Soil Biology & Biochemistry 115 (2017) 556–567

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

# Biosolids and conservation tillage: Impacts on soil fungal communities in dryland wheat-fallow cropping systems

Daniel C. Schlatter [a], William F. Schillinger [b], Andy I. Bary [c], Brenton Sharratt [d], Timothy C. Paulitz [a,*]

[a] USDA-ARS, Wheat Health, Genetics and Quality Research Unit, Pullman, WA 99164, United States
[b] Department of Crop and Soil Sciences, Washington State University, Pullman, WA 99164, United States
[c] Washington State University, Puyallup Research and Extension Center, Puyallup, WA 98371, United States
[d] USDA-ARS, Northwest Sustainable Agroecosystems Research Unit, Pullman, WA 99164, United States

ARTICLE INFO

*Article history:*
Received 9 June 2017
Received in revised form
10 September 2017
Accepted 20 September 2017
Available online 5 October 2017

*Keywords:*
Biosolids
Fungi
Soil microbiome
Undercutter
Wheat
Conservation tillage

ABSTRACT

Organic amendments and conservation tillage are important management tools for reducing soil erosion and improving soil health in agricultural systems, yet the impacts of these practices on soil microbial communities is poorly understood. We evaluated the effects of biosolid amendments and conservation tillage on soil fungal communities in a dryland wheat (*Triticum aestivum* L.) –summer fallow cropping system in the inland Pacific Northwest, USA (PNW). Biosolids or synthetic fertilizer was used in combination with conventional (disk) or conservation (undercutter) tillage. Fungal communities were characterized from soil and biosolid aggregates after the second application of biosolids in 2015 and before and after the second application of biosolids in 2016 using high-throughput amplicon sequencing. Biosolid amendments substantially altered fungal community composition, but not diversity, relative to synthetic fertilizer. In contrast, although many more fungal taxa were influenced by conservation tillage when synthetic fertilizer was applied, conservation tillage had relatively little effect on soil fungal communities receiving biosolids, suggesting that the form of N supplied (mineral or organic) may mediate the effects of increasing surface crop residue on fungal communities. Biosolid-mediated shifts in fungal communities were correlated with differences in soil characteristics, especially C, N, and P, and were persistent for at least three years after the initial biosolid application. A small number of taxa, including *Fusarium, Ulocladium, Gymnoascus, Mortierella,* and *Neurospora*, were highly enriched by biosolids in soil and dominated fungal communities of biosolid aggregates. Results show biosolids can have strong and lasting impacts on soil fungal communities, likely due to their effects on soil nutrients, and select for a small number of fungi capable of utilizing biosolids as a food source.

Published by Elsevier Ltd.

## 1. Introduction

Soil loss is a global problem for the long-term sustainability of agricultural systems as the rate of soil loss is 10–40 times greater than that of soil formation (Uri and Lewis, 1999). Billions of tons of topsoil are lost to erosion in the US every year (Montgomery, 2007; Uri, 2001) with a social cost in the billions of dollars (Crosson, 1995; Pimentel et al., 1995). Wind erosion is an especially serious problem for tillage-intensive dryland wheat production in the low-precipitation (<350 mm annual) region of the Pacific Northwest (PNW) (Singh et al., 2012). The major cropping system is a 2-year winter wheat-summer fallow rotation where only one crop is produced every other year on a given parcel of land. Soils are primarily composed of silt or fine sand, have low organic matter (<1%), and are poorly aggregated. Moreover, because of often meager residue cover on the soil surface, tillage during fallow, drought, and high winds makes these soils especially prone to wind erosion and $PM_{10}$ small particulate emissions (Sharratt and Schillinger, 2016; Singh et al., 2012). Adoption of management practices to minimize or eliminate tillage and increase residue cover are key for mitigating soil loss from windblown dust and enhance the sustainability and security of agriculture. Although there has been substantial improvement in management practices to control wind erosion and their acceptance by growers (Wade et al., 2015),

* Corresponding author.
*E-mail address:* timothy.paulitz@ars.usda.gov (T.C. Paulitz).

https://doi.org/10.1016/j.soilbio.2017.09.021
0038-0717/Published by Elsevier Ltd.

information is lacking on how these practices impact biotic components of soil health, such as soil fungal communities.

Tillage is a historic hallmark of agricultural systems and has a large impact on the rate of soil loss (Lal et al., 2007; Montgomery, 2007). In the PNW, tillage during spring of the fallow year is practiced by most growers to help maintain seed-zone moisture to ensure successful late-summer planting of winter wheat. A rod-weeder implement is used once or twice during the late spring and summer to control broadleaf weeds. The dry soil mulch created by tillage helps restrict evaporation by cutting off capillary flow of water from the seed zone and by thermally insulating the moist subsoil (Wuest and Schillinger, 2011). Tillage also disrupts soil aggregates and fungal mycelial networks, promotes microbial activity and decomposition of residue, reduces soil organic matter, and accelerates soil erosion (Hobbs et al., 2008; Ritz and Young, 2004; Young and Ritz, 2000). Because of these drawbacks, no-till or direct seeding, is increasingly practiced around the world (Wade et al., 2015). No-till summer fallow is practiced by an increasing number of growers in the winter wheat-summer region of the PNW, but the majority of growers continue to use tillage during spring of the fallow cycle for the aforementioned seed-zone moisture retention benefits.

The undercutter method of conservation tillage has been promoted as a best management practice for summer fallow during the past 15 years and the USDA Natural Resources Conservation Service has provided cost-sharing to growers to purchase undercutter implements. The undercutter implement has overlapping V-shaped blades that slice beneath the soil at the desired depth to sever capillary pores to preserve soil moisture during the warm, dry summer. With the undercutter, there is minimal soil inversion and most residue remains on the soil surface. In contrast, a tandem disk implement is a conventional primary spring tillage implement that mixes and stirs the surface soil, buries considerable residue, and can pulverize surface soil aggregates (Papendick, 2004; Sharratt and Feng, 2009; Sharratt et al., 2012).

Amending soils with organic material is a management practice used to stabilize soils, reduce erosion, and improve soil heath (Diacono and Montemurro, 2010; Medina et al., 2015; Reardon and Wuest, 2016). Re-purposing of processed sewage sludge, or biosolids, for application to agricultural land can be an economical means to use human waste and enhance soil quality and plant productivity. Biosolids are produced from wastewater where the solid fraction is separated, digested to stabilize organic matter and reduce pathogen loads, and concentrated prior to field application (Lu et al., 2012). Biosolids have high (up to 50%) organic matter and are rich in N, and P, as well as several plant micronutrients (Lu et al., 2012; Rigby et al., 2016; Stehouwer et al., 2000). Biosolid application enhances soil organic matter and soil aggregate size and stability, and can completely replace the use of synthetic fertilizers (Brown et al., 2011; Cogger et al., 2013a; Powlson et al., 2012).

Fungi are critical components of all soils and are intimately associated with plant and soil health as saprophytes, pathogens, symbionts, and decomposers. Tillage can substantially restructure soil fungal communities by disrupting soil aggregates and mycelial networks, altering the accessibility of plant residue to degradation, and modifying the soil chemical and physical environment (Acosta-Martínez et al., 2007; Ritz and Young, 2004; Simmons and Coleman, 2008; Young and Ritz, 2000). Although tillage may be detrimental to some beneficial components of the soil community, such as arbuscular mycorrhizal fungi, populations of some major soilborne plant pathogens, such as *Rhizoctonia* or *Fusarium*, may proliferate when tillage is reduced or eliminated (Bailey, 1996; Paulitz et al., 2002; Pumphrey et al., 1987). Biosolid amendments may also stimulate soil microbial activity and alter soil microbial community structure and diversity (Barbarick et al., 2004; Sullivan et al., 2006; Zerzghi et al., 2010). However, with some exceptions (Hazard et al., 2014), many questions remain on how fungal communities respond to biosolid applications. Biosolids can impact soil fungal communities via the introduction of organic substrates, which may benefit those taxa able to use biosolids as a food source. In addition, the presence of antimicrobials or other toxic compounds (eg., heavy metals, pharmaceutical compounds, nanomaterials) sometimes found in biosolids may have detrimental impacts on soil microbes (Anderson et al., 2008; Colman et al., 2013; Judy et al., 2015; Kao et al., 2006; Waller and Kookana, 2009). Together, biosolid amendments and conservation tillage have the potential to significantly improve soil quality by increasing organic matter, reducing wind erosion, and increasing the financial sustainability of dryland wheat production in the PNW. However, how a combination of these practices impacts soil communities, especially plant pathogens, remains unknown. In this work we investigate the impacts of conventional and conservation tillage and biosolid amendments on soil fungal communities in a winter wheat-summer fallow cropping system. We hypothesize that biosolid amendments and conservation tillage will modify the soil fungal community and increase fungal diversity relative to conventional tillage and fertilization.

## 2. Materials and methods

### 2.1. Field experimental design

Field plots were sampled at the Washington State University Dryland Research Station near Lind, Washington (47°00′N, 118 °34′W) in 2015 and 2016. This site receives on average 242 mm annual precipitation. The study was conducted on a Ritzville silt loam (coarse-silty, mixed, superactive, mesic Calcidic Haploxerolls) in 2015 and a Shano silt loam (coarse-silty, mixed, superactive, mesic, Xeric Haplocambids) in 2016. Ritzville silt loam is composed of 13% clay, 61% silt, and 26% sand while Shano silt loam is composed of 9% clay, 56% silt, and 35% sand. Organic matter content in the surface 15 cm is 0.7%. The soils had a pH of 6.7 and an EC (1:1) value of 0.24 m. mhos/cm. Water holding capacity of soils at Lind are 2.5 inches of water per foot of soil. Experimental treatments were established in a split-plot design with tillage (conventional vs. conservation) as the main-plot factors and fertilizer (biosolids vs. synthetic) as the secondary factor. Size of individual main plots was $76 \times 8$ m and subplots $38 \times 8$ m. Each treatment combination was replicated four times. Glyphosate [N-(phosphonomethyl) glycine] was applied in mid-March at a rate of 0.43 kg acid equivalents/ha to control weeds. Biosolid material (Class B) was obtained from the King County Wastewater Treatment Division, Seattle, WA, and was applied with a manure spreader on 4 May in 2015 and on 19 April 2016 at a rate of 6508 kg/ha (dry weight) to meet the nutrient requirements of two wheat crops. Each plot had a previous history of biosolid use; the 2015 plots first received an application of biosolids in 2011 and the 2016 plots first received an application of biosolids in 2012. No biosolids were applied in the intervening fallow years. Synthetic fertilizers were applied every 2 years to meet the nutrient requirements of each crop. Conventional tillage was with a tandem disk implement and conservation tillage with an undercutter implement. Tillage was conducted immediately after biosolid application during both years. For the synthetic fertilizer treatments, liquid aqua $NH_3$-N plus thiosol was applied at a rate of 56 kg N plus 11 kg S/ha. With conventional tillage, fertilizer was stream jetted on the soil surface with a sprayer fitted with large-orifice nozzles and immediately incorporated into the soil with the tandem disk. For conservation tillage, fertilizer was injected into the soil with the undercutter implement. Depth of tillage was 13 cm. Plots were subsequently rodweeded at a depth of 10 cm on