Complex feedbacks can make agronomic management of greenhouse gas emissions difficult in subtropical agricultural systems.

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Abstract
One method for sequestering carbon (C) within agricultural soils is to increase productivity and therefore C input into the soil. However, there is a potential trade-off between decreased C emissions and increased nitrous oxide (N_2O) emissions if this is achieved via nitrogenous fertilisers. An alternative is to incorporate legumes into cropping rotations to provide a biological source of nitrogen (N). However, the impacts on C input and N_2O emissions when replacing cereal crops with legumes are unknown. Consequently, an analysis has been undertaken for a subtropical cropping system where soil, climate and management are conducive to denitrification losses.
Scenarios covering a range of cropping rotations, N fertiliser applications and leguminous crops were tested using the Agricultural Production Systems Simulator (APSIM). The model was tested using long term data from the Brigalow Catchment Study site near Theodore, Queensland, Australia.
Scenario analyses demonstrated that soil C can be managed to some degree via simple changes in agronomic practice. However, reductions in carbon dioxide (CO_2) emissions were often offset by increased N_2O emissions. The use of legumes within cereal rotations was not always as effective in reducing N_2O emissions as improved fertiliser practice. For example, replacing wheat crops with chickpea did not reduce N_2O emissions relative to fertilised systems and did not assist in increasing soil C relative to unfertilised systems. The fact that some interventions proved counterproductive due to complex feedbacks highlights the need for careful consideration of agronomic interventions to manage greenhouse gas emissions.

Key Words
APSIM, model, greenhouse gas, legumes, fertiliser, soil carbon

Introduction
One method for increasing the sequestration of carbon (C) within agricultural soils is to increase crop productivity and therefore C input into the soil. However, if this is achieved via nitrogenous fertilisers, there is a potential trade-off between decreased C emissions and increased nitrous oxide (N_2O) emissions because the radiative effect of N_2O is much higher than for an equivalent volume of CO_2. An alternative is to incorporate leguminous crops into cropping rotations to provide a biological source of nitrogen (N). However, the likely impacts on C input and N_2O emissions when replacing cereal crops with legumes are unknown. Consequently, an analysis of the likely impacts has been undertaken for a subtropical dryland cropping system in Queensland, Australia where soil, climate and management are conducive to denitrification losses.

Methods
A series of scenarios embracing a range of cropping rotations, nitrogen fertiliser applications and leguminous crops was tested using the Agricultural Production Systems Simulator (APSIM) (Keating et al. 2003). The model configuration was tested using long term data from the Brigalow Catchment study site near Theodore, Queensland, Australia (24.81° S, 149.80° E) (Cowie et al. 2007). A wide range of data was used in testing the model for the major components in the C, N and water balances (Radford et al. 2007; Thornton et al. 2007). A detailed description of the model parameterisation and evaluation is available in Huth et al. (2010). The model configured and tested above was used to estimate the changes in soil C and N_2O emissions for the following cropping systems:
1) WS – Wheat and Sorghum with no fertiliser (historical local practice)
2) WS+N – Wheat and Sorghum with fertiliser (current local practice)
3) WS+N Split – Wheat and Sorghum with a split application of fertiliser
4) CS – Chickpea and Sorghum, only Sorghum fertilised
5) WM – Wheat and Mungbean, only Wheat fertilised

All agronomy was specified according to local best practice. Fertiliser requirements were calculated at sowing so as to raise the soil mineral N within the crop root zone to 100 kg N/ha. Fertiliser was added as urea. Initial soil C levels were set to those simulated for 2005 during the model testing exercise as these represent the soil organic C status of much of the farming land within the region that has been cropped for many decades since the Brigalow forest was cleared. Simulations were undertaken using weather data from 1950 to 2005 to provide a long sample of local climatic conditions. Partial accounting for greenhouse gas emissions and economic return was applied to provide a simple comparison of the relative performance of the scenarios. Calculated emissions included CO_2 and N_2O emission from the field. No accounting for off-field emissions such as in transport or fertiliser production is included. The global warming potential for N_2O was assumed to be 298 times that for CO_2. Gross margin calculations include machinery, seed, fertiliser, herbicide, pesticide, and harvesting costs, but owner or labour costs were excluded.

Results

APSIM was able to adequately describe the major processes and resultant changes in crop productivity and soil C and N content within the surface (0-0.3 m) soil layers for the chosen test dataset (Figure 1). The ability of the model to capture the observed decrease in grain protein indicates that the model is capturing important nutritional constraints at the site. Although neither denitrification nor N_2O emissions were measured as part of this long term study, confidence in the model predictions of these processes can be obtained by comparing the model predictions of the main drivers of denitrification such as C, water and N and by accounting for all N loss mechanisms as part of the overall observed decline in soil N (Figure 2).

A summary of the results from the scenario analyses are included in Table 1. The addition of N to the system via fertiliser or legumes increased crop growth and slowed the rundown of soil C while halving CO_2 emissions. Fertiliser application increased N_2O losses, though this was slightly lower when split applications were used to better match the time of crop N demand. The introduction of mungbean crops reduced fertiliser application and N_2O losses while increasing profitability. However, the use of chickpea in these systems resulted in similar N_2O emission and higher CO_2 emission than fertilised systems due to its low level of stubble cover, and therefore, adverse impact on fallowing efficiency. Lower fallow moisture storage following chickpea decreased growth and therefore C input of the following summer cereal.

The increases in N_2O emissions above those for the unfertilised scenario represent approximately 2.2% of the fertiliser N applied for WS+N and 1.9% for WS+N Split. These emissions relative to fertiliser N application are slightly higher than estimates employed for inventory reporting purposes (IPCC 2000) but are comparable to previous measurements from a Brigalow clay soil (Weier et al. 1991).

In all systems, seasonal trends in N_2O emissions on Brigalow soils in response to temperature and C and N supply are evident (Figure 3). The overall impact on N_2O emissions of the different cropping systems varied when compared to a standard WS+N rotation. N_2O emissions during summer and winter planting windows are reduced by split application of N (WS+ N Split) due to the reduced amounts of soil nitrate during crop establishment. For WM there is a slight increase in N_2O emissions in winter as mungbean residues mineralise through autumn. However, there is a large decrease in N_2O emissions in summer when N fertiliser use is no longer required. The CS rotation shows a slight decrease in N_2O emissions in winter when N fertiliser is no longer needed but a large increase in summer when decomposition of chickpea residues increases denitrification (Figure 3). The vast difference in these scenarios illustrates the need to consider the complex feedbacks and agronomic impacts of various greenhouse gas intervention strategies. Approaches to decrease emissions, such as incorporating legumes, will need to be tailored to individual cropping systems or the outcomes may be counterproductive.

Conclusion

Scenario analyses of alternative management systems including the use of fertiliser, grain legumes or forage crops within cereal rotations demonstrated that soil C can be managed to some degree via simple changes in agronomic practice. The use of legumes within cereal rotations was not always as effective as improved fertiliser practice in reducing N_2O emissions. In fact, the use of chickpea crops to replace wheat crops did not reduce N_2O emissions relative to fertilised systems and did not assist in slowing soil C decline. The fact that some interventions proved counterproductive due to complex feedbacks highlights the need for careful consideration of agronomic interventions to manage greenhouse gas emissions.

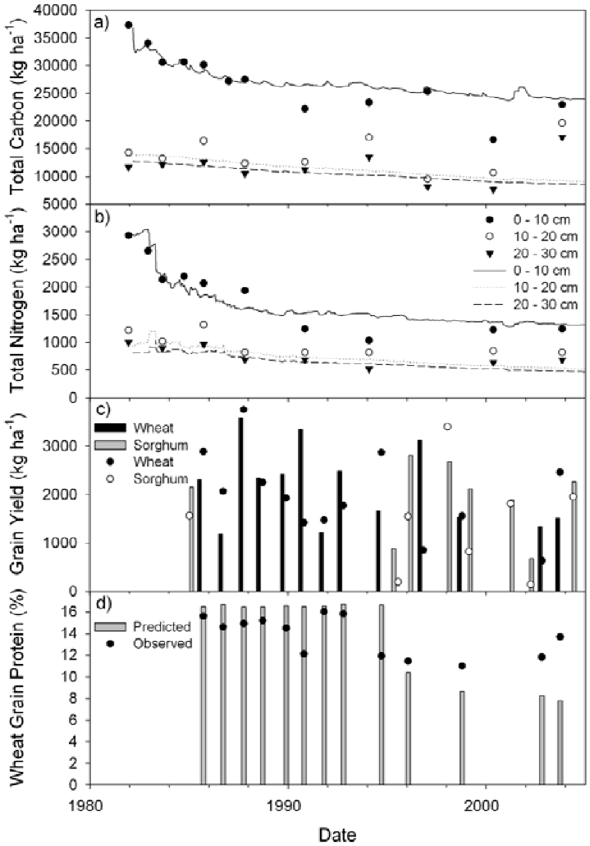

Figure 1. Observed and predicted time courses of a) soil carbon and b) total soil nitrogen (observed as symbols and predicted as lines, see legend) as well as c) grain yield and d) wheat grain protein content for the model test dataset (observed as symbols, predicted as bars).

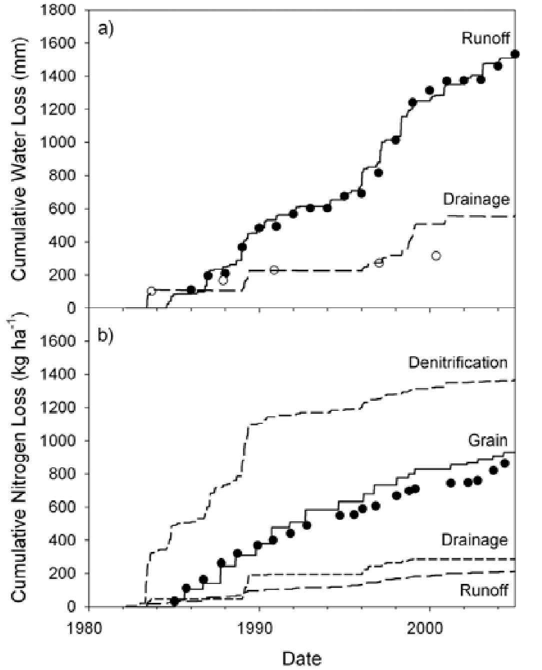

Figure 2. Observed and predicted accumulated losses for a) water (runoff and drainage) and b) nitrogen (export in grain, runoff water or drainage and denitrification) for the model test dataset. In both figures observations are as symbols and predictions as lines.

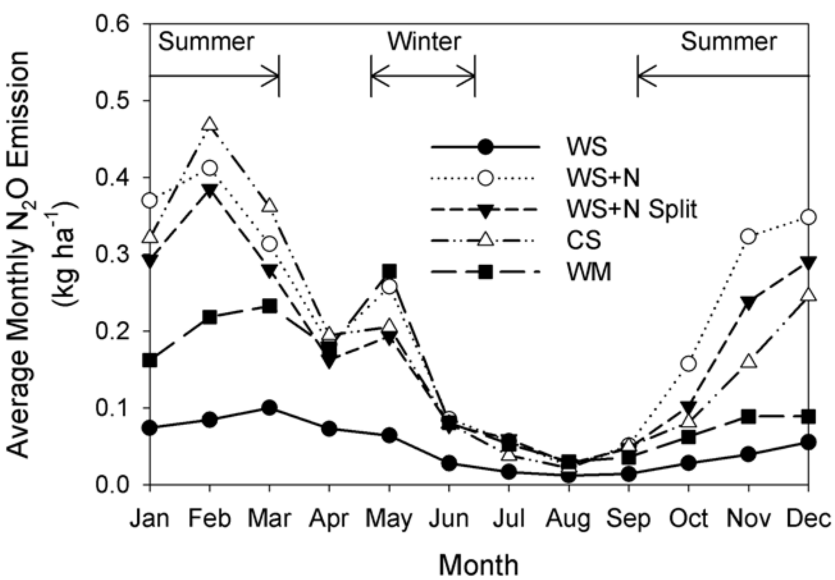

Figure 3. Predicted changes in seasonal N_2O emissions due to cropping/fertiliser management. Approximate winter and summer planting windows are shown to indicate likely periods of fertiliser application.

Table 1. Simulated (1950-2005) average production, fertiliser N input, soil CO_2 and N_2O emissions and economic return for the five management scenarios. Scenarios are described within the text.

	System				
	WS	WS+N	WS+Nsplit	CS	WM
Average grain yield (kg/ha) (number of crops in parentheses)					
Winter Crop	847 (48)	2484 (34)	2552 (32)	1805 (32)	2564 (33)
Summer Crop	1460 (56)	3539 (51)	3553 (51)	3203 (42)	1438 (55)
Average annual N application (kg/ha/y)					
Winter Crop	0.0	32.6	31.1	0.0	25.6
Summer Crop	0.0	55.1	52.6	36.4	0.0
Total	0.0	87.7	83.7	36.4	25.6
Average annual emissions (t CO_2e/ha/y)					
Carbon dioxide (CO_2)	0.96	0.48	0.50	0.63	0.49
Nitrous oxide (N_2O)	0.27	1.20	1.00	1.03	0.70
Total	1.23	1.68	1.50	1.67	1.20
Average annual gross margin ($ AUD/ha/y)					
Winter Crop	19.5	237.2	236.1	331.2	251.3
Summer Crop	-15.0	304.3	310.9	221.5	526.4
Total	4.5	541.5	547.0	552.7	777.7
Economic return on emission ($ AUD/t CO_2e)					
	3.6	323.2	364.2	331.3	650.2

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