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Ground cover, erosion risk and production implications of targeted management practices in Australian mixed farming systems: Lessons from the Grain and Graze program

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A B S T R A C T

Maintaining the productive capacity of the agricultural soils of Australia's broadacre cropping zone requires careful management, given a highly variable climate and soils that are susceptible to degradation. Mixed crop-livestock farming systems are the predominant land use across these regions and managers must operate farms for long-term sustainability as well as shorter-term profitability. Achieving profitable and sustainable businesses has required ongoing innovation and productivity gains, of which the integration of crop and livestock enterprises has been an important part. Production-soil erosion trade-offs associated with enterprise integration is critical information that has not been investigated to date at a whole-farm level. The objective of this study was to systematically evaluate management options developed in Grain and Graze (an integrated program of research, development and extension targeting mixed farms) to identify farm systems responses to soil erosion risks across seven regions spanning the mixed-farming area of Australia. To evaluate production-soil erosion trade-offs, we linked the APSIM soil water, soil nutrient cycling, annual crop and surface residue simulation models to the GRAZPLAN pasture and ruminant simulation models, using the AusFarm modelling software. Our results demonstrate that the management options tested in Grain and Graze support the principles of conservation agriculture and inform the sustainable intensification of mixed farming systems. Across the regions considered we found that: (1) Increasing pasture legume content and soil fertility can consistently benefit farm production and environmental indicators, (2) management interventions that target direct management of ground cover have the greatest potential to reduce soil erosion rates, (3) management during critical periods of naturally high soil erodibility and wind/water erosivity can substantially increase or decrease erosion risk; the timing of management interventions is therefore critical, and (4) grazing management to balance use of crop residues and pasture biomass is required to avoid developing hot spots of erosion and soil degradation.

1. Introduction

Managing soil erosion is critical to meet the demands of agricultural production and ensure long-term global food security (Lal, 2001; Webb et al., 2017). The need to maintain healthy and productive soils is superimposed on the challenges of adapting agriculture to climate change and meeting consumer demands for food and fibre in systems that have often experienced some level of historical soil degradation (Moore and Ghahramani, 2013; Peterson and Snapp, 2015). Solutions require land management practices and systems that carefully balance soil conservation and agricultural production outcomes (Rockström et al., 2017). However, balancing production goals with efforts to conserve soils and maintain or improve soil health is often challenging for land managers. Social and economic barriers can slow adoption rates of soil conservation practices, leaving producers highly exposed to climate variability and market forces (Pannell et al., 2006; Marshall et al., 2014). While the basic tenants of sustainable agriculture have been known for many years, integrating this knowledge into the management of mixed (crop-livestock) farming systems remains a major obstacle to resilience building in agricultural systems (Hansen, 1996; Giller et al., 1997; Franzluebbers et al., 2014). Analysing the production and soil conservation trade-offs in integrated farming systems is critical to understand the possible barriers for adoption of soil conservation practices and potential for integrated crop-livestock practices to

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sustainably intensify agriculture (Sanderson et al., 2013; Cowie et al., 2018).

Wind and water erosion are key causes of soil degradation in agricultural lands (Van Pelt et al., 2017). The processes result in soil nutrient decline and impact carbon cycling, affecting land productivity (UNEP-IRP, 2016) and production vulnerability to climate variability and change (Reed and Stringer, 2016). Farm land use and management practices typically affect the disturbance and surface cover of soils and hence their resistance to wind and water erosion (Koch et al., 2015; Pierre et al., 2017). In mixed farming systems where both crop and livestock production are important, current management factors that influence provision of surface cover and potential soil erosion are the selection of crop and pasture types, soil fertility, crop residue management (e.g. grazing, harvesting practice), cultivation practices and grazing management (Ewing and Flugge, 2004; Freebairn and Silburn, 2004; Kirkegaard et al., 2014). Enterprise diversification and increasing land use intensity has enabled productivity gains, however the design and evolution of modern farming systems has also contributed to soil erosion (Chappell and Baldock, 2016) and changes in soil fertility (Liebig et al., 2017). The costs to farming systems have been significant (Robertson et al., 2009; ELD Initiative, 2015). Diversified rotations that include break crops (secondary crops used to break disease cycles and increase diversity within crop rotations, e.g. legumes or oilseeds) often produce lower and more readily degradable biomass in these paddocks compared with cereal crops. As a result, soils of break crop paddocks can be more susceptible to wind and water erosion during the dry season (McPhee and Muehlbauer, 1999; Krupinsky et al., 2007). Similarly, grazing livestock on crop residues over summer may further reduce vegetation cover and break up the soil surface, increasing soil susceptibility to wind erosion (van Gool et al., 2008). Management options that effectively balance the production benefits of mixed farming systems with negative trade-offs to ecosystem services must be identified and tested (e.g., Bonaudo et al., 2014; Lemaire et al., 2014).

In Australia, a series of research, development and extension programs have been examining the opportunity to improve both production and soil management in crop-livestock systems (Hacker et al., 2009; Bell et al., 2014). In particular, 'Grain and Graze' has been a national program spanning Australia's crop-livestock regions which has involved participatory evaluation of farming systems innovations aimed at improving the profitability and resilience of mixed farming businesses. Issues that have been targeted have included grazing immature or dual-purpose crops (Dove and McMullen, 2009; Bell et al., 2015), pasture cropping (Millar and Badgery, 2009; Lawes et al., 2014; Thomas et al., 2014), ground cover management (Lilley and Moore, 2009), and changes to the combination and integration of enterprises (Robertson et al., 2009; Bell and Moore, 2012). Similarly, the potential to sustainably intensify crop-livestock systems has been increasingly examined in North and South America (e.g., Liebig et al., 2012; Kunrath et al., 2014), Europe (e.g., Peyraud et al., 2014) and Africa (e.g., Thornton and Herrero, 2015). However, the impacts of changes in crop-livestock systems on soil erosion, ground cover, and other ecosystem services in agricultural landscapes over the long-term have been rarely examined. This is a challenging problem as there are a range of interactions between the crop and livestock enterprises that occur at the whole farm level and these are greatly influenced by the climatic and edaphic conditions. Climatic variability is particularly important in Australia where risks for erosion are likely to be exacerbated under drier than normal conditions; hence evaluating the resilience of systems to these climate shocks is critical for sustainable intensification of Australian agriculture (Revell et al., 2012; Allan et al., 2016; Hochman et al., 2017), but requires long-term analyses.

The objective of this study was to identify key trends, responses and thresholds in agricultural production and soil erosion metrics in response to a range of changes to crop-livestock systems that were investigated in the Grain and Graze program across Australia. The agricultural system processes of interest in this study – especially soil erosion – depend on the frequency and magnitude of episodic events that are best evaluated over the long term. To evaluate these processes we used biophysical simulation models, parameterised for representative locations and management systems across Australia's mixed crop-livestock farming zone. Scenarios involving proposed management interventions were then simulated in each location to explore the impacts on ground cover, erosion, productivity and other system functions over the whole farm. The modelling approach allowed us to examine to what extent enterprise management can counter episodic erosion events and identify joint environmental and production benefits. As a result, the study has enabled a novel understanding of outcomes for soil conservation in relation to recent opportunities in land management through applying a substantive biophysical modelling framework to farming systems innovations that are currently being developed and applied. The extension of our biophysical analysis to the economic interactions between mixed farming management and erosion risks is a necessary step that is beyond the scope of this paper.

2. Materials and methods

2.1. Integrated farming systems analysis

We have used AusFarm modelling software, linking the Agricultural Production Systems sIMulator (APSIM; McCown et al., 1996) and GRAZPLAN (Donnelly et al., 1997), to investigate the long-term impacts of changes in management practices in the mixed farming agricultural region of southern Australia. The modelling framework has been developed and used extensively to examine mixed farming scenarios of southern Australia, and was the most suitable option to examine a range of biophysical outputs over a long sequence of historical seasons (based on meteorological input data). The biophysical modelling framework is described in detail below, it is run on a daily time step using input weather data files over a period of 50 years. Summary data is generally aggregated and presented as annual mean values. Holzworth et al. (2014) provide a comprehensive review of the model and performance analysis. Here, we parameterised the model to represent mixed farming systems and management practices for regional case studies across southern Australia and informed by local producer knowledge. Lessons learned were expected to be consistent with existing knowledge of the effectiveness of soil conservation practices in crop-livestock systems (e.g., Valbuena et al., 2012; Lemaire et al., 2014), with our simulation approach enabling analysis of regional production and soil erosion responses to farm management practices over the long term.

2.2. Regional case studies

One representative location was selected in each of the 7 Grain and Graze regions across Australia to serve as a case study to examine the outcomes for soil management resulting from various interventions in agricultural practice (Fig. 1). Semi-structured interviews with experienced land managers from each region were used, together with land use and production statistics from the Australian Bureau of Statistics' 2011 Agricultural Census (ABS, 2011), to identify management practices typical of a well-run mixed farm at each location (Table 1). At each location, 1 to 4 soil types typical of the region were included in the description of the physical resources on the farm. At 6 of the 7 locations, patterns of land use were described as a set of fixed land use sequences (or rotations), with a substantial proportion of land (ranging from 36% at Hamilton to 100% at Waikerie) rotated between grain crops and pastures. A seed pool reset for annual pastures was included at the end of cropping sequences to ensure the productivity of pastures was maintained. Reset values were selected to maintain a pasture composition consistent with best practice in mixed farming in each region. This modelling approach substituted for the real-world requirement to renovate ley pastures occasionally to ensure their ongoing productivity, particularly at the conclusion of long cropping sequences