The economics of alternative crop production systems in the context of farmer participation in carbon trading markets

Abstract

Using scaled up data from an experimental farm platform in Scotland, we examined the relative economics of a conventional and a low-carbon integrated management system for two (otherwise identical) farms. By employing a novel market based approach, we factored the market costs of greenhouse gas (GHG) emissions on the relative economics of both systems. Specifically, farmers are considered to be awarded emission credits in accordance with Scotland's agricultural emissions reduction targets. Farmers are then considered to trade their net GHG emissions in an emissions trading scheme, with the integrated system expected to benefit from this arrangement due to its lower emissions. In further sensitivity analyses, we also considered the effect of premium pricing of integrated system crops on the relative economics of both systems. We find that in both the status quo and emissions trading scenarios, the conventional system is significantly more profitable. In the emissions trading scenario, an emissions price roughly three times the reported median prices over the last five years is required for the integrated system's profitability to break-even with the conventional system. However, even at prevailing emissions prices, a 20% premium pricing of the integrated system crops enables near parity in the profitability of both systems. We conclude that in order to facilitate greater adoption of low-carbon systems, policies may be needed to encourage farmers' realisation of the cost of their externalities, in particular GHG emissions. At the same time, support should be given to a market system that recognises premium prices for low-carbon system products.

Keywords: Conventional agriculture; Integrated agriculture; Economics; Carbon emissions trade; Premium prices

1 Introduction

Within the scientific community there is a recognition that agriculture contributes significantly to environmental externalities, in particular, the greenhouse gases (GHGs) that cause global warming (Bellarby et al. 2013, Galloway et al. 2007, Herrero et al. 2011, Bell, Cloy, and Rees 2014). Other externalities include soil degradation, biodiversity loss, water pollution and accumulation of chemical residues in food chains (Crowder and Reganold 2015, Godfray et al. 2010, Rockström et al. 2009). Under the Paris Agreement, the community of developed nations have committed to reducing overall GHG emissions to 40% below the 1990 levels by 2030 (European Commission 2017). The targets are even greater in Scotland, with the Scottish Government through Scotland's Climate Change Act (2009) setting an ambitious statutory target of reducing GHG emissions by 42% by 2020 towards an 80% target by 2050. In Scotland, GHG emissions from 'agriculture and related land use'[1] contribute about 20% of total GHG emissions (Scottish Government 2011c). It is expected therefore that reductions in emissions from agriculture and related land use would contribute significantly to the overall Scottish Government emissions reduction targets. To this end, there is growing consensus for adopting agricultural management systems that limit GHG emissions (Renwick and Wreford 2011, Feliciano et al. 2013, Bell, Cloy, and Rees 2014).

Farmers use a range of different agricultural management systems which vary in terms of their contribution to GHG emissions. There is a need for greater understanding of the relative contribution of different management systems to these emissions, and the implications of adopting management systems with less emissions on a farm's profitability and worth as this will be critical in influencing farmers' adoption decisions. In this context, two different types of agricultural management systems are typically distinguished in the literature. These are the conventional, high agrochemical input system and low-carbon systems. Variants of low-carbon management systems include 'integrated', 'sustainable', and 'organic' systems. Although differences exist in management practices implied by the different low-carbon systems, all centre on the proposition of reducing agrochemical input use intensity to protect the environment, enhance food health and safety and promote agricultural sustainability.

[1] This includes agricultural soils, fuel and agrochemical use, cropland conversion, livestock manure storage, enteric fermentation, stationary on-farm combustion sources, etc.

Two strands of research have emerged in the literature relating to conventional and low-carbon systems. One strand has typically focused on the relative economics of both systems (Hanson et al. 1990, Hanson, Lichtenberg, and Peters 1997, Dobbs and Smolik 1997, Brumfield, Rimal, and Reiners 2000, Delate et al. 2003, Pimentel et al. 2005) whilst the other has largely focused on their relative contributions to GHG emissions (Flessa et al. 2002, Vleeshouwers and Verhagen 2002, Wood et al. 2006, Ruan and Philip Robertson 2013). Results from the former have typically found low-carbon management systems to be relatively less profitable (Hanson et al. 1990, Hanson, Lichtenberg, and Peters 1997, Dobbs and Smolik 1997) hence limiting the economic incentives to their adoption by farmers, whilst results from the latter have confirmed the extent to which low-carbon management systems contribute less to GHG emissions (Flessa et al. 2002, Vleeshouwers and Verhagen 2002, Wood et al. 2006, Ruan and Philip Robertson 2013). Both strands of research have largely been independent.

Given the prevailing policy environment however, and in particular emissions targets, it is desirable to combine both research strands as this provides a better basis for understanding the extent to which market based policy incentives will be needed to encourage farmers to adopt more environmentally sustainable production systems. Currently, the Scottish Government's policies and proposals for adoption of low-carbon systems farming are centred on maximising farmers' voluntary uptake of these systems whilst maintaining a productive and competitive agricultural sector. Existing policies and proposals include Farming for a Better Climate (FFBC) which is a targeted communication strategy designed to encourage adoption of low-carbon farming systems; Scottish Soil Framework (SSF) which promotes sustainable soils management; peatland restoration schemes (e.g. SNH Peatland Action), support for Anaerobic Digestion projects on farms through the Feed-in-Tariff and Renewable-Heat-Incentive schemes; and adoption of the Greening Policy under Pillar I of the EU Common Agricultural Policy (CAP). Encouraging farmers' realisations of the market costs of their environmental externalities is arguably the most effective way of incentivising their adoption of low-carbon farming systems.

This paper presents an analysis of the relative economics of two (otherwise identical) model arable farms, each managed under one of two contrasting agricultural management systems – a conventional system and a low-carbon integrated system. The integrated system here involves cover crops, legumes, conservation tillage, reduced mineral fertiliser, pesticide and herbicide applications and soil amendments to increase soil carbon content. The analysis takes into consideration the market cost of the model farms' relative contributions to GHG emissions through voluntary or regulatory farm participation in carbon emissions trading markets.

We use six years of experimental field level data from The James Hutton Institute's Centre for Sustainable Cropping (CSC) farm in Balruddery (Dundee, Scotland) (Hawes 2017). The experimental field level data is scaled up to the equivalent of the two model farms respectively, one operating on a conventional system basis, and the other an integrated system basis. Specific annual budgets for the model farms are then constructed and their relative economics determined, taking into consideration the cost of their GHG emissions.

Under the status quo scenario of not costing of GHG emissions, we find that consistent with the literature, the relative financial performance of the conventional farm system is better than the low-carbon integrated farm system. The difference is reduced but still evident when the costs of emissions from both farm systems are considered. When potential price premiums from integrated crop harvests are factored, the relative economics of both farm systems are comparable within range of reported price premiums for integrated system produce. This suggests that policies that encourage farm participation in carbon emissions trading markets, and the right market conditions such as encouraging price premiums are required to increase adoption of low-carbon farming systems, leading in turn to greater reductions in GHG emissions. This could significantly contribute to the Scottish Government's larger emission reduction targets.

The rest of the paper is organised as follows. In Section 2, we present the study background and framework, describing the model arable farms and the methodology for economic analysis and GHG emission calculations. In Section 3, we present the CSC data. In Section 4, we present our results. We conclude in Section 5 with a discussion of our findings and their implications for agricultural policy in Scotland, the wider UK and comparable locations in the developed world.

2 Study background and framework

The James Hutton Institute established the CSC as a long term experimental farm platform in 2009 to integrate all aspects of sustainability research on arable ecosystems. The CSC provides a research facility to test and demonstrate the economic, ecological and environmental trade-offs of integrated arable land management to the whole arable ecosystem. After two years baseline study (2009 and 2010), the six fields making up the CSC experimental farm were each divided into two plots and integrated and conventional system treatments randomly allocated to each. Each system therefore has six crop entry points in each year, with each of the entry points hosting a different crop. Crop yields, fertiliser and pesticide use, machinery type, time and fuel use, rate of GHG emissions (i.e. carbon dioxide, methane and nitrous oxide) were recorded for each plot.

This paper utilises the six years of CSC data collected over the period 2011-2016 to assess the relative economics of conventional and integrated management systems in the context of their contributions to GHG emissions. We ask 'what would have happened in a model farm over the same period if they had followed either of the two agricultural management systems as applied to the CSC fields?' We assume the model farms are awarded annual emission credits based on government emission reduction targets for agriculture and related land use and participate in carbon trading markets. Net emissions above or below the awarded credit determines a farm's purchase or sale of credits which then impacts the economics of the farm. We conduct a whole farm financial analysis involving annual income statements and balance sheets to examine the relative economics of both farm management systems using two financial indicators: profitability and worth (equity).

2.1 The farms

Potatoes, beans and four cereals (i.e. winter wheat, winter barley, winter oilseed rape and spring barley) were rotated on the CSC fields. We model the farms based on average data for general cropping farms, as classified and described in the 2012-2013 Farm Business Income (FBI) data for Scotland (Scottish Government 2014). Consequently, our model farms each have 176 hectares of tillable cropland of which 8.88 ha is allocated to potato production and 33.44 ha allocated to each of the remaining five crops. Following (Hanson et al. 1990), we assume that the machinery complement of the farms include equipment for tillage, planting, cultivating and spraying. Harvesting and fertiliser application equipment are custom hired by the farms. We assume labour on the farms is paid at the prevailing market wage rate for each CSC operation year (Scottish Government 2011a). As specific labour hours are not recorded in the CSC operations, we assume that the total labour hours correspond with the total recorded machinery hours for each farm. In order to focus attention on production costs and returns, we do not consider government paid farm subsidies. Integrated management systems require a systems approach of greater complexity than conventional farming (Brumfield, Rimal, and Reiners

2000) hence managerial abilities can significantly factor in the outcomes of both systems (Delate et al. 2003). We however assume equal managerial abilities for both model farms therefore we may be underestimating to some extent the full costs of the integrated approach.

Consistent with the average statistics for tenanted general cropping farms in the FBI data, we assume that the model farms have a debt to asset ratio of 22%. We also assume an outstanding debt level of £150,000. The outstanding debt has a repayment term of 15 years and interest rate of 10%. We assume that principal and interest payments are made each year so that the outstanding debt at the end of the debt repayment period is zero. Based on Scottish government data for average opening and closing balance sheets by farm tenure, we assume the following composition of the farms' opening balance sheets; 10% liquid asset holding, 10% machine asset value, 20% in building value and 60% in land value (Scottish Government 2007). Since both model farm systems have the same initial resources, a direct comparison of their relative economics over the six years of the CSC data can be made.

2.2 Methodology

2.2.1 Financial analysis based on CSC input and output data

The whole farm financial analysis we conduct simulates what would have happened to two model arable farms in the period 2011-2016 if they had each followed one of the two farm management systems (i.e. conventional vs. integrated) as applied to the CSC fields. To do so, we first adapt the CSC field data to fit the model farm sizes by scaling up. All relevant parameters (labour, fertiliser use, pesticide use, fuel use, etc.) are proportionately scaled up to the 176 ha model farm equivalents, whilst allowing for adjustments where standard farm management conversion rates are needed. All production costs and output revenues are converted to constant 2011 values using the producer price index for agricultural products (ONS 2017). Table A1 and Table A2 in the Appendix present key parameter and some miscellaneous assumptions used in adapting the field level data to the model farm equivalents.

Having scaled up the data from field level to the equivalent model farms, the second step was to develop crop enterprise budgets based on the annual input (costs) and output (revenues) amounts of each farm. These budgets are then summarised as annual income statements and balance sheets. We assume that balance sheets are captured at the end of each year. The balance sheets for the farms for end year 2010 is the same, and is developed based on assumptions about their financial positions as described in Section 2.1 above. We assume the income statements are also produced at the end of each year. There is no inventory carried over from one year to another. All inflows and outflows are concluded in each financial year. Table A2 in the Appendix summarises the construction of the annual income statement. Notice the addition of the market value of annual net farm emissions to the costs of the farm. This is key to the approach used in this paper, and has important implications for the relative economics of the two farm management systems under study.

The annual income statement at the end of each year is used to update the balance sheet at the end of that year. The updated balance sheet then constitutes the beginning balance sheet for the following year. Using the information from the income statements and balance sheets developed for each farm system, we are able to conduct a financial trend analysis for the period 2011-2016, examining factors such as profitability and worth of the respective model farm systems.

2.2.2 Incorporating GHG effects

In terms of the measuring of the GHG emissions of farms, researchers have used two approaches; life cycle analysis and whole farm analysis (Soils Association 2016). In life cycle analysis the footprint associated with a particular farm product is calculated in order to highlight the sources of emissions within the lifecycle of that product. In whole farm analysis, the total GHG emission of a farm enterprise is calculated. The present study lends itself to a whole farm analysis approach. Under this approach, assumptions about the boundaries of the analysis are needed in order to accurately allocate emissions and their sources. A direct approach considers emissions from sources that are directly owned and controlled by the farm enterprise (Soils Association 2016). These include emissions due to fuel use (in machinery and heating), farming practices (such as tillage and non-tillage), degree of organic and inorganic fertiliser use, etc. An indirect approach considers these direct emissions plus indirect emissions associated with the production, processing and distribution of farm inputs and outputs. For example, emissions due to the factory production of fertiliser, extraction and refinery of fuel, etc. are considered. It can be argued that the direct approach does not give a holistic picture of a farm enterprise's emissions due to the omission of the indirect emission sources. We therefore adopt the indirect approach and account for all emission sources that can be linked to the farm enterprise, recognising that this represents an upper bound to the overall emissions of the farm.

There are three main GHGs associated with farm emissions. These are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Although periodic point emissions data for these gases due to the two farming systems were collected on the CSC fields, it was difficult to use this data to calculate the total annual emissions due to each system. This was partly due to potential volatility in emissions arising from seasonality in weather conditions, etc. A number of bespoke calculators for determining GHG emissions on farm enterprises are however available online or as standalone spreadsheets. Among these are the Cool Farm Tool calculator (Cool Farm Alliance 2016), the Carbon Accounting for Land Managers calculator (CLA 2009), and the Climate Friendly Food calculator (Farm Carbon Calculator 2016). We adopt the interactive online based Cool Farm Tool calculator due to its comprehensiveness and ease of use for calculating net agricultural GHG emissions (Hillier et al. 2011). The tool works globally and across farming systems and has been adopted for GHG estimations in many academic publications (e.g. Aryal et al. 2015, Whittaker et al. 2013, Rahn et al. 2014).

There are two data entry levels in the Cool Farm Tool that induce some variation in GHG emissions due to conventional and integrated farming systems. The first level captures soil characteristics such as soil texture, drainage, pH level and organic matter content. Differences in these characteristics for the two farming systems can influence their levels of GHG emissions. For example, the greater the soil organic matter content, the lesser the level of GHGs that would be emitted. The second data entry level captures type and amount of fertiliser use. A difference in types and amounts of fertiliser use is a significant determinant to the level of GHG emissions on farms. For example, greater use of synthetic fertiliser in conventional systems leads to large amounts of reactive nitrogen being added to soils. Under most conditions, increased use of nitrogen stock in soils leads to greater nitrous oxide emissions. Nitrous oxide has 310 times the global warming potential of carbon dioxide (Shine et al. 2005).

We use the Cool Farm Tool to create annual emission accounts for all crops under the respective farm systems. The sum of emissions for crops due to each farm system then amounts to the total GHG emission for that farm system. We seek to incorporate the market costs of GHG emissions in the relative economics of both systems, through farmer participation in carbon trading markets. There is currently no specific legislation addressing agricultural gas emissions in the UK. Instead, industry has adopted a voluntary approach. For example, organisations in England have developed the Agricultural Industry GHG Action Plan (Industry Delivery Partners 2011) and the cereals and oilseed industry have developed a roadmap to encourage emission reductions (HGCA 2012). We proceed under the assumption that both the model farms participate in carbon trading markets in the data period (i.e. 2011-2016). Hence farms were allowed credit for emissions and they buy/sell carbon credits in the market based on net deficit or credit in their emissions. Net earnings due to participation in the carbon emissions market then impact the farms' financial performances. The principle underlying this market based scheme rewards cost efficiency relative to lower GHG emissions. To this end, the extent to which the market price of emissions deviates from the marginal cost of reducing emissions on the farm determines farmers' propensity for low-carbon farming systems, or otherwise. Specifically, the lower the marginal costs of emissions reductions on the farm relative to the market price, the higher the propensity for farmers to cut emissions and vice versa.

As there is no formal framework awarding carbon credits to farmers in Scotland, we estimate carbon credits for arable general cropping farmers in Scotland at a level consistent with Scottish government targets for total GHG emissions. Specifically, total net GHG emissions due to agriculture and related land use in Scotland for 2010 was 10.46 million tonnes carbon dioxide equivalent (Mt CO_2eq) (Scottish Government 2010). In our use of the Cool Farm Tool calculator, we account for emissions from soils and agrochemicals/fuels use only. Scottish emissions due to these factors are about 50% [2] of the total emissions i.e. 5.23 Mt CO_2eq (Bell, Cloy, and Rees 2014). The Scottish government has set an ambitious statutory target of reducing GHG emissions by 42% between 2010 and 2022 (Scottish Government 2011b), which is about 3.5% target annual reductions in that period. If agricultural emissions due to soils and agrochemicals/fuels contribute proportionately to this target, we can estimate the total GHG emission allowances for these factors in the period 2011-2016. This calculates to about 5.05, 4.87, 4.70, 4.54, 4.38 and 4.22 Mt CO_2eq respectively for the respective years.[3] The total area of agricultural holdings in Scotland is about 5.6 million hectares, of which 10% (i.e. 0.56 million ha) is used for cropping (Scottish Government 2016). The total emission allowance per hectare of cropland in Scotland for the period 2011-2016 can therefore be calculated as 9.02, 8.7, 8.39, 8.11, 7.82 and 7.54 tCO_2eq per ha respectively.[4] These figures constitute our assumed emission credits for the model farm systems. For the farms under each system, the level of

[2] The proportion of total emissions due to agriculture and related land use in Scotland is about 42% for soils, 8% for fuels and agrochemicals, 19% for cropland conversion, 6% for manure storage and 25% for livestock enteric fermentation

[3] For 2011 for example, this is calculated as [(1-0.035)*5.23 = 5.05]

[4] For 2011 for example, dividing total emissions by the total size of agricultural land gives [(5.05 million tCO_2eq) / (0.56 million) ha] = 9.02 tCO_2eq/ha

emissions below or above this credit determines whether a purchase or sale of credit is required. A sale of credits enters the income statement as an income hence increases the relative economics of a system. A purchase of credits enters the income statement as a cost hence reducing the relative economics of a system.

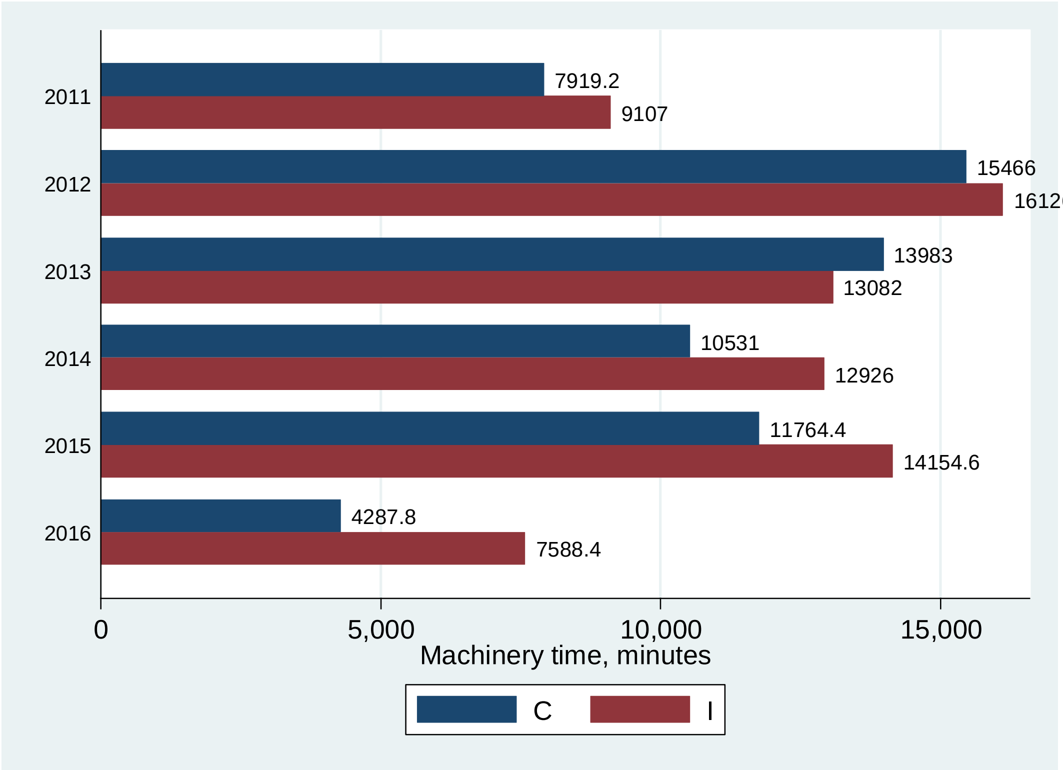
3 Data

3.1 Inputs

Table A3 in the Appendix shows the rotations used on the six CSC farm fields. Each field is partitioned into two parts, and each half is treated with one of the two management systems, i.e. conventional or integrated. Although the intention was to annually host a different crop on each field until a rotation of the six crops is completed, there are repetitions in the rotations for some fields. For example, winter barley on the field PYLON is re-introduced in 2013 after first entry in 2011, although the full cycle of crops have not been completed for that field. This was due to some operational adjustments.

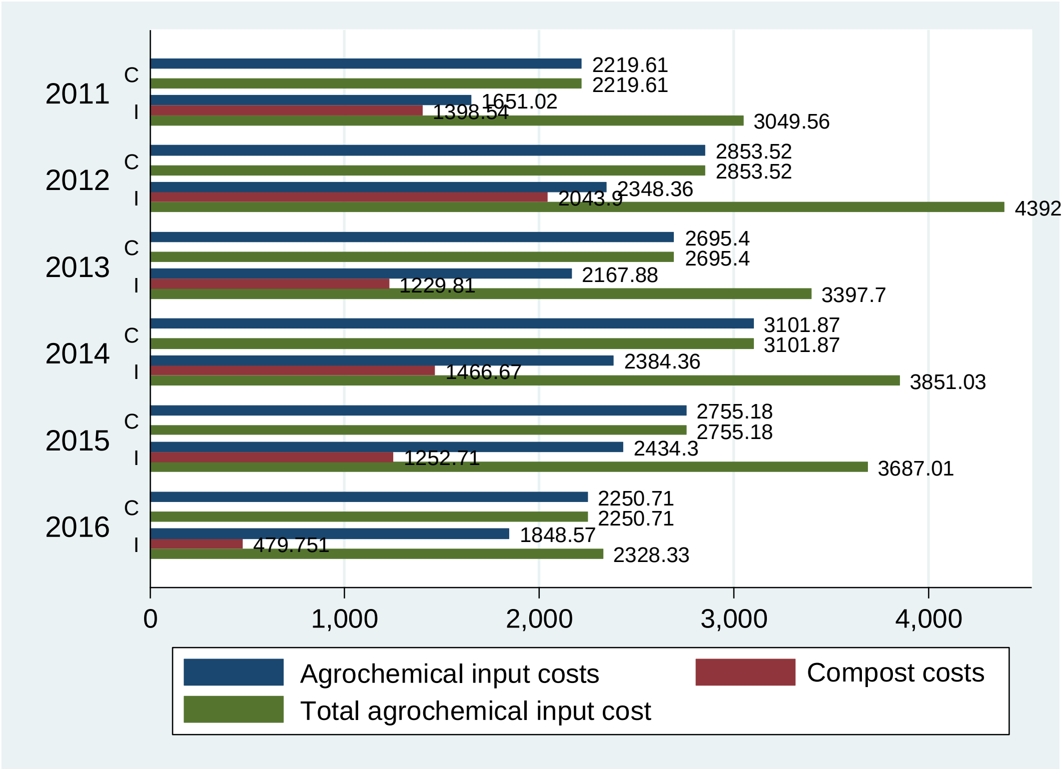
Figure 1 presents the total annual machinery time on the conventional and integrated fields, showing that the intensity of operations varies considerably from year to year with changing weather conditions and that in most years intensity on the integrated fields is higher. This is consistent with the literature (Hanson, Lichtenberg, and Peters 1997). The higher operations intensity of integrated management has important implications for labour costs, fuel costs as well as the depreciation costs of machinery as higher frequency and intensity of machinery use leads to greater rate of depreciation (Reff 2011). Through experience and learning-by-doing effects however, management and operations costs of integrated farms may fall significantly overtime, hence favourably impacting their relative costs.

Figure 1: Total machinery time used for all operations on CSC fields for conventional (C) and integrated (I) field treatments



Integrated system management does not preclude the use of synthetic agrochemicals. Rather, it involves reduced dosages of these chemicals. Data on compostand synthetic fertiliser application rates for both management systems are available from the authors on request. As expected, use of synthetic nitrogen fertilisers is significantly higher in the conventional system treatment than in the integrated system treatment for all mixes. However, whilst compost is not used in conventional treatment, it is significantly used in the integrated treatment, with average applications of up to about 35000 kg per hectare. The relative costs of compost and synthetic fertilisers, as well as the costs of pesticides, herbicides, fungicides and other agrochemicals and their rates of applications in both management systems have important implications for the costs of both systems. Figure 2 presents the relative input costs of both management systems on the CSC fields, showing that the total input costs for the integrated system is higher than the conventional system for all years. Although the cost of synthetic agrochemicals is lower in the integrated management system due to lower application rates, the high application rates of compost in the integrated system more than compensates for its lower cost of synthetic chemicals, resulting in the overall higher cost of inputs for the integrated system.

Figure 2: Input costs (including compost, synthetic fertilisers, pesticides, herbicides, fungicides, etc.) for all operations on CSC fields for conventional (C) and integrated (I) field treatments. All costs in constant 2011 £



3.2 Outputs

Although winter wheat showed the only statistically significant difference in yield in a REML analysis of crop yields over the full rotation (Hawes et al. 2017), annual averages are presented here as the basis for calculation of yearly financial margins. Table 1 below shows these annual averages and standard deviations of crops for both systems. Only in a few instances are the integrated system yields greater than the conventional system yields. For example, integrated system yields for potatoes in 2014 are greater than those of the conventional system. In most instances, the conventional system yields are greater than the integrated system yields. This is consistent with the results of (Mäder et al. 2002) who find that average yields of crops from low-carbon systems are on average lower than yields of conventionally grown crops. In our case for instance, the conventional system yields for beans in 2011 and for winter oilseed rape in 2013 are more than twice the integrated system yields for the respective crops and years. All conventional system yields for 2011 and 2016 are greater than yields for integrated systems. Similarly, all conventional system yields for winter wheat across the years is greater than that of the integrated system yields.

These results are expected given that the CSC fields are within the first six years of operation and it takes up to six years or more on average for yield benefits associated with integrated systems to be realised (USDA 1980, Hanson et al. 1990, USDA 2000). The standard deviation in yields appears not to follow a consistent order but has implications for the stability of profits for both management systems. Greater deviations in yields induce farm production uncertainty, leading to greater instability in farm income realisations.

Table 1: Average and standard deviation (SD) of crop yields (t/ha) for conventional and integrated treatments

Year	Indicator	Beans		Potato		Spring barley		Winter barley		Winter oilseed		Winter wheat	
		C	I	C	I	C	I	C	I	C	I	C	I
2011	Mean	5.66	2.46	47.19	43.22	6.70	6.68	7.03	6.43	3.77	2.40	9.11	6.14
	SD	0.47	1.21	8.08	9.73	0.92	0.70	1.73	0.32	0.40	0.28	0.58	0.31
2012	Mean	5.11	6.59	34.03	34.63	6.04	5.48	7.06	7.40	2.06	2.09	6.37	4.39
	SD	1.14	0.78	7.17	8.27	0.37	0.39	0.40	0.68	0.37	0.29	0.91	0.25
2013	Mean	5.02	4.56	48.43	47.98	6.76	6.79	10.21	8.80	3.94	1.62	10.68	8.13
	SD	0.91	1.42	3.73	3.41	0.49	0.29	0.41	0.83	0.47	0.34	0.66	0.68
2014	Mean	8.06	9.05	52.06	56.74	8.57	7.18	9.98	6.63	2.87	3.04	11.00	10.20
	SD	2.26	0.99	6.04	7.41	0.86	0.56	0.95	1.66	0.33	0.45	0.65	0.93
2015	Mean	6.43	6.48	61.77	56.66	7.73	7.76	11.45	9.08	3.68	4.15	9.54	7.08
	SD	1.05	0.85	5.04	4.59	0.26	0.94	1.23	1.15	0.89	0.36	1.21	1.06
2016	Mean	4.82	3.95	53.18	45.87	6.28	5.90	10.02	9.73	4.13	3.96	10.32	7.01
	SD	0.81	0.90	7.95	6.50	0.53	0.78	0.50	0.27	1.04	1.61	0.59	0.88

Total GHG emissions for each farm system and year using the Cool Farm Tool calculator are presented in Figure 3. The distribution of emissions across the six crops is also shown. The results highlight the total GHG emissions for the conventional and integrated model farms, showing that the integrated system farm is an emission sink whilst the conventional system farm is a positive emitter. This has implications for the economics of both model farm systems, as the cost of participation in the emission trading scheme for the model integrated farm is lower than for the conventional model farm.

Figure 3: Total emissions for 176 ha conventional (C) and integrated (I) farm systems as calculated from the Cool Farm Tool application using scaled up CSC data (whiskers show emission distribution across crops)

4 Results

Since 2005, the European Union has been operating a carbon market to govern and reduce the GHG emissions from a number of industrial sectors. The scheme requires participating manufacturers to surrender permits for each metric tonne of CO_2 they emit. The permits are distributed to and traded between companies with - in theory - the price of permits being pushed up to the point where it equals the cost of the most polluting emitter reducing emissions by one additional ton of carbon. In practice, the implementation of the scheme has faced a number of challenges and most agree that the price of permits has been too low as a result of initial issues in the scheme's implementation, changing market conditions, and an over generous emissions cap on the supply of permits (Martin et al. 2014). The cost of emissions under the EU emissions trading scheme for 2011 to 2016 are 12.4, 6.4, 4, 4.9, 5.6 and 4.2 £ per tCO_2eq respectively (DBEIS 2017b, a). This is low when compared with the expected price of 23 £ per tCO_2eq (Martin et al. 2014). Despite this discrepancy, the actual carbon prices that prevailed in each year were used in the analysis. Based on these figures and the data presented in section 3, we are able to calculate the net emissions and emission costs for both farm systems, as shown in Table 2.

Table 2: Net emissions and trading costs for 176 ha conventional and integrated farm systems

System	Year	Total Emission (tCO_2eq)	Credit, (tCO_2eq)	Net emission (tCO_2eq)	Nominal emission costs, £*	Real emission costs £*
Conventional	2011	2334.75	1587.52	747.23	9265.60	-9265.60
	2012	1892.18	1531.20	360.98	2310.25	-2296.47
	2013	2588.06	1476.64	1111.42	4445.69	-4602.16
	2014	2531.10	1427.36	1103.74	5408.34	-5723.11
	2015	2811.77	1376.32	1435.45	8038.50	-8718.55
	2016	1679.66	1327.04	352.62	1481.00	-1537.91
Integrated	2011	-1816.90	1587.52	-3404.42	-42214.86	42214.86
	2012	-2617.83	1531.20	-4149.03	-26553.82	26395.45
	2013	-1533.48	1476.64	-3010.12	-12040.50	12464.28
	2014	-1567.63	1427.36	-2994.99	-14675.47	15529.60
	2015	-1515.18	1376.32	-2891.50	-16192.37	17562.23
	2016	-834.98	1327.04	-2162.02	-9080.49	9429.38

*Positive emissions costs represent a cost to the farm system. Negative emissions costs represent a revenue gain for the farm system. Real emission costs in constant 2011 £

By participating in the emissions trading market, the net emissions costs of the conventional system model farm ranges from about £1,400 to £9,200; whilst the net emissions revenue gain for the integrated farm system ranges from about £9,000 to £42,000. The high net emissions revenue for the integrated system is predominantly driven by its high levels of net carbon sequestration. These emission costs and revenues have important implications for the relative economics of both farming systems.

We now provide results of financial performance indicators for the two model farms as a way of determining their relative economics. The two indicators considered are profitability and farm worth (equity) as they are the bottom line to farmers' adoption of systems (and technologies). In our base case results, we examine the effects of participation in carbon trading markets only. We then conduct a sensitivity analysis to examine the effects of premium pricing of integrated system crops.

4.1 Base results

4.1.1 Profitability

A detailed illustration of the calculations of the model farms' income statements is available from the authors on request. Table 3 summarises the profitability of both farms, given their state of participation in emissions trading markets. Annual profitability is highly variable within and across the farm systems and states of participation in emissions trading. Within the farm systems, profitability appears to be largely driven by crop yields. For example, poor potato, winter oilseed rape and winter wheat yields (see Table 1) for the conventional model farm system in 2012 explains the loss of about £51,000 in its non-participation scenario. For the same year, poor potato, spring barley and winter wheat yields for the integrated farm system explains its loss of about £92,000 in the non-participation scenario.

In the non-participation scenario, annual profits (losses) for the conventional farm system are greater (less) than the integrated farm system for all years. On average, annual profit for the non-participating conventional farm system is about £23,000 whilst that of the non-participating integrated farm system is an annual loss of about £31,000. In the participation scenario also, annual profits (losses) for the conventional farm system are greater (less) than the integrated farm system for all years. However, due to net revenues from emissions trading for the integrated farm system, and net costs for the conventional farm system, the competitiveness of the integrated farm system is enhanced. Annual average profit for the conventional system is decreased to about £19,000 whilst the average annual loss of the integrated farm system is reduced to about £11,000. Compared to the non-participation scenario therefore, the conventional farm system is about £4,300 worse off annually due to the payment of costs of emissions whilst the integrated farm system is about £20,000 better off due to its net sequestration of emissions. Although participation in emissions trading markets enhances the economics of the integrated farm system, it is not by a sufficient amount to compete favourably with the conventional farm system as the profits (losses) of the latter are still significantly higher (lower) in most years.

Table 3: Profitability of conventional and integrated farm systems, given the state of farm participation in emission trading markets

	Non participation		**Participation**	
	C	**I**	**C**	**I**
2011	44,055.48	- 37,846.09	36,642.95	3,495.07
2012	- 51,161.39	- 91,893.04	- 53,457.89	- 65,497.56
2013	45,765.70	- 23,443.66	42,083.91	- 10,979.35
2014	52,504.57	9,309.43	47,926.09	21,733.09
2015	14,314.40	- 28,755.86	7,339.59	- 11,193.60
2016	35,028.90	- 14,535.74	33,798.58	- 5,106.41

We calculated the critical price of emissions at which the profitability of the integrated farm system breaks-even with the conventional farm system to be 15.30 £ per tCO_2eq. This price equalises the present values of cashflows for both systems over the six years of the data. At this emissions price, famers are indifferent as to adopting a conventional or integrated farm management system. This has important implications for policy regarding use of the emissions trading mechanism to incentivise adoption of environmentally sustainable farm management systems. For example, the median market price of emissions in the period 2012- 2016 is about 5.02 £ per tCO_2eq. This is about three times lower than the break-even price calculated, hence highlighting the extent to which emission prices need to be raised in that period in order for integrated farming systems to be competitive with conventional farming systems.

4.1.2 Worth

Farm worth (equity) is the product of the farms' annual balance sheets, as updated by the farms' annual profits and losses from their income statements. We do not consider payment of dividends to farm shareholders hence all annual profits and losses, cash, repair and re-investments in machinery, buildings and infrastructure, etc. impact balance sheets directly. A detailed exhibition of the calculations of the farms' balance sheets is available from the authors on request.

Table 4 summarises the worth (equity) of the farms given their states of participation in emissions trading markets. For parity, we had assumed equal resources for each model farm system at the beginning of the first year. By the end of year 2016, the non-participating conventional farm system had increased its worth by 61% whilst the non-participating integrated farm had increased its worth by only 25%. Note that although the integrated farm system records losses in most years, the total worth of the farm still increased due to annual re-investments in machinery and building upgrades. Similarly, by year 2016, the participating conventional system farm had increased its worth by 59% whilst the participating integrated farm had increased its worth by about 63%. In the participation scenario therefore, the conventional farm system's worth had increased by a lesser margin due to net emission trading costs, whilst the integrated system had increased its worth by a higher margin due to net emission trading gains. The conventional farm system is however more solvent than the integrated model farm system in both scenarios, although by a lesser margin in the participation scenario.

Table 4: Equity of conventional and integrated farm systems, given the state of farm participation in emission trading markets

	Non participation		Participation	
	C	I	C	I
2011	626,276.54	544,374.97	618,864.02	585,716.14
2012	627,525.35	504,816.23	617,816.34	572,552.87
2013	727,732.92	535,684.28	714,342.11	615,885.24
2014	836,942.72	601,494.93	818,973.44	694,119.54
2015	910,501.44	631,690.22	885,557.35	741,877.09
2016	1,007,491.69	678,784.98	981,317.28	798,401.18

4.2 Sensitivity analysis of premium pricing

Low-carbon produce is perceived to have health benefits associated with its lower input use of synthetic agrochemicals (Wilkins and Hillers 1994). Consumers are also increasingly aware of climate change and its adverse environmental impacts hence the need to reduce carbon emissions. As a result of these factors, consumers are increasingly sourcing low-carbon produce and paying extra as a way of improving their food health and contributing to reductions in their carbon footprints. Products of low-carbon agriculture therefore elicit higher market premiums. Prices for low-carbon crops are reported to be 20% to 140% higher than for counterpart conventional system crops (Dobbs 1998, Bertramsen and Dobbs 2002, Rodale Institute 2016, Jaenicke and Carlson 2015). Other factors contributing to the higher premiums for low-carbon produce include lower supply and higher production costs.

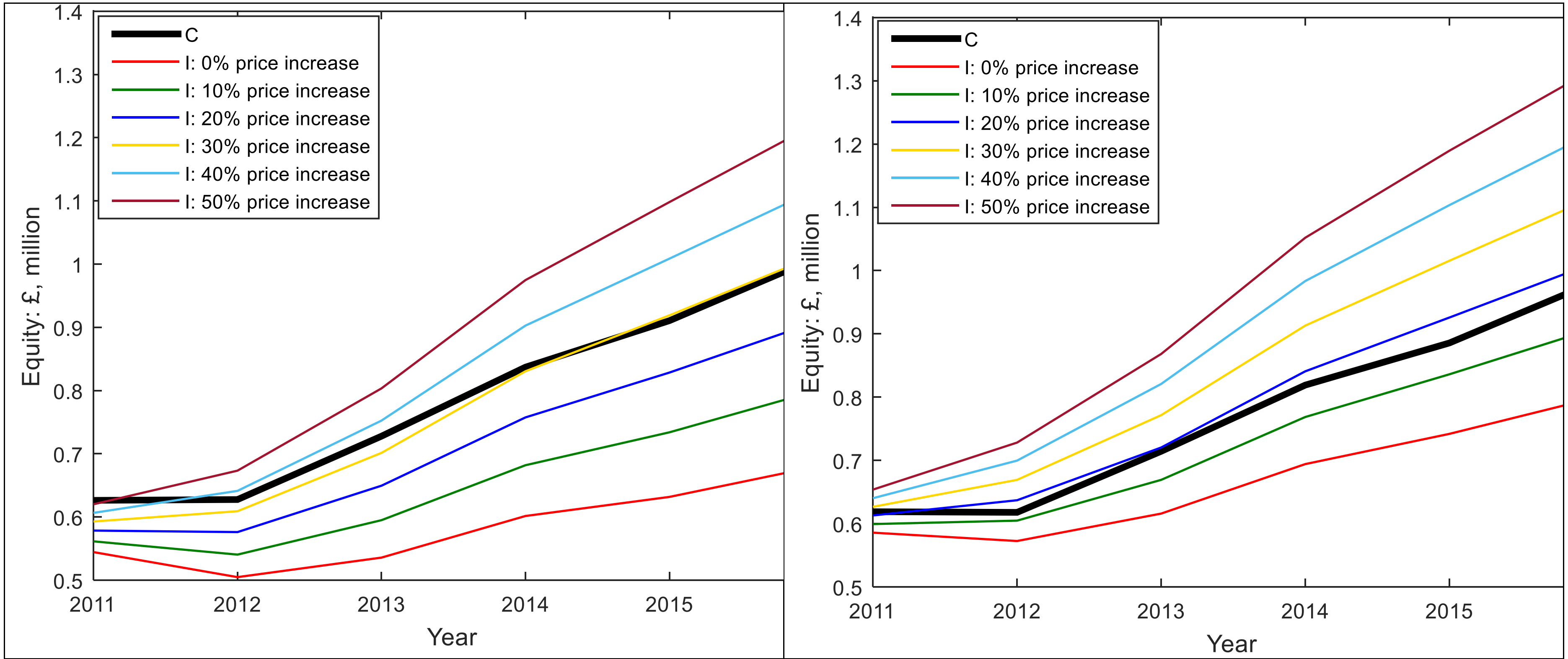
In the alternative agriculture literature, there are arguments for and against the inclusion of premium prices in comparing the economics of low and high input systems (Smolik, Dobbs, and Rickerl 1995, Welsh 1999). However premium prices are a significant driver incentivising adoption of low input systems (Delate 2002) hence should be factored as a way of recognising farmers’ decision making as well as their economic realities. Here, we examine the impact of higher integrated crop price premiums on the relative economics of integrated and conventional farming systems.

Figure 4 shows the impact of 0 – 50% integrated produce price premiums on the relative profitability of both systems. When farms do not participate in emission trading markets, which represent the status quo, price premiums of about 30% only ensure that the relative profitability of both farming systems are comparable. When farms participate in emission trading markets however, their relative profitability is comparable at 20% price premiums only. In both cases, the price premiums required for the integrated farm system to be competitive with the conventional farm system is arguably at the lower end of the range of reported price premiums for integrated farming produce. Figure 5 shows a similar effect of premium pricing on farm worth, showing that a 30% and 20% premium pricing ensures comparable growth in the worth of the conventional and integrated systems in the non-participation and participation scenarios respectively.

Figure 4: Profitability of conventional and integrated farm systems, given the state of farm participation in emission trading markets and percent increase in the price of integrated system crops

Annual profits: Non participation in emissions trading markets	Annual profits: Participation in emissions trading markets

Figure 5: Equity of conventional and integrated farm systems, given the state of farm participation in emission trading markets and percent increase in the price of integrated system crops



Farm equity: Non participation in emissions trading markets	Farm equity: Participation in emissions trading markets

5 Discussions and conclusions

Using scaled up experimental field level data from The James Hutton Institute's CSC platform in Balruddery (Dundee, Scotland), we examined the relative economics (i.e. profitability and worth) of a conventional and a low-carbon integrated agricultural management system for two model farms. By employing a novel market based approach, we factored the market costs of GHG emission externalities on the relative economics of both systems. Further sensitivity analyses were conducted to examine the effects of premium prices for integrated system products associated with their environmental and potential health benefits.

We find that under the status quo environment where GHG emission externalities are not costed, conventional management systems are significantly more profitable than integrated management systems, accruing greater farm worth over time. This arises from their lower production costs and higher yields. When the economic cost of GHG emissions are factored in based on the actual carbon prices that prevailed during the period, the economics of both systems are still not comparable with the conventional management system still more profitable, although to a lesser extent than in the status quo scenario. The critical emissions price at which the profitability of the integrated system reaches parity with the conventional system is about 15.30 £ per tCO_2eq annually. This is about three times the median recorded emission prices over the last five years but considerably lower than the expected equilibrium price. When price premiums of up to 20% for integrated system crops are applied, the relative economics of both farm systems are more comparable even with the low prevailing carbon prices. This level of price premium is within range of reported price premiums for integrated system produce.

Our study broadly agrees with the body of evidence in the literature that suggests that the economics of low-carbon management systems does not favourably compare with conventional management systems. We have contributed to this literature by showing that this is the case even when the economic cost of GHG emissions are considered in a free market based framework, where farmers are mandated to participate in trading their net emissions, or they choose to do so voluntarily. For low-carbon systems to compete with conventional systems, premium prices of their produce would play a significant role, along with the costing of GHG emission externalities at appropriate prices.

Our results offer important policy choices around the implementation of an emissions trading scheme and/or a premium pricing scheme as a way of reducing GHG emissions from agriculture and related land use. A natural policy question that flows from our results for example is would it be better to implement an emissions trading scheme that requires about three times the prevailing emissions prices to be effective in encouraging low-carbon farming systems; or rather a premium pricing policy (e.g. through price subsidies, product labelling, education programs, etc.) that would enable parity in the competitiveness of low-carbon farming systems relative to conventional systems. Or both? Arguably, the premium pricing policy approach is more sustainable in the long run as education increases public demand for more environmentally friendly products, with the public attitude being slower to short run changes than a government policy implemented through a trading scheme. Further studies may be needed to assess the relative implementation and outcome effectiveness of these potential policy choices.

It has been shown in the literature that it takes up to six years or more for the long term production cost and yield effects of low-carbon management systems to become evident. Adoption of a low-carbon system also requires a period of iterative adjustment of management practices to achieve the desired goals of environmental health whilst maintaining yield and product quality. As we have only six years of data at the CSC experimental platform, our results and conclusions should be regarded as showing the short term relative economics of both systems only and the information gathered over this initial set-up period will be used to refine the integrated, low-carbon system to improve on the overall levels of sustainability and financial margins that were achieved. This has implications for policy aimed at enhancing adoption of low-carbon management systems not least in the so called early ‘transition period’ which is considered the most challenging period of implementing these systems due to higher costs, lower yields (i.e. “yield drag”), and managerial difficulties due to low levels of experience. Specifically, policies may be needed to encourage farmers’ realisation of the cost of their externalities in particular GHG emissions. Also a market system that recognises and encourages premium prices for low-carbon system products can be encouraged.

Further developments of this research will be required to expand on the two basic scenarios presented here to include alternative rotations and other common cropping systems. Although the crops studied at the CSC are typical of the region and can be used to inform agronomic practices and policy decisions, the combination of all six crops in a single rotation is unlikely to occur commercially. Most arable farms will include multiple cereals before each break crop and there is therefore scope to adapt the crop sequence presented here to model a series of typical crop rotations, including intensive winter cereal dominated rotations compared to less intensive spring based cereals and mixed cropping. The magnitude of the differences between conventional and low-carbon systems presented here may vary considerably according to the specific rotation adopted as well as other external factors, including soil type and climate. All of these factors need to be considered when formulating policy that aims to encourage adoption of new, environmentally beneficial farming practices.

In the following years of the CSC, further research will examine the long term economic performances of both systems as the benefits of implementing low-carbon integrated management systems become apparent.

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Appendix

Table A1: Key data and miscellaneous assumptions used in adapting the field level data to the model farm equivalent

Parameter	**Miscellaneous assumption**	**Source of assumptions**
Output/revenue related parameters		
Crop yield reduction factor	Yields were reduced by 20% to better approximate yields on larger commercial farms	(Hanson et al. 1990)
Input/cost related parameters		
Indirect labour requirement	Direct time requirements as recorded by the CSC are inflated by 15% to allow for indirect labour requirements on the farm.	(Hanson et al. 1990)
Fuel use and cost	Directly scaled up from the CSC field recorded amounts to the model farm equivalent, and adjusted by a factor of 15% increase to account for inefficiencies on a larger commercial farm	-
Fertiliser use and cost	Directly scaled up from the CSC field recorded amounts to the model farm equivalent, and adjusted by a factor of 15% increase to account for inefficiencies on a larger commercial farm	-
Pesticide use and cost	Directly scaled up from the CSC field recorded amounts to the model farm equivalent, and adjusted by a factor of 15% increase to account for inefficiencies on a larger commercial farm	-
Machinery depreciation rate	We assume a base straight line depreciation rate of 10% per annum. However, an additional depreciation rate, which is a function of machinery time, is added to the base level. The additional rate reflects the tendency of machinery to depreciate quicker due to intensity of use. If machinery is used more often on a particular farming system, then the machinery depreciation for that system should be higher. The additional depreciation schedule is based on the equation "**Additional depreciation (%) = 0.008342+0.0000238*machineryTime(hrs) - 1.54exp-9*machineryTime(hrs)**2**", which was calculated based on a nonlinear regression model on data in (Edwards 2011)	(Edwards 2011)
Building depreciation rate	Building depreciation rate is assumed to be 6% per annum.	-
Annual machinery purchase/restoration cost	The farmer purchases new machinery each year at the rate of 15% of the current year's beginning asset value.	
Annual building improvement costs	The farmer makes yearly building improvements at the rate of 15% of the current year's beginning asset value.	(Hanson et al. 1990)
Corporation tax	We assume a corporation tax rate of 20%	(FWI 2017)

Table A2: Construction of the income statement.

Income statement variable	Calculation
Revenue	For each farm system in each year, revenue is a function of crop prices and yields and carbon prices and emission levels
EBITDA (Earnings before interest, taxes depreciation and amortisation)	= Revenue – fuel cost – labour cost – inorganic fertiliser cost – organic fertiliser cost – pesticide cost
EBIT (Earnings before interest and taxes)	= EBITDA – loan repayment cost – depreciation cost of machinery and buildings – purchase cost of machinery and building improvements
Profit	= EBIT – tax rate*(EBIT)

Table A3: Rotations used on the six CSC farm fields.

Year	**Field**					
	ROAD	ESTATE	MIDDLE EAST	KENNELS	PYLON	DEN SOUTH
2011	Potato	Winter wheat	Spring barley	Winter oilseed	Winter barley	Beans
2012	Winter wheat	Beans	Potato	Winter barley	Winter oilseed	Spring barley
2013	Winter oilseed	Spring barley	Winter wheat	Beans	Winter barley	Potato
2014	Spring barley	Potato	Beans	Winter barley	Winter oilseed	Winter wheat
2015	Winter oilseed/ Winter wheat	Winter wheat	Spring barley Winter oilseed	Potato/ Winter wheat	Winter barley	Beans
2016	Winter barley	Beans	Winter oilseed	Winter wheat	Potato	Spring barley