010). In March 2010, these plots were amended with a sandy loam soil (72.6% sand, 13.6% silt, 13.8% clay, 1.3% O.M., pH 6.6) from an adjacent field that had been infested with H. avenae (averages between 48 and 62 cysts per 100 ml soil one year after infestation), and had been in oat monoculture (MOMS) at this location since 1968 (Steudel and Rumpenhorst, 1978). On average of samples from sand and loam soil, this field had ca. 3000 eggs per 100 ml of soil in the early years between 1971 and 1976 and anecdotal evidence reports of plant damage associated with the nematode. In 2010, only 35 eggs per 100 g of soil were found in the soil used for the plot amendments. Other plant-parasitic nematodes were observed but considered of minor importance for plant growth. No cereal cyst nematode-induced plant damage was observed during 2010, 2011 and 2012 (Westphal, unpublished). Entire microplots served as main plots: (1) heat-treated amendment ($180 \, °C$ for 2 h), and (2) non-heated amendment. An amount of 7.5 l of such soil amendment (equivalent of 5% of 0–15 cm of the soil depth) was spread on the soil surface and incorporated into the 0–15 cm soil layer. Main plots were subdivided into 0.5 m × 1.0 m subplots for planting to oat, Avena sativa L. 'Nordstern' (susceptible to H. avenae, resistant to H. filipjevi) or oat 'Sang' (susceptible to