Least cost greenhouse gas abatement – opportunities in Australian grain farms

E.A. Meier[1], **P.J. Thorburn[1]**, N.P. Dumbrell[2], J. Palmer[1], J.S. Biggs[1] and M.E. Kragt[3]

[1] CSIRO Agriculture and Food, 306 Carmody Rd, St Lucia, QLD 4067, www.csiro.au, peter.thorburn@csiro.au
[2] Centre for Global Food and Resources, The University of Adelaide, 10 Pulteney St, Adelaide, SA 5005
[3] University of Western Australia, 35 Stirling Highway, Perth, WA 6009

Abstract
Australian agriculture is a significant source of greenhouse gas (GHG) emissions and finding low cost abatement opportunities will allow this sector to contribute to GHG mitigation efforts. Biophysical and whole-farm economic modelling was used to predict GHG abatement, crop yields and farm profitability under different management practices and current and projected climates for representative case study farms (a total of 76 management-farm combinations) in Australia's grain growing regions. A range of management practices (38 of the 76 combinations) could reduce GHG emissions, but there were substantial differences in the profitability of practices that delivered abatement. Of the 38 management-farm combinations that reduced GHG emissions, 11 were predicted to increase whole-farm profitability. However, the management scenarios that provided the most abatement tended to have the highest operating costs. For the 27 combinations where reduced GHG emissions came at reduced farm profits, the cost of abatement in most was greater than the average price paid for abatement from the Emissions Reduction Fund (ERF) to date. Reductions in nitrous oxide (N_2O) emissions from soils were most important for net abatement on farms in the northern grains regions; increasing soil organic carbon (SOC) was most important for abatement at farms with low rainfall and sandy soils (predominantly the western grain region). Including ungrazed improved pastures in crop rotations was an option for abatement that maintained or increased profitability for sites. Reducing N_2O emission becomes more important relative to SOC sequestration for achieving abatement over longer times (e.g. 100 years). These conclusions are likely to be valid under projected future climates.

Keywords
Global warming potential, soil carbon, nitrous oxide, Emissions Reduction Fund, APSIM, operating profit.

Introduction
Agriculture is the source of 16 % of Australia's greenhouse gas (GHG) emissions (Department of the Environment 2016). Broadacre cropping occupies ~31 million ha in Australia (ABS 2016), so changes in farm management practices have potential to contribute to GHG abatement. Excluding machinery use, transport and electricity, broadacre cropping contributes to on-site GHG emissions predominantly through carbon dioxide (CO_2) and nitrous oxide (N_2O) emissions from soils. Farm management practices offer potential to reduce GHG emissions by storing carbon in soils or vegetation (IPCC 2014) or reducing N_2O emissions from soil. However, GHG reductions may not be achieved because practices that maximise soil carbon or reduce N_2O emissions may reduce farm profitability or fit poorly within farm management. For these practices, funding to support practice change may be available through the Emissions Reduction Fund (ERF) to support voluntary adoption of emissions reduction activities (~$10-14/t C; Clean Energy Regulator 2016a). The purpose of this study was therefore to examine a range of farm management practices to identify the potential to: (1) generate GHG abatement from soil carbon sequestration and/or reduced N_2O emissions, and (2) estimate the whole-farm financial effects of these practices.

Methods
Case study farms
The biophysical, management and economic properties of eight case study farms (Figure 1) were described in collaboration with local farm owners and advisors. The farms were located in each of the three Grains Research and Development Corporation (GRDC) grain growing regions and represented a wide range of climates, soils, crops and management practices.

Management scenarios
Fifteen management scenarios were developed that could potentially provide GHG abatement at the case study farms (Table 1). The objective of the scenarios was to (1) increase inputs of carbon to the soil by retaining instead of burning stubble (S2, S5–S15), applying manure (S7 and S15), increasing cropping intensity with short-term green manure crops in fallows or unimproved pastures (S8-S10, S13-S14), or

growing potentially larger crops (S12), and/or (2) reducing N_2O emissions by modifying nitrogen (N) fertiliser management (S3–S6, S11). Scenarios S2–S10 were simulated for farms in the western and southern grain growing regions and the Moree case study farm. A different set of scenarios (S2–S7 and S11–S15) were simulated for farms in the northern grain growing regions to accommodate summer cropping practices. Results from all scenarios were presented as differences from a baseline (S1).

Figure 1. Location of case study farms in the GRDC's northern, southern and western grain regions (GRDC).

Table 1. Greenhouse gas abatement scenarios simulated for the case study farms.

Scenario	Management practice description
S1 BASELINE	Baseline = Stubble burnt, chemical fallows, pastures in rotations are unimproved
Scenarios simulated for all farms	
S2 +STUB	Stubble retained, chemical fallows
S3 –STUB+N	Stubble burnt, chemical fallows + 25% extra N fertiliser
S4 –STUB-N	Stubble burnt, chemical fallows - 25% less N fertiliser
S5 +STUB+N	Stubble retained, chemical fallows + 25% extra N fertiliser
S6 +STUB-N	Stubble retained, chemical fallows - 25% less N fertiliser
S7 FL-MAN	Stubble retained, chemical fallows + 5 t/ha of feedlot manure every 5 years
Additional scenarios simulated for farms at Moree and in the western and southern grain regions	
S8 SUM-CROP	Stubble retained + short-term summer green manure crop
S9 PASTURE	Stubble retained, winter fallows/pasture phases replaced with improved pasture
S10 SUM-PAS	Stubble retained, short-term summer green manure crops, improved pastures
Additional scenarios simulated for farms in the northern grain region	
S11 N-SOW	Stubble retained + N applied at sowing (instead of 4 weeks prior to sowing)
S12 FABA	Stubble retained + replace chickpea crops with faba bean crops
S13 LEG-MAN	Stubble retained + replace fallows with a short term legume as green manure
S14 CER-MAN	Stubble retained + replace fallows with a short term non-legume as green manure
S15 CHKN-MAN	Stubble retained + 5 t/ha of chicken manure compost every 5 years

Simulations

Applicable scenarios were simulated for each case study farm with the Agricultural Production Systems sIMulator v7.5 (APSIM; Holzworth et al. 2014), configured with modules for soil nitrogen (APSIM-SoilN; Probert et al. 1998), soil water (APSIM-SoilWat; Probert et al. 1998), residue (APSIM-SurfaceOM; Probert et al. 1998) and crop growth. Soil parameters for representative local soils were measured in other soil characterisation activities and obtained from the APSoil data base (Holzworth et al. 2014). Crop management information for each scenario was provided by collaborators or from the literature. Simulations were conducted for 25 and 100 year periods, consistent with the permanence requirements in the ERF policy (Clean Energy Regulator 2016b). Each simulation was run using historical weather data obtained from the SILO database (Jeffrey et al. 2001), and using 10 different starting years (1906-1915) in order to avoid cyclical patterns in the climate data affecting initial conditions (especially soil carbon) and subsequent changes in soil carbon dynamics and N_2O emissions. A subset of scenarios that provided significant GHG abatement were rerun under the GFDL-CM3 and MIROC5 climate projections to 2050 (Thorburn 2016).

GHG calculations

Changes in SOC-stocks (0.0-0.3 m) and N_2O emissions were converted to carbon dioxide equivalents (CO_2e) using conversion factors of 3.67 and 298 respectively (IPCC 2013), and summed to predict the average annual net global warming potential (GWP) for each abatement scenario.

Economic analysis
The financial effect of management scenarios was evaluated in terms of operating profit (earnings before interest and tax). This was calculated as the sum of farm crop revenue (APSIM crop yield × crop price), less variable costs directly associated with crop production (e.g. seed, fertiliser) and less operating costs incurred regardless of whether crops were grown (e.g. accounting services, the farmer's salary).

Results

Historical climates
Results for each location were expressed as differences relative to the baseline scenario (S1) for global warming potential and operating profit. For example, in Figure 2 (the Dalwallinu case study farm), all scenarios other than stubble burning (S2, S5-S10) delivered GHG abatement relative to Scenario S1, but only Scenarios S5 and S9 were profitable to adopt. The remaining scenarios (S6-S8, S10) provided abatement but were unprofitable and could benefit from incentives to support adoption. For all scenario-farm combinations, 38 of the 76 combinations reduced GHG emissions, but there was substantial heterogeneity in the profitability of practices that delivered abatement (data not presented). Of the 38 management-farm combinations that reduce GHG emissions, 11 were predicted to have increased whole-farm profitability. For the 27 combinations where reduced GHG emissions came at reduced farm profits, the cost of abatement was highly variable (up to \$798/t CO_2e at the Chinchilla case study farm) and in most was greater than the current average price paid for abatement from the ERF. Management scenarios that provided the most abatement (S8 and S10) tended to also have the highest cost. Reductions in N_2O emissions from soils were most important for net abatement on farms in the northern grains regions, since heavy clay soils and warm and wet summer conditions increased the likelihood that conditions promoting N_2O emissions occurred. For farms with low rainfall and well-drained soils (principally farms in the western grains region), conditions that promoted N_2O emissions occurred less frequently than for the north, so increasing soil organic carbon (SOC) was more important for abatement than managing N_2O emissions. Including ungrazed improved pastures in crop rotations (S9, S13, S14) was an option for abatement and maintained or increased profitability. Reducing N_2O emissions became more important relative to SOC sequestration for achieving abatement over longer times (e.g. 100 years) because SOC approached equilibrium values toward the end of this time. The practices that both (1) maintained or reduced GHG emissions and (2) were profitable relative to the baseline (S1) are summarised in Table 2.

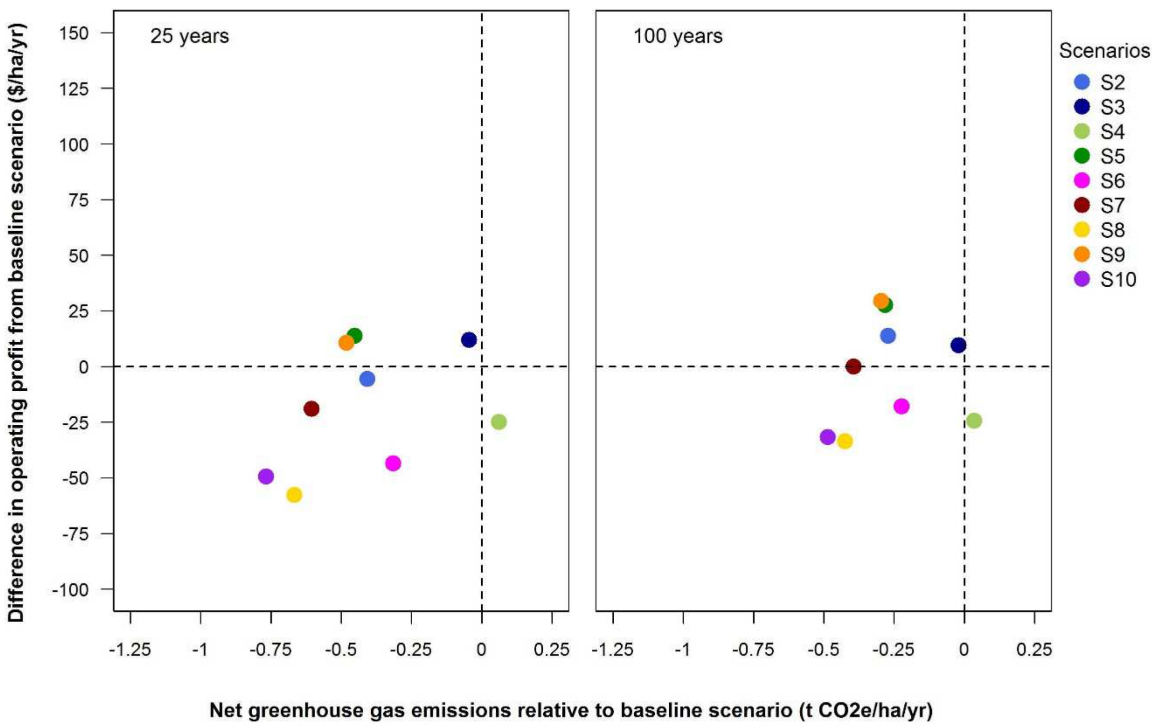

Figure 2. Difference in operating profit and net CO_2e from scenarios relative to the baseline practice for (a) 25 and (b) 100 year simulation periods at the Dalwallinu case study farm. Points left of the dotted vertical line provide abatement relative to the baseline scenario (S1). Points above the dotted horizontal line generate greater operating profits relative to the baseline scenario (S1). Scenarios are described in Table 1.

Table 2. Scenarios that reduced net greenhouse gas emissions and maintained or increased operating profit relative to baseline scenario S1 over a 25 year simulation period.

Case study farm	Scenario
Brigalow	S2 (+STUB), S6 (+STUB-N), S11 (N-SOW), S12 (FABA)
Chinchilla	S2 (+STUB), S11 (N-SOW), S12 (FABA)
Moree	S2 (+STUB), S5 (+STUB+N), S6 (+STUB-N), S7 (FL-MAN), S9 (PASTURE)
Mulwala	S3 (-STUB+N), S5 (+STUB+N), S7 (FL-MAN), S9 (PASTURE)
Southern Mallee	S2 (+STUB), S6 (+STUB-N)
Wimmera	S5 (+STUB+N), S7 (FL-MAN), S9 (PASTURE)
Dalwallinu	S3 (-STUB+N), S5 (+STUB+N), S9 (PASTURE)
Kellerberrin	S3 (-STUB+N), S5 (+STUB+N), S7 (FL-MAN), S9 (PASTURE)

Future climates

The abatement-profitability outcome (i.e. location within the abatement-profitability grid in Figure 2) for scenarios under projected climates were essentially the same as those under current climates for each case study farm.

Conclusion

The GHG abatement that could be achieved by changing management practices was site-specific. Practices that provided abatement but were unprofitable reduced operating profits by varying amounts (depending on the farm) and these losses were less than payments currently available under the ERF. Abatement within the grains industry may therefore be best achieved through practices that are inherently profitable (Table 2). Practices that provided abatement under historical weather continued to do so under projected climates.

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