Ecological Economics 123 (2016) 14–22

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

Potential and economic efficiency of using reduced tillage to mitigate climate effects in Danish agriculture

Marianne Zandersen [a,*], Sisse Liv Jørgensen [c], Doan Nainggolan [a], Steen Gyldenkærne [a], Anne Winding [a], Mogens Humlekrog Greve [b], Mette Termansen [a]

[a] Department of Environmental Science, Aarhus University, Frederiksborgvej 399, DK-4000 Roskilde, Denmark
[b] Department of Agroecology, Aarhus University, Blichers Allé 20, DK-8830 Tjele, Denmark
[c] Danish Energy Agency, Amaliegade 44, 1256 Copenhagen, Denmark

ARTICLE INFO

Article history:
Received 29 April 2015
Received in revised form 14 October 2015
Accepted 11 December 2015
Available online 24 January 2016

Keywords:
Payment for Ecosystem Services (PES)
Climate regulating services
Soil organic carbon (SOC)
Reduced tillage
Sequestration
Choice experiment

ABSTRACT

Soil organic carbon (SOC)[1] plays a crucial role in regulating the global carbon cycle and its feedbacks within the Earth system. Compelling evidence exists that soil carbon stocks have reduced in many regions of the world, with these reductions often associated with agriculture. In a Danish context, research also suggests that soil carbon stocks are declining. The scope of Payment for Ecosystem Service (PES) approaches to effectively and efficiently address climate regulation will depend on the spatial distribution of the carbon assimilation capacity, current land use, the value of avoided emissions and land owners' objectives and preferences in terms of participating in initiatives to increase SOC. We map the carbon sequestration potential under different scenarios, value the potential sequestered carbon in terms of marginal costs of using voluntary agreements with agricultural land managers and compare these to the marginal abatement costs curve used in Danish climate policy. The cost effectiveness of reduced tillage as a climate mitigation PES scheme critically depends on the current debate on the net effects of carbon sequestration in reduced tillage practices. Based on existing IPCC guidelines, we find that reduced tillage has considerable potential for contributing to a cost effective climate mitigation policy.

1. Introduction

Soil organic carbon (SOC) plays a crucial role in the regulation of the global carbon cycle and its feedbacks within the Earth system. As one of five global C pools, soils represent some 1550 Pg of SOC and 950 Pg of Soil Inorganic Carbon down to 1 m depth. This is the third largest C pool and contains more than three times the C in the atmosphere (Lal, 2010). Given the sheer size of the C pool of world soils, even small changes in global SOC would represent a significant feedback on the climate system; Kirschbaum (2000), for instance, estimates that a change of just 10% in global SOC would be equivalent to the total anthropogenic emissions over 30 years. Likewise, the Danish commitment to reduce 40% of greenhouse gasses by 2020 compared to 1990 levels would be equivalent to a yearly relative increase in the C pool of Danish agricultural soils of 2.0% (8.1 million tC).[2]

However, compelling evidence exists that soil carbon stocks have significantly reduced in most regions of the world with an estimated total depletion of more than 320 Pg C (Ruddiman, 2003; Lal, 2010), caused by deforestation, biomass burning, soil cultivation and drainage of peatlands since the start of settled agriculture some 10,000 years ago. Since 1945, at least 17% of vegetated land has undergone soil degradation and loss of productivity as a direct effect of human land use practices, causing soil organic matter levels to decline, often to half or less of original levels (Tilman et al., 2002). In a Danish context, research also strongly suggests that carbon stocks are declining. Mineral agricultural soils, which represent 98% of all agricultural

* Corresponding author.
E-mail addresses: mz@envs.au.dk (M. Zandersen), slj@ens.dk (S.L. Jørgensen), dna@envs.au.dk (D. Nainggolan), sgy@envs.au.dk (S. Gyldenkærne), aw@envs.au.dk (A. Winding), mogensh.greve@agro.au.dk (M.H. Greve), mter@envs.au.dk (M. Termansen).

[1] SOC: Soil Organic Carbon.

[2] Agricultural soil contains on average 142 tC/ha (Taghizadeh-Toosi et al., 2014); Danish agricultural soil covers 2.7 million ha (Nielsen et al., 2013a). Total carbon stock in agricultural soil = 383.4 MtC (142 tC/ha ∗ 2.7 Mha). Emission reduction target by 2020 compared to 1990: 8.09 MtC. Emission reduction share of total SOC in agricultural soil = 2% (8.09/383.4 MtC).

http://dx.doi.org/10.1016/j.ecolecon.2015.12.002
0921-8009/

land, are estimated to loose annually approximately 367,000 tC per year[3] (0.15 tC/ha) (Nielsen et al., 2013a) compared to estimated 564,000 tC/year (8.7 tC/ha) from organic soils, which represent the remaining 2% (Nielsen et al., 2013b; Greve et al., 2014). Although Denmark has lost some estimated 7.6 MtC from agricultural mineral soils between 1990 and 2013 (Nielsen et al., 2015), changes in cropland and grassland management have led to a reduced loss of SOC representing approximately 169,000 tC per year through the ban of straw burning and the requirement of more catch crops.[4] This reduced level of emissions of SOC contributes to Denmark's emission reduction commitments. Despite the reductions in SOC emissions from agricultural soils in Denmark, current intensive agricultural land use practices are responsible for significant emissions leading to a reduced flow of climate regulating services.

An important factor in regulating soil quality and soil organic carbon is crop rotation. If crop rotation includes grassland, for instance, SOC will increase (Taghizadeh-Toosi et al., 2014). Another cause of degrading soil quality, due to declining soil carbon stocks, is conventional soil tillage, which speeds up decomposition of soil organic matter and the release of mineral nutrients (Tilman et al., 2002). Changing the soil tillage system can have significant effects on the vertical distribution and quantity of organic matter (Schjønning et al., 2009a). Out of 11 national field trials across Denmark, which compared mouldboard ploughing to shallow tillage, six sites showed a statistically significant increase in SOC in the upper 0–20 cm, independent of the age of the field trials, which were between 3 and 36 years old (Schjønning and Thomsen, 2006). IPCC guidelines exist for the calculation of organic soil carbon changes with changing tillage systems across management systems and climate zones (IPCC, 2006). The guidance is used by countries in their reporting of greenhouse gas inventories to the UNFCCC and is based on a careful review process of scientific studies. Some studies indicate that changing tillage practices may affect the distribution of C at different depths, but may be limited or have no effects on net greenhouse gas sequestration (Hermle et al., 2008; Schjønning and Thomsen, 2013; Powlson et al., 2014). However, in this study, we follow the IPCC guidelines as these represent the existing rules that apply for national greenhouse gas reporting to the UNFCCC.

Other potential benefits to society from reduced tillage arise in crop production and soil quality maintenance. For instance, reduced tillage may contribute to maintaining sustainable levels of SOC compared to clay in the soil. Dexter et al. (2008) find that a ratio between SOC to clay (called the Dexter ratio) above 10 is critical. Soils with a high Dexter ratio are characterised by free clay particles that are not bound to organic matter, have poorer soil structure (preventing farmers to access the fields in the early spring months and necessitating additional harrowing treatments to prepare a proper seed bed which subsequently contributes to additional soil compaction), increased risks of nutrient leakage and soil erosion, decreased ability to retain water, decreased exchange rate of oxygen, and poorer germination and plant growth (Schjønning et al., 2009b; René Gislum, Aarhus University, personal communication).

Payments for ecosystem services (PES) schemes are increasingly promoted as potentially effective tools for providing increased levels of ecosystem services through compensation to farmers for changing land management practices (Engel et al., 2008; Pagiola, 2008; Wunder et al., 2008). Policies can be made more effective by taking preferences of farmers into consideration. Successful implementation of schemes can be determined by the rate of participation, compensation requirement and characteristics of participating farms in terms of the effect achieved (Crabtree et al., 1998). Hence, much of the research evaluating the effectiveness of potential payment schemes have

Table 1
IPCC guidelines on carbon stock effects of tillage practices.

Default reference		Stock change factors			
T C ha^{-1}		F_I Medium input	F_{LU} >20 years	F_{MG} Full tillage	Reduced tillage
HAC soils	95				
LAC soils	85	1	0.69 (+/−12%)	1	1.08 (+/−5%)
Sandy soils	71				

Source: IPCC (2006); parentheses indicate errors.

explored the influence of farm/farmer characteristics and scheme attributes on willingness to participate (Brotherton, 1989; Espinosa-Goded et al., 2010; Pagiola et al., 2005; Ruto and Garrod, 2009). Furthermore, researchers have emphasized the spatial characteristics and variations (Broch et al., 2013; Campbell et al., 2009) of participation behaviour.

Several methods have been used to evaluate farmer responses to new policy implementation. Choice experiments (CE) are particularly suited for situations where the policy scenarios are hypothetical and no real market data exists to evaluate farmer responses. CE was originally developed for application in marketing and transport studies (Louviere and Hensher, 1982) but is increasingly being used in environmental valuation studies. Various studies have used CE for estimating the economic value of environmental goods e.g. recreation (Adamowicz et al., 1994; Bateman, 1996; Scarpa and Thiene, 2005), evaluation of water management (Birol and Cox, 2007; Birol et al., 2006), and alternative land management (Colombo et al., 2005; Espinosa-Goded et al., 2009). Various studies have also used CE specifically in agro-ecosystem management and the associated provision of ecosystem services (such as Beharry-Borg et al., 2013; Broch and Vedel, 2012; Espinosa-Goded et al., 2010; Ruto and Garrod, 2009; Tesfaye and Brouwer, 2012). In this context, CE is typically used to elicit respondents' preferences for specific scheme attributes. The respondents have to choose one scheme out of a given number of alternative schemes. The inclusion of a payment attribute makes it possible to obtain, indirectly, respondents' willingness to accept compensation in return for changing their land management activities.

In this paper we investigate the scope for applying reduced soil tillage as one among several measures for countering declining SOC levels. We conducted a CE among farmers across Denmark, which was designed to elicit the willingness among Danish farmers to accept a voluntary performance contract to change land management practices towards reduced tillage. The paper evaluates the potential to sequester SOC in Danish mineral agricultural soils in terms of farmers' willingness to accept a voluntary change of tillage practices from mouldboard ploughing to reduced tillage. We estimate the cost of convincing farmers to change practices voluntarily and investigate the underlying explanatory factors for farmers' preferences. We subsequently calculate and map SOC sequestration potential across soil types using IPCC guidelines for estimating C stock changes resulting from reduced tillage (IPCC, 2006). Integrating the information on the SOC sequestration and the compensation requirements leads to estimates of the cost of climate regulation, which we compare to alternative carbon abatement measures. Section 2 describes the methods applied; Sections 3 and 4 data and survey details; Section 5 the results while Section 6 concludes and discusses.

2. Methods

2.1. Choice Modelling

We compare a standard conditional logit model (CL) with a latent class model (LCM). CL assumes homogenous preferences across the population, with the possibility of introducing preference variation

[3] Between 1990 and 1994, average loss of SOC from mineral soils was 405,000 tC per year. This loss has been reduced to 236,000 tC per year over the period 2009-2013. The reduced loss is the difference

[4] Average emissions 2006–2010.