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A farm level approach to explore farm gross margin effects of soil organic carbon management

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ABSTRACT

This paper investigates farm gross margin effects of management measures aimed at enhancing soil organic carbon (SOC) stocks to maintain soil fertility while providing important ecosystem services. An optimising farm level model, ScotFarm, is used to investigate the farm gross margin effects of selected SOC management measures for arable farms in Scotland (UK) and Aragon (Spain). The sensitivity of model results to effects on crop yields and costs of production is tested for each measure. The results suggest that considerable regional differences in the financial viability of SOC measures exist. Tillage management is the only measure with positive effects on farm gross margins of Scottish farms at baseline levels of yield effects and input costs. In the case of farms in Aragon, Spain, fertiliser management, crop rotations (with legumes) and tillage management (in later years) show improvements in gross margins. Residue management is estimated to have a negative effect on farm gross margins for both Scottish and Spanish crop farms. Results of the sensitivity analysis indicate that effects of SOC management on farm gross margins are more sensitive to a change in crop yields than to changes in input costs. The findings point to further research needs with respect to the trade-offs between yield effects and changes in input costs arising from the adoption of SOC management measures, and have implications for agricultural policy design aimed at enhancing SOC stocks under a changing climate.

1. Introduction

The stocks of Soil Organic Carbon (SOC) interact in a complex manner with soil properties and functions that ultimately impacts on the provision of ecosystem services (Robinson et al., 2013; Dominati et al., 2010). Management of SOC in arable agricultural systems can affect the productive capacity of land as a final ecosystem service by improving the growth conditions for crops and therefore yields, and by increasing nutrient use efficiency that may affect the amount of fertiliser input required for optimal plant growth (e.g., Luxhøi et al., 2007; Pan et al., 2010). These effects are related to intermediate services that are governed by soil organic matter stocks and flows, including the provision of plant available nutrients, the control of erosion/loss of topsoil, the provision of a platform for (root) growth, the provision of a moisture regime that is suitable for plant growth, levels of biological diversity influencing pest/disease control, and the provision of a habitat for soil-based pollinators (Glenk et al., 2013). Additionally, management of SOC has been associated with a wide range of potentially beneficial (co-)effects, notably the potential to contribute to climate change mitigation via soil-based carbon sequestration, to help improve water quality at catchment level, and to enhance sub-soil and aboveground biodiversity (Freibauer et al., 2004; Feng and Kling, 2005; Smith et al., 2007a; Glenk and Colombo, 2011).

Despite an increasing policy interest in increasing SOC stocks (EC, 2011), there is a lack of evidence on the magnitude of private benefits of changes to SOC management to farmers. Such evidence is needed, however, to provide meaningful guidance to farmers and to inform considerations of policy support aimed at enhancing the uptake of SOC management measures. This paper contributes to filling this evidence gap. The objective of this study is to investigate the effects on farm gross margins of adopting suitable SOC management measures for a number of representative arable farms in two EU-regions (Scotland, UK; Aragon, Spain).

Additionally, this study aims at assessing the robustness of farm gross margin effects to changes in effects on nutrient availability and yield. Nutrient availability and yield effects are of great relevance in the context of moving to sustainable agricultural systems that provide food security in the mid- and long term (Kahiluoto et al., 2014), where food demand is expected to increase and substitution of organic

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fertilisers through inorganic ones may become increasingly challenging (Cordell et al., 2009).

Effects of SOC management on crop production are climate, soil and crop specific (Sánchez et al., 2016a), and therefore differ between the investigated SOC management measures, which include, for example, cover crops, residue management, and zero and reduced tillage. Within the SOC management measures and under given environmental conditions, there is considerable uncertainty regarding their effect on nutrient availability, yield and other effects on variable costs of farming including pest control and changes in farming operations, which are highly dependent on spatial context and farm characteristics (Morris et al., 2010; Rickson et al., 2010). This paper uses plausible ranges of key parameters regarding the effects on nutrient availability, yield, pest control and farming operations derived from expert knowledge and guided by available literature. Data on plausible ranges of effects then enter a sensitivity analysis using an optimising farm level model to reveal the robustness of SOC management measures to changes in input costs and yield effects. High levels of variability in farm gross margin effects can act as a barrier to uptake especially by risk averse farmers.

2. Methodology

2.1. Model structure

The profit maximising dynamic farm level model ScotFarm (Shrestha et al., 2014) is used to investigate farm gross margin effects of different SOC management measures for representative crop farms in each of the two EU study regions (Scotland, UK; Aragon, Spain). The model follows the classic linear programming structure as provided in Eq. (1) below.

$$\text{Max } z = (p-c) * x + SFP \text{ subject to } A * x \leq R \text{ and } x \geq 0 \tag{1}$$

where z is the farm gross margin, x is the quantity of each crop produced on farm per hectare, p is the revenue collected from activity x, c are the costs incurred to produce activity x, SFP is the farm payment (subsidy), A is an input-output coefficient of activity x, and R is a limiting farm resource.

The model is based on farming system analysis (Fresco, 1988; Keating and McCown, 2001), where all existing farm activities and interactions between farm structure, management, activities and management are taken into account. The model structure is represented in Fig. 1 below.

It is assumed that farmers are profit oriented and maximise farm gross margins within a set of limiting farm resources. The farm gross margin is comprised of the accumulated revenue from the final products of different farm activities and from farm subsidy payments, minus the cost incurred for inputs for the farming activities. ScotFarm is an optimising model, hence it should be noted that the results provided by the model are based on achieving all farm activities and farm management to the optimal level.

There is an emphasis on the crop component of the model in this study. The model encompasses crop production that is limited within fixed available land (Eq. 2).

$$A_{LAND} \geq \sum_{c=1}^{C} A_{CROP_c} \qquad \forall f, y \tag{2}$$

where A_{LAND} is the total area of arable land available for farm f in year y and A_{CROPc} is the land area under crop c of a total of C crops available.

All major crops in each region are available for selection in the model. The area of total farm land is fixed (A_{LAND}), but the model re-allocates arable land under each of the crops from year to year. The area under each crop is assumed to be at least 50% of the area under the same crop in the previous year to facilitate a smooth transition in change in crop activity. The model selects the most profitable crop based on revenues collected, which is determined by yield and the price of the crop, and the costs of production incurred (Eq. 3).

$$C\rho = \sum_{c=1}^{C} A_{CROP_c} \times (Y_c \times P_c - C_c) \tag{3}$$

where $C\rho$ is the crop gross margin, A_{CROPc} is the land area under crop c, Y_c is crop yield of crop c, P_c is the price of crop c and C_c are the costs of production (fertiliser use, sprays, seeds and machinery costs) for each crop c. The model is used to analyse the effect on farm gross margins of changes in crop yields and costs of production for a range of SOC management measures and representative farm types in each of two study

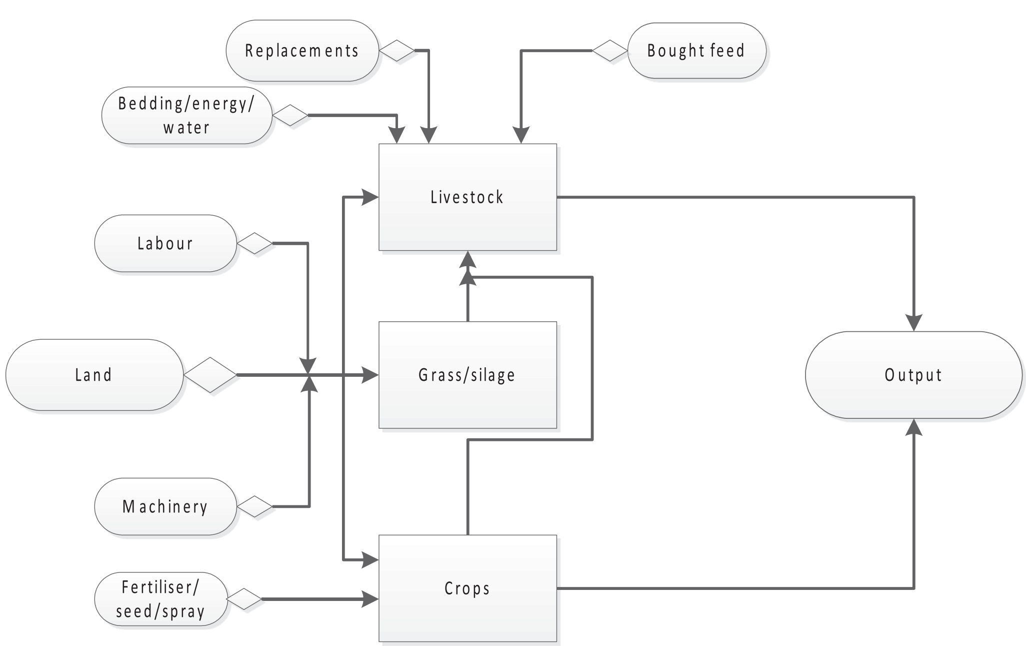

Fig. 1. A schematic diagram of ScotFarm.