Model simulations of carbon storage and fluxes in native perennial and temperate grass-based pastures

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Abstract

The SGS Pasture Model was used to predict carbon (C) values for pasture, soil and animal components of a native perennial grass-based pasture and an improved grass-legume pasture at Glen Innes, New South Wales for a 102-year period (1907−2008). For both pasture systems, increasing stocking rate decreased the predicted soil organic C level (0-0.3 m depth). Also, soil C saturation was observed in both systems, with predicted soil C sequestration rates being highest in the first 5 years (1.3−3.6 t C/ha/year), but declined to <1.0 t C/ha/year after 50 years. Predicted net soil C sequestration (0−2.0 m depth) at a stocking rate of 1 wether/ha over the 102-year period was 141.4 t $C0_2$ equivalents/ha (38.5 t C/ha) for the improved pasture and 29.7 t $C0_2$ equivalents/ha (8.2 t C/ha) for the native pasture. Annual rainfall had a substantial effect on both predicted soil C input and soil C losses, with both being highest in the wetter years.

Key Words

net soil carbon, climate variability, stocking rate, respiration, methane

Introduction

Recently, there has been a view expressed that soils under pastures could be used as a carbon (C) sink to sequester or store C, with the possibility that land owners could receive benefits under a C trading scheme. However, as pointed out by Sackett (2009) to be effective a C sink (mainly the above ground plant material, plant roots and soil) must retain the C for a long period and forests are 10 times more effective at storing C than grasslands. Carbon stocks of ecosystems increase with woody plant content and decrease with annual species content compared with perennial grasses (Eady *et al.* 2009), as a result of both the long-lived C in woody stems and higher soil organic matter (OM) to depth.

Net C gain by an ecosystem can be positive or negative in any one year depending on seasonal weather, management and episodic disturbances such as drought or fire (Eady *et al.* 2009). Ecosystem C stocks are continually changing with inputs from plant growth and litter decay being offset by losses from soil OM decomposition, microbial respiration and animal emissions. In any one year, the increase in C stocks in a system (i.e. its net sequestration) is the small difference between the inputs and the losses and may be positive or negative depending on seasonal conditions, management and soil C levels. Hence it is unlikely that all C inputs will remain in a sequestered repository and so pasture systems will always be in considerable flux. To fully understand the dynamics of these fluxes and so the likely rates of C sequestration requires the use of models; measures of the C content of plants, litter, soil and products only allows monitoring of the system states that occur as a result of these fluxes. Measures of soil C stocks (0−0.2 m depth) in fertilised kikuyu (*Pennisetum clandestinum*) and unfertilised native grass pastures on the mid-north coast of New South Wales (NSW), indicated that the soil C sequestration rate of the improved pasture was up to 1.5 t C/ha/year higher than that of the native pasture (Chan and McCoy 2009). However, since C saturation (the point at which soil organic C levels can no longer increase regardless of management, production or external inputs) occurs over time (Walcott *et al.* 2009) some care needs to be taken when extrapolating the long-term consequences of such data for soil C sequestration. After disturbance and a change of residue input into a system a period of up to 100 years of constant management may be required for a new steady state equilibrium to be reached (Swift 2001).

In this paper, we describe the use of the Sustainable Grazing Systems (SGS) Pasture Model (Johnson *et al.* 2003) to simulate the C fluxes in the plant, soil and animal components of two different grazed, temperate pasture systems in northern NSW over a 102-year period of variable climate. The main focus of these analyses was to highlight the substantial fluxes that occurred over time and the effect of management or initial soil C levels on the predicted relative C values of different components of the system, rather than to report the absolute values of the system states.

Methods

The SGS Pasture Model was used to simulate two pasture systems; a C_3/C_4 native perennial grass pasture (native pasture, NP) and a tall fescue (*Lolium arundinaceum* syn *Festuca arundinacea*) white clover (*Trifolium repens*) pasture (improved pasture, IP) growing at Glen Innes (29 42'S; 151 42'E) on the northern tablelands of NSW (average annual rainfall (1907−2008), 831 mm/year). Parameterised values for these pasture species are available within the model and have been widely tested. The soil type was a generic clay-loam and simulations were for 23 soil layers to a total depth of 2.0 m. The model includes C assimilation through photosynthesis and respiration as well as tissue growth, turnover and senescence. A soil nutrient dynamics component considers OM turnover in three pools, inert, slow and fast with the microbial biomass incorporated into the fast pool. Carbon associated with animal respiration and methane output is accounted for in the animal module.

Long-term (1907−2008) daily interpolated weather data for the site latitude/longitude coordinates were abstracted from the SILO Data Drill (Jeffery *et al.* 2001). For all simulations, fertiliser was applied to maintain soil nitrogen above a growth limiting factor (GLF, Johnson *et al.* 2003) of 0.75; for the improved pasture phosphorus, sulfur and potassium were also maintained above this GLF level. Initial soil C values for the profile were set at a stable equilibrium value obtained from multiple model runs at a stocking rate of 7 wethers/ha, which was the maximum rate at which supplementary feeding was not required in most years. Pastures were grazed with Merino wethers (60 kg liveweight) and simulations were run at a range of continuously grazed stocking rates as well as a variable stocking rate (stocking rate adjusted monthly according to feed availability). In the model, wethers were supplementary fed to maintain metabolisable energy intake at >60% of daily requirement; supplementation was required at some time during the simulation for all rates, except the 1 wether/ha and variable stocking rates. Variable stocking rates averaged 13.1 wethers/ha for the native pasture and 16.5 wethers/ha for the improved pasture. All simulations were for a 100 ha area.

For the simulations described, daily changes in pasture, soil and animal parameters were modelled for both the native and improved pastures and used to compile annual summaries. Predicted soil C values (tonnes (t)/ha) for 1 January each year were calculated for stocking rates of 1, 5, 10 and 15 wethers/ha for a soil depth of 0−0.3 m. Annual predicted soil C inputs and losses (t of carbon dioxide ($C0_2$) equivalents/ha) and rainfall are presented for the full profile (0−2.0 m) for the 1 wether/ha stocking rate over the 102-year period, since this was the only rate at which soil C was likely to be sequestered. Simulations were also run with initial soil C values of 1 and 3% in the soil surface layers and the effects of stocking rates and the pasture systems compared for predicted C (t $C0_2$ equivalents/ha/yr) in the plant, soil and animal components in each.

Results and discussion

At a stocking rate of 1 wether/ha predicted soil C for the native pasture increased from 77.2 to 97.5 t/ha, but for stocking rates of 5, 10 and 15 wethers/ha the changes in predicted soil C over time were 8.6, -6.7 and -13.9 t/ha, respectively (data not presented). Responses were similar for the 0−2.0 m depth, with the predicted soil C values at 1 wether/ha increasing over time from 136 to 158 t C/ha. As stocking rate increased predicted animal intake of pasture increased, decreasing the amount of plant material available for litter decay and input into soil OM.

However, even at a low stocking rate soil C saturation was evident, with the predicted C sequestration rates (0−2.0 m) 5, 10, 20, 50 and 100 years after 1907 being 1.3, 0.6, 0.4, 0.2 and 0.1 t C/ha/yr, respectively for the native pasture and 3.6, 1.8, 1.3, 0.8 and 0.4 t C/ha/yr, respectively for the improved pasture. Using a lower initial soil C level in the surface layers (1 *v.* 3%) had little effect on the predicted long-term (100-year) C sequestration rate increasing it from 0.1 to 0.45 t C/ha/yr for the native pasture and from 0.4 to 0.55 t C/ha/yr for the improved pasture. For both pasture types and initial soil C values, predicted soil C sequestration rates were highest initially (1−5 years), but declined to <1.0 t C/ha/yr after 50 years.

For the improved pasture, predicted soil C inputs (0−2.0 m depth) ranged from 16.5 to 72.2 t $C0_2$ equivalents/ha/yr, with a mean value of 42.4 t $C0_2$ equivalents/ha/yr (Fig. 1*a*) and predicted soil C losses ranged from 19.9 to 62.2 t $C0_2$ equivalents/ha/yr (mean value of 41.0 t $C0_2$ equivalents/ha/yr). Predicted values were lower for the native pasture (Fig. 1*a*) with soil C inputs ranging from 15.5 to 31.3 t $C0_2$ equivalents/ha/yr (mean value 24.4 t $C0_2$ equivalents/ha/yr) and losses ranging from 14.9 to 33.0 t $C0_2$ equivalents/ha/yr (mean 24.5 t $C0_2$ equivalents/ha/yr). As a consequence predicted net soil C

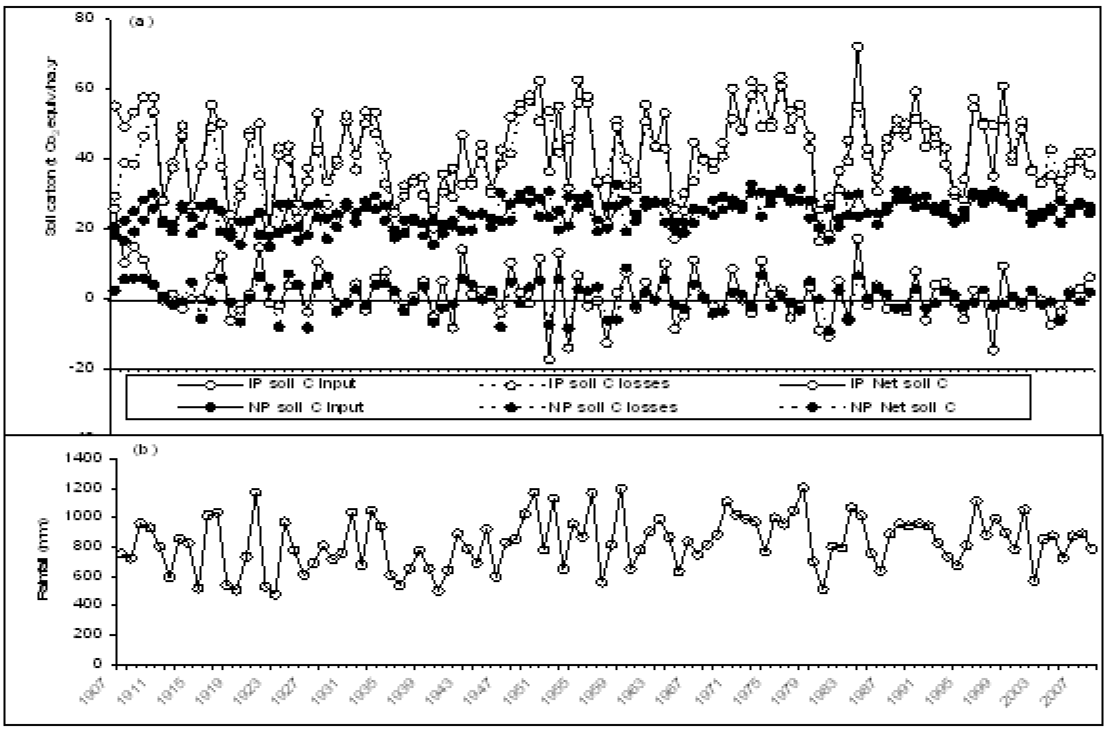

Figure. 1. (*a*) Predicted soil carbon (0-2.0 m depth) annual inputs and losses (t $C0_2$ equivalents/ha/yr)

for a native (NP) and improved pasture (IP) at Glen Innes, NSW, continuously grazed at 1 wether/ha

for a 102-year period, together with (*b*) annual rainfall (mm), interpolated data) for Glen Innes, NSW

from 1907 to 2008.

sequestration (0−2.0 m) over the 102-year period was 141.4 t $C0_2$ equivalents/ha (38.5 t C/ha) for the improved pasture and 29.7 t $C0_2$ equivalents/ha (8.2 t C/ha) for the native pasture (Table 1).

Annual rainfall (Fig. 1*b*) had a marked effect on both predicted soil C input and soil C losses, since it affected both plant growth and decay, as well as soil microbial activity. The correlation coefficient

(*r*−value) for the linear relationship between predicted soil C inputs and losses and annual rainfall was

Table 1. Effect of pasture type and stocking rate (SR) on the different system components of predicted mean annual C (t $C0_2$ equivalents/ha.yr), together with the predicted net soil C sequestration over the 102-year period.

System components	Native pasture				Tall fescue/white clover		
?	1 wether/ha		Variable SR		1 wether/ha		Variable SR
	t $C0_2$ equivalents/ha/yr						
Pasture C fixed	26.9		20.5		42.1		38.4
Soil C input	24.8		13.4		42.4		33.5
Soil C losses	24.5		13.5		41.0		32.5
Nitrous oxide emissions	0.5		0.2		1.2		1.2
Sheep $C0_2$ respiration	0.4		4.6		0.3		3.7
Sheep methane emissions	0.2		2.1		0.1		1.6
Soil C sequestration for							
102 yrs (t $C0_2$ equivalents/ha)	29.7	?	-8.7	?	141.4	?	101.9

significant (P < 0.05) for both pasture types, although it was strongest (r>0.75) for soil C losses. In wetter years (annual rainfall >900 mm), pasture growth was highest, but moist conditions also favoured high soil C losses, probably as a result of high levels of soil microbial activity. Therefore drier years (annual rainfall ~650−800 mm) with intermediate soil C losses, tended to have higher net positive rates of soil C sequestration, which may have implications for future climate variability and climate change forecasts.

Mean annual predicted pasture and soil C components were lower for variable stocking rates than those for 1 wether/ha and lower for the native pasture than the improved pasture (Table 1). This reflected the higher intake of pasture at the variable stocking rate and the higher growth of the improved compared with the native pasture. Predicted mean annual sheep C losses associated with $C0_2$ respiration and methane emissions were <2.5% of the mean annual soil C losses in the low stocking rate 1 wether/ha systems (Table 1), but up to 50% of the losses in the variably stocked native pasture and ~20% of those in the variably stocked improved pasture.

Conclusions

Modelling the fluxes in C levels in pasture, soil and animal components of two pasture systems for different initial soil C levels, stocking rates and grazing systems provided valuable insights into the possible interactions between pasture management and long-term C dynamics. These preliminary investigations indicated that high levels of soil C sequestration were unlikely for the soil and pasture types, stocking rates and climatic conditions modelled over the 102-year period. Further modelling is required to determine if similar outcomes are likely for different environments, grazing and pasture systems.

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