The cost effectiveness of a policy to store carbon in Australian agricultural soils to abate greenhouse gas emissions

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Abstract. Data for cropping and pastoral enterprises in south eastern Australia were used in a cost-effectiveness analysis to assess the feasibility of abating greenhouse gas (GHG) emissions through storing soil carbon (C) as soil organic matter under the Australian government’s Carbon Farming Initiative. We used the C credit value for 2013-14 of $24.15 per tonne of CO$_2$-equivalent (CO$_2$-e) and a C storage rate of 0.5 tonne C/hectare/year for conversion of cropland to pasture. Given that a change of enterprise is driven primarily by farmer returns, we found that none of the changes were feasible at current prices, with the exception of wheat to cattle or sheep in an irrigated system, and dryland cotton to cattle or sheep. Given that our model scenario assumed the most favourable economic factors, it is unlikely that increased soil C storage through a change from cropping to pasture can make a significant contribution to abating Australia’s CO$_2$ emissions. However, of greater concern to society is the methane emissions from grazing cattle or sheep, which would negate any gain in soil C under pasture, except for a switch from dryland cropping to sheep.

1. Introduction

The Australian government has a stated objective of decreasing Australia’s greenhouse gas (GHG) emissions by 5 percent by the year 2020. Through a Direct Action Policy, the government’s objective will be achieved by “abatement .... purchased via a market mechanism to achieve the lowest price....The lowest cost abatement may be a mix of energy efficiency, cleaning up waste coal mine gas, cleaning up power stations and landfill gas. It may be reafforestation of marginal lands or revegetation or improvement of soil carbon” [1]. This policy is currently being implemented through an Emissions Reduction Fund (ERF), under the Carbon Farming Initiative (CFI) for which there is a Carbon Credits (Sequestration of Carbon in Soil Using Modelled Abatement Estimates) Methodology Determination 2014 [2]. Currently, this ‘determination’ sets out possible acceptable ‘project types’ as being ‘sustainable intensification’, ‘conversion to pasture’ and ‘stubble retention’.

The modelled abatement estimates for carbon (C) storage are derived from the Australian Government’s National Inventory System soil carbon model (the Full Carbon Accounting Model – FullCAM) and the parameters used to generate National Inventory reports for agricultural systems [2]. The estimates currently range from 0.122 to 0.5 tonnes (t) C per hectare (ha) per year (yr), that is, 0.449 to 1.835 t carbon dioxide equivalent (CO$_2$-e)/ha/yr, the highest figure being for conversion from cropland to pasture. These C storage estimates are consistent with the range of 0.3-0.6 t C/ha/yr reported in a review of national and international literature by Sanderman et al. [3], but higher than reported for intensively managed pastures under dryland or irrigation in recent New Zealand research [4, 5]. However, the estimates are much lower than that claimed for ‘biological farming systems’ of a
0.15% increase in soil organic carbon (SOC) annually (amounting to 3 t C/ha/yr for a soil of 1% C) [6].

Given the wide disparity between these estimates of SOC storage potential and the fact that farmers will be reluctant to change from a profitable farming enterprise to a less profitable one that may require new skills, capital input, and incur a compliance cost for an approved project, the aim of this paper is to analyze the economic consequences for farmers who change their current farming system to other systems for the purpose of storing SOC. A range of common farming systems and their C storage potentials is considered, as are the changes to farmers’ gross margins, the cost of compliance with government policy, and a notional value of a C credit (which as from 1 July 2015 will be set by a ‘reverse auction’ process). Two measures are used to assess the viability of the program - the cost effectiveness per ha of making a change (a measure of the incentive farmers need to partake), and the cost effectiveness per t C (a measure of what the government might expect from the program). These measures are calculated for the short term (1 yr), reflecting the immediate incentive to change, and the longer term of 25 yrs, as will be permitted under the CFI policy from 1 July 2015. However, it should be noted that projects approved after that date will be subject to a 20% reduction in any credits earned if they are based on a 25-yr ‘permanence period’ [7].

2. Methods
Cost-effectiveness analysis is a technique that assists in ensuring the efficient use of investment resources in sectors where benefits may be difficult to evaluate [8]. The technique can be used to select amongst alternative projects or practices which have the same objectives (quantified in physical terms). The approach can be used to identify the alternative that minimizes the actual value of costs to provide a given level of output; or conversely, the value of costs that maximizes the output level. The result of the analysis is a cost-effectiveness ratio of outputs to costs that can be used to measure the impact of a policy.

This study is confined to the cost-effectiveness of changing from a cropping to pasture-based livestock enterprise, assuming a C accumulation under grazed pasture of 0.5 t C/ha/yr (amounting to 1.835 t CO₂-e/ha/yr) [2]. Although SOC will approach a new equilibrium value asymptotically, this may take 80-120 years [9] so the assumption of a linear change over the first 25 yr is justified. Although a wide range of cropping systems is possible, for simplicity we have chosen representative irrigated cropping systems in southern New South Wales and dryland cropping systems in northern New South Wales, for which data are readily available [10], and assessed the cost-effectiveness of a change to a cattle or sheep enterprise. The costs are those associated with making a change from one enterprise to another and those of complying with the policy. It is assumed that farmers who undertake the change do so just once and do not opt in and out of the program. This assumption is in line with the analysis undertaken by Cowan et al. [11] who argued that farmers, while being tactically flexible within a production system, persist with their existing production systems despite adverse commodity prices. The ‘effect’ is the amount of C stored per ha, which measured over time is the difference between the increased SOC under the new enterprise compared with the SOC under ‘business as usual’. This effect will often be larger than the difference calculated between SOC under the new enterprise and SOC at time zero (the baseline).

The costs of changing enterprises are simplified by assuming they are confined to a change in the gross margin a farmer receives from his enterprise. This assumes that the capital costs associated with the change are non-existent. In table 1, data on gross margins for various dryland and irrigation cropping and livestock enterprises are presented [10]. The costs of compliance will depend on the costs of auditing the project and reporting, and the costs of SOC measurement to verify FullCAM’s performance. At present, these costs cannot be quantified and so the compliance cost has been set at zero in the analysis.
Table 1. Gross margins for irrigated and dryland wheat, soybeans, lucerne, cotton, sheep and cattle enterprises in southern and northern NSW

| Enterprise | Soybeans | Maize | Wheat | Lucerne | Cotton | Sheep | Cattle |
|------------|----------|-------|-------|---------|--------|-------|--------|
| Irrigated systems | | | | | | | |
| Farm price ($/t) | 625 | 290 | 200 | 310 | 2400 | - | - |
| Yield (t/ha) | 4 | 11 | 3.5 | 15 | 2.025 | 10 | 2.6 |
| Gross revenue ($/ha) | 2500 | 3190 | 700 | 4650 | 5348 | 1116 | 1497 |
| Gross Costs ($/ha) | 622 | 1396 | 442 | 2249 | 3167 | 609 | 594 |
| Gross Margin ($/ha) | 1878 | 1794 | 258 | 2401 | 2181 | 903 | 903 |
| Dryland systems | | | | | | | |
| Farm price ($/t) | 475 | 240 | 265 | 288 | 1992 | - | - |
| Yield (t/ha) | 1.5 | 3.75 | 3.5 | 4 | 0.6075 | 2 | 0.45 |
| Gross revenue ($/ha) | 713 | 900 | 928 | 1152 | 1210 | 223 | 183 |
| Gross Costs ($/ha) | 393 | 583 | 430 | 781 | 1160 | 122 | 55 |
| Gross Margin ($/ha) | 320 | 317 | 498 | 371 | 50 | 101 | 127 |

Notes: 1. Irrigated - Soybeans (edible) – Beds Murrumbidgee Valley Summer 2012-13. Dryland – Soybeans (no-till) North East NSW Summer 2012-13.
2. Irrigated Maize-Grits (beds) – Murrumbidgee Valley Summer 2012-13. Dryland – Maize (no-till) North East NSW Summer 2012-13.
3. Irrigated Wheat-Biscuit (Flood irrigated contour bay/sod sown) – Murrumbidgee Valley Winter 2012. Dryland – Wheat (no-till, long fallow, after sorghum) North East NSW Winter 2012.
4. Irrigated Lucerne (Flood irrigated, maintenance) – Murrumbidgee Valley Summer 2012-13. Dryland – Lucerne Hay Northern Zone NSW Summer 2010-11.
5. Irrigated Cotton (Roundup ready) – Murrumbidgee Valley Summer 2012-13. Dryland – Cotton (Roundup ready) North West NSW Summer 2011-12.
6. Sheep – Merino Ewes (20 micron) wether lambs finished, December 2012, on irrigated pasture and on dryland (native pasture).
7. Irrigated Cattle – Yearlings Southern/Central NSW (pasture improved) December 2012. Dryland Cattle – Inland Weaners (native pasture).
The sheep enterprise is assumed to be a 1000 ewe flock run at 10 dry stock equivalents (dse)/ha (irrigated pasture) and 2 dse on dryland (native pasture). The cattle herd is assumed to be a 100 head mob, run at 2.6 livestock units (lsu)/ha (irrigated) and 0.5 lsu (dryland). Source: NSW Department of Primary Industries (2012) Farm Budgets and Costs [10].

These costs and their effects need to be measured against the benefits to a farmer from undertaking the change. The value of a C credit was taken as the Australian value of $24.15 per t CO$_2$-e for 2013-14, which was used in two ways. First, it is incorporated into the farm-level analysis as a benefit to farmers from undertaking the change, and so is subtracted from the costs of change and compliance. Although it is assumed the C credit is paid for every year of the analysis, it must be prorated up as the difference in SOC accumulated increases over time, in this case over 25 yrs. Second, the C credit value can be used to assess the whole policy, when it becomes the basic price the government has to pay to implement soil C sequestration as part of the policy. In this way, the value of a C credit necessary to achieve a desired level of abatement can be determined. This then determines the national cost of the policy, which can be compared with the sum of money the government is prepared to allocate to the policy.

3. Results and Discussion
The results of the analysis presented in table 2 have three main components. First, there is the distinction between changing enterprises from one of five main crops to either sheep or cattle, in two different farming systems: irrigated and dryland. Second, there is the difference between the cost of...
saving a tonne of CO$_2$-e to society and the cost to the farmer of saving CO$_2$-e per ha, for each of the two farming systems. Third, there is a distinction between the short-term annual costs and the long-term costs (over 25 years discounted using net present value (NPV) techniques at 7% per yr) in the two different farming systems. Note that the adjustment costs of making a change between enterprises and the compliance cost of a project are assumed to be zero.

The main findings to note are (a) for society, with the exception of wheat in the irrigated system, the net costs per t CO$_2$-e abated are between $462 and $1033 per yr. In the dryland system; with the exception of dryland cotton, the net costs per t CO$_2$-e abated are between $79 and $192 per yr. (b) For society as a whole, with the exception of irrigated wheat, in the long term these costs accumulate and in NPV terms amount to between $5444 and $11820 per t CO$_2$-e abated. In the dryland system, with the exception of cotton, the long term costs (in NPV terms) are between $1145 and $2458 per t of CO$_2$-e abated. (c) Farmers need an incentive to change enterprises and, with the exception of irrigated wheat, the net costs (i.e. loss of income) of changes in the irrigated system are between $847 and $1850 per ha in the first year. In the long term, the net costs increase substantially to between $9980 and $21670 per ha. In the dryland system, with the exception of cotton, the costs of changing enterprises is between $145 and $352 per ha in the first year. Over 25 yrs the net costs in the dryland system increase to between $2099 and $4507 per ha. (d) The negative results for irrigated wheat and dryland cotton are interpreted as the opposite to a cost; in other words these are the benefits of changing. A change from irrigated wheat to cattle is estimated to yield a benefit of $376 per t CO$_2$-e abated in one year and $4320 per t CO$_2$-e in the long term. Per ha, irrigated wheat farmers would improve earnings by an estimated $689 in the short term and $7920 over 25 yrs. The benefits are less appealing in a change from irrigated wheat to sheep. In the case of dryland, cotton producers changing to cattle is estimated to yield a benefit of $66 per t CO$_2$-e abated in one year and $550 per t CO$_2$-e over 25 yrs. Per ha, dryland cotton farmers would improve earnings by an estimated $121 in one year and $1008 over 25 yrs. The benefits are less appealing in a move from dryland cotton to sheep. (e) The question arises why farmers do not abandon irrigated wheat or dryland cotton and take up cattle? Regardless of the benefits of C storage, this would appear to be a profitable move at current commodity prices. However, a shortcoming of this analysis is that the costs of making the change have not been incorporated and these would need to be (in the case of irrigated wheat) less than $689 per ha in the first year and less than $7920 per ha over 25 yrs. Although the costs needed to make a similar change from dryland cotton to cattle, or from either irrigated wheat or dryland cotton to sheep are less, the same principle applies. In addition, while the losses in the long term would be less if a lower discount rate (say 4%) were used, any change from a cropping to a livestock enterprise (with the exception of those stated above) would still result in a loss. (f) Although changing from a cropping enterprise to sheep appears less cost-effective than a change to cattle, the adjustment cost of making this change may be less.

The government’s draft Carbon Credits Determination Methodology 2014 identifies several factors that could change the net CO$_2$-e abatement for a change from a cropping to pasture [12], of which the most significant is the net negative effect of methane (CH$_4$) emissions from cattle or sheep grazing the pasture, which should be an overriding concern for society. The median values for these emissions for cattle [13] and sheep [14] are 83.5 and 7.3 kg CH$_4$/head/yr, respectively. Taking the global warming potential of CH$_4$ relative to CO$_2$ over 25 yrs as 63 [15], the effect of the CH$_4$ emissions from irrigated pasture is estimated to be 13.7 and 4.6 t CO$_2$-e/ha/yr for the cattle and sheep systems, respectively; for dryland pasture, the CH$_4$ effect would be 2.6 and 0.9 t CO$_2$-e/ha/yr. Notwithstanding the uncertainties in these estimates, the CH$_4$ emissions (in t CO$_2$-e/ha/yr) are much greater for irrigated pasture than the abatement of 1.835 t CO$_2$-e/ha/yr achieved through an increase in soil C under pasture. For dryland pastures, the situation is more favourable for sheep, which provide a net abatement benefit, but not for cattle.
Table 2. The net cost (per t CO$_2$-e and per ha) of changing from a cropping to a livestock enterprise to store soil C (assuming an average soil C storage of 0.5 t C/ha/yr).

| Item | Irrigation | Units | Soybeans | Maize | Wheat | Lucerne | Cotton |
|------|------------|-------|----------|-------|-------|---------|--------|
|      | To society |       |          |       |       |         |        |
|      | Immediate  | (1 yr) |          |       |       |         |        |
|      | - to cattle | $/t CO$_2$-e | 508 | 462 | -376 | 793 | 673 |
|      | - to sheep  | $/t CO$_2$-e | 748 | 702 | -136 | 1033 | 913 |
|      | Long term   | (25 yrs) |          |       |       |         |        |
|      | - to cattle | $/t CO$_2$-e | 5977 | 5444 | -4320 | 9302 | 7906 |
|      | - to sheep  | $/t CO$_2$-e | 8496 | 7962 | -1802 | 11820 | 10425 |
|      | To the farmer |       |          |       |       |         |        |
|      | Immediate  | (1 yr) |          |       |       |         |        |
|      | - to cattle | $/ha | 931 | 847 | -689 | 1454 | 1234 |
|      | - to sheep  | $/ha | 1327 | 1243 | -293 | 1850 | 1630 |
|      | Long term   | (25 yrs) |          |       |       |         |        |
|      | - to cattle | $/ha | 10959 | 9980 | -7920 | 17054 | 14495 |
|      | - to sheep  | $/ha | 15576 | 14597 | -3303 | 21670 | 19112 |
|      | Dryland     |       |          |       |       |         |        |
|      | To society  |       |          |       |       |         |        |
|      | Immediate  | (1 yr) |          |       |       |         |        |
|      | - to cattle | $/t CO$_2$-e | 81 | 79 | 178 | 109 | -66 |
|      | - to sheep  | $/t CO$_2$-e | 95 | 93 | 192 | 123 | -52 |
|      | Long term   | (25 yrs) |          |       |       |         |        |
|      | - to cattle | $/t CO$_2$-e | 1165 | 1145 | 2294 | 1493 | -550 |
|      | - to sheep  | $/t CO$_2$-e | 1329 | 1309 | 2458 | 1657 | -386 |
|      | To the farmer |       |          |       |       |         |        |
|      | Immediate  | (1 yr) |          |       |       |         |        |
|      | - to cattle | $/ha | 148 | 145 | 326 | 200 | -121 |
|      | - to sheep  | $/ha | 174 | 171 | 352 | 226 | -96 |
|      | Long term   | (25 yrs) |          |       |       |         |        |
|      | - to cattle | $/ha | 2136 | 2099 | 4206 | 2737 | -1008 |
|      | - to sheep  | $/ha | 2437 | 2399 | 4507 | 3038 | -708 |

4. Conclusions

These results emphasize that enterprise choice is driven primarily by returns to the farmer. Thus, unless an incentive to change enterprises (such as a C credit) is large, change will not occur. This analysis, conducted over five different enterprises and two different farming systems, shows the best possible outcome because we have ignored the adjustment costs of any change, the compliance costs, and the intended 20% discount of a C credit for a 25-yr project. We have also assumed a generous value for an ACCU that is not likely to be achieved under the Direct Action Plan starting on 1 July 2015 (indeed the indicative cost of a C credit realized in the first auction held in April 2015 is $13.95 per t CO$_2$-e). Hence all real situations present a worse-case scenario than that we have modelled here. With the exception of irrigated wheat and dryland cotton production, changing to grazed pasture to store soil C will not be a cost-effective way of abating GHG emissions. At a wheat price of $200 per t, a change to cattle or sheep could be profitable provided the initial adjustment cost is less than $689/ha.
or $293/ha for a change to cattle or sheep, respectively. All the commodity prices considered here will fluctuate over time; in particular, wheat prices have been as high as $300 per t which would make a change from wheat to cattle or sheep much less attractive than appears in our analysis.

Overall, the generally unfavourable cost-effectiveness of a change from cropping to pasture means that farmers are unlikely to make this change specifically to sequester soil C, but this general conclusion should not preclude individual farmers or farming groups from undertaking a more detailed analysis of the policy. However, irrespective of these financial results, the negative effect on net CO$_2$-e emissions of CH$_4$ emissions from cattle pastures (irrigated and dryland) and irrigated sheep pastures makes a change from cropping to grazed pastures an unsatisfactory option for abating GHG emissions nationally.

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