Modeling the effects of mixed farming systems on soil carbon and crop-livestock productivity in central-west NSW

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Abstract

Simulation models are increasingly used for improvement of agricultural productivity through studying the interactions among biophysical processes in an agricultural farming system. In this study we used AusFarm (agricultural systems analysis model) to simulate crop and livestock performance including long-term soil organic carbon (SOC) dynamics under different management options such as conventional and reduced tillage, non-tillage with continuous cropping and perennial pasture in a grazing system. The AusFarm model was able to explain 70% of the observed variability in wheat grain yield with a RMSD of 554 kg/ha and showed good agreement between observed and simulated livestock performance. Simulated crop yield and gross margins were higher in conventional and reduced tillage with 2 -years annual pastures-cropping rotations than continuous cropping. In the long-term field experiment, the observed SOC increased initially, and were comparatively higher in reduced tillage than conventional practices. However, observed SOC decreased by 2012 in all other management options though SOC are higher in perennial pasture. The simulated trends of SOC under different farming system treatments were generally comparable with the observed field trial data. Although crops, pastures and livestock performance is related to timing of rainfall and amount of rainfall, equally, soil fertility decline can influence crop-livestock productivity. Long-term simulations suggest, cropping frequencies including crop-livestock rotation adjustments and soil-nutrient management are needed for productive mixed farming with environmental gains.

Key words

AusFarm, Crop rotation, Soil carbon, Simulation, Yield, Sheep weight

Introduction

With a focus on increasing productivity of mixed farms in the livestock dominate farming regions of NSW; practices involving reduced tillage, diverse crop rotations and altering the length of pasture phases may offer advantages. A key question is how modifications to this mixed farming system influence soil fertility through changes in SOC and the influence this has on crop and livestock productivity. In this study, long-term observations from the Central West Farming Systems trial at the Condobolin Research Station were used to validate AusFarm (Donnelly *et al*. 2002; Moore *et al*. 2007) with different management options for soil carbon and crop-livestock productivity. The other objective is to apply the validated AusFarm model to investigate SOC dynamics and crop-livestock performance as influenced by different mixed farming practices.

Methods

Site and treatment: This study involves a long-term field experiment conducted by Central West Farming Systems (CWFS) that commenced in 1998 and is continuing at Condobolin Research Station (33.07°S, 147.23°E). The site is characterised by a hot semi-arid climate with an average annual precipitation of 442 mm and a mean annual temperature of 17.4°C. The soil is a Red kandosol soil (Isbell 1996) with SOC content of about 1.30% in 0-10 cm soil depth. This is a representative of a rainfed crop-livestock growing location in the central-west NSW. The CWFS site covers 160 ha area. This area is divided into 40 ha blocks. 10 ha areas within each block are randomly assigned to 1 of 4 farming system: a traditional farming system with conventional tillage (CT), reduced tillage with livestock (RT), zero-tillage with no livestock(ZT) and perennial pastures (PP). The CT represents a mixed farming system that uses conventional tillage with a pasture phase, wheat phase of long fallow wheat (LFW) and short fallow wheat (SFW) under-sown with pasture combinations. The RT represents reduced tillage with rotations of LFW, SFW, grazed pasture and a period of rest and naturalised pasture between wheat crops. The ZT represents continuous a cropping rotation with wheat, barley and field pea.

Simulation

The AusFarm model (http://www.grazplan.csiro.au) was used to link the APSIM crop and soil models (Keating *et al*. 2003) and the GRAZPLAN pasture and animal management models (Freer *et al*. 1997; Donnelly *et al*. 2002; Moore *et al*. 2007) are used to represent CT, RT and ZT mixed crop-livestock farming practices. Briefly, AusFarm simulates biological and physical processes in a mixed-farming system in response to climate (daily maximum and minimum temperature, rainfall and solar radiation), in-crop management, livestock enterprises and animal husbandry practices. Crop yield and animal performance (Medium Merino) data from 1998 to 2012 comprising CT, RT and ZT farming systems were used to validate the AusFarm model. Performance was evaluated against the observed measurement by comparing the coefficient of determination and root mean square deviation (RMSD). The effects of tillage and frequencies of cropping with annual pasture phase on SOC and in turn to crop-livestock productivity were examined by long-term simulations (1 January 1889–31 December 2014) using historical climate (daily solar radiation, maximum temperature, minimum temperature and rainfall) data obtained from SILO patched point datasets (http://www.longpaddock.qld.gov.au/silo/ppd/index). A mixed crop-livestock farming scenario representative of central-west NSW was developed in the AusFarm platform. Parameters information available in Primefacts (http://www.dpi.nsw.gov.au/aboutus/resources/factsheets/agriculture) pertaining to crop management, sheep enterprises and animal husbandry practices were used in the simulations setup which is similar to existing mixed-farming system in central-west NSW region. The farm area assigned in the simulation is 1000 hectare, where 30% constitutes permanent pastures (phalaris) to represent naturalised grazing pasture for use sheep grazing (Medium Merino of 5.25 Ewes/farm ha) and reminder 70% as arable land divided into seven paddocks to facilitate crop sequences and annual pastures (sub-clover and annual Ryegrass). We considered four simulation treatments: (1) CT_APCW represents conventional tillage (CT) with a rotation of 2 -years annual pasture (AP)/wheat/canola/wheat/canola; (2) CT_CW represents CT with continuous canola and wheat; (3) RT_APCW represents reduced tillage (RT) with a rotation of 2 -years annual pasture/wheat/canola/wheat/canola and (4) RT_CW represents RT with continuous canola and wheat. Gross margins ($/ha) were estimated using the variable costs based on 2012 farm budget and costs data (http://www.dpi.nsw.gov.au/agriculture/farm-business/budgets).

Results and Discussion

The AusFarm model was able to explain 70% of the observed variability in wheat grain yield with a RMSD of 554 kg/ha (Fig. 1A). In 2002 (the only year with records), comparison of simulated and observed lamb sale weight and fleece weight showed adequate level of prediction (Fig. 1B and C).

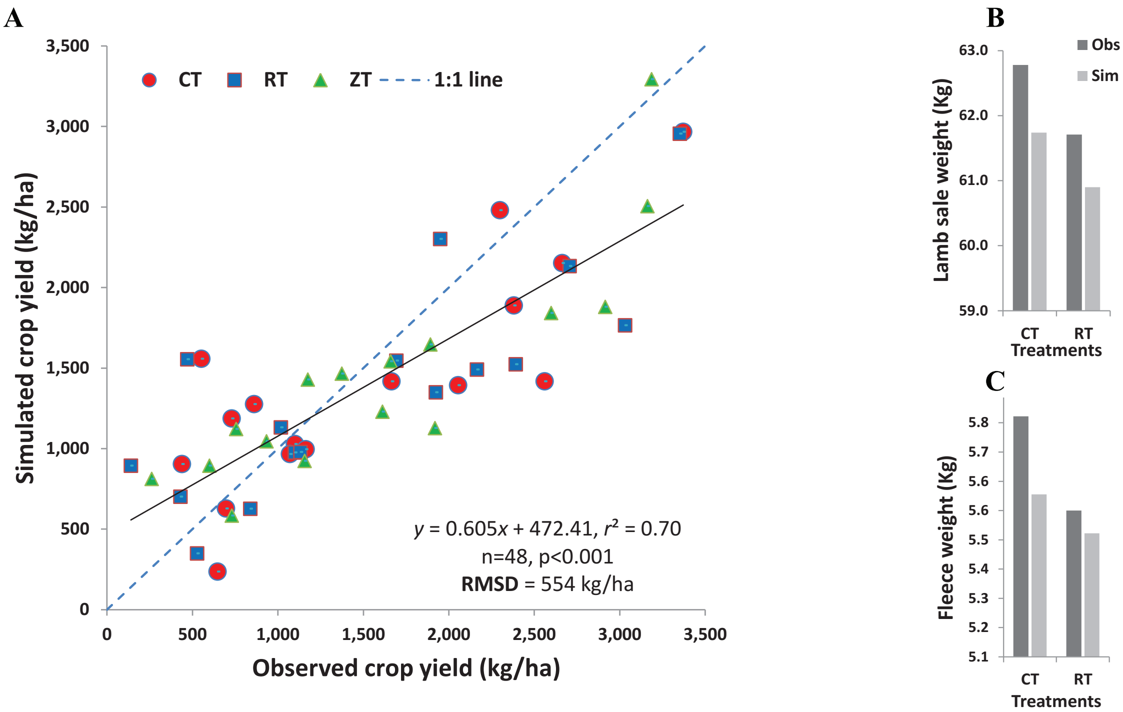

Figure 1. Comparison of simulated and observed wheat yields (A), animal weight (B) and fleece weight (C) for experimental data comprising traditional farming system (CT), reduced tillage with livestock (RT) and zero-tillage with no-livestock (ZT). Animal weight and fleece weight were only for year 2002.

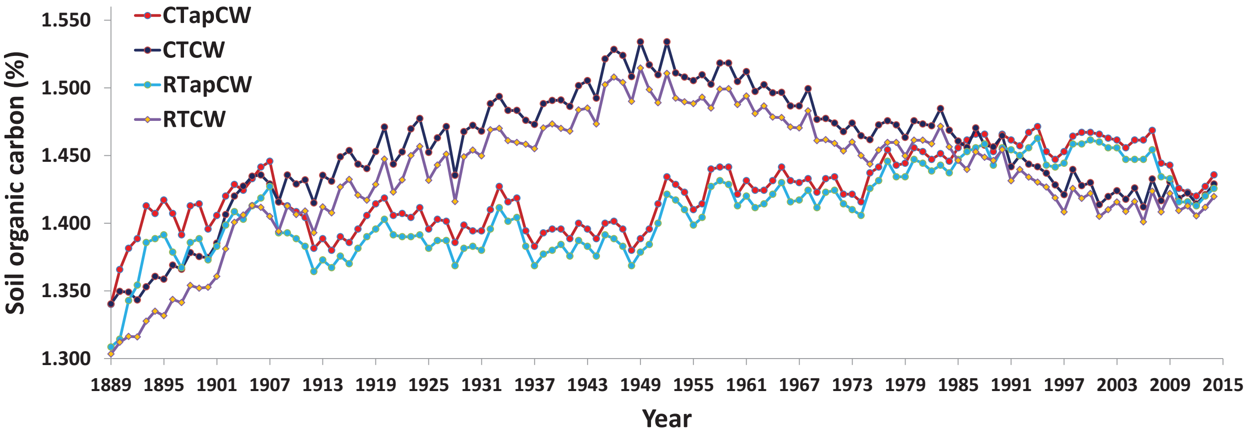

Figure 2. Simulated soil organic carbon (%) in the 0 – 10 cm soil profile across conventional tillage (CT) with pasture-cropping rotation (CT_APCW), CT with continuous cropping (CT_CW), reduced tillage (RT) with pasture-cropping rotation (RT_APCW) and RT with continuous cropping (RT_CW).

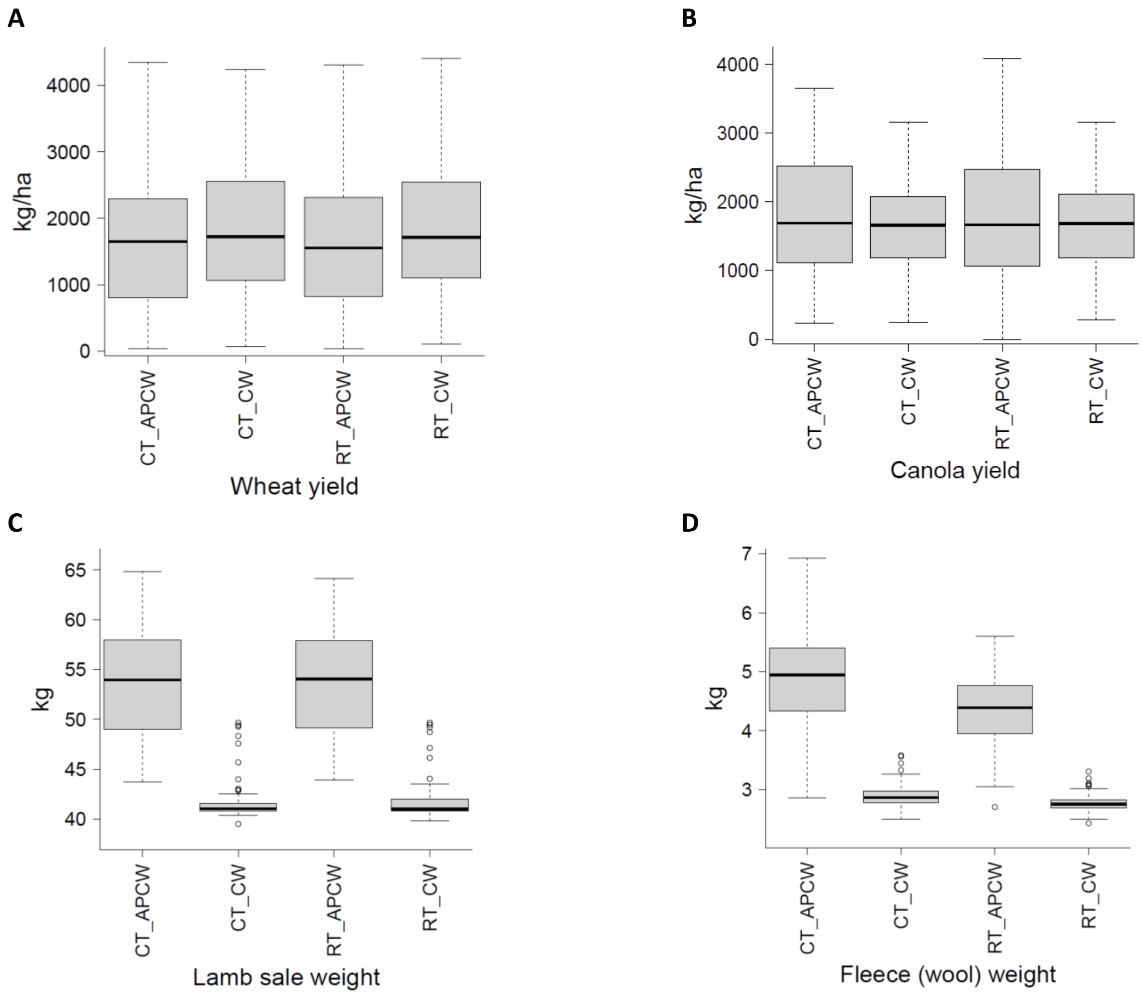

Figure 3. Box-plot of simulated crop yields (A and B), animal and fleece weight (C and D) across conventional tillage (CT) with pasture-cropping rotation (CT_APCW), CT with continuous cropping (CT_CW), reduced tillage (RT) with pasture-cropping rotation (RT_APCW) and RT with continuous cropping (RT_CW) treatments. Livestock in all systems have access to permanent phalaris pasture.

In the long-term field experiment observed SOC increased initially, and were comparatively higher in reduced tillage than conventional practices (data not shown). However, in the long-term field experiment, the observed SOC decreased by 2012 in all other management options though SOC are higher in perennial pasture. Likewise, simulated SOC increased continuously during the long-term (Fig. 2) across all farming practices. However, after an initial increase, modelled SOC under CT_CW and RT_CW declines rapidly after 1950, implying more organic inputs due to higher frequencies of cropping, and later decline could be attributed to reduced microbial substrate for biochemical activity. In contrast, increasing SOC under CT_APCW and RT_APCW is fairly stable (Chan *et al*. 2010).

The simulated median crop (wheat and canola) were not different between the four mixed farming systems (Fig. 3). However, dispersion of the distribution of long-term canola yield reduced (Fig. 3B) in CT_CW and RT_CW farming systems. Performance of sheep in terms of lamb sale weight and fleece weight was highest (Fig. 3C and D) with the introduction of 2-years annual pastures in the cropping rotation (CT_APCW and RT_APCW). With the introduction of annual pasture component in the farming system, gross margins were higher in CT_APCW and RT_APCW compared to CT_CW and RT_CW (Fig. 4). In a mixed crop-livestock systems including pasture can reduce supplementary feeding costs, complementing better farm profitability.

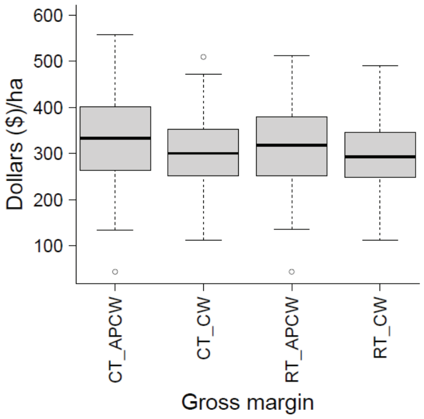

Figure 4. Relative frequency (%) distribution (125 years) of Gross Margins ($/ha) calculated from simulated crop-livestock productivity across conventional tillage (CT) with pasture-cropping rotation (CT_APCW), CT with continuous cropping (CT_CW), reduced tillage (RT) with pasture-cropping rotation (RT_APCW) and RT with continuous cropping (RT_CW) treatments.

Conclusion

Simulations indicate that Ausfarm captured the physiological processes satisfactorily for different tillage managements, and the model was able to explain 70% of the observed variability in crop yield with a RMSD of 554 kg/ha. The simulated trends of SOC under different farming system treatments were generally comparable with the observed field trial trends. There were stable trends of increasing of SOC in both conventional and reduced tillage with 2 -years annual pasture-cropping rotations than continuous cropping.

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