Impact of agronomic management on the soil microbiome: a southern Australian dryland broadacre perspective

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Abstract

A better understanding of the soil microbiome functions and processes associated with adapting agronomic management practices will be key to maintaining sustainable broadacre farming in the future. This is primarily due to the irreplaceable roles of the soil microbiome in soil to plant interactions, human health and ecosystem functions and stability. We approached this challenge by reviewing how different land management practices influence soil microbial communities. The important role that the soil microbiome plays in cropping systems was analysed in the context of an overview of changes in land management over the past two decades using southern Australian dryland farming as a case study. Many major changes in management have occurred in this system during this time, including i) reduction in tillage, with a corresponding increase in direct drilling and stubble retention, ii) inclusion of oilseeds and pulses in cereal-dominated rotation systems, iii) decrease in the pasture-dominated grain production systems, iv) increased use of agrochemicals, v) different soil amelioration applications and vi) development of innovative agricultural technology. We reviewed the overarching role of climate extremes in impacting agronomic management practices in southern Australian farming systems. In all, we demonstrate the complex interplay between land management changes and the activity, diversity and functions of the soil microbiome, with reference to changes in agronomic management practices.

Keywords

Conventional farming; Conservation farming; Land management; Microbial community; Sustainability

Introduction

Globally, there is an increasing demand for food and fibre production due to the rising human population and increasing per capita consumption. It is estimated that global food demand will rise by 70% in the coming decades [1], and farming systems will, by necessity, continue to become more intensive. While future farming systems will undoubtably rely on high-yielding, high-quality and disease-resistance cultivars, fertiliser application, various agrochemical products for weed and disease control and other emerging technologies, it is anticipated that the role of the microbiome will also become more prominent. Over 40% of the terrestrial surface area on Earth is classed as dryland, including 45% of the world's agricultural land[2]. Given the increasing rate of soil aridity globally [2,3], the stress on productive systems will increase in many of these dryland regions due to the increased variability in the availability and accessibility of water, and difficulty in maintaining efficient uptake and utilisation of nutrients.

Thus, to develop more sustainable dryland farming systems, it is vital to understand the effects of past changes in land management practices on current farming systems, including the soil microbiome.

The soil ecosystem is one of the key components of a farming system. This includes the soil microbiome which plays a crucial role in ecosystem health and functionality. The soil microbiome describes the residing soil organisms, all their produced molecules, and the molecules produced from their coexisting hosts, all of which are further mediated by the external environment[4,5]. The soil microbiome provides numerous ecosystem services including: regulation of the Earth's biogeochemical cycles[6,7], modification of ecosystem health [4,8], supply of assimilable nutrients to plants[7,9,10], plant growth and health maintenance [4,11], remediation of soil contaminants [12-14] and water purification[15]. Recent reviews highlighted the central role of the soil microbiome in regulating the health of plants, animals, humans and the entire environment [4,9,11,16,17]. Further, there are close interconnections between the soil microbiome and microbial communities within other biomes (e.g., plant communities). Hence, the soil microbiome can regulate the health, growth and yield of plants. Therefore, in order to develop agronomic practices that will harness the benefits of the soil microbiome in future dryland farming systems, it is important to understand how different land management practices influence the structure, diversity and function of the soil microbial community.

Over the past two decades, management practices in dryland broadacre farms in Australia have changed, driven by the domestic and international markets, the changes in technology (e.g., machinery), the stakeholders' awareness of the importance of soil health, or the impact of climate extremes. For example, there has been a reduction in tillage, with a corresponding increase in adoption in direct drilling and stubble retention[18-20]. Other major changes in management practices have been the inclusion of oilseeds and pulses in cereal-dominated crop rotation systems, replacing pasture-dominated grain production systems, increases in mixed cropping (cropping and livestock grazing), new weed and disease resistant crop varieties, increased targeted use of agrochemicals, greater use of lime applications in response to soil acidity, greater use of organic amendment addition to the soil and changes in the amount of N, P, K & S fertilisers and trace elements. Since these management practices directly or indirectly alter soil microbial habitat, as well as the food and water supply for soil microorganisms, it follows that there will in turn be impacts on the structure, diversity and function of soil microbial communities. Yet, to date, there has been no systematic review of the effects of changes in farming systems on the soil microbiome in Australian dryland cropping regions and the potential influence(s) of these changes. In this study, we used southern Australian dryland farm as the focal region and aim to provide a mechanistic and thorough understanding on how the soil microbiome is influenced by changes in management practices. This will shed light on how to harness the biological functions of the soil microbiome towards future productive and sustainable farming systems in other dryland ecosystems. The outcomes of this review have been published in Shi, et al. [21] and are summarised in this article.

Method and structure of review

In this review, we examined the effect of management practices on soil microbial communities *via* their influence on food (substrate type and supply), water (its availability and accessibility) and shelter (soil physical disturbances). For this reason, we categorised the changes in agronomic management impacting soil microbiome into five different groups, namely i) crop type, ii) stubble management/tillage, iii) synthetic product applications, iv) soil amelioration and v) new technology (Fig. 1). By focussing on their impacts on food, water and shelter for soil microbiome, we can establish causal linkages as to whether the changes in agronomic management practices have impacts on soil microbial community composition and function. In this review, we illustrated an overview of changes in land management using southern Australian dryland farming as a case study. This is followed by the influences of different agronomic management changes on soil microbiome in the order of five major groups (Fig. 1), focussing on the impacts *via* food, water or shelter for soil microbiome. In addition, we also discussed the overarching role of climate extremes in regulating the changes in agronomic management practices.

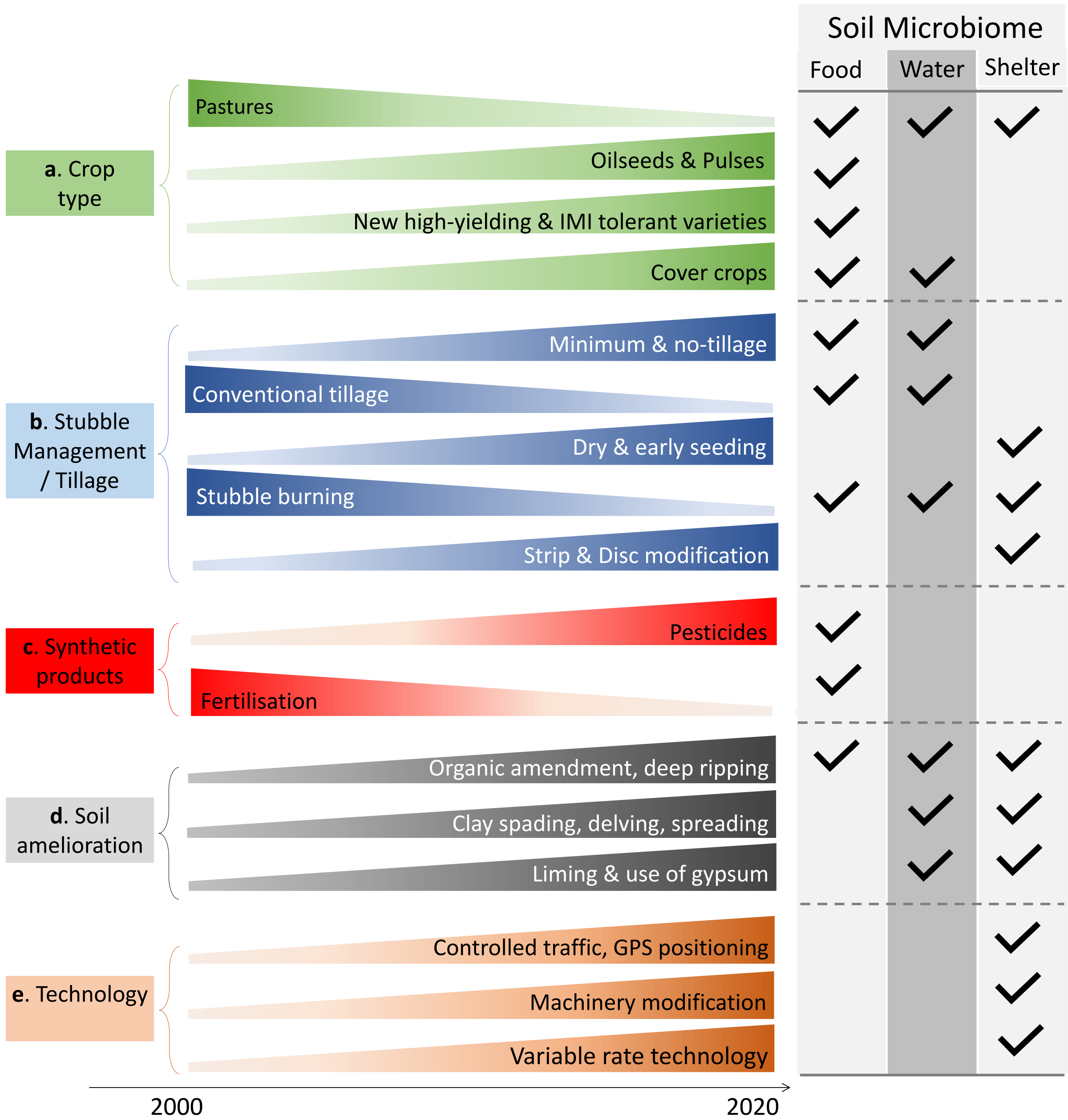

Figure 1. The structural framework of the changes in land management practices over the recent two decades in Southern Australian dryland broadacre farming system (between 2000 and 2020), and their potential impact of practices on either food (access to C substances and nutrients source), water (availability and accessibility of water) or shelter (soil physical disturbances) of soil microbiome (marked by the 'Tick' symbol). The management practices are categorised into five different groups ('a' to 'e') given their inter-connections. The width of the bar indicates the relative relevance/importance of corresponding management practice. Source: Shi et al., 2024 available at: https://doi.org/10.1016/bs.agron.2024.02.008

Concluding remarks

Our review shows the highly dynamic nature of soil microbiome to the identified major changes in land management practices over the past two decades in southern Australian dryland farming systems. Despite the complexity, some causal linkages could be established between specific land management practice and the response in soil microbiome structure and activity. Such linkages would be difficult for direct comparison between studies or knowledge translation, given unique Australian agroecosystems, soil properties and climate conditions, as well as different molecular technique applied among numerous studies. Nevertheless, countless evidence continues to confirm the interplay between land management changes and the shifts in structure and function of soil microbiome, which could guide decision makers who aim to achieve better realisation of microbial roles in farming system. We conclude that to maintain sustainable farming in the future, the complete realisation of microbiome functions and processes associated with adapting land management practices will be the key, owing to the irreplaceable roles of soil microbiome in soil and plant interactions, human health and ecosystem functions and stability.

Reference:

1 Coban, O., de Deyn, G. B. & van der Ploeg, M. J.*Science* **375**, abe0725-abe0725

2 Moreno-Jiménez, E. *et al.Nature sustainability* **2**, 371-377

3 Huang, J., Yu, H., Guan, X., Wang, G. & Guo, R.*Nature Climate Change* **6**, 166-171

4 Banerjee, S. & van der Heijden, M. G. A.*Nature Reviews Microbiology* **21**, 6-20

5 Jansson, J. K. & Hofmockel, K. S.*Nature reviews. Microbiology* **18**, 35-46

6 Bardgett, R. D. & van der Putten, W. H.*Nature* **515**, 505-511

7 van der Heijden, M. G. A., Bardgett, R. D. & van Straalen, N. M.*Ecology letters* **11**, 296-310

8 Dick, R.*CSANews (Madison, Wis.)* **63**, 12-17

9 Berendsen, R. L., Pieterse, C. M. & Bakker, P. A.*Trends Plant Sci* **17**, 478-486

10 Brussaard, L., de Ruiter, P. C. & Brown, G. G.*Agriculture, Ecosystems & Environment* **121**, 233-244

11 Suman, J. *et al.Frontiers in Soil Science* **2**

12 Semple, K. T., Doick, K. J., Wick, L. Y. & Harms, H.*Environmental Pollution* **150**, 166-176

13 Margesin, R., Zimmerbauer, A. & Schinner, F.*Chemosphere* **40**, 339-346

14 Ajona, M. & Vasanthi, P.*Materials Today: Proceedings* **45**, 7117-7122

15 Dodds, W. K. *et al.BioScience* **70**, 548-562

16 Toju, H. *et al.Nature plants* **4**, 247-257

17 Raaijmakers, J. M. & Mazzola, M.*Science* **352**, 1392-1393

18 Anderson, W. K., Stephens, D. & Siddique, K. H. M. in *Innovations in dryland agriculture* (eds M Farooq & Kadambot H. M. Siddique) 299-319 (Springer International Publishing AG 2016, 2017).

19 Kirkegaard, J. & van Rees, H. in *Australian agriculture in 2020: From conservation to automation* (eds J. E. Pratley & John A. Kirkegaard) 47-64 (Agronomy Australia, 2019).

20 Llewellyn, R. S. & Ouzman, J. in *Australian agriculture in 2020: From conservation to automation* (eds J. E. Pratley & John A. Kirkegaard) 21-31 (Agronomy Australia, 2019).

21 Shi, A. *et al.* in *Advances in Agronomy* Vol. 186 (ed Donald L. Sparks) 113-171 (Academic Press, 2024).