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The Costs and Benefits of Approved Methods for Sequestering Carbon in Soil Through the Australian Government's Emissions Reduction Fund

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Abstract

This paper investigates the net benefits of sequestering carbon in soil from a biophysical and economic perspective. This study is important because sequestering carbon (C) in soil is a key component of the Australian government's Direct Action Policy to offset the nation's greenhouse gas (GHG) emissions. The biophysical potential for sequestering C using one of four permitted project management activities (new irrigation, managing soil acidity, stubble retention and converting cropland to permanent pasture) was calculated according to the Methodology Determination - Carbon Credits (Carbon Farming Initiative) Estimating Sequestration of Carbon in Soil Using Default Values, 2015. The economic prospects of those activities that show a net C abatement were then evaluated to determine whether they were profitable for a farmer to implement. Finally, the costs and benefits from society's perspective of those activities found to be profitable were calculated. Of these activities only stubble retention and liming provided net benefits to a farmer, although there were limitations as to how widely these activities could be implemented nationally. We estimated a cost to government of approximately \$35 M annually to achieve a net abatement of 2.84 M t CO_2-e. Because this represents only 0.52 percent of Australia's annual GHG emissions of 549 M t CO_2-e, the policy is both expensive and relatively ineffective as a C offset policy alone. However, if viewed as an investment in farmland sustainability, this payment to farmers could be good public policy.

Keywords: carbon farming initiative, direct action policy, economic analysis, soil carbon sequestration

1. Introduction

The Australian Government's Carbon Farming Initiative (CFI), being part of its Emission Reductions Fund (ERF), is an evolving program. Previously, we analysed the cost-effectiveness from the viewpoint of the taxpayer (society) and the individual farmer (farming for profit) for a change from cropland to pasture grazed by sheep or cattle (White & Davidson, 2015). We followed the approved methodology detailed in Carbon Credits (Carbon Farming Initiative) (Sequestering Carbon in Soils in Grazing Systems) Methodology Determination 2014, which applied to the conversion of cropland to pasture where changes in soil C stocks were estimated by direct measurement (Australian Government, 2015a). The expected C sequestration for this management change was 1.835 tonnes of carbon dioxide equivalent (t CO_2-e) per hectare (ha) per year (yr). Subsequently, under the Government's revised CFI, a new methodology with new C sequestration values was approved (Carbon Credits (Carbon Farming Initiative) Estimating Sequestration of Carbon in Soil Using Default Values, Methodology Determination 2015 (Australian Government, 2015b). Based on the Full Carbon Accounting Model (FullCAM), this methodology allows a farmer to obtain a modelled estimate of potential C sequestration for several acceptable 'project management activities' (PMAs) carried out on the land.

Under this new Determination, the opportunities for farmers to participate in the CFI through an eligible offsets project are potentially much greater. On the other hand, the value of a C Unit (replacing the Australian C Credit Unit) has decreased from a fixed \$24.15 per t CO_2-e in the final year of the previous scheme to \$13.95 and

\$12.25 per t CO_2-e, in the first and second auctions, respectively, of the Direct Action Policy (Clean Energy Regulator, 2016).

With these changes in mind, the aim in this paper is to determine both the costs and benefits for individual farmers to engage in the revised CFI, and the cost-effectiveness of society's commitment to pay for overall sequestration of C in soil. First, we analyse the changes in the net revenue for typical cropping farms on eligible land in Australia that participate in the revised CFI for soil C sequestration, following our previous approach (White & Davidson, 2015). Second, we calculate the cost-effectiveness for the government, representing the Australian taxpayer, to implement this scheme nationally, based on expected C abatements in eligible regions and likely uptake rates.

2. Methods

2.1 Background

An acceptable PMA must occur in an area identified as agricultural land that has been cropped, grazed or bare fallowed at least once in the past five years, based on definitions used in ABARES Catchment Scale Land Use of Australia, version 5 (ABARES, 2014). To be eligible, a soil C project must involve one of three acceptable PMAs as follows:

(a) sustainable intensification, requiring actions such as nutrient management, new irrigation, managing soil acidity or pasture renovation;

(b) stubble retention, where crop residue that was previously removed through burning or baling is retained in field; and

(c) conversion to pasture, where land under continuous cropping is permanently converted to pasture.

To participate in the scheme a farmer must identify spatially a Carbon Estimation Area (CEA) within an area of eligible land from the CFI Mapping Tool (CMT) (2015). A modelled sequestration value for the identified CEA is obtained for the region in which the CEA falls. The sequestration values for all acceptable PMAs across all regions, as derived from the Carbon Farming Tool Help Manual V6.01 (2015), are presented in Table 1.

The net C abatement for a given CEA presented in Table 1 is calculated as the sequestration value minus the change in project emissions. The result of this calculation is summed over the reporting period of the project and if the result is negative, the project is deemed ineligible. Although a PMA must be undertaken for a nominated permanence period of 25 or 100 yrs, landholders have the flexibility to move between different management actions in recognition of changing conditions on agricultural land. In our analysis we have calculated changes in emissions and net C abatement for a range of PMAs for the first year only to determine which practices are likely to qualify as an approved offsets project.

For a given CEA, a positive C abatement is eligible for a C credit, the value of which is determined through a national reverse auction (Clean Energy Regulator, 2016). However, multiplying the net rate of carbon abatement by the price of carbon is not a sufficient indicator of whether a farmer should undertake a PMA: it is also necessary to add any net changes in both the revenue resulting from an increase in yield arising from each PMA and the associated costs of implementing each. Once these farm financial gross margins are known, some estimate of the costs and benefits for society of a prospective PMA can be gauged by assuming a likely uptake rate and the potential area of land that can be affected.

Table 1. Modelled Sequestration Values (t CO_2-e/ha/yr) for a Given PMA in CEAs in Regions of Different Sequestration Potential

Project management activity	Not modelled (ineligible land)	Marginal benefit	Some benefit	More benefit
Sustainable intensification	No value	0.11	0.59	1.65
Stubble retention	No value	0.07	0.29	0.73
Conversion to pasture	No value	0.22	0.44	0.84

Source: Carbon Farming Tool Help Manual V6.01 (http://ncat.climatechange.gov.au/CMT/Help/CMTHelp.pdf).

2.2 Example Calculations for Qualifying PMAs

In the case of sustainable intensification, a farmer must choose any two of four permissible management actions. Nutrient management is the most difficult to quantify because the extent and range of nutrient deficiencies will vary from farm to farm, and therefore remediation would be variable. Also, actual changes in farm productivity from pasture renovation are difficult to quantify. Hence we chose as examples of 'sustainable intensification' the options of new irrigation and managing soil acidity. The first choice, which requires at least 2 megalitres (ML) of water per ha to be applied annually, can involve a new water allocation or gaining water from efficiencies achieved outside the CEA. The second choice requires that the average soil pH in the CEA, measured in calcium chloride (0.01 M $CaCl_2$), be less than 5.5 in the topsoil (0-10 cm) or 4.8 in the subsoil (>10 cm depth), and that the topsoil pH be raised above 5.5 within five years.

Greenhouse gas (GHG) emissions and hence net C abatements for each PMA were calculated following the procedures laid down in Carbon Credits (Carbon Farming Initiative— Estimating Sequestration of Carbon in Soil Using Default Values) Methodology Determination 2015 (Australian Government, 2015b). The necessary parameters for calculating emissions were taken from the web-based pdf 'Standard Parameters and Emissions Factors' (Clean Energy Regulator, 2016). To set a baseline operation, we used the farming of wheat, because it is the most important cereal crop produced in Australia. We used average yields from the most up-to-date (2012-13) ABARES statistics for South Australia (SA), Victoria, Queensland and New South Wales (NSW) where the average wheat yields were 1.98, 2.0, 2.19 and 2.33 t/ha, respectively (Australian Government, 2013). We excluded Tasmania because there were no data for that state and initially Western Australia (WA) because the average wheat yield was only 1.17 t/ha and, according to the CMT, there were no regions mapped of 'some' or 'more benefit' (i.e. medium or high sequestration potential).

Soil C sequestration is promoted not only for offsetting national GHG emissions but also for improving a farm's productivity. We therefore assumed that a farmer would seek to optimize productivity after the implementation of a PMA. Thus crop yields, or animal stocking rates when crop land was converted to pasture, were increased to meet this expectation where inputs were maintained. However, the FullCAM model values for C sequestration (see Table 1) were derived on the assumption that plant biomass would increase by 20 percent, so that where plant residues are retained in the soil their emissions need to be adjusted according to the methodology given in Australian Government (2015b) (equations R 12 and R13, p.47).

The input variables for the calculations for each chosen PMA were as follows:

2.2.1 Sustainable intensification choice 1 – new irrigation using a new water allocation

We chose this intervention because it was difficult to establish costs for the alternative (new irrigation achieved through water saved by off-site efficiencies). However, a leakage discount factor of 0.75 needed to be applied to the modelled C sequestration value (Australian Government, 2015b). Although we made calculations for NSW, Queensland, Victoria and SA, we found the outcomes were very similar so we focused on NSW and Victoria, states which covered the range of average yields and where new irrigation was more likely. For NSW, we took two baseline options (a) a yield of 2.33 t/ha achieved with 25 kg N/ha/yr applied as urea (low input scenario) and (b) 2.33 t/ha with 50 kg N/ha/yr applied as urea (high input scenario). With new irrigation, option (a) yield increased to 3.5 t/ha with 50 kg N/ha/yr and 2.5 ML/ha of water, and option (b) yield increased to 4.5 t/ha with 100 kg N/ha and 4 ML/ha of water. The same scenarios were run for Victoria except that the baseline yield was 2 t/ha. We assumed electricity provided the energy for pumping water at a consumption rate of 10 kW hr per 0.5 ML/ha (50 mm application).

2.2.2 Sustainable intensification choice 2 – managing soil acidity through liming

Again for NSW and Victoria, where there are large areas of acid soils, we chose a baseline wheat yield with 25 kg N/ha/yr as urea, with a change to 2 or 4 t/ha of lime applied (100% $CaCO_3$) and 25 kg N/ha/yr as urea. The higher rate of lime was used because the amount required to raise soil pH to 5.5 and keep it there for five years will vary with the pH buffering capacity of the soil. Consistent with FullCAM modelling, we assumed a 20 percent increase in yield with lime. Hence there was a small increase in emissions from crop residues after liming. Emissions from lime itself were calculated according to the National Inventory Emission Factor for Carbonates (t $CaCO_3$ x 0.13). Baseline GHG emissions in this PMA are taken as zero, but in calculating emissions after liming we made an allowance for fuel consumed in one tillage pass to incorporate the lime.

2.2.3 Stubble retention

Consistent with FullCAM modelling, a 20 percent increase in yield was assumed for this practice. GHG emissions are the same before and after the change, except for emissions from the above-ground crop residues and those contributed by one tillage pass to incorporate stubble and spray for weeds. As examples, we calculated the net C abatement for wheat in both NSW and Victoria, with and without irrigation, and with 25 and 100 kg N/ha/yr as urea for dryland and irrigated wheat, respectively.

2.2.4 Conversion to permanent pasture

This practice is applicable to land that has been under crop or bare fallow for at least five years before the start of the project. Emissions from all sources were calculated before and after the change.

As examples, we calculated the net C abatement for wheat land in NSW and Victoria converted to pasture grazed by sheep or cattle. Offsetting allowances were made for four tractor passes not required under pasture and for a reduction in urea input under pasture compared to the crop, assuming there would be a contribution of legume N under pasture. There was a low input scenario under dryland (25 kg N/ha/yr as urea, falling to zero after conversion) and a high input scenario with irrigation (100 kg N/ha/yr as urea, falling to 50 kg N/ha). Wheat yields were the same as those under sustainable intensification. Average stocking rates for dryland, as taken from ABARES (2013), were 0.6 and 0.5 head/ha in NSW and 3.3 and 0.9 in Victoria for sheep and cattle, respectively. For irrigated pasture, the sheep stocking rates were adjusted to 3 ewes and 3 lambs for NSW, and 6 ewes and 6 lambs for Victoria. The cattle stocking rates on irrigated pasture were adjusted to 1.5 head/ha in NSW and 2 in Victoria.

A sensitivity analysis was conducted to determine the effect of a ±25 percent change in yield or stocking rates on net C abatements, and consequently the potential revenue from soil C sequestration.

2.3 Gross Margin Analysis of Practice Change for Individual Farmers

The incentives for individual farmers adopting any of the PMAs will depend not only on the returns from sequestering C, but also on the returns received from changes in yields (or animal products) arising from implementing a PMA, less the costs associated with implementing that PMA.

The returns from sequestering C are equal to the net C abatement (subsection 2.2) multiplied by the price of C, which in the past two reverse auctions was \$13.95 and \$12.25 per t CO_2-e, respectively. The more recent price of \$12.25 per t CO_2-e was used in this analysis. The commodity returns were calculated by multiplying the assumed change in wheat yields (t/ha) for a given PMA by the value (\$/t) of wheat, or the value per ha of livestock in the case of the Conversion to Pasture PMA. These values were derived from the ABARES survey of broad-acre agricultural industries (Australian Government, 2013). In Victoria, farmers' returns from wheat were estimated to be \$239.90/t and \$262.46/t in NSW. The value of sheep grazing in NSW and Victoria was estimated to be \$90.27 and \$94.82 per head, respectively, while the returns from cattle were estimated to be \$721.83 and \$635 per head, respectively. The net returns to grazing livestock also needed to include the losses from forgoing wheat production, which were calculated by subtracting the costs of hiring labour, fertilizer, chemicals and fuel from the gross receipts from wheat reported in the ABARES survey (Australian Government, 2013). This yielded a reduction in income of \$139.83/ha and \$82.26/ha from not producing wheat in NSW and Victoria, respectively.

The costs associated with each PMA depended on the activity undertaken. The price of N used was \$628/t of urea (Dairy Australia, 2016), the price of lime was \$33/t (pers. comm. Greg Williams, Batesford Quarries), and the price of glyphosate (needed for weed control under stubble retention) estimated to be \$5.30/L. The application rates of water, N and glyphosate were in accordance with supplier's recommendations. The cost of delivering and spreading lime and spraying glyphosate were estimated to be \$44/t (pers. comm. Greg Williams, Batesford Quarries). The effect of lime should last for 5 yrs so an annualized amortized value of the cost of liming was estimated to be \$17.71/ha, assuming an annual interest rate of 7 percent. The price of irrigation water was derived from PSI Delta (2013) and estimated to be \$772/ML and \$635/ML in NSW and Victoria, respectively. The cost of energy used in pumping the water was estimated to be \$0.13/kWh (Electricity Wizard, 2016), with 10 kWh being consumed to pump 0.5 ML.

The difference between the sum of the returns (including the C credit) and the sum of the costs gave the net benefit to the farmer from implementing a PMA.

2.4 Estimation of the Costs and Benefits of Soil C Sequestration for Society

The benefits to society will depend on the total C abatement achieved that can be used to offset Australia's GHG emissions. The costs to society will depend on the annual C abatement (t CO_2-e) and the value (\$/t) of a C credit achieved through the reverse auction process.

To estimate the total C abatement, we calculated net C abatements per ha for each of the PMAs described above. These net C abatements needed to be multiplied by the potential land areas in which these practices could be applied. We estimated the national areas of the 'marginal', 'some' and 'more benefit' regions using the 'measure' facility in the CMT. Because these areas were large in aggregate but individually had irregular boundaries, the CMT could only be used at a very small scale, so the accuracy in measuring these areas was only ±5 percent. We then matched our calculated values of net C abatement to the areas of appropriate regions to obtain estimates of total C abatement, assuming a range of landholder uptake rates.

3. Results

3.1 Estimated Net C Abatement Under Various PMAs

3.1.1 Sustainable intensification choice 1

The changes in GHG emissions and net C abatements for the example of new irrigation on a wheat crop under low or high inputs in NSW and Victoria are shown in Table 2.

The change in emissions in all these examples exceeded the modelled C sequestration in a 'marginal benefit' region, so this PMA would not qualify as an eligible offset project in any such region shown in the CMT Map (includes all the land mapped in WA). The net C abatement would be small (0.25-0.33 t CO_2-e/ha/yr) in the 'some benefit' regions, and substantial (1.05-1.12 t CO_2-e/ha/yr) only in the 'more benefit' regions.

Table 2. GHG Emissions and Net C Abatements for the PMA Sustainable Intensification of Wheat with New Irrigation Water in NSW or Victoria

		Modelled values for soil C sequestration (t CO_2-e/ha/yr)		
		Marginal benefit = 0.11	Some benefit = 0.59	More benefit = 1.65
Location and input level	Net change in emissions (t CO_2-e/ha/yr)	Net C abatement (t CO_2-e/ha/yr)[1]		
NSW low input	0.112	0	0.33[2]	1.12
NSW high input	0.119	0	0.25	1.05
Victoria low input	0.112	0	0.33	1.12
Victoria high input	0.119	0	0.25	1.05

[1]Where the net C abatement is negative, the value must be entered as zero

[2]All net C abatement values have been rounded to two decimal places consistent with the modelled values given in Table 1

3.1.2 Sustainable Intensification Choice 2

Table 3 shows GHG emissions and net C abatement for examples of wheat land where the soil pH is raised through liming. Emissions generated in the production of lime are not accounted for in the CFI methodology. However, the higher the rate of lime applied, the greater the GHG emissions from the soil as shown in the Table 3. There were no differences between NSW and Victoria. Again, only projects located in regions of high sequestration potential ('more benefit') achieved substantial net C abatement (1.09-1.35 t CO_2-e/ha/yr).

Table 3. GHG Emissions and Net C Abatements for the PMA Sustainable Intensification Achieved through Lime Applied at 2 or 4 t/ha for Wheat in NSW or Victoria

			Modelled values for soil C sequestration (t CO_2-e/ha/yr)		
			Marginal benefit CEA = 0.11	Some benefit CEA = 0.59	More benefit CEA = 1.65
Location and input level	Rate of lime (t $CaCO_3$/ha)	Net change in emissions (t CO_2-e/ha/yr)	Net C abatement[1] (t CO_2-e/ha/yr)		
NSW 25kgN/ha	2	0.303	0	0.29	1.35
NSW 25 kg N/ha	4	0.563	0	0.03	1.09
Victoria, 25 kg N/ha	2	0.302	0	0.29	1.35
Victoria, 25 kg N/ha	4	0.562	0	0.03	1.09

[1]Where the net C abatement is negative, the value must be entered as zero.

Table 4. GHG Emissions and Net C Abatements for the PMA Stubble Retention for Dryland and Irrigated Wheat in NSW or Victoria

		Modelled values for soil C sequestration ($t\ CO_2$-e/ha/yr)		
		Marginal benefit CEA = 0.07	Some benefit CEA = 0.29	More benefit CEA = 0.73
Location and input level	Net change in emissions ($t\ CO_2$-e/ha/yr)	Net C abatement[1] ($t\ CO_2$-e/ha/yr)		
NSW dryland wheat, low N	0.054	0.02	0.24	0.68
NSW irrigated wheat, high N	0.074	0	0.22	0.66
Victoria dryland wheat, low N	0.051	0.02	0.24	0.68
Victoria irrigated wheat, high N	0.074	0	0.22	0.66

[1]Where the net C abatement is negative, the value must be entered as zero.

3.1.3 Stubble Retention

Table 4 shows GHG emissions and net C abatements for examples of wheat land that was previously fallow or had stubble burnt, or had stubble baled and removed and now retained.

In each State, the C emissions are slightly greater for wheat under irrigation and with higher urea inputs because of the larger amount of residues retained on the land. Net C abatement in 'marginal benefit' land is close to zero. Only the 'more benefit' regions produce a substantial net C abatement in the range 0.66-0.68 t CO_2-e/ha/yr. However, this abatement is only about 60 percent of the abatement achieved with the introduction of new irrigation (see Table 2) and about half of that achieved through applying lime at 2 t/ha (see Table 3).

3.1.4 Conversion to Pasture

Table 5 shows GHG emissions and net C abatement for examples of wheat land converted to permanent pasture. White and Davidson (2015) analysed the cost-effectiveness of this change under the methodology Carbon Credits (Carbon Farming Initiative) (Sequestering Carbon in Soils in Grazing Systems) Methodology Determination 2014 (Australian Government, 2015a). However, the revised CFI legislation provides for more nuanced model estimates of C sequestration based on the sequestration potential of different sites, which is primarily influenced by the regional climate (rainfall and temperature) and soil clay content (Rabbi et al., 2015).

Table 5. GHG Emissions and Net C Abatement for the PMA Conversion to Pasture of Wheat Land now under Pasture Grazed by Sheep or Cattle under Dryland or Irrigated Conditions in NSW or Victoria

		Modelled values for soil C sequestration ($t\ CO_2$-e/ha/yr)		
		Marginal benefit CEA = 0.22	Some benefit CEA = 0.44	More benefit CEA = 0.84
Location and animal enterprise	Net change in emissions ($t\ CO_2$-e/ha/yr)	Net C abatement ($t\ CO_2$-e/ha/yr)[1]		
NSW dryland sheep	-0.08	0.22	0.44	0.84
NSW dryland cattle	0.74	0	0	0.10
NSW irrigated sheep	1.30	0	0	0
NSW irrigated cattle	2.52	0	0	0
Victoria dryland sheep	0.534	0	0	0.31
Victoria dryland cattle	1.47	0	0	0
Victoria irrigated sheep	2.23	0	0	0
Victoria irrigated cattle	3.44	0	0	0

[1]Where the net C abatement is negative, the value must be entered as zero.

Table 5 shows that the only practice change where there is substantial net C abatement, equal to the modelled estimates for all regions, was the conversion to dryland pasture grazed by sheep in NSW. Dryland cattle pasture achieved a very small net abatement in 'more benefit' regions, and in such regions in Victoria dryland sheep pasture achieved 0.31 t CO_2-e/ha/yr of net abatement.

3.2 Sensitivity Tests for Net C Abatement

The effect on net C abatement of changing wheat yields by ±25 percent was negligible for liming and stubble retention; similarly for new irrigation with low inputs. An effect of yield change was apparent (approximately 6 percent) only for new irrigation at high inputs in 'more benefit' regions.

The effect of stocking rate change in Conversion to Pasture produced relatively greater effects on C abatement for those grazing systems where positive abatements were possible. This is primarily due to the relatively large contribution that methane (CH_4) emissions from the grazing animals make to GHG emissions (White & Davidson, 2015). Net C abatement changed from 0.13 to 0.48 t CO_2-e/ha/yr for dryland sheep in Victoria, and from -0.13 to 0.33 t CO_2-e/ha/yr for dryland cattle in NSW. Net C abatement remained negative for all other changes. There was no effect of a ±25 percent stocking rate change for dryland sheep in NSW because the change was within the range where the maximum net C abatement was achievable.

In all examples, the more intensive the activity leading to higher yields or stocking rates, the greater the emissions and hence the less the net C abatement.

3.3 Changes in Gross Margins on the Implementation of Various PMAs

Carbon Estimation Areas in regions where the net C abatement is zero (see Tables 2-5) do not qualify for approved projects. As shown in Table 6, the net costs with new water under Sustainable Intensification were more than \$1000 and \$2000+ per ha under low and high input systems, respectively. Much higher yields and lower water costs would need to be achieved to make this PMA profitable. The effect of increasing the C price to \$100/t CO_2-e, for example, made little difference to the net negative returns. Although conversion to dryland sheep in NSW gave positive C abatements in all regions, the net returns on farm were negative. The C price would have to be more than \$50/t CO_2-e for this activity to be profitable in the 'more benefit' region only. Small net C abatements occurred for dryland cattle in NSW and dryland sheep in Victoria, giving positive returns, but only in the 'more benefit' region. Where net C abatements occurred, the profitability of the activity was insensitive to the C price.

Sustainable Intensification –liming – and Stubble Retention gave positive returns in 'some' and 'more benefit' regions. Stubble Retention even returned a profit for dryland wheat in 'marginal' regions. Liming is only profitable if the cost of liming and spreading is amortized over five years. Again, the net returns were relatively insensitive to changes in the C price. Note that for Sustainable Intensification, a farmer is required to implement two changes, such as new irrigation and liming in our examples, which would be unprofitable overall. However, if another option such as pasture renovation was combined with liming in regions of 'some' or 'more benefit' the combination might be profitable.

The paradox revealed by these results is that the more intensive the farming activity – new irrigation introduced, or irrigation compared to dryland, or using more water, lime or urea N – the smaller the C abatement and the more likely the change will be unprofitable for the farmer. This is an unintended consequence of the FullCAM model producing default estimates for C sequestration potential (see Table 2) on the assumption that yield increases are only 20 percent for any one PMA. While this might be a reasonable assumption for liming and stubble retention, as we have pointed out above (see subsection *2.2 Example calculations for qualifying PMAs*), farmers will strive to optimize returns from their PMAs so that the GHG emissions from residues, fertilizer and water use will increase considerably with the change. For the accounting of a net C abatement to be valid, these higher emissions must be calculated and deducted from the default sequestration estimates obtained from the CMT. This shortcoming in the methodology could make many proposed projects ineligible.

3.4 Cost and Benefits of Soil C Sequestration for Society

Tables 3-5 show that in 'marginal benefit' land, net C abatement is near zero or zero (negative in practice) except for stubble retention in dryland wheat (very small) and the conversion of wheat to dryland pasture grazed by sheep in NSW. However, Table 6 shows that even this small abatement under stubble retention in 'marginal' regions was profitable under dryland wheat in NSW and Victoria, and by extension in SA and Queensland where yields were very similar to those in the former States and the price of wheat was comparable or greater. Given this result, it was necessary to review stubble retention in WA where all the land mapped was 'marginal' and the average wheat yield was much lower at 1.17 t/ha. The result was net C abatements of 0.03, 0.25 and 0.69 t

CO_2-e/ha/yr. This was very similar to the C abatement in NSW and Victoria and, with an average wheat price of \$351/t, gave very favourable positive returns also.

ABARES data for 2012-13 show the total area of land sown to wheat on cropping farms and mixed livestock farms, broken down by State, was 5 525 000 ha (Australian Government 2013). Of this area, we needed to estimate the proportion on which farmers may qualify for eligible CFI projects involving the PMAs Stubble Retention or Sustainable Intensification through liming.

Table 6. Changes in Farm Gross Margins (\$/ha/yr) after Implementation of a PMA in Regions of Different C Sequestration Potential

Project management activity	Soil C sequestration potential		
Sustainable Intensification – irrigation with new water	Marginal benefit regions	Some benefit regions	More benefit regions
NSW low input	0	-1660	-1651
NSW high input	0	-2595	-2585
Victoria low input	0	-1264	-1254
Victoria high input	0	-2015	-2006
Sustainable Intensification - liming			
NSW 2 t lime/ha	0	91	104
NSW 4 t lime/ha	0	52	65
Victoria 2 t lime/ha	0	64	77
Victoria 4 t lime/ha	0	25	38
Stubble Retention			
NSW dryland wheat	119	122	128
NSW irrigated wheat	0	236	241
Victoria dryland wheat	93	96	101
Victoria irrigated wheat	0	215	220
Conversion to Pasture			
NSW dryland sheep	-49	-46	-41
NSW dryland cattle	0	0	256
NSW irrigated sheep	0	0	0
NSW irrigated cattle	0	0	0
Victoria dryland sheep	0	0	265
Victoria dryland cattle	0	0	0
Victoria irrigated sheep	0	0	0
Victoria irrigated cattle	0	0.00	0

[1]Where the net C abatement is negative, the project is ineligible for C credits.

3.4.1 Potential for Stubble Retention

Table 7 shows on a State-by-State basis the areas sown to wheat and, as derived from the CMT, the areas of 'marginal', 'some' and 'more benefit' land out of a total eligible area of approximately 215 M ha. Estimates for the national potential to sequester soil C by stubble retention were calculated as follows.

(a) For NSW, Victoria, Queensland and SA, the area sown to wheat was 3 159 000 ha, which overall we can assign 50:50 to 'some, and 'more' benefit regions (consistent with Table 7), for which the C abatement values are given in Table 4. The potential C abatement is

$$1\ 580\ 000 \times 0.24 + 1\ 580\ 000 \times 0.68 = 1\ 453\ 600\ t\ CO_2 - e\ per\ yr$$

(b) Because there is land of 'marginal benefit' only in WA, the potential C abatement there is

$$2\ 366\ 000 \times 0.03 = 70\ 980\ t\ CO_2 - e\ per\ yr$$

The area sown to wheat shows some variation from year to year. For example, preliminary ABARES data for 2013-14 shows the combined area sown to wheat was 3 247 000 ha in NSW, Victoria, Queensland and SA and 2

639 000 ha in WA. However, given the uncertainties in these estimates, this variation does not materially alter the conclusion that the maximum C abatement achievable through Stubble Retention is approximately 1.524 M t CO_2-e per year. Given a notional C price of \$12.25 per t CO_2-e, the annual cost to the Australian government would be \$18.669 million.

Three caveats should be applied to our calculation of the maximum C abatement achievable through Stubble Retention. First, in parts of Australia's wheat lands, notably in WA and the Mallee district in Victoria, stubble retention is already extensively practised, which would make this land ineligible for new projects under the CFI. Second, Kirkegaard (1995) found from a survey of Australian field trials that yields were not increased under stubble retention, contrary to the assumption made in FullCAM modelling, which may explain why stubble retention is not widely popular, for example, in central and southern NSW (Scott et al., 2010). Third, some farmers will lose income from selling baled straw if they convert to stubble retention. Due to these factors, farmers in some Australian wheat belt regions will be unwilling or unable to take up Stubble Retention, and the potential for soil C sequestration through this PMA will be much reduced.

Table 7. Areas of Defined C Sequestration Potential Derived from the CMT, and ABARES Areas for Sown Wheat on a State by State Basis[1]

		Area of defined C sequestration potential (,000 ha)			
State	Total area sown to wheat 2012-13 (,000 ha)	Marginal benefit	Some benefit	More benefit	Total area of land eligible for sequestration (,000)
NSW	928	51 087	2425	5488	59 000
Victoria	581	8554	8570	8276	25 400
WA	2366	29 500	0	0	29 500
Queensland	709	80 974	2890	3579	87 443
SA	941	6243	5802	1555	13 600
Totals	5525	176 358	19 687	18 898	214 943

[1]No data are collected for Tasmania and the Northern Territory because of their very small wheat areas.

3.4.2 Potential for Sustainable Intensification

Liming, which is profitable in 'some' and 'more benefit' regions, must be combined with another activity such as new irrigation, nutrient management or pasture renovation in the same CEA. For the wheat belt, the best of these options is probably nutrient management, but the economics of this option are very farm-specific and do not lend themselves to generic calculations. For this reason, we consider only the maximum potential for C abatement through liming.

The area of soils in Australia of pH ($CaCl_2$) ≤5.5 in the top 15 cm was estimated to be between 23 and 49 M ha in 2001 (Dolling et al., 2001). Table 4 of their report shows that about half this area (15-22 M ha) is spread through NSW, Victoria, Queensland and SA (WA is excluded because all the land mapped there is of 'marginal benefit' only, for which there is no financial incentive to lime). From Table 7, the estimated total area of wheat land in these four States is 3 159 000 ha. However, because of neutral to alkaline soils in the wheat lands of the Darling Downs, southeast Queensland, the Wimmera-Mallee, northwest Victoria, and the York and Eyre Peninsulas SA, the maximum area for potential C abatement through liming will be much less than the 3.16 M ha. Assuming the qualifying area is approximately half the maximum of 3.16 M ha, and subdividing this area 50:50 to 'some' and 'more benefit' land for which there is net C abatement (see Table 3), we have a total C abatement of

$$800\,000 \times 0.29 + 800\,000 \times 1.35 = 1\,312\,000\ t\ CO_2 - e\ per\ yr$$

This estimate of 1.312 M t CO_2-e per yr could be augmented by eligible liming projects on soils of pH <5.5 under other land uses in NSW, Victoria, Queensland and SA. However, this augmentation is probably balanced by acid soils that have been limed since the land and water audit of 2001. Thus, we adhere to our estimate of a total potential abatement of 1.312 M t CO_2-e per yr. Given a notional C price of \$12.25 per t CO_2-e, the annual cost to the Australian government would be \$16.072 million.

3.4.3 Potential for Conversion to Pasture

As shown in Table 5, although potential net C abatement exists in all benefit regions in NSW, there is no financial incentive for farmers to participate (see Table 6). The financial incentive is positive for conversion to dryland cattle and dryland sheep in Victoria, but the C abatements there were quite sensitive to changes in stocking rate of ±25 percent (ranging from -0.13 to 0.33 and 0.13 to 0.48 t CO_2-e per yr in NSW and Victoria, respectively). Hence there may not be much uptake of this practice change in these cases.

4. Discussion and Conclusions

There are two interrelated ways of looking at the results from the analysis of a farmers' gross margins. The first is whether a farmer has the incentive to implement a PMA and the second is what C price would be required to induce a change. Notably, the first deals with situations where the gross margin is positive and the second where it is negative. Clearly, whether farmers might be induced to undertake a particular PMA depends on the activity and the situation in which farmers find themselves. Although liming on its own would pay, this activity needs to be combined with another to qualify under Sustainable Intensification. Combining liming with new irrigation clearly does not pay. Stubble retention appears to pay, even on dryland that is of 'marginal benefit' for C sequestration. In two situations converting from wheat to dryland livestock in 'more benefit' regions is profitable at current commodity prices. Otherwise the C price would need to be \$40-50/t CO_2-e if conversion to dryland sheep in NSW is worthwhile, and up to more than \$1200/t CO_2-e if new irrigation is introduced. Given the current C price of approximately \$12/t CO_2-e, such increases seem unlikely.

Other analyses of the economics of soil C sequestration were similarly discouraging, For example, we found previously that the conversion of several cropping systems to livestock was unprofitable for all crops except for irrigated wheat (at \$200/t for wheat and a C price of \$24.15/t CO_2-e), provided that the adjustment costs of making this change were less than \$689/ha and \$293/ha for cattle and sheep, respectively (White & Davidson, 2015). Combining modelled soil C sequestration rates using IPCC methodology with local economic data for the grains industry in southern Australia, Grace, Antle, Ogle, Paustian, & Basso (2010) found that, although the best option for net C sequestration was no-till, even at a C price of \$200/t C (\$54.5/t CO_2-e) only one-third of the C sequestration potential for the region would be achieved over 20 yrs. Moreover, Grace et al. (2010) used a 100 yr global warming potential (GWP) for CH_4 and nitrous oxide of 23 and 296, respectively, in their calculations instead of GWP values of 72 and 289, respectively, appropriate to a 20 yr period (IPCC, 2007). Thus, the value of one-third will be an overestimate of net C sequestration under no-till.

We infer from all these results that C sequestration itself does not determine the outcome of the economic analysis. Because the prevailing price of C is relatively low and the quantities of C sequestered are small, the influence of that component of the analysis is swamped by the costs of implementing a PMA and the returns derived from such an activity. In cases where sequestration does not pay, the benefits from increased yields resulting from a PMA are less than the costs of implementing the PMA. Also the changes in net returns from improvements in yields are far greater than the returns a farmer would receive from sequestering C alone.

From a national perspective, paying approximately \$35 M annually to sequester 2.84 M t CO_2-e as soil C is expensive, given that this represents only 0.52 percent of Australia's annual GHG emissions of 549 M t CO_2-e (Department of the Environment, 2016). Note that there are provisos to these estimates, particularly with respect to the contribution of stubble retention, which suggest that the actual amount of C sequestration will be substantially less. Unfortunately, we cannot directly compare our estimate with published figures, which only report 28 M t CO_2-e (called 'abatement') for sequestration by 'multiple methods' in the first auction, and 4 M t of abatement for 'agriculture' in the second auction (Clean Energy Regulator, 2016). However, it seems likely that soil C sequestration has made little contribution to the total figure of 32 M t of abatement attributed to 'sequestration' and 'agriculture'.

To secure the long-term sustainability of agriculture, paying an incentive to farmers to implement recommended soil amelioration practices, such as stubble retention and liming acid soils, can be seen as good public policy. In this case, although this represents a direct government subsidy to private farming in Australia, it can be justified as an investment for future prosperity.

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