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Greenhouse gas abatement on southern Australian grains farms: Biophysical potential and financial impacts

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ABSTRACT

The agricultural sector generates a substantial proportion of global greenhouse gas (GHG) emissions through emissions of carbon dioxide (CO_2) and nitrous oxide (N_2O). Changes to agricultural practices can provide GHG abatement by maintaining or increasing soil organic carbon (SOC) stored in soils or vegetation, or by decreasing N_2O emissions. However, it can be difficult to identify practices that achieve net abatement because practices that increase SOC stocks may also increase N_2O emissions from the soil. This study simulated the net on-farm GHG abatement and gross margins for a range of management scenarios on two grain farms from the western and southern grain growing regions of Australia using the Agricultural Production Systems sIMulator (APSIM) model. The soils and practices selected for the study were typical of these regions. Increased cropping intensity consistently provided emissions reductions for all site-soil combinations. The practice of replacing uncropped or unmanaged pasture fallows with a winter legume crop was the only one of nine scenarios to decrease GHG emissions and increase gross margins relative to baseline practice at both locations over the 100-year simulation period. The greatest abatement was obtained by combining this practice with an additional summer legume crop grown for a short period as green manure. However, adding the summer legume decreased farm gross margins because the summer crop used soil moisture otherwise available to the following cash crop, thus reducing yield and revenue. Annual N_2O emissions from the soil were an order of magnitude lower from sandy-well-drained soils at the Western Australian location (Dalwallinu) than at the other location (Wimmera) with clay soil, highlighting the importance of interactions between climate and soil properties in determining appropriate GHG abatement practices. Thus, greatest abatement at Dalwallinu was obtained from maintaining or increasing SOC, but managing both N_2O emissions and SOC storage were important for providing abatement at Wimmera.

1. Introduction

The rate of climate change has increased since the 1950s (IPCC, 2014a), linked with substantial (10–30%) increases in atmospheric concentrations of the GHGs CO_2, N_2O and methane (CH_4). While increased concentrations of CO_2 can improve crop productivity, increased concentrations of these GHGs in combination have increased temperatures and altered rainfall distribution, and it is very likely that they will also cause an increase in heat waves and extreme rainfall events. These climate changes are predicted to decrease crop productivity in many regions globally (IPCC, 2014a). However, this decrease in capacity to produce food coincides with a predicted increase in world population of a third by 2050 (FAO, 2009). Thus there is a risk that global food deficits may occur if GHG abatement measures are not adopted.

The agricultural sector contributes 25% to the global GHG inventory (IPCC, 2014a), and thus decreasing agricultural emissions is important to provide GHG abatement. The potential for agriculture to contribute to GHG mitigation is less in developed countries, where agriculture typically forms ~10% of national GHG inventories (Eurostat, 2015; US

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EPA, 2015). However, there are some developed countries (e.g. Australia and New Zealand; Thorburn et al., 2013) where agriculture is a relatively important part of the GHG profile (14 and 49%, respectively), and so a focus on GHG abatement is a high priority (DoE, 2016; Ministry for the Environment, 2016a). In both Australia and New Zealand, economic incentives are available to businesses in the land sector to voluntarily enter projects that deliver GHG abatement (Clean Energy Regulator, 2016a; Ministry for the Environment, 2016b). Funding is available on a project basis, which effectively delivers on-site emissions reductions. In order for projects to be eligible, they must comply with an approved method focusing on management of forestry in New Zealand, or on forestry, livestock, pastures or irrigated cotton in Australia. However, farmers could also mitigate on-farm GHG emissions from cropping systems by maintaining or increasing SOC stocks and decreasing N_2O and CH_4 emissions from soils (IPCC, 2014b). Emissions of CH_4 from cropping systems other than rice are minor (DoE, 2016). Therefore additional strategies for mitigating GHG emissions from the soil in grain farming systems would focus on maintaining or increasing stocks of SOC and decreasing N_2O emissions.

A range of agricultural management practices can contribute to SOC stocks and thereby provide GHG abatement (Luo et al., 2010; Stockmann et al., 2013). Such practices include, for example, increasing cropping intensity, reducing tillage, retaining stubble, and changing nitrogen fertiliser and irrigation management. However, other studies suggest that the contribution of SOC storage to climate change abatement is likely to be modest (Baldock et al., 2012; Lal, 2004), and that the potential for increasing the stocks of SOC in Australian soils is limited (Lam et al., 2013; Robertson and Nash, 2013).

The potential for soil N_2O emissions to occur is greater in environments that favour N_2O-producing microorganisms. These include: water-filled pore space between 40 and 80%, increasing temperatures up to 37 °C, pH values of 7–8, and a supply of nitrate and decomposable carbon (Dalal et al., 2003). There is potential for these conditions to occur widely, so many management practices aim to limit soil nitrate loss by matching the supply of nitrate with the demand for nitrate by crops. Practices include matching the rate, timing and placement of nitrogenous fertiliser or other inputs with plant requirements, replacing nitrogenous fertiliser with nitrogen sourced from legumes or manure, and managing irrigation and drainage to avoid anaerobic conditions (Cameron et al., 2013; Li et al., 2013; Rees et al., 2013). These practices may conflict with practices aimed at increasing SOC storage. For example, retaining instead of burning crop stubble can increase stocks of SOC. However, it can also decrease evaporation of soil moisture and thus increase the likelihood that the soil will attain a water filled pore space that favours N_2O production.

The tradeoff in abatement from different GHGs, and the influence of site-specific conditions makes it difficult to generalise about the contribution that different practices could make to climate change abatement. The purpose of this study was to identify (a) additional practices that could decrease the net on-farm GHG emissions arising from SOC storage and N_2O emissions from cropping systems on Australian grain farms, and (b) the extent to which financial objectives are needed to prompt adoption of practices that provide abatement. To achieve this, we describe the biophysical properties, net GHG abatement potential, and average gross margins for a range of on-farm practices for two grain farms from contrasting locations in Australia.

Table 1
Biophysical properties, management practices and GHG emissions for baseline conditions at the Dalwallinu and Wimmera case study farms.

Description	Case study farm		
	Dalwallinu, Western Australia		Wimmera, Victoria
General information			
Location	30.1°S, 116.6°E		36.6°S, 142.6°E
Area (ha)	6000		2300
Management			
Crop 'rotations' representative of typical sequence and proportion of crops	'Legume rotation' (canola/wheat/lupin/wheat/wheat) 'Cereal rotation' (canola/wheat/wheat/barley) 'Pasture rotation' (canola/pasture/wheat/wheat/barley)		'Average rotation' (chickpea/canola/wheat/barley/faba bean/wheat/barley/oaten hay/fallow/wheat)
Target N inputs (supplied by fertiliser and soil mineral N)	40 kg N ha^{-1} (tonne of harvested grain)$^{-1}$		5–80 kg N ha^{-1} $crop^{-1}$
N fertiliser splits	60% at sowing; 40% at 40 d after sowing		5–10 kg N ha^{-1} at sowing; 0–70 kg N ha^{-1} after sowing
Tillage	Minimum tillage		Minimum tillage
Soils			
Soil types[a]	Texture contrast (Chromosol)	Sand (Tenosol)	Medium clay (Vertosol)
APSsoil number[b]	487	613	746
Total soil C (%, 0.0–0.3 m)	1.6	0.4	2.0
Predicted C after 100 yr (%, 0.0–0.3 m)	1.4	0.5	1.6
Soil pH (0.00–0.15 m)	5.3	5.8	5.3
Plant available water (mm)	66	90	203
Rooting depth (m)	0.8 m	1.5 m	1.6
Drainage	Moderate	Free	Slow
Mean GHG emissions[c] *(100 yr)*			
SOC sequestered (kg C ha^{-1} yr^{-1})	− 94	25	− 175
N_2O emitted (kg N_2O-N ha^{-1} yr^{-1})	0.12	0.07	1.25
Net GWP (kg CO_2e ha^{-1} yr^{-1})	401	58	1229
Mean gross margins ($AUD ha^{-1} yr^{-1})[c]	185	226	497

[a] Isbell (2002).

[b] Holzworth et al. (2014).

[c] Average from 100-year simulations (described in Section 2.5).

2. Methods

2.1. Case study farms

Two case study farms were defined for the western and southern regions of the Australian grains industry. The researchers collaborated with local farmer groups and agronomists to describe representative soils and typical practices on farms in those regions. The soil types represented were among the most commonly occurring soils in the Western Australian-North and South Australian-Victorian Bordertown-Wimmera GRDC agro-ecological zones (GRDC, 1998; Western Australian Department of Agriculture), and findings were intended to be relevant to a broader region than the immediate farms. For example, the Dalwallinu farm in Western Australia was designed to represent a larger region of > 1 million ha in the local area (Liebe Group, 2015), and be representative of other low rainfall grain farming environments across Australia, e.g. the Eyre Peninsula in South Australia.

2.1.1. The Dalwallinu case study farm

The Dalwallinu case study farm was conceptualized in collaboration with a local farming group (www.liebegroup.org.au; Table 1). The farm is located in a grassland climate zone which is characterised by hot dry summers (Stern et al., 2000) and cooler winters with winter-dominant rainfall (Table 2). The soils represented in the model farm were based