Potential greenhouse gas abatement from converting croplands to pastures negated by emissions from livestock

Meier E.A.[1], Thorburn P.J.[1], Bell L.W.[1], Harrison M.T.[2], Biggs J.S.[1], Dumbrell N.P.[3] and Kragt M.E.[4]

[1] CSIRO Agriculture and Food, Queensland Bioscience Precinct, The University of Queensland, 306 Carmody Road, St Lucia, QLD 4067, www.csiro.au, elizabeth.meier@csiro.au
[2] Tasmanian Institute of Agriculture, University of Tasmania, Hobart, TAS 7320
[3] Centre for Global Food and Resources, The University of Adelaide, 10 Pulteney St, Adelaide, SA 5005
[4] University of Western Australia, 35 Stirling Highway, Perth, WA 6009

Abstract
Australian agriculture is a significant emitter of global greenhouse gases (GHG) and so has a role in reducing those emissions. Replacing cropland with permanent pastures is a practice that has potential to provide abatement by increasing stocks of soil organic carbon (SOC) and thereby reducing the flux of atmospheric carbon dioxide (CO_2). However, pastures frequently support livestock, which produce other GHG emissions (principally methane, CH_4) that could negate abatement from increases in SOC. Three contrasting cropping and livestock systems were simulated at Kellerberrin (Western Australia), Southern Mallee (Victoria) and Chinchilla (Queensland). Cropping scenarios were defined that had increasing amounts of dry matter inputs: C1, crop residues burned before sowing; C2, crop residues retained; and C3, uncropped fallow phases replaced with short-term green manure legume crops. The on-farm GHG emissions profile of the cropping scenarios was calculated and compared with that from two livestock scenarios utilising continuous stocking on: L1, permanent grass pasture; and L2, permanent grass-legume pasture. We found that the permanent grazed pastures in livestock systems did not necessarily provide net GHG emissions reductions compared to cropping systems when the emissions from livestock were included. This finding highlights the importance of including all emissions when calculating the net GHG profile for practices.

Keywords
Global warming potential, soil organic carbon, APSIM, Feed Demand Calculator, Accounting Framework.

Introduction
The ‘Agriculture, Forestry and Other Land Use’ economic sector emits 24.8% of global greenhouse gases (GHGs; Smith et al. 2014). The main emissions from Australian agricultural practices are carbon dioxide (CO_2) from changes in soil organic carbon (ΔSOC), nitrous oxide (N_2O) (predominantly from cropping systems) and methane (CH_4; predominantly from livestock as enteric methane, E-CH_4). Pastures can store SOC (Lal 2004), and conversion of crop lands to pastures is a suggested way to reduce GHG emissions (Sanderman et al. 2010). However, pastures often support livestock (Bell and Moore 2012), so the potential for permanent pastures to provide GHG abatement by sequestering SOC could be offset by emissions from livestock (Meyer et al. 2016). The purpose of this study was to compare the net on-farm emissions from livestock systems using permanent pastures with those from cropping systems for three Australian farms located in cropping areas that also supported livestock.

Methods
Case study farms
The biophysical properties for three case study farms were defined in collaboration with the farm owners and their advisors (Table 1). Soil properties including initial SOC were obtained from measured values in cropped lands recorded in the APSoil database (Dalgleish et al. 2012). These soils have different histories and so SOC at each site was not necessarily at equilibrium. Separate crop and livestock systems were described for each farm, using the same weather and initial soil data (Table 1) to facilitate comparison of emissions from both systems.

Simulation approach
GHG emissions from the crop and livestock systems were calculated using an integrated approach to combine (a) emissions from crop and pasture production of ΔSOC and emissions of N_2O from soil (S-N_2O), with (b) emissions from livestock systems of N_2O from manure and urine (L-N_2O) and CH_4 from enteric sources (E-CH_4) and manure (M-CH_4).

Table 1. Selected information for the Kellerberrin, Southern Mallee and Chinchilla case study farms.

	Kellerberrin, WA			Southern Mallee, VIC		Chinchilla, Qld
Area (ha)		4,000		5,400		777
Rainfall (mm/yr)		320		379		649
Crop rotations[1]		CnxWtxWtxBy LuxWtxWtxBy PsxWtxWtxBy		WtxByxOaxPs PsxCnxWtxByxCpxWt OaxFpxWtxBy CnxWtxByxCp		xxCtxxSo with opportunistic Wt and Cp in place of xx
N fertiliser (kg urea-N/ha/yr)		40-60		5-70		50-80
Soils[2]	Loamy earth	Texture contrast	Sandy earth	Clay loam	Sandy clay loam	Clay
APSoil number	444	407	410	730	573	025
Soil C (%, 0.0-0.3 m)	0.6	0.5	0.6	1.1	1.5	1.1
Soil pH (0.0-0.3 m)	7.3	6.1	7.3	8.2	8.5	8.4
Soil pH (0.9-1.2 m)	8.3	7.1	8.2	8.8	8.5	7.4
PAWC[3] (mm)	254	50	117	193	267	204
Drainage[4]	MWD	MWD to SD	MWD	MWD to SD	MWD to SD	SD

[1]Crops: Wt, wheat; By, barley; Cn, canola; Lu, lupins; Oa, oats; Cp, chickpea; Fp, field pea; Ct, Cotton; Ps, weedy pasture phase; x, uncropped summer fallow; xx, uncropped winter fallow with weed control; [2]Dalgleish et al., 2012; [3]PAWC, plant available water capacity; [4]Drainage: MWD, moderately well-drained; SD, slowly-drained.

Emissions from crop and pasture production of ΔSOC and S-N_2O

Crop and pasture production, ΔSOC and S-N_2O were simulated for a 100-yr period with the Agricultural Production Systems sIMulator (APSIM) v7.5 model (Holzworth et al. 2014). Each farm-soil-rotation-scenario was simulated for 10 different starting years (1906 to 1915) to prevent potential cyclical patterns in the climate data interacting with the patterns in crop rotations. All crops were simulated under rainfed conditions and with minimum tillage. Fallows were uncropped and weed-free.

Pastures of annual ryegrass (*Lolium rigidum*) or clover (*Trifolium subterraneum* 'Dalkeith') were simulated for the Kellerberrin and Southern Mallee case study farms in APSIM with the Ausfarm v1.4.13 Established Pasture module. For the Chinchilla case study farm, a Bambatsi (*Panicum coloratum*) and Bambatsi-medic (*Medicago truncatula*) pasture were simulated with the APSIM Bambatsi module and Ausfarm v1.4.13 Established Pasture module (medic). Pasture biomass was cut and removed at monthly intervals to simulate removal of biomass by grazing. The nitrogen (N) recycled in livestock urine and manure was approximated by uniformly applying manure each month at rates proportional to the number of livestock. Fertiliser was applied to L1 pastures at the rate of 12.5-50 kg urea-N ha/yr to maintain productivity over the 100-year simulation period; L2 pastures included legumes and were not fertilised with N.

Simulated values were validated against point estimates of crop yields provided by farm owners, and to values in the literature for pasture growth rates and stocking rates (data not presented). In all cases, the range of simulated crop yields, pasture growth rates and stocking rates were consistent with reference values and so the simulated values were considered representative for the farms.

Five scenarios were simulated to assess their relative GHG emission status in cropping-only and livestock-only systems. The cropping scenarios simulated were:

- C1: the usual cropping system at the farms (Table 1) with 70% of stubble removed by burning
- C2: the usual cropping system with stubble retained after harvest, and
- C3: a cropping system with high organic matter input where pasture phases and uncropped fallows (Table 1) were replaced with a green manure legume crops. The brown manure crops were sown after harvest of the preceding cash crop and were not fertilised with N. After 60 days the crop was sprayed out and the residues were retained on the soil surface.

The livestock scenarios involved pastures with livestock grazing to an average 30% utilisation on:

- L1: a fertilised grass pasture, and
- L2: a legume pasture that was not fertilised with N.

Emissions from livestock systems of L-N_2O, E-CH_4 and M-CH_4

Emissions from livestock systems were calculated in a two-step process. In the first step, long-term pasture growth rates simulated with APSIM were input to the Feed Demand Calculator (MLA 2013) to determine the monthly pasture that was available to support the livestock enterprise throughout the year at the case study farms. The number of livestock for each farm was set by comparing average annual feed supply with the livestock demand for energy while maintaining a long-term pasture utilisation rate of 30% of net primary pasture growth per year. Livestock at the Kellerberrin and Southern Mallee case study farms consisted of a breeding flock of Merino sheep. The sheep were supplemented from February to May with lupin grain. Livestock at the Chinchilla case study farm consisted of a trading herd of British x *Bos indicus* steers. In the second step for calculating emissions from livestock systems, E-CH_4, M-CH_4 and L-N_2O were calculated using the Sheep or Beef Greenhouse Gas Accounting Framework emissions calculators (S-GAF and B-GAF, respectively; http://www.greenhouse.unimelb.edu.au/Tools.htm; Browne et al. 2011).

Net global warming potential (GWP) and statistical analyses

The GWP for N_2O, CH_4 and ΔSOC was converted to carbon dioxide-equivalents (CO_2-e) using 100-year conversion factors of 298, 34 and 3.67, respectively (IPCC 2013). The net on-farm GWP of scenarios for each site-scenario combination was calculated as the sum in CO_2e/ha of GHG emissions (ΔSOC, S-N_2O, L-N_2O, E-CH_4 and M-CH_4). The GWPs calculated for scenarios were restricted to on-farm emissions from crop and livestock systems and excluded emissions from off-farm activities (e.g. manufacture and transport of N fertiliser). Annual average values for ΔSOC, N_2O, CH_4 and GWP were compared using Tukey's Honestly Significant Difference (HSD) method using group means.

Results

Long-term average GHG profiles for scenarios

The average annual GWP of scenarios varied between locations (Figure 1). Net emissions were lowest at Kellerberrin, linked to low rainfall and well-drained soils at this location. These factors favoured drier conditions that slowed SOC decomposition and limited N_2O emissions. By comparison, Chinchilla had slowly-drained soils and a climate in which warm summer temperatures coincided with summer-dominant rainfall. These factors increased the potential for warm, wet conditions favouring SOC decomposition and N_2O generation compared to conditions at the Kellerberrin and Southern Mallee farms.

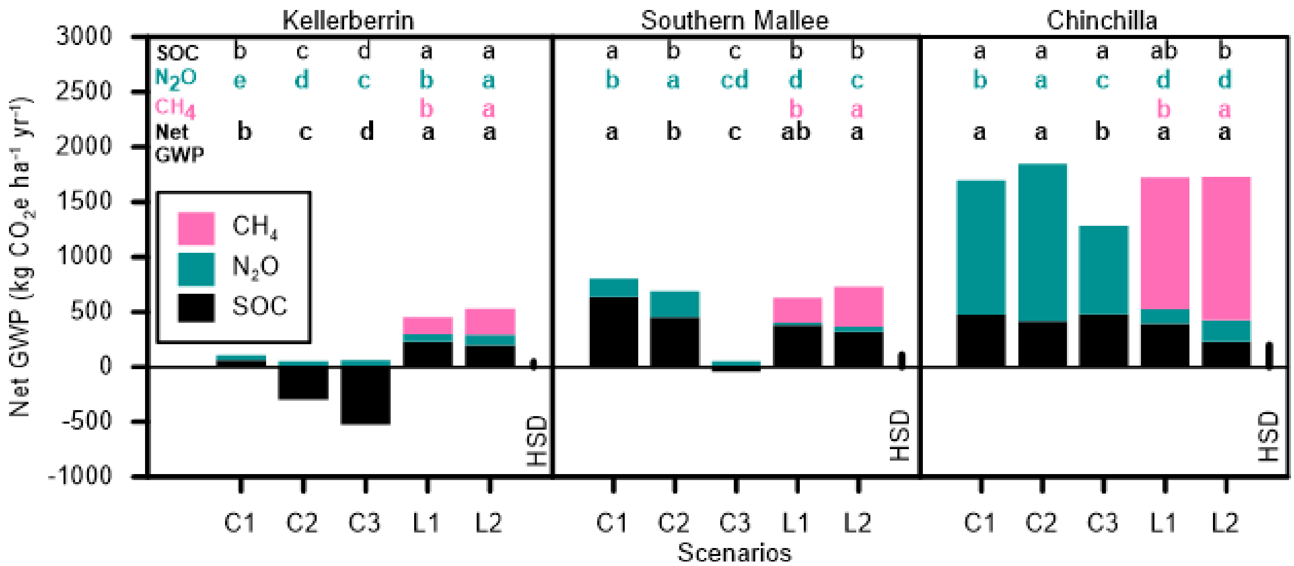

Figure 1. Average annual on-farm emissions in CO_2e from change in soil organic carbon (ΔSOC), N_2O from soil, manure and urine, and CH_4 from enteric fermentation and from manure, for scenarios at the Kellerberrin, Southern Mallee and Chinchilla case study farms. Cropping scenarios C1-C3 had increasing amounts of organic matter inputs; livestock scenarios had permanent grass (L1) or legume-based (L2) pastures. Emissions represent the average of values from the 100 yr simulation period. Scenarios that differ in average annual ΔSOC, N_2O and CH_4 within each site have a different letter shown at the top of the panel; these scenarios differ by more than the honestly significant difference (HSD) value. Significant differences identified by HSD between the total global warming potential (GWP) of combined emissions within each site are shown in bold letters at the top of the figure. Negative values for net GWP represent abatement from the scenarios.

At all sites, loss of SOC was reduced as organic matter returns increased from scenario C1 to C2, and from scenario L1 to L2 (Figure 1). In scenario C3 there were additional short-term green manure crops grown in fallow periods. At Kellerberrin and in the Southern Mallee there is low summer rainfall so these additional crops did not compete with usual crops grown in rotations, and so provided additional organic matter inputs that increased SOC compared to scenario C2. At Chinchilla, fallows are used to store soil water in the clay soils. Additional crops in C3 used some of this stored soil water, reducing the soil water available to usual crops in rotations which reduced the overall SOC storage in C3 compared to C2. Differences in ΔSOC between the cropping and livestock scenarios were determined by differences in the timing and amount of inputs of carbon to soils, and the effects of the scenarios on soil moisture. This led to a difference in ΔSOC between C2 and L2 that was not significantly different at Southern Mallee and Chinchilla. At Kellerberrin, significantly more emissions from ΔSOC were simulated to occur from the livestock compared with the cropping scenarios. Emissions of N_2O increased from scenario C1 to C2 (Figure 1) as evaporation decreased and soil water increased under stubble retention, and decreased when soil water decreased under increased cropping intensity from scenario C2 to C3 (data not presented). Emissions of CH_4 increased from scenario L1 to L2 (Figure 1), as the stocking rate increased on the better pastures of L2 (data not presented). For the Southern Mallee and Chinchilla farms, the pattern of these emissions for C1, C2, L1 and L2 was similar in that all were a substantial part of the GHG profile. When these emissions were combined with ΔSOC for the Southern Mallee and Chinchilla farms, the net GWP from the L1 and L2 scenarios were not consistently greater than that from the C1 and C2 cropping systems.

Conclusion

For the conditions we studied, replacing cropland with permanent grazed pastures did not significantly increase SOC or reduce net GWP compared with cropping systems once emissions from livestock were considered. The livestock emissions which were of equal or greater magnitude to ΔSOC. Our findings contrast with some others concerning the value of pastures for GHG abatement, and having different initial SOC values would change ΔSOC and hence the net abatement. Nevertheless, this study highlights the importance of considering net GWP rather than ΔSOC alone when evaluating the abatement potential of different practices.

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