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Plasticulture changes soil invertebrate assemblages of strawberry fields and decreases diversity and soil microbial activity

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ABSTRACT

In agriculture, the use of plastic mulch (plasticulture) is globally increasing. Besides beneficial effects on crop yield and quality, possible adverse environmental effects associated with plastic mulch are currently under debate. Aside from the obvious disadvantages of substantial amounts of (micro)plastic waste, adverse effects on soil quality and biodiversity might be assumed. We compared the effect of plastic mulch and organic mulch (straw) systems in strawberry cultivation on soil invertebrates and biological activity in an observational field study in the Upper Rhine valley, Germany. Soil invertebrates were collected using pitfall traps and Berlese-Tullgren-funnels, earthworms by hand sorting. Soil biological activity was determined using bait-lamina sticks and the MicroResp™ system. Soil samples from test fields were analysed for physicochemical and microbial parameters. Despite minor effects on soil physicochemical parameters, our results showed that the mulch system had a significant effect on the community structure of soil invertebrates. In strawberry fields with plastic mulch we found a decreased taxonomic richness and taxonomic richness decreased with increasing soil temperature. About 50% of the analysed taxa had significantly lower abundances in plastic mulched fields compared to fields with organic mulch. No investigated taxon had a higher abundance in plastic mulched fields. Soil moisture was the most important environmental variable in explaining invertebrate abundances. The soil microbial activity was significantly lower in plastic mulched fields than in fields with organic mulch. Our results indicate that even little shifts in abiotic (e.g. temperature, water content) and biotic (e.g. food availability) conditions associated with the plastic mulch system can have strong effects on soil invertebrates and soil microbial activity. Hence, plastic mulch might pose a threat to soil biodiversity and related ecosystem functions in agroecosystems. We call for further studies analysing the influence of plasticulture, to better evaluate the long-term consequences on agrobiodiversity and soil quality as well as sustainability.

1. Introduction

Agricultural intensification can contribute to meet the globally growing demand for crop production (Tilman et al., 2011). However, yield increase associated with agricultural intensification causes many environmental costs including the loss of biodiversity, climate change (greenhouse gas emissions), nitrogen and phosphorous pollution and soil degradation (Foley et al., 2011; Steffen et al., 2015; Tscharntke et al., 2012). The challenge is therefore to find agricultural production practices which enable greater yields and at the same time lower environmental impacts.

Plasticulture is a globally used agricultural practice to increase yield. Thereby a polyethylene film is used as a mulch layer applied to the soil surface. Plasticulture, often used in combination with drip irrigation, has several benefits for farmers and worldwide the use has strongly increased in the last years (Briassoulis et al., 2013; Liu et al., 2014; Scarascia-Mugnozza et al., 2011). The use of plastic mulch increases the soil temperature, decreases water loss from evapotranspiration, prevents seedlings from rotting through direct soil contact, and suppresses weeds (Kasirajan and Ngouajio, 2012; Lamont, 1993). This results in improved crop quality, allows earlier planting dates and extended harvest seasons. The obtained higher yields provide economic benefits for farmers (Ingman et al., 2015) and explain the widespread use of plastic mulch in agriculture.

Besides these benefits, possible adverse environmental effects associated with plastic mulch are currently under debate. According to the review of Steinmetz et al. (2016), plastic mulch can change the long-term soil quality by increased soil water repellency and surface runoff of pesticides. Moreover, the pollution of soils with plastic additives (Wang et al., 2016) and with large amounts of residual plastic

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films (Liu et al., 2014; Vox et al., 2016) has also been documented. Because of this and the associated modified abiotic parameters, changes in the diversity and activity of soil organisms influencing soil functions can be expected. Soil organisms extensively contribute to a wide range of services that are essential to the sustainable function of soil ecosystems (Barrios, 2007). For that reason, abundance and activity (or respiration rate) of soil organisms are used as soil quality indicators (Doran and Zeiss, 2000). The impact of plastic mulch on soil organism biodiversity and soil quality is not well understood (Steinmetz et al., 2016). Replicated field studies are still scarce, but urgently needed to increase our knowledge of the ecological impacts of plastic mulch. Moreover, results of the few existing case studies analyzing the effect of plastic mulch on soil organisms are ambiguous. For example, Addison et al. (2013) found positive effects of plastic mulch on arthropod diversity and omnivorous insects. Touvinen et al. (2006) found no differences in carabid beetle diversity and abundance between plastic and organic mulch (and six other cover types) in an experimental strawberry field. Also, Miñarro and Dapena (2003) found no differences in carabid beetle diversity between plastic and organic mulch types but observed decreased carabid beetle abundance under plastic covers. Negative impacts of plastic mulch were also found for springtails (Addison et al., 2013), earthworms (Schonbeck and Evanylo, 1998), parasitic and predatory organisms and the soil food-web structure (Stirling, 2008). Moreover, plastic mulch has been described to play a significant role in shaping the bacterial (Farmer et al., 2017) and fungal (Liu et al., 2011; Muñoz et al., 2015) community structure.

In Central Europe, plastic and organic mulch are standard used practices in strawberry cultivation (Daugaard, 2008; Lieten et al., 2002; Lieten, 2005). In plastic mulched fields, strawberries are planted in plant rows into elevated ridges covered by black polyethylene films interrupted by row spaces (ridge planting system). Strawberries in fields with organic mulch are also planted in regular rows but with no height differences between plant rows and row spaces (matted row system). Moreover, organic mulch (usually cereal straw) application is not restricted to the rows but covers also the row spaces.

In light of the significant increase in the use of plastic mulch in agriculture and the influence of intensive agricultural practices on soil sustainability (Power, 2010; Tilman et al., 2002), we asked how the use of plastic mulch and associated modified soil conditions affect the diversity and activity of soil organisms and soil ecosystem functions. We, therefore, conducted an exploratory field study in Germany by comparing conventional strawberry fields with plastic and organic (straw) mulch. We hypothesized that plastic mulch and associated altered soil physicochemical parameters (i) affect invertebrate abundances and the community structure in strawberry fields and (ii) affect taxonomic diversity, soil biological and microbial activity. Thereby, we expect (iii) differences between positions within fields (plant row vs. row space) to be more pronounced in fields with plastic mulch than in fields with organic mulch.

2. Material and methods

2.1. Study area and site selection

The study was conducted in the Upper Rhine Valley, Germany, near the city of Ludwigshafen. The area is dominated by intensive agriculture of cash crops like wine, strawberry, and asparagus. It is one of the sunniest (> 1,800 h of sun) and warmest (average annual temperature ca. 10 °C) region in Germany, and the climate is classified as warm temperate with an average rainfall between 500–700 mm a^{-1} (REKLISO, 2006).

Most of the outdoor strawberry production in Germany is carried out using either plastic or organic mulch. Plastic mulch is used as continuous coverage, with an average duration of two years. Strawberry plants are usually planted in autumn and harvested through April and June. For each mulch system (plastic and organic) we selected five conventional strawberry fields from different farmers (Table A1). Field size ranged between about 1 and 5 ha. Soil types ranged from clayey to loamy sands but were not systematically different between mulch systems (Table A1). In plastic mulched fields, black polyethylene was used as coverage while in fields with organic mulch wheat straw was used. Strawberries with plastic mulch were cultivated in a ridge planting system, where specialized tractors create elevated ridges and cover them with plastic mulch. Additionally, a tube is laid several centimetres below the soil surface for drip irrigation. Per ridge (width: ca. 80 cm, height: ca. 15 cm) two rows of strawberry plants were cultivated (= plant rows). Plant rows were interrupted by row spaces (width: ca. 80 cm) to allow access for harvesters. Plant rows were dominated by bare soil with some occurring weeds (no intentional planting). In contrast, strawberries in fields with organic mulch were sprinkler irrigated and cultivated in a matted row system. Strawberries were also planted double-rowed (width: ca. 80 cm). However, there were no height differences between plant rows and row spaces, and the organic mulch application is not restricted to the plant rows but also covers the row spaces.

2.2. Soil physicochemical and microbial parameters

Soil sample collection was done at the harvest period in May 2016. In each field (N = 5 replicates per mulch system), two plant rows and two row spaces were sampled. A total of three soil samples (10 cm depth, volume = 0.39 l) in distances of 5 m were collected from each plant row and each row space. Soil samples of the plant rows ($N_{subsamples} = 6$) and from the row spaces ($N_{subsamples} = 6$) were then mixed to obtain one pooled soil sample for the plant row and one for the row space per field. Water content was obtained via gravimetric method (ISO 11465: 1993-12). The soil pH was measured in 0.01 M $CaCl_2$ solution (DIN ISO, 10390:, 2005-02). Analysis of nitrogen (N_{tot}) and total carbon (C_{tot}) was estimated as weight percentage of each element to dry soil after dry combustion (Vario micro cube, Elementar Analysensysteme GmbH, Germany). The content of soil organic carbon (C_{org}) was calculated by subtraction of the content of carbonate C from acid fumigated samples. C:N ratios were obtained from the quotient between C_{org} and N_{tot} in the sample. Soil microbial biomass C (C_{mic}) was determined using the chloroform fumigation-extraction method within 24 h after sampling (ISO, 11465 ISO 14240-2: 2011-09; Vance et al., 1987). In brief, 20 g of the fresh soil samples (sieved < 2mm) were extracted with 80 mL of 0.5 M K_2SO_4 before and after a 24 h $CHCl_3$-fumigation. Extracted organic C was quantified via multiNC 2100S (Analytik Jena, Germany). Calibration was done using potassium hydrogen phthalate (Merck, Darmstadt, Germany) as external standard. The ratio C_{mic}:C_{org} was intended in this study as a soil quality parameter (Anderson, 2003). Soil temperature was measured at a depth of 3 cm in one ridge and one corridor per field using temperature loggers (Maxim Dallas, San Jose, USA). Temperature was logged hourly from 07 to 25 May, and we calculated the mean and maximum temperature per plant row and row space per field.

2.3. Invertebrates

First, we sampled invertebrates using pitfall traps. In each strawberry field, pitfall traps were placed along transects in two plant rows and row spaces, respectively. Per transect, three pitfall traps (6.5 cm in diameter, 7 cm deep) with a distance of 5 m were set level with the soil surface cutting either a hole in the plastic mulch or raking away organic mulch or other litter. Pitfall traps were filled to one-third with a 1:2