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Functional Land Management for managing soil functions: A case-study of the trade-off between primary productivity and carbon storage in response to the intervention of drainage systems in Ireland

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ABSTRACT

Globally, there is growing demand for increased agricultural outputs. At the same time, the agricultural industry is expected to meet increasingly stringent environmental targets. Thus, there is an urgent pressure on the soil resource to deliver multiple functions simultaneously. The Functional Land Management framework (Schulte et al., 2014) is a conceptual tool designed to support policy making to manage soil functions to meet these multiple demands. This paper provides a first example of a practical application of the Functional Land Management concept relevant to policy stakeholders. In this study we examine the trade-offs, between the soil functions 'primary productivity' and 'carbon cycling and storage', in response to the intervention of land drainage systems applied to 'imperfectly' and 'poorly' draining managed grasslands in Ireland. These trade-offs are explored as a function of the nominal price of 'Certified Emission Reductions' or 'carbon credits'. Also, these trade-offs are characterised spatially using ArcGIS to account for spatial variability in the supply of soil functions.

To manage soil functions, it is essential to understand how individual soil functions are prioritised by those that are responsible for the supply of soil functions – generally farmers and foresters, and those who frame demand for soil functions – policy makers. Here, in relation to these two soil functions, a gap exists in relation to this prioritisation between these two stakeholder groups. Currently, the prioritisation and incentivisation of these competing soil functions is primarily a function of CO_2 price. At current CO_2 prices, the agronomic benefits outweigh the monetised environmental costs. The value of CO_2 loss would only exceed productivity gains at either higher CO_2 prices or at a reduced discount period rate. Finally, this study shows large geographic variation in the environmental cost: agronomic benefit ratio. Therein, the Functional Land Management framework can support the development of policies that are more tailored to contrasting biophysical environments and are therefore more effective than 'blanket approaches' allowing more specific and effective prioritisation of contrasting soil functions.

Introduction

The challenge for agriculture – food security and the environment

A growing global population and dietary changes are amongst the factors that are fuelling a demand for increased agricultural output (Godfray et al., 2010). Increasing demand places urgent and growing pressure on soils to support the intensification of agriculture, which is an essential component of food security (RSC, 2012). The productive capacity of soils is diminishing and has already diminished in many parts of the world and there are limited opportunities for land expansion (Wild, 2003). Thus far, agricultural intensification has been very effective at achieving increased production. Production increases of 115% between 1967 and 2007 have been achieved on modest land area increases of approximately 8% (Foresight, 2011). However, a further increase

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in productivity is likely to be associated with additional stress on the natural resource base. Whilst not synonymous, in many cases intensification has been accompanied by unsustainable environmental impacts such as biodiversity loss and the use of resources such as inorganic nitrogen, phosphate fertiliser, fuel use, and water (Foresight, 2011; UK NEA, 2011). Concerns about these deleterious impacts have stimulated a societal demand for improved environmental sustainability. Consequently, the agricultural industry along with increasing productivity is also expected to meet increasingly stringent environmental targets. Within the European Union (EU), environmental targets include inter alia targets such as those under the Sustainable Use Directive (2009/128/EC) (EU, 2009a) and the Water Framework Directive (2000/60/EC) (EU, 2000) that requires that water bodies be of good ecological status. In Ireland, the Nitrates Directive (91/676/EEC) is the agricultural programme of measures (POM) that sets out a regulatory framework for nutrient management (EU, 1991) to achieve this status. Also, the Habitats Directive (92/43/EEC) (EU, 1992), Birds Directive (2009/147/EC) (EU, 2009b), and EU EIA Directive (2011/92/EU) (EU, 2012) through Natura 2000 seek to halt the loss of biodiversity. In summary, the world needs more food (Godfray et al., 2010), notwithstanding this, agricultural development cannot be intensified beyond the carrying capacity of soils, ecosystems and the socio-economic environment (Mueller et al., 2011).

In this context, ecosystem services are the benefits that people obtain from ecosystems and include the attributes and processes through which natural and managed ecosystems can sustain ecosystem functions (MA, 2005). Many ecosystem services rely on soils and land use for their delivery (Bouma, 2014). These include provisioning services such as food and water, regulating services such as disease control, cultural services and supporting services such as nutrient cycling (Haygarth and Ritz, 2009). This subset of ecosystem services, hereafter soil functions, are described in the Thematic Strategy for Soil Protection (EC, 2006), and these define the role of soils in the contribution to ecosystem services (Bouma, 2014). Although the concept of ecosystem services has been extensively studied and reviewed (Abson et al., 2014), there are a lack of tools to understand and manage multifunctional landscapes (O'Farrell and Anderson, 2010). A major challenge exists in how to satisfy all demands on land and soil simultaneously, particularly as these are often competing demands. The demand for solutions that support the co-existence of environmental sustainability with increased food outputs has prompted the development of the Functional Land Management framework (Schulte et al., 2014).

Functional Land Management

Functional Land Management seeks to optimise the agronomic and environmental returns from land and relies on the multifunctionality of soils. This framework focuses on five soil functions that are specifically related to agricultural land use: (1) Primary production; (2) Water purification and regulation; (3) Carbon cycling and storage; (4) Functional and intrinsic biodiversity, and (5) Nutrient cycling and provision (Bouma et al., 2012; Schulte et al., 2014). Although soils are multifunctional, the heterogeneity of soils means that soils will vary in their relative capacity to deliver individual soil functions which means that challenges to sustainability will vary spatially based on location. Ultimately, the suite of soil functions that a soil provides depends on both land use and soil type. To meet the challenge of the sustainable intensification of agriculture, Functional Land Management seeks to optimise the suite of soil functions that it provides by matching the supply of soil functions with demand (Schulte et al., 2014). For example, the demand for the soil function 'Water purification' is framed by the Nitrates Directive, which requires groundwater nitrates concentrations to be maintained below 50 mg l^{-1}, through denitrification of (part of) the nitrogen surplus. To present the delivery of soil functions, Schulte et al. (2014) used Ireland as a case-study. Importantly, Functional Land Management is not designed as a tool for zoning, but for use at a scale that can consider what Benton et al. (2011) refer to as the net landscape effect across all affected land.

Case study: agriculture in Ireland – trade-offs between two soil functions

Ireland's response to the global imperative of food security is captured in the *Food Harvest 2020* strategy. *Food Harvest 2020* is the industry-led roadmap for agricultural growth in Ireland. The abolition of the EU milk quota in 2015 is a prime driver that will allow farmers to increase their dairy output. As a result, the roadmap foresees a volume increase target of 50% for the dairy sector by 2020, in contrast to the targets for other agricultural sectors, which are value based (DAFF, 2010). The dairy volume increase target for the dairy sector requires a level of intensification, expansion or augmented resource use efficiency, to be achieved. All targets under *Food Harvest 2020* aim to both intensify output whilst concurrently reducing the environmental footprint of production. For example, a target of increasing dairy production by 50% will simultaneously seek to reduce greenhouse gas (GHG) emissions for every litre of milk produced and provide sustainable returns (DAFF, 2010).

Ireland has a temperate maritime climate which means that it has a natural advantage in relation to grass growing potential. Ireland's success as a major milk producer globally relies on its grass based system and it is this low-cost system that provides Ireland with its competitive advantage. In general, the volatility of agricultural input prices, such as fertilisers or concentrates, requires producers to adjust to minimise this impact on their profitability (Donnellan et al., 2011). In Ireland, whilst a grass-based system allows producers a level of insulation against these input price fluctuations, seasonality and lower yields can represent a challenge not associated with intensive concentrate based systems (Donnellan et al., 2011). Amongst other measures, improved grass utilisation and extending the grazing season are essential to the continued success and competitiveness of the Irish dairy sector. Furthermore, in relation to GHG emission, temperate grass-based systems like Ireland and New Zealand have the lowest emissions per unit fat and protein-correct milk when compared to tropical and arid grassland systems (Teagasc, 2011a). Thus, to reduce the potential of carbon (C) leakage associated with dairy production, the environmental rationale to optimise production in temperate grass-based systems, such as in Ireland, exists.

In North Atlantic maritime climates, however, excess soil moisture is a key constraint to achieving these twin targets, as it simultaneously constrains primary productivity and increases the risk of negative environmental impacts (Schulte et al., 2012). Wet soils are easily damaged and so their ability to deliver soil functions can be compromised. Surface compaction and subsurface compaction have been identified as major threats associated with the climatic regime of North Atlantic Europe related to the trafficking or working of soil under inappropriate soil moisture conditions (Creamer et al., 2010). Wet soils have lower load-bearing capacity and grazing damage can lower herbage production by 20% or more (Humphreys et al., 2011). Furthermore, Schulte et al. (2006) demonstrated that the length of the grass growing season can be reduced by as many as five months at a regional level as a result of excess soil moisture conditions. Overall, wet soil conditions are considered the most important factor limiting the utilisation of grazed grass on Irish farms (Shalloo et al., 2004; Creighton et al., 2011).

In this setting, land drainage systems on existing land in production or on new land areas that fulfil EIA criteria, offer potential as part of a suite of measures to overcome such constraints. Any land drainage works aim to siphon excess water from the soil and