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The challenge of managing soil functions at multiple scales: An optimisation study of the synergistic and antagonistic trade-offs between soil functions in Ireland

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ABSTRACT

Recent forecasts show a need to increase agricultural production globally by 60% from 2005 to 2050, in order to meet a rising demand from a growing population. This poses challenges for scientists and policy makers to formulate solutions on how to increase food production and simultaneously meet environmental targets such as the conservation and protection of water, the conservation of biodiversity, and the mitigation of greenhouse gas emissions. As soil and land are subject to growing pressure to meet both agronomic and environmental targets, there is an urgent need to understand to what extent these diverging targets can be met simultaneously. Previously, the concept of Functional Land Management (FLM) was developed as a framework for managing the multifunctionality of land. In this paper, we deploy and evaluate the concept of FLM, using a real case-study of Irish agriculture. We investigate a number of scenarios, encompassing combinations of intensification, expansion and land drainage, for managing three soil functions, namely primary productivity, water purification and carbon sequestration. We use proxy-indicators (milk production, nitrate concentrations and area of new afforestation) to quantify the 'supply' of these three soil functions, and identify the relevant policy targets to frame the 'demand' for these soil functions.

Specifically, this paper assesses how soil management and land use management interact in meeting these multiple targets simultaneously, by employing a non-spatial land use model for livestock production in Ireland that assesses the supply of soil functions for contrasting soil drainage and land use categories. Our results show that, in principle, it is possible to manage these three soil functions to meet both agronomic and environmental objectives, but as we add more soil functions, the management requirements become increasingly complex. In theory, an expansion scenario could meet all of the objectives simultaneously. However, this scenario is highly unlikely to materialise due to farm fragmentation, low land mobility rates and the challenging afforestation rates required for achieving the greenhouse gas reduction targets. In the absence of targeted policy interventions, an unmanaged combination of scenarios is more likely to emerge. The challenge for policy formation on future land use is how to move from an unmanaged combination scenario towards a managed combination scenario, in which the soil functions are purposefully managed to meet current and future agronomic and environmental targets, through a targeted combination of intensification, expansion and land drainage. Such purposeful management requires that the supply of each soil function is managed at the spatial scale at which the corresponding demand manifests itself. This spatial scale may differ between the soil functions, and may range from farm scale to national scale. Finally, our research identifies the need for future research to also consider and address the misalignment of temporal scales between the supply and demand of soil functions.

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1. Introduction

Recent forecasts indicate that world population will grow by 2.5 billion from 2015 to 2050 (PRB, 2015). By that time, agriculture production globally must have increased by 60% from 2005 levels (WWDR, 2015). This poses challenges for scientists and policy makers to derive solutions on how to increase food production and at the same time meet environmental targets such as water protection, conservation of biodiversity or climate change mitigation. For example, the European Union (EU) Water Framework Directive (2000/60/EC) provides a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater (EU, 2000). It requires Member States (MS) to establish river basin districts and an associated management plan for each river basin. It supersedes the Nitrates directive (91/676/EEC) which was developed to reduce water pollution caused by nitrates from agricultural sources (EU, 2010). Similarly, in 2011 the EU adopted its EU Biodiversity Strategy to 2020 to halt the loss of biodiversity and ecosystem services by 2020 (EU, 2015a). In relation to mitigating climate change, in 2007, the EU committed to reducing greenhouse gas (GHG) emissions in the year 2020 by 20% compared to 1990 levels, increasing renewable energy use by 20%, and to improving energy efficiency by 20% (EU, 2014), as part of the "EU Energy and Climate Package 2020". This policy will be replaced by the new "EU Climate and Energy framework 2030" for the period between 2020 and 2030 (EU, 2015b), which proposes to reduce GHG emissions by 2030 by 40% compared to 1990, and to increase renewable energy use and energy savings by at least 27% compared with the business-as-usual scenario (EU, 2015b).

The growing societal pressures on the soil resource prompted the European Commission (EC) to publish the EU Thematic Strategy for Soil Protection in 2006, which set a common EU framework for action to preserve, protect and restore soil by implementing actions customised to local situations (EC, 2006). This strategy considers the different functions that the soil can perform, and also the main threats to soil quality. Soil based ecosystem services, also known as soil functions, have previously been described in a number of studies including Bouma and Droogers (2007); Haygart and Ritz (2009) and Calzolari et al. (2015). In the Netherlands, Bouma and Droogers (2007) proposed a six-step procedure for a water management unit using existing soil data related to the soil topics of soil functions, threats and quality. Haygart and Ritz (2009) proposed 18 ecosystem services that are critical for soil and land use in the United Kingdom. Also, a methodological framework of eight soil functions has been developed by Calzolari et al. (2015).

In many countries, the diverging policies put pressure on land and soil to meet both agronomic and environmental targets, necessitating a better understanding as to how and to what extent these targets can be achieved simultaneously. In response, Schulte et al. (2014) developed the concept of Functional Land Management (FLM) as a framework for optimising the delivery of five soil functions, specifically for agricultural land use:

1 Primary productivity;
2 Water purification and regulation;
3 Carbon sequestration and regulation;
4 Provision of habitat for biodiversity;
5 Nutrient cycling and provision.

Within the FLM framework the supply of these soil functions is dependent upon land use and soil type while demand is framed as policy drivers. Accordingly, challenges to sustainability will vary spatially across locations. To meet the challenge of intensifying agriculture sustainably, FLM seeks to match the supply of soil functions with demand (Schulte et al., 2014).

The FLM framework is underpinned by the multifunctionality of soils: which is that all soils perform all of these five functions simultaneously, but some parts of the land perform some functions better than others (Schulte et al., 2014; O'Sullivan et al., 2015). Central to the FLM framework is that land and soil management is aimed at optimising, rather than maximising, the supply of each of the soil functions. While maximising would seek to achieve the highest total delivery of soil functions, optimising gives priority to meeting demands at the spatial and temporal scales required by policy objectives (Schulte et al., 2015a).

Coyle et al. (2016) elaborated on the FLM framework, by relating the delivery of multiple functions to land use and soil properties, using the Atlantic pedo-climatic zone of Europe as their geographical region of interest. They showed that in this region, the delivery of soil functions is mainly determined by soil drainage properties and that augmentation of one soil function is likely to result in the alteration of other soil functions (see also O'Sullivan et al., 2015).

Furthermore, Schulte et al. (2015a) explored how the demand for different soil functions operates at different scales. For example, the demand for water purification manifests itself at a local scale, whereas the demand for carbon sequestration exists at national scale. The authors conclude that this has implications for the management of the supply for soil functions, namely: soil management for water quality at local scale, and land use management for climate mitigation at national scale.

So far, the FLM framework, and the exploration of trade-offs and synergies between the various soil functions have been largely conceptual, with the exception of the study by O'Sullivan et al. (2015) into the trade-offs between primary productivity and carbon sequestration. In this current paper, we used empirical data to explore scenarios for FLM, aimed at meeting multiple agronomic and environmental policy objectives. Using Ireland as a case study, we assessed how soil management and land use management interact in meeting multiple targets simultaneously. For simplicity, we limited our analysis to the three functions primary productivity, water purification and carbon sequestration. Two of these soil functions are part of the set investigated by Calzolari et al. (2015).

2. Materials and methods

2.1. Case study

For our case study, we used Ireland as a national example of the challenges facing the agricultural sector in relation to meeting both agronomic and environmental targets. Dairy and livestock production play a central role in Irish agriculture: 80% of agricultural land is grassland (Teagasc, 2015), and most of the herbage is grazed *in situ*, with the remainder harvested as silage that is fed during the relatively short housing seasons (2–5 months), during which it may be supplemented with various amounts of concentrates (Schulte et al., 2014). Food Harvest 2020 represents the industry strategy, supported by the Irish government, to increase national milk production between 2010 and 2020 by 50%. The abolition of the milk quota in Europe in 2015 gives Irish farmers for the first time in over 30 years the opportunity to increase their production without being constrained by quota. Food Harvest 2020 has now been followed by the Food Wise 2025 strategy which foresees a further rising of ambitions, however without defining further volume targets for production. Both strategies aim to keep volume outputs of other agricultural sectors stable while increasing export values. Following a Strategic Environmental Assessment (SEA) (EU, 2001), the preferred pathway for implementation is the 'Sustainable Growth' scenario, in which the increase in dairy output is achieved through sustainable intensification, that is without significant increases in pressures on the environment.