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Belowground effects of organic and conventional farming on aboveground plant–herbivore and plant–pathogen interactions

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Abstract

Soil organisms may significantly affect the aboveground system. However, the influence of farming practices in modifying the effects of soil organisms on aboveground systems is poorly understood. The aim of our study was to investigate: (1) How important are soil organisms for plant growth and the development of herbivores and pathogens above the ground? (2) How do agricultural management practices affect interactions between soil organisms, plants and their aboveground herbivores and pathogens? To answer these questions we investigated the effect of experimental defaunation of soils from organic versus conventional farms on growth of wheat, abundance of aphids and infection of wheat by *Septoria* fungi. Plant biomass in soil from conventional farms exceeded that of soils from organic farms, presumably due to the higher nutrient input in the conventional farming system. Soil defaunation likely mobilized nutrients that increased plant growth. Aphid abundance and *Septoria* infection was reduced by defaunation but only in organic soils. This suggests that soil organisms in organic farming systems are more important for aphid performance and the infection rate by *Septoria* than in conventional systems. Hence, changes in the soil animal food web caused by farming practice feed back on aboveground organisms, and this appears to be more pronounced in organic farming systems. Further, the results indicate that soil organisms may modify higher trophic levels (aphid and pathogen infection) without significantly affecting lower trophic levels (plant growth).

Keywords: Aphids; Cereals; Defaunation; Farming systems; Soil organisms; *Septoria* spp

1. Introduction

Terrestrial ecosystems have a belowground and an aboveground subsystem. These subsystems depend on each other, since above the ground primary producers are the main source of organic carbon for the system, whereas below the ground soil organisms are responsible for the breakdown and recycling of organic matter and the mineralization of the nutrients therein (Scheu and Setälä, 2002; Wardle, 2002; Porazinska et al., 2003). To understand community and ecosystem level processes it is necessary to study the interactions within and between these subsystems. However, most ecologists have investigated belowground and aboveground communities separately, leaving the interactions between the subsystems unstudied (but see Wardle et al., 1999; Wardle, 2002; Bonkowski et al., 2001; Masters et al., 2001; Van der Putten et al., 2001; Brown and Gange, 2002).

Current agricultural practices include the loss or degradation of non-crop habitats, the removal of weeds from within and around crops, enlargement of field sizes, tillage operations of varying degrees of intensity, and the use of chemicals to control pests and weeds in order to increase crop yield (reviewed by Gurr et al., 2003). These practices have caused serious ecological problems such as water contamination, habitat degradation and biodiversity loss (Matson et al., 1997; Krebs et al., 1999; Tilman et al., 2002), also affecting ecological functions such as pollination and

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biological control (Kruess and Tscharntke, 1994, 2000; Matthies et al., 1995; Didham et al., 1996). In the belief that low intensity farming systems are beneficial for the agricultural environment, the European Union is supporting organic farming systems as an alternative to conventional agriculture (EU, 2002). In some European countries up to 8% of the agricultural area is managed organically (Mäder et al., 2002). Organic farming systems have a lower nutrient and pesticide input and an improved biological activity and biodiversity (Mäder et al., 2002; Hole et al., 2005).

Although there are several studies showing how belowground biota affect aboveground organisms (Gange and Brown, 1989; Masters et al., 1993, 2001; Masters, 1995; Masters and Brown, 1997; Bezemer et al., 2002; Poveda et al., 2003, in press), studies comparing the importance of soil organisms in soils from different farming systems are missing. In order to study the importance of the soil biota on plant growth and the development of higher trophic levels and to analyze how farming systems affect the interactions between belowground and aboveground organisms we designed a replicated field experiment using wheat plants as model system. We investigated the effect of experimental defaunation in soils from organic farms and conventional farms on the growth of wheat plants and the performance of aphids and fungi on them. Two main questions were addressed: (1) How important are soil organisms for plant growth and the development of herbivores and fungi on these plants? and (2) How does the agricultural management practice of the soil affect interactions between soil organisms, plants and their aboveground herbivores and pathogens?

Our expectations were that soil organisms would increase plant growth in both soil types. However, since soils from the conventionally managed farms receive an increased input of fertilizers we expected that soil organisms would be more important for plant growth in soils from organic farms, and that this would also be reflected on the second trophic level, i.e. in the infestation rate of pathogens and herbivores.

2. Materials and methods

2.1. Experimental set-up

The experiment was carried out in the vicinity of Göttingen in the summer of 2003. Effects of farming practice (conventional versus organic) and the presence or absence of soil organisms (defaunated versus control soil) on wheat growth, aphid development and *Septoria* spp. infection were investigated in five landscape sectors. The landscape sectors were separated by 17.27 ±8.26 km (mean ± S.D.). They were chosen to represent the regional landscape and used as blocks. In the centre of each landscape sector, we selected one conventionally managed winter wheat field. In the middle of these conventional fields a plot of 700 m^2 (20 m × 35 m) not treated with insecticides was established, where the experiment took place. Nearby we selected an organically farmed winter wheat field from which soil samples were taken. From each field (five conventionally farmed and five organically farmed) 200 L of soil were collected and taken in plastic bags to a greenhouse. Half of the soil (100 L) were defaunated by freezing at −20 °C for 3 days which significantly reduces the number of soil microarthropods and annelids (Huhta et al., 1989). The soil was put into 10 L pots that were covered at the bottom with a 200 μm mesh to prevent colonization by soil meso- and macro-fauna. In each pot 80 wheat (*Triticum aestivum*) seeds were sown on April 30th 2003. After germinating, the wheat plants grew in the greenhouse until May 23rd, when pots were set out in the fields. The experiment was set up in a randomized complete two factorial design with the factors farming system (soil from organic farming system versus soil from conventional farming system) and defaunation treatment (defaunated versus control soil). The full complement of combinations was set up (defaunated organic, control organic, defaunated conventional and control conventional) with five replicates per treatment (soils from five different sites) in each landscape sector. Plants were left to be naturally colonized by aphids and infected by *Septoria* (mainly *S. tritici*) fungi during the experiment. Starting on June 10 2003, the aphids were identified and the number of aphids on 25 plants per pot was counted each week. The percentage infection of *Septoria* fungi was estimated by relating the amount of stems and leaves infected by *Septoria* to the total amount of stems and leaves in 25 plants in each pot. These measurements were repeated each week during 6 weeks, until the wheat was harvested on July 17 2002. Plants were collected and oven dried for 3 days at 60 °C to determine dry weight of roots, shoots and ears. The number of ears per pot was counted.

2.2. Statistics

To analyze the effects of defaunation and soil farming practice on plant growth we used a multiple analysis of variance (MANOVA) with farming practice and defaunation as categorical variables and the landscape sector as block. When significant, protected ANOVA's were performed to locate which of the dependent variables responded most to the factors studied (Scheiner and Gurevitch, 2001). This procedure was preferred to Bonferroni corrections to avoid increasing the probability of type I errors (Legendre and Legendre, 1998; Moran, 2003). There were significantly more differences than expected by chance (Moran, 2003; Table 1; the probability that 8 out of 15 possible tests are significant by chance is 0.175×10^{-6} according to the Bernoulli equation). Differences between means were inspected using Tukey's honestly significant difference test. Data on aphid abundance was cumulated for all weeks and the number of aphids per unit plant biomass was calculated by dividing the number of aphids per pot by the total biomass of the plants. This was done to correct for the differences in aphid abundance due to differences in plant biomass. Data