

The potential for summer active perennial grasses to improve soil biological health in mixed farming systems

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Abstract

Summer active perennial grasses can provide a rich source of carbon and environment for soil microorganisms during the non-crop summer period. Additionally, they fill the summer-autumn feed-gaps generally faced in the winter rainfall dominated regions of southern and Western Australia. We analysed rhizosphere bacterial communities (taxonomic and functional) associated with summer active perennial grasses including *Panicum* species Petrie and Bambatsi, Rhodes grass and *Digitaria* sp. Samples were collected from field experiments on sandy-textured soils at Karoonda, South Australia and Moora, Western Australia. Summer active perennial grasses altered the genetic and catabolic diversity of microbial communities, microbial activity and biological processes involved in C, N mineralisation and supply in both the field experiments. Greater rhizosphere bacterial diversity under perennial grasses coupled with higher carbon inputs and greater volume of rhizosphere soil resulted in significant changes in the C and N cycling processes compared with cropped soils. However, the grasses were found to host soilborne plant pathogens such as *Rhizoctonia solani* AG8 during the non-crop period thereby increasing pathogen inoculum levels resulting in higher disease incidence during the cropping phase. These changes in key functions, populations of beneficial and pathogenic microbes and resilience reflect the status of soil biological health with implications to plant nutrition and health, productivity and long-term soil C status.

Keywords

Microbial biomass, nitrogen, mineralisation, microbial diversity.

Introduction

In the lower rainfall mixed farming regions of southern Australia perennial pasture species are recommended for economic and environmental sustainability. Summer-growing perennial grasses have been recommended to fill the summer-autumn feed-gaps generally faced in the winter rainfall dominated regions of southern Australia (Ward et al. 2004). Crews et al. (2016) suggest that mid-successional grain agriculture that includes a perennial pasture component (e.g. summer growing perennial grass and winter crops) should feature ecological functions with improved synchrony between N supply and demand, more active soil organic matter pools and active and resilient soil microbiome. Perennial grasses grown during summer in South Australia and Western Australia provide dense rhizosphere environments (considered N-limited) in particular during the non-crop summer period with significant inputs of C through rhizodeposition providing a C-rich environment for soil microbial communities. In these low organic matter soils, C inputs by the summer active perennial grasses have the potential to influence microbial populations and activities related to C turnover, N mineralisation and loss, non-symbiotic (NS) N₂ fixation and soilborne plant diseases.

Methods

Replicated field experiments on sandy-textured soils located at Karoonda, South Australia and Moora, Western Australia were used for all the biological measurements. The experiment at Karoonda on a sandy Calcarosol (Organic C 1.04-1.17%) was established in October 2010 (Gupta et al. 2014a) and the experiment at Moora on a Bleached, Yellow-Orthic Tenosol (Organic C 0.8-1.1) was established in 2008 (Ward et al. 2014). Surface soil samples collected from perennial grass (*Megathyrsus maximus* Jacq. cv. *Petrie* (*Petrie*), *Panicum coloratum* L. cv. *Bambatsi* (*Bambatsi*), *Chloris gayana* Kunth cv. *Katambora* (*Rhodes grass*)), *Digitaria* sp., grass-pasture (*Petrie*-wheat) and crop plots during the summer and during cereal crop season (2011-13) were analysed for microbial properties including: microbial biomass, N availability, abundance (qPCR) and composition of total bacteria (16S amplicon sequencing), N₂-fixing bacteria (*nifH*-TRFLP) and the amount of non-symbiotic ¹⁵N₂ fixation (Figure 1). Additionally, *Rhizoctonia solani* AG8 inoculum levels

were measured in soils collected during October 2013 and *Rhizoctonia* disease incidence was measured in Pea plants collected in early August 2014. Biological resilience of soils was measured using a laboratory incubation assay.

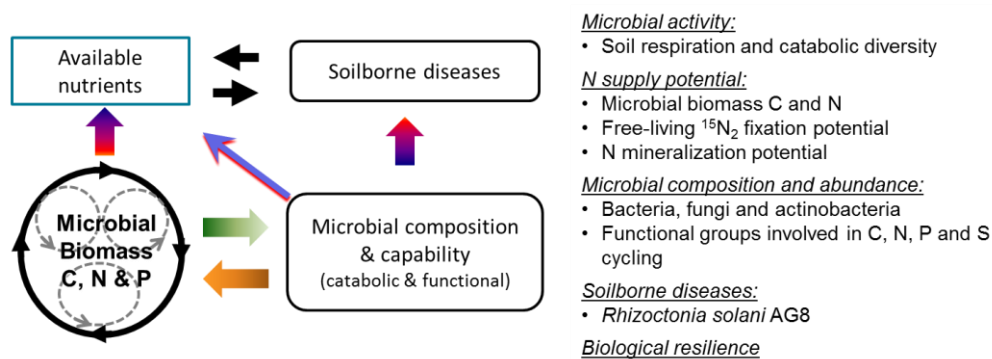


Figure 1. Soil biological properties that can be influenced by the summer active perennial grasses and those measured in the field experiments.

Results and Discussion

During the 2011 summer, C inputs from the aboveground biomass of different summer active perennial grasses in the Karoonda experiment ranged from 1.02 to 1.44 t/ha, which was more than from a cereal crop in that season (0.3 t/ha). Due to the extra biomass, amounts of root derived C are generally considered higher for the perennial grasses compared to that observed in a cereal crop (root biomass approx. 30-35% and 25% of aboveground biomass for grasses and crops, respectively). Carbon from the root exudates and rhizodeposits generally promote the proliferation of microbial communities, even altering their composition and changing biological processes involved in C and nutrient cycling. Carbon inputs from rhizodeposition are readily utilised by soil microorganisms and coupled with warmer temperatures during the summer-autumn period contribute to greater turnover of C in the rhizosphere of grasses compared to the winter crops. Greater turnover of C from a more extensive root system and hence rhizosphere volume during summer with a carryover effect of higher microbial activity during winter periods also results in the lack of build-up of C, in the short-term, in the perennial grass soils.

Table 1. Microbial activity and nitrogen mineralisation properties in soils collected prior to sowing in 2013 as influenced by summer active perennial grass and pasture-crop treatments in the field experiment at Karoonda, SA.

Treatment	Microbial biomass (mg C/kg soil)	Activity (AMR) ($\mu\text{g CO}_2\text{-C}/5\text{h}$)	Catabolic Diversity Index	Mineral Nitrogen (mg N/kg soil)	Potential min N
0-10 cm					
Petrie Pasture	350.9	0.295	22.1	14.6	13.6
Petrie Pasture - Crop	387.5	0.302	21.8	19.9	17.2
Crop	283.4	0.227	18.6	15.4	15.2
10-20 cm					
Petrie Pasture	174.4	0.083	11	6.2	6.6
Petrie Pasture - Crop	199.5	0.107	12.9	14.5	8.5
Crop	116.8	0.057	5.8	6.7	5.4
LSD - Treatment	32.4	0.051	3.8	2.4	2.7
LSD - Depth	26.4	0.041	3.1	1.9	2.3

Note: Catabolic diversity index was calculated based on the proportional use of multiple carbon substrates in a laboratory assay.

The greater volume of rhizosphere soil under perennial grasses and C inputs belowground have a significant influence on microbial biomass (MB) and microbial activity and diversity in the surface soil (Tables 1 and 2). For example, MB-C and N and microbial activity levels in the surface 0-10 cm of soil were generally significantly higher (>20%) in the perennial grass and pasture-crop treatments compared to that in the cereal crop soils. The positive effect of pasture presence was even greater (>50%) in the 10-20cm soil layer (Table 1). Similarly, N mineralisation potential was higher in the pasture-crop treatment compared to the crop only

treatment (Tables 1 and 2). The pasture only treatment at Karoonda received no fertiliser application but maintained mineral N levels similar to that in the crop treatment. Higher MB, activity and catabolic diversity under perennial grasses is likely to have altered the balance between N immobilisation and mineralisation processes in the surface soils in favour of immobilisation which in turn also contributes to reduced N losses due to leaching.

Table 2. Microbial activity and nitrogen mineralisation properties (average \pm standard error) in the surface (0-10 cm) soil collected prior to sowing in 2012 as influenced by summer active perennial grass and pasture-crop treatments in the field experiment at Moora, WA.

Treatments	Microbial activity	Catabolic diversity	Microbial		N mineralization		Pot C: Pot N ratio
	$\mu\text{g CO}_2/\text{d}$	index	biomass Carbon $\mu\text{g C/g}$	MB-N $\mu\text{g N/g}$	Mineral N $\mu\text{g/g}$	potential [#] $\mu\text{g N/g/10d}$	
Pasture Cropped	5.45 \pm 0.27	13.4 \pm 1.8	351 \pm 18	50 \pm 2.5	7.53 \pm 0.41	5.53 \pm 0.92	0.13
Continuous Crop	4.54 \pm 0.74	7.7 \pm 2.3	298 \pm 29	42 \pm 4.1	12.43 \pm 0.87	4.94 \pm 0.10	0.10
Permanent Pasture	6.56 \pm 0.47	14.1 \pm 0.9	451 \pm 42	64 \pm 6.0	8.48 \pm 1.15	7.16 \pm 0.10	0.37

Note: Permanent pasture and Pasture-cropped contained Petrie species. #—based on lab-incubation analysis

The genetic diversity of bacteria was higher in the grass rhizosphere compared to that in the barley rhizosphere. Proteobacteria were the dominant species in both grass and barley rhizospheres, although there were significant differences in Phyla level composition. For example, members of phyla Proteobacteria, Actinobacteria and Firmicutes were higher in the Bambatsi Panic rhizosphere whereas Acidobacteria and Gemmatimonadetes were higher in the Barley rhizosphere. In general, microbial functions in Panicum pasture soils were more resilient to repeated wet-dry stresses compared to the soils under cereal crops. In rainfed farming systems, biological resilience generally refers to the ability of biotic components of the system (soil biota and biological functions) to recover from drought or soil degradation. The stability of soil biota communities is important for their continued functional capability when exposed to different external stresses such as repeated wet-dry cycles, tillage and chemical application). Results from soil biota-responses to exposure to repeated wet-dry cycles indicated significantly greater resilience with MB, bacteria involved in N mineralisation (e.g. nitrifying bacteria) in pasture soils compared to the annual grain crop soils (data not presented). However, the resilience in diazotrophic (non-symbiotic N₂ fixing) microorganisms was lower in the pasture soils. Soil microbes in cropping soils generally go through boom-bust cycles for C availability and moisture whereas the summer active perennial grasses provide C-rich microsites, arrest the depletion of biologically available C and maintain the functional capability or biological health of soils. Nitrogen fixation by NS-N₂ fixing bacteria occurs with non-leguminous plants, cereals and grasses, both in temperate and tropical agricultural systems and includes N₂ fixation by bacteria which are free-living or in endophytic associations. In Australian cropping soils, lack of adequate available C is one of the critical factors limiting the amount of N₂ fixation by NS-N₂ fixing bacteria. The rhizosphere environment of grasses and cereal plants are generally considered as N-limited and favour NS-N₂ fixing bacteria. NS-N₂ fixation estimates for the grass roots ranged between 0.92 and 2.35 mg ¹⁵N per kg root per day. Whereas, under optimal conditions, potential rates of N₂ fixation for the grass-rhizosphere soils were 0.84 to 1.4mg ¹⁵N per kg soil per day. In contrast, the amount of NS-N₂ fixation in the bulk soil varied from 0.1 to 0.58 mg ¹⁵N per kg soil per day. It is important to know that the number of optimal days per season for N₂ fixation does vary in different agricultural regions hence the amount of NS-N₂ fixation varies with season. Some legume species also maintained N₂ fixation in October (spring), when the summer active perennial grasses were dormant, similar to that in soils under a cereal crop. Populations of NS-N₂ fixing bacteria in the grass rhizosphere soils were similar to populations in the roots but the diversity of diazotrophic bacteria was significantly higher in the rhizosphere compared to the roots. Different grass species promoted the abundance of specific members of the NS-N₂ fixing community suggesting a plant based selection from the rhizosphere microbial community.

We found high levels of *Rhizoctonia inoculum* (major soilborne pathogen found at the site) in the pasture grasses even when they were dormant during October 2013 (Table 3). The presence of grass plants during summer 2013/14 provide a host for the rhizoctonia pathogen and thus inoculum build-up would occur. Other research in the southern and western Australian cropping regions has shown that cereal crops and grasses promote the build-up of soilborne pathogens such as *Rhizoctonia solani* AG8 (Gupta et al. 2014b). In addition, the grasses would not facilitate the proper removal of a ‘green bridge’ that is known to be critical during the 3 weeks prior to sowing to reduce rhizoctonia root rot. *Rhizoctonia* disease incidence was

significantly higher in the pasture cropped Pea crop compared to that in the continuous cropping treatment. The significant reduction in the pea plant biomass reflects the impact of the rhizoctonia disease.

Table 3. *Rhizoctonia solani* AG8 inoculum levels during 2013 crop season and disease incidence in Pea crop during 2014 in the field experiment at Karoonda, SA.

Treatment	<i>R. solani</i> AG 8 (pg DNA/g soil) [§]	Disease rating [#] (0-5 rating scale)	Pea biomass (g/plant)
<i>Panicum cv Petrie</i>	606 (high risk)	-	-
<i>Panicum cv Petrie</i> pasture cropping	401 (high risk)	1.82	0.268
Crop (2013-Barley & 2014-Pea)	316 (high risk)	0.56	0.553
<i>Digitaria cv premier</i> pasture cropping	-	1.52	0.242
<i>Panicum cv Bambatsi</i> pasture cropping	-	1.55	0.194
Rhodes grass pasture	337 (high risk)	-	-
F test	Not sig	0.001	0.001
LSD (P<0.05)		0.55	0.089

§ Soil samples collected in 2013 crop (wheat) season

Rhizoctonia root rot disease incidence in the 2014 Pea crop

Conclusions

Summer active perennial grasses significantly modified the genetic and catabolic diversity of microbial communities and soil biological health causing changes in microbial activity, decomposition, N mineralisation and supply in the Mediterranean cropping regions in South and Western Australia. Higher and more diverse carbon inputs and greater volumes of rhizosphere soil with perennial grasses may have resulted in greater rhizosphere bacterial diversity and changes in the C and N cycling processes compared with cropped soils. These grasses were also found to host soilborne plant pathogens such as *Rhizoctonia solani* during the non-crop period and thus could increase pathogen inoculum levels and disease impacts in a cropping system. Overall, all these changes in key functions, populations of beneficial and pathogenic microbes and resilience reflect soil biological health, affecting plant nutrition and health, productivity and long-term soil C status.

Implications for commercial practice

- Summer active perennial pasture grasses add above and below-ground carbon inputs that are vital for maintaining and even enhancing biological functions in cropping soils.
- Perennial grasses significantly increased the microbial diversity, microbial biomass, activity and N mineralisation potential in the surface 20 cm of soil compared to crop only.
- Rhizosphere and root environments of summer active perennial grasses support significant amounts of non-symbiotic N₂ fixation during the summer months compared to cropping soils thus contributing biological N inputs into the soil N cycle.
- Soilborne diseases such as rhizoctonia root rot could compromise the nutrient supply-related benefits to crops through less water supply and nutrient uptake in summer active grass pasture-crop systems.

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