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Crop rotations including ley and manure can promote ecosystem services in conventional farming systems

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ABSTRACT

Agricultural intensification has contributed substantially to the increase in food production, but has come at the expense of soil degradation and environmental problems. Management of soil based ecosystem services need to be considered in agricultural management since intensive management implies not only costs to the farmer but also to society. In this study we used data from four long-term (55 years) agricultural experiments in southern Sweden to assess the effects of two arable farming systems on a range of indicators of soil ecosystem services. One farming system used only annual commodity crops (ACC system) while the other integrated one year of ley (ley system) into the crop rotation. Nitrogen (N) fertiliser was applied annually in both farming systems at two rates (0 and 150 kg N ha^{-1}). The ley farming system had an addition of farmyard manure (FYM) once every fourth year. Soil organic carbon, total N, phosphorous, potassium, pH and water holding capacity were used as indicators of regulating services; bacterial and fungal biomass were used as indicators of supporting services; grain yield and protein content were used as indicators of provisioning services. We analysed each of the indicators separately, to identify effects of the farming systems, using linear mixed effects models. In addition, we used principal components analysis to bundle the individual indicators together to create latent variables representing categories of ecosystem services. Yields of wheat were greatest in the plots that received N fertiliser, irrespective of farming system, while mycorrhizal fungal biomass was greatest in the ley system with no inorganic N fertiliser. The rest of the indicators were similar in both farming systems although the lowest values of all ecosystem service indicators were found in the ACC system with no N fertiliser. When bundling the indicators, no trade-offs were found between regulating, supporting and provisioning services. Regulating and supporting services were positively correlated, as were regulating and provisioning services. The ley system with N fertiliser had significantly greater values of regulating and provisioning services relative to the other treatments. The results indicate that different farming systems can have large effects on ecosystem service flows, and that integrating leys into arable rotations can enhance the delivery of soil ecosystem services.

1. Introduction

Agricultural intensification has contributed substantially to the increase in food production but has come at the expense of soil degradation and environmental problems (Montanarella, 2007). Intensification typically incorporates intensive tillage regimes, increased application of fertilisers, and reductions in crop diversity both in time and in the landscape (in space) (Matson et al., 1997). Agricultural intensification can reduce the diversity and abundance of soil organisms, which in turn affects soil processes and a number of ecosystem services (De Vries et al., 2013; Tsiafouli et al., 2015). Management and cascading effects on soil based ecosystem services are key factors to be considered since intensification of agriculture does not only imply a reduction of services to the farmer but also to society at large, including contribution to greenhouse gas emissions, eutrophication of surface waters and soil erosion.

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In the search for the highest production of multiple ecosystem services we need to increase our knowledge about trade-offs and synergies among provisioning (e.g., crop production), regulating (e.g., soil carbon storage) and supporting (e.g., soil biodiversity) services under different agricultural systems. By applying a framework of multiple ecosystem services according to the definition of the Millennium Ecosystem Assessment (MEA, 2005), we are avoiding maximizing just a single service at the expense of others, e.g., SOC retention, or yields (De Groot et al., 2010). Trade-offs can be managed in order to reduce their associated costs to society and to the farmer by enhancing multi-functionality (Bennett et al., 2009). Normally, soil ecosystem services trade-offs have been shown between provisioning services (crop production) and regulating services (SOC storage) (Raudsepp-Hearne et al., 2010). This trade-off incurs costs for society in terms of reduced SOC storage while in the short term producing benefits for farmers (income) and society (food). However, in the long term regulating and supporting services can play important roles in the delivery of provisioning services. For example, the sequestration of organic matter for soil fertility is critical for crop yields but at the same time helps to mitigate climate change. This is also true for crop quality since protein levels in plant seeds are mainly correlated with nitrogen (N) available in the soil (Zhao et al., 2005).

While grain yields and protein content can be used as indicators of provisioning services, the supply of other soil ecosystem services can be estimated by a range of soil properties with strong links to the individual services—ecosystem service indicators (Dale and Polasky, 2007). Changes in the levels of SOC can be used not only as an indicator of the stock of carbon under different management regimes, but also of N retention, as SOC and TN are usually positively correlated (Gattinger et al., 2012; Williams and Hedlund, 2013) and can be associated with regulating services (Power, 2010). Soil microbial communities decompose organic matter and mineralise nutrients, as well as are important for fixing atmospheric nitrogen (Zelles, 1999). As such, microbial biomass can be used as an indicator of supporting soil services.

There is a lack of evidence on how intensive agricultural management influences multiple ecosystem services in different farming systems. In this paper we contrasted two conventional arable farming systems, representing crop production farms with and without livestock. The farming system without livestock had a four-year crop rotation using only annual commodity crops (ACC system). The farming system with livestock had three annual commodity crops in the rotation and included one year of ley (grass fodder production) (ley system). Both farming systems received two levels of N fertilisation (0 and 150 kg inorganic N ha^{-1} yr^{-1}) and the ley system received farmyard manure (FYM) every fourth year. Both farming systems have been managed in this way as a long-term experiment since 1957 (Carlgren and Mattsson, 2001). This allowed us to investigate the long-term effects of N inputs and crop rotations in the different farming systems and the effects this had on the production of soil ecosystem services.

This study aimed to investigate whether incorporating ley into a conventional arable production system led to an increase in soil ecosystem services compared to a dedicated commodity crop production system, and could therefore help to achieve sustainable intensification of agriculture, i.e., providing high levels of food production while maintaining a more balanced set of ecosystem services (Bommarco et al., 2013; Godfray and Garnett, 2014). Thus, we hypothesised that the ACC system would trade-off the supply of regulating and supporting ecosystem services with the supply of provisioning services, while the ley system would promote higher levels of all soil ecosystem services. The inclusion of ley can result in higher levels of soil biodiversity (Tsiafouli et al., 2015); we therefore hypothesised that a rotation with ley could produce more ecosystem services than a rotation with only annual commodity crops. We further hypothesized that the addition of N fertiliser would enhance the delivery of ecosystem services associated with crop biomass, particularly root biomass, and yield production, thereby contributing positively to regulating and provisioning services, respectively (Alvarez, 2005; Kätterer et al., 2011).

2. Material and methods

2.1. Site description

Data and soil were collected from long term agricultural experiments at four sites in Scania, southwest Sweden, that are part of the Swedish Soil Fertility Experiments, established in 1957 (Carlgren and Mattsson, 2001). A brief description of each site and soil follows (Kirchmann et al., 1999; Kirchmann and Eriksson, 1993):

1. Fjärdingslöv (54°24′N, 13°14′E): sandy loam with increasing clay and calcium carbonate content down to 100 cm depth. Classified as a Haplic Phaeozem.
2. Orup (55°49′N, 13°30′E): sandy loam throughout the profile from 0 to 100 cm. Classified as a Haplic Phaeozem.
3. Örja (55°53′N, 12°52′E): sandy clay loam with a small calcium carbonate content throughout the profile. Classified as a Eutric Cambisol.
4. Ekebo (55°59′N, 12°52′E): coarse–loamy soil. Classified as a Eutric Cambisol.

All four sites have been under cultivation for at least 100 years before the start of the experiment. The climate is cold-temperate (annual mean temperature range 7–8 °C) and humid (655 mm annual precipitation) at all sites.

2.2. Experimental design and soil sampling

The experiments tested two main factors: arable farming systems with or without ley, and with or without N fertiliser, replicated on four different farms in the intensively farmed region of Scania (Björklund et al., 1999). There were two different four year crop rotation treatments: one with a grass ley in the rotation and amendment with manure once every fourth year (ley system), while the other crop rotation had only annual commodity crops (ACC system). The four-year crop rotations were: ley system: spring barley (*Hordeum vulgare* L.) – grass ley – winter wheat (*Triticum aestivum* L.) – sugar beet (*Beta vulgaris* L.); ACC system: spring barley (*Hordeum vulgare* L.), spring oil seed rape (*Brassica napus* L.), winter wheat (*Triticum aestivum* L.) – sugar beet (*Beta vulgaris* L.). Crop residues were removed in the ley system, but were incorporated into the soil in the ACC system. In the ley system, 20–30 t ha^{-1} (fresh weight) of manure were applied to all plots after winter wheat harvest. The second factor – inorganic N fertiliser addition – had a number of levels in the experiment (0, 50, 100 and 150 kg N ha^{-1} $year^{-1}$). However, we only analysed data from plots with 0 or 150 kg N ha^{-1} year. Phosphorous (P) and potassium (K) were applied to all the plots to replace what was annually harvested from each plot. The experiments were established as a randomized block design with two replicate blocks at each farm. Each plot in the block design was 125 m^2.

Soil samples were taken from 0 to 20 cm depth in each plot as at this depth most of the effects of crop management are expected to be seen (Farley et al., 2004). Samples for K, P, N and SOC were collected every fourth year in August (1962–2011) for the long term experiment, after the winter wheat harvest and data from 2011 was used. Additional samples to analyze PLFAs were taken