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Physicochemical and microbial soil quality indicators as affected by the agricultural management system in strawberry cultivation using straw or black polyethylene mulching

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ABSTRACT

The aim of this study was to understand the differences in physicochemical and microbial soil quality resulting from the use of either wheat straw or black polyethylene, two widely used practices in strawberry cultivation. Soil samples were collected from strawberry crops used during 4 years as mono-cropping system, covered by either straw or black polyethylene (plastic mulching). Soil physicochemical properties included water content, pH, effective cation exchange capacity, elemental analysis of total carbon and nitrogen, dissolved and total organic carbon, and soil stability by percentage of water-stable aggregates (>0.2 mm). Soil microbial analysis comprised soil microbial biomass (C_{mic} and N_{mic} and DNA concentrations) and estimation of soil eco-physiological conditions C_{mic}:C_{org} and N_{mic}:N_{tot}. Soil bacteria and a fraction of cultivable fungi were studied respectively by molecular analysis and counting of colony-forming units (CFU values). Mycotoxin concentration in soil (deoxynivalenol) was used as an indirect indicator of fungal stress. The plastic mulching system showed positive effects on soil physicochemical properties as compared to straw mulching: Higher soil carbon content and better aggregate stability were observed in soils under plastic film, and the values for soil microbial biomass were comparable in both systems. Yet, soil eco-physiological conditions under plastic mulching were less appropriate compared to straw, as reflected by a reduced C_{mic}:C_{org} ratio (1.3 ± 0.3%), followed by a decline of the number of bacteria (18%), a six-fold reduction of the biomass of soil cultivable fungi, and finally by a two-times higher deoxynivalenol concentration in soil (mean 2.2 ± 2.4 $\mu g\,kg^{-1}$). This indicates that the plastic mulching system led to less favourable soil conditions and that the production of mycotoxins can be understood as a stress induced response by fungi. Further information is therefore needed to assess how the quality of soil is restricted by the shift of soil microbial communities and by the production of mycotoxins, especially in intensive agriculture with long-term plastic coverage.

1. Introduction

Wheat straw and black polyethylene are the most frequently applied soil mulching treatments in strawberry cultivation. In the last years, the use of plastic mulching in agriculture has increased significantly (Espí et al., 2006; Picuno et al., 2011) due to several advantages of polyethylene covers over other mulching materials. Plastic mulching supports higher soil temperature early in the year (Ham et al., 1993), which is correlated with an early growth (Lament, 1993; Hancock and Simpson, 1995; Lieten et al., 2002) and extended harvest periods (Masny and Zurawiez, 2015). It generates a suppressive effect on weeds (Schonbeck, 1999) and lower amounts of herbicides are needed. The evaporation of water is reduced under plastic mulches, with significant economic benefits for farmers (Ingman et al., 2015; Jabran et al., 2016). In general, the polyethylene sheets, mainly black polyethylene (Fig. 1), are used in a ridge-furrow system as continuous coverage in the field. Soil under plastic mulching is not mechanically disturbed by tillage, and strawberry plants are supplied with subsurface irrigation and fertilization. In order to protect plants against pests, diverse agrochemicals are used aimed to avoid the dissemination of

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Fig. 1. Investigated agricultural management systems for strawberry cultivation: a) straw mulching (organic mulching) in open fields, b) plastic mulching (black polyethylene film) in combination with high tunnels.

common fungal diseases in strawberries (Vorotnikova et al., 2013). These measures enable to extend and to improve the strawberry production significantly in several countries with moderate climates (Poling, 1993; Lieten et al., 2002; Lieten, 2005; Mezzetti, 2013).

The current literature about plastic mulching in strawberry cultivation is mainly oriented to the effects on product yield and quality. However, recent studies have shown that plastic mulching may lead to negative effects on soil quality exceeding the short-term economic benefit (Liu et al., 2014; Steinmetz et al., 2016). Plastic mulching has been associated with the runoff of pesticides from plastic covered fields (Rice et al., 2001; Dietrich and Gallagher, 2002), with undesirable effects for non-target organisms in adjacent ecosystem (Arnold et al., 2004). For example, the increase of soil temperature due to plastic mulching (using coextruded black and white film) resulted in an increased phytoaccumulation of metals or metalloids such as boron, aluminium and arsenic in tubers (Baghour et al., 2001, 2002), which may imply a risk for consumers. Another risk in soils covered with plastic is the presence of phthalate esters (Wang et al., 2016), and their uptake by plants (Sun et al., 2015). Additionally, pesticide accumulation on agricultural plastics (up to 45% of the total applied) was observed for polyethylene mulching in strawberry fields (Querejeta et al., 2012), hindering their recycling (Delgado and Stenmark, 2006; Delgado et al., 2007). Thus, disposal of high amounts of non-recyclable plastic (Scarascia-Mugnozza et al., 2012; Vox et al., 2016) and field pollution with plastic residues (Liu et al., 2014; Ramos et al., 2015) is a direct consequence of the intensification of the plasticulture. Recently, the effect of plastic mulching on soil temperature has been linked to changes on the biomass of soil microorganisms (Almeida et al., 2011; Li et al., 2014) and to mycotoxin production by soil fungi (Muñoz et al., 2015). The increasing soil temperatures and the consequences for soil quality have been a frequently studied issue in climate change research (Davidson and Janssens, 2006). However, few information is so far available about how the microclimatic conditions originated under plastic mulching affect the physics and chemistry of soil, later the microbiology, and finally the quality of the soil via C and N cycling processes.

The aim of the present study is to gain knowledge on the effects of two widely used mulching systems, namely wheat straw and black polyethylene as major component of the agricultural management systems on soil quality based on soil physicochemical and microbial parameters. It can be assumed that the modification of soil environmental conditions and soil chemistry as consequences of the mulching system will primarily affect the abundance of soil microorganisms. We hypothesized that the soil conditions as originated as consequence of the agricultural management system are less favourable in plastic than in straw mulching. This was expected to lead to a lower soil microbial biomass or to a restructuring of soil microbial communities, which will furthermore be reflected in the production of mycotoxins in soils, depending inversely on fungal growth.

To test these hypotheses, we have compared physicochemical and microbial soil properties on two fields after four years of either wheat straw or black polyethylene mulching. Soil physicochemical parameters included water content and pH, soil carbon content and soil stability. Soil microbial biomass, analysis of soil bacteria and a fraction of cultivable soil fungi were the microbial parameters used. Additionally, microbial ratios such as C_{mic}:N_{mic}, C_{mic}:C_{org}, N_{mic}:N_{tot} were used to investigate the structure of the microbial community and for estimations of the quantities of nutrients in the microbial biomass (Moore et al., 2000). Especially the C_{mic}:C_{org} ratio can be used as a reliable indicator of soil quality (Anderson, 2003). Finally, the mycotoxin concentration in soil was used as indicator of stress conditions for soil fungi, since physiological requirements for fungal growth oppose those necessary for the mycotoxin production (Hope et al., 2005; Schmidt-Heydt et al., 2008, 2015). Furthermore, assuming that each mulching system modifies in a certain way the chemistry and physics of soil, dissimilar values in term of soil microbial parameters and mycotoxin production are expected. This was investigated by comparing soil under regular strawberry cultivation with straw mulching versus plastic mulching system.

2. Materials and methods

2.1. Site description and sampling

The strawberry fields are located in Offenbach an der Queich, Germany (latitude 49°11′29.6", longitude 8°10′35.1") elevation is 130 m above sea level. Two different agricultural management systems in strawberry cultivation were compared: wheat straw mulching with conventional planting rows and black polyethylene film, the latter laid out in a ridge-furrow-ridge system in combination with high tunnels. The soil was classified as Eutric Cambisol with a silty loam texture. For both mulching systems, first planting of strawberries was in 2011 using the same strawberry variety (*Fragaria x ananassa*). Irrigation systems differed between crops, under plastic mulching subsurface drip irrigation was