Greenhouse gas mitigation potential and profitability of practices on Australian grain farms

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Abstract
Australian farm owners are being encouraged to mitigate emissions of greenhouse gases such as carbon dioxide (CO_2) and nitrous oxide (N_2O). However, trade-offs exist between mitigation strategies as practices that sequester carbon (hence reducing CO_2 emissions) may increase N_2O emissions. Further, the amount of CO_2 (via carbon sequestration) or N_2O emitted may change with time and vary with location characteristics including weather and soil type. In this study the net global warming potential and financial effect of on-farm practices designed to abate greenhouse gas emissions was assessed for a case study farm in the Western Australian wheatbelt (low carbon soil-low rainfall environment). The usual farm management formed the baseline against which alternative scenarios aimed at mitigating greenhouse gas production were evaluated for a 100 yr period. Simulated yield and nitrogen fertiliser rates from the APSIM model were used to estimate the annual gross margin. Scenarios that involved retention instead of burning stubble or adding additional organic matter decreased the net global warming potential without reducing gross margins. Scenarios that used a lower nitrogen fertiliser rate than the baseline resulted in a decrease in yield and profitability with little effect on net global warming potential.

Key words
Greenhouse gas abatement, APSIM, economic analysis

Introduction
Under the new Emissions Reduction Fund policy, Australian farm owners can be paid for greenhouse gas abatement if they bid the least cost delivery price through a reverse auction process. Farm owners therefore need information about the effect of practices on soil carbon and N_2O emissions, productivity and gross margins. However, trade-offs exist between mitigation strategies as practices that sequester carbon - thus reducing CO_2 emissions - may increase N_2O emissions. The potential trade-offs are not always obvious and may reduce the potential for Australian grains farms to mitigate GHG emissions. In addition, suitable mitigation practices may vary across regions, reduce whole farm profitability or fit poorly within farm management. To better understand these trade-offs, we estimated the net, whole-farm GHG mitigation balance and financial impact of various management practices applicable to Australian grains farms.

Methods
Case study farm
We established six representative farms in collaboration with farmer groups across the northern, southern and western grain growing regions of Australia. The usual cropping systems and management employed by the farmers were developed into a set of standard rules to support modelling with APSIM and formed the baseline for analyses at each farm. In this paper, we present results for one of the case study farms, located at Dalwallinu (30.27°S, 116.66°E) in Western Australia. Average climatic conditions include annual (winter-dominant) rainfall of 310 mm yr^{-1} and minimum-maximum temperatures of 16 to 36°C in summer and 6 to 17°C in winter. The most common soil types on the 6,000 ha case study farm are sands and sandy duplexes. For this study, simulations were made for a single representative soil (deep sand; 0.7% carbon in 0.0-0.1 m). The simulated farming system included three different rotations (Table 1) based on canola, wheat, barley, lupins and pasture combined with bare summer fallows. Simulated crops were sown between 25 April and 15 June after receiving accumulated rainfall of 10 mm within the previous 10 d; otherwise crops were dry sown at the end of the period. The amount of nitrogen (N) fertiliser applied to crops was calculated at sowing at the rate of approximately 40 kg N ha^{-1} per tonne of harvested grain based on average historical farm yields described by the collaborating farm owners. This target was met through a combination of nitrogen fertiliser supplemented with soil mineral N measured in the surface 0.1 m layer of soil at sowing.

Table 1. Crop rotations at the case study farm

Name	Crops in rotation (x denotes bare summer fallow in usual practices)
'Cereal'	Canola x wheat x wheat x barley
'Legume'	Canola x wheat x lupin x wheat x wheat
'Pasture'	Canola–weedy pasture during summer/winter/summer-wheat x wheat x barley

Scenarios

A set of alternative practices (Scenarios 2-9, Table 2) aimed at abating GHG emissions relative to usual practices (Scenario 1) was developed. Practices in the alternative scenarios were the same as for the Baseline except as described in Table 2. Simulated cowpea crops produced biomass > 1 t ha^{-1} approximately once every 5 years.

Table 2. Usual practices (Baseline, Scenario 1) and alternative practices (Scenarios 2-9) at the case study farm

No.	Name	Description
1	Baseline	Stubble burnt, bare summer fallow, weedy pasture in the pasture rotation
2	NoBurn	Stubble retained
3	Baseline+N	Stubble burnt, 125% of baseline N fertiliser rate
4	Baseline-N	Stubble burnt, 75% of baseline N fertiliser rate
5	NoBurn+N	Stubble retained, 125% of baseline N fertiliser rate
6	NoBurn-N	Stubble retained, 75% of baseline N fertiliser rate
7	Manure[1]	Stubble retained, 5 Mg ha^{-1} manure applied every 5 years, fully incorporated in 0.1 m topsoil
8	SummerCrop	Stubble retained, summer fallow green manure crop (cowpea) sown every year and sprayed out at end of February
9	ImprPasture	Stubble retained, winter legume crop (sprayed out at maturity) and bare summer fallows in place of weedy pasture

1 80% dry weight, 20% carbon, C:N ratio 30

APSIM modelling

All practices were simulated over 100 yr with the APSIM model (Holzworth et al., 2014; www.apsim.info) using Wubin climate data from the SILO database (Jeffrey et al., 2001). APSIM' performance in simulating baseline conditions and organic matter additions was evaluated by modeling a soil biology field experiment (http://www.liebegroup.org.au/trial-programs-3/) near the farm and other measurements for N_2O (Barton et al., 2013). Yield, soil organic carbon and nitrous oxide emissions were simulated in accordance with observations (data not shown).

Calculations

Amounts of carbon sequestered in the soil and N_2O emitted were converted to CO_2 equivalents (CO_2e) using conversion factors of 1 and 298, respectively (IPCC, 2013) to evaluate the global warming potential of different practices.

Economic analysis

Gross margins were calculated at the paddock scale as income (yield x average price received in the past 5 yr) minus variable costs (e.g. fertiliser, chemicals, fuel, manure) for each year across the 100 yr simulation. The gross margins were then averaged across each rotation to allow comparisons of profitability between rotations and across abatement scenarios. Economic data were sourced from the Department of Agriculture and Food Western Australia (DAFWA, 2012).

Results

Greenhouse gas emissions and net global warming potential

Soil organic carbon (Fig. 1a-c) increased by 0.12 to 0.24 % relative to baseline values in the scenarios where stubble was retained (Scenarios 2, 5 and 6). A further increase in soil carbon of around 0.04 to 0.08 % occurred when additional organic matter inputs from manure (Scenario 7), summer crops (Scenario 8) or improved pasture (Scenario 9) were added to these systems. There was little change in soil carbon relative to baseline values when stubble was not retained (Scenarios 3 and 4). Average N_2O emissions (Fig. 1d-f) were greater than the baseline (0.07 kg N_2O -N ha^{-1} yr^{-1}, consistent with field observations; Barton et al., 2013) in all scenarios unless nitrogen fertiliser applications were reduced (Scenarios 4 and 6).

The net global warming potential from combined changes in sequestered carbon and N_2O emissions was dominated by the changes in soil carbon (Fig. 1g-i).Soil carbon increased by 0.04-0.07% in the baseline scenarios and so net global warming potential was small (<5,900 kg CO_2e ha^{-1} for the simulation period) for the baseline. There was little difference in global warming potential between the baseline (Scenario 1) and other Scenarios where stubbles were also burnt (Scenarios 3 and 4). For scenarios where carbon was sequestered through retaining stubble or other additions from soil organic matter (manure, summer crops and improved pasture), the cumulative net global warming potential was reduced by 30-50 Mg CO_2e ha^{-1} over the 100 yr simulation period relative to the baseline values.

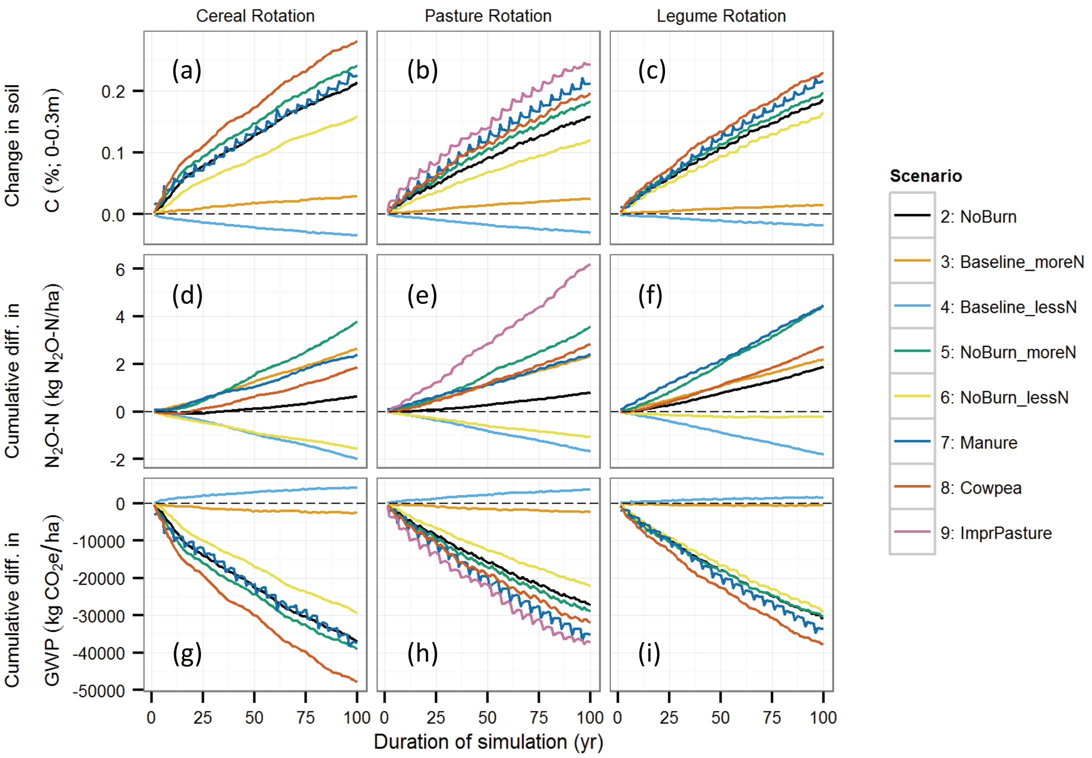

Figure 1. Differences in (a-c) soil organic carbon, (d-f) N2O emissions, and (g-i) net global warming potential between alternative scenarios (Scenarios 2-9) and farm usual practice (baseline, Scenario 1). Differences represent the accumulated annual difference during the 100 yr simulation period.

Yield

The median yield (e.g. for the cereal rotation, Figure 2) of all crops increased, and yield variability decreased, in response to applications of manure (Scenario 7). Median crop yields for canola, wheat and barley also increased in response to added nitrogen fertiliser (Scenarios 3 and 5) and decreased when nitrogen fertiliser was reduced (Scenarios 4 and 6). Wheat yields in the pasture rotation also increased in response to improved pasture (Scenario 9 in the pasture rotation; data not shown) but the yield of other crops in this rotation was not affected by inclusion of improved pasture. The use of a summer crop (Scenario 8) had little effect on the median yield of any crop but increased yield variability. The range and variability of crop yields in the cereal rotation (Fig. 2) were similar to those obtained in the pasture and legume rotations (data not presented).

Gross margins

The median and range in gross margins (Figure 3) for the different scenarios was closely related to values obtained for crop yields (Figure 2). The largest gross margins ($263-356) occurred when manure was applied. The median gross margin for improved legume pasture in the pasture rotation ($215) was greater than the baseline weedy pasture ($155) and delivered N savings to later crops. Crops in Scenarios 2, 3 and 5 had the same or a greater rate of N fertiliser and also had similar gross margins ($157-238 in the three rotations) to the baseline ($154-211). The median gross margin was lower for scenarios with reduced N fertiliser ($123-201 in the three rotations) or cowpea ($137-163). Thus the lower revenue from smaller crop yields (Scenarios 4-6) was not compensated by savings in fertiliser. For cowpea, more variable yields and the costs of cowpea management were not compensated by any savings in N fertiliser permitted by N added from cowpea.

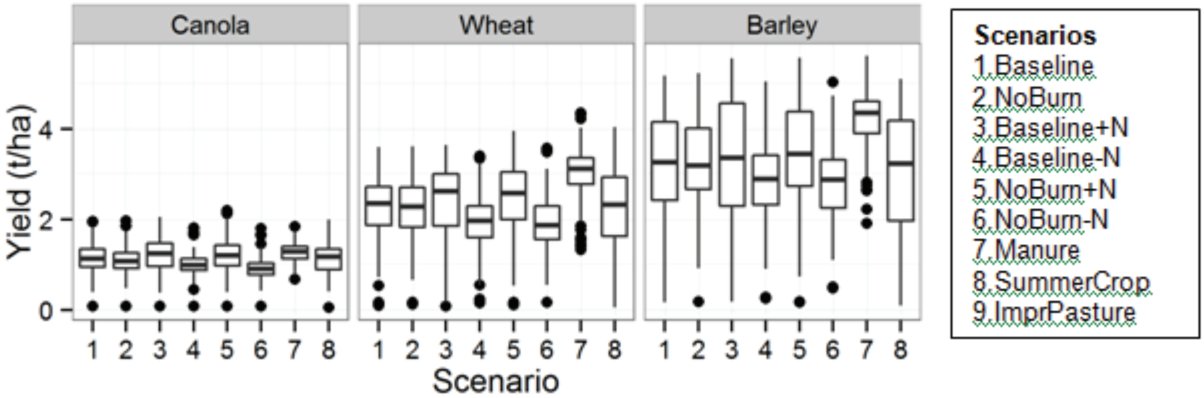

Figure 2. Boxplots (bars showing 1.5 x interquartile range) for yield of canola, wheat and barley in the cereal rotation. Plots represent the yields obtained in response to usual (Scenario 1) and alternative (Scenarios 2-9) practices (described in Table 2). Scenario 9 (improved pasture) was not applied in the cereal or legume rotation. Median values and variability of yields were similar to results obtained for the pasture and legume rotations (data not presented).

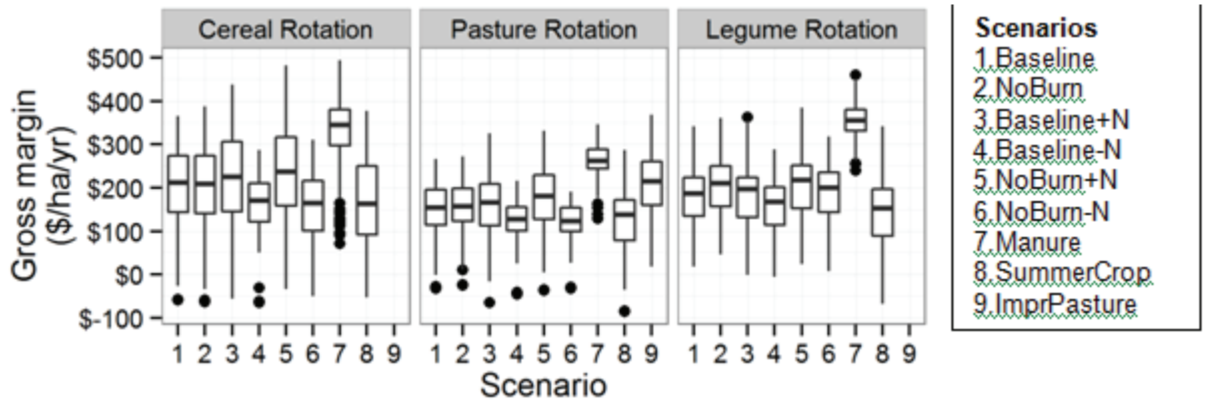

Figure 3. Average annual gross margins (bars showing 1.5 x interquartile range) for scenarios (described in Table 2) at the case study farm. Scenario 9 (improved pasture) was not applied in the cereal or legume rotation.

Conclusion

A number of practices were available to the case study farm which had potential to reduce net global warming potential relative to baseline practices. These practices were based on increasing soil carbon by retaining stubble or increasing inputs of other organic matter, and could be achieved without reducing gross margins. By comparison, reducing the amount of N fertiliser applied resulted in lower yield, lower profitability, and little change in or reduced carbon sequestration. The potential to increase carbon is limited for many Australian soils (Lam et al., 2013), and so this finding may be limited to situations such as this case study farm where initial soil carbon and typical N_2O emissions are both low. The applicability of these results to locations with higher N_2O emissions requires further investigation.

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