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Valuation of ecosystem services in organic cereal crop production systems with different management practices in relation to organic matter input

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ABSTRACT

As the degradation of global ecosystem services (ES) continues in the last five decades, maintaining or even enhancing the ES of agro-ecosystem is one of the approaches to mitigate the global ES loss. This study provides the first estimate of an economic valuation of ES provided by organic cereal crop production systems with different management practices in relation to organic matter input (low, medium and high). Our results show that organic matter inputs significantly affect the total ES value on organic cereal crop production systems. The system with high organic matter input has the highest gross total ES value (US$ 1969 ha^{-1} yr^{-1}), followed by the low organic matter input system (US$ 1688 ha^{-1} yr^{-1}), and the lowest ES value are found in the medium organic matter input system (US$ 1492 ha^{-1} yr^{-1}). Organic matter inputs have strong positive relationship with non-marketable ES values, while this relationship was not found in marketable ES values. Monetizing the ES can be used by land managers and policy makers to adjust management practices in terms of organic matter input in cereal production system with a long term goal for sustainable agriculture.

1. Introduction

Ecosystem services (ES) are defined as the benefits human beings derive from nature and categorized as provisioning, regulating, culture, and supporting services (MEA, 2005). ES include the production of food and fuel, soil regeneration, climate regulation, nutrient cycling and a range of non-material benefits (Costanza et al., 1998; MEA, 2005). Agro-ecosystems cover nearly 40% of the earth's terrestrial surface and are primarily managed to provide food and fiber (FAOSTAT, 2014). In order to deliver these ES, agro-ecosystems also consume ES from other natural systems by using limited resources which may result in adverse effects to human beings such as competition for water, discharge of underutilized fertilizer and soil degradation (Swinton et al., 2007; Zhang et al., 2007; Ango et al., 2014). Therefore, agro-ecosystems have large potential either for reducing global ES or enhancing them via ecologically informed approaches (Porter et al., 2009). With a tremendous pressure to feed an increasing global population (FAOSTAT, 2014) and a diet changing towards more meat consumption (Gerbens-Leenes and Nonhebel, 2002; Pretty, 2013), agro-ecosystems face the challenge of obtaining a high level of production while protecting the environment (Tilman et al., 2002, 2011). Organic farming emphasizes a preference for the use of management practices over external agricultural inputs, and is often suggested as one of the potential solutions that can help alleviate the inadvertent detrimental impacts of intensive agriculture, due to its environmentally friendly nature (Garg, 2014; Duru et al., 2015; Reganold and Wachter, 2016). Some researchers have criticized organic farming due to its lower crop yields and greater demand for land to maintain production at a given level in comparison to conventional agriculture (Emsley, 2001; Trewavas, 2001, 2004; Connor and Mínguez, 2012). They argue that this increased demand for land could lead to widespread biodiversity loss, therefore undermining the environmental benefits provided by organic farming. In contrast other researchers have showed that the crop yield of organic farming can nearly match conventional yields under certain conditions (Seufert et al., 2012) and the yield gap between organic and conventional systems can be reduced with good management practices (Jensen et al., 2015; Ponisio et al., 2015). Organic farming highly emphasizes crop rotation, biodiversity and biological pest control to minimize environmental damage as much as possible while sustaining an economically viable level of production and ensuring a variety of high quality products (Reganold and Wachter, 2016). Due to restrictions on using synthetic pesticides and mineral fertilizers in Europe, organic farming puts greater emphasis on protecting the environment and supporting ecological processes than conventional agricultural systems (ECC, 2007; Oxouzi and Bagiatis, 2012). Organic farming has considerably developed over the past decade in Europe and the market for organic foods has steadily grown (Willer and Schaack,

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2015). In 2014, 10.3 million hectares of organic farmland constituted 5.9% of the total agricultural land of the total EU-28 (EUOF, 2015). The organic area and number of the organic farms in the EU-28 increased by more than 50% in the last decade (Eurostat, 2015). With respect to the organic share of the total cultivated area, Denmark is within the top-ten countries in Europe (Willer and Schaack, 2015). With increasing organic agricultural land area, number of (organic) farmers and growing market for organic products, organic farming plays an increasingly more important role in EU agroecosystems.

Management practices strongly influence agroecosystem functions at field and farm scale and are determining factors for the supply of ES. Intensive agricultural practices such as deep tillage, poor irrigation, and overuse of mineral fertilizers and pesticides might can lead to soil erosion, nutrient runoff, water pollution and soil degradation and result in global ES loss (Weil et al., 1993; Tilman et al., 2002). Nevertheless, appropriate agricultural management can ameliorate these negative impacts while simultaneously maintaining provisioning services. For instances, Chen et al. (2016) showed that shallow flooding under optimal rate of N use could enhance the ES of conventional rice cropping systems in China. Albizua et al. (2015) reported that ley incorporation and farmyard manure application could promote ES in conventional farming systems in Sweden. Ghaley and Porter (2014) reported that management practices significantly affected soil organic matter content, have effects on the total ES of a conventional winter wheat production system in Denmark. Several studies has focused on comparing ES between organic and conventional systems from different aspects (Macfadyen et al., 2009; Geiger et al., 2010; Kremen and Miles, 2012; Winqvist et al., 2012; Garg, 2014; Andersson et al., 2015). These studies show that organic farming could provide more environmentally significant ES than conventional farming, while few studies have accounted for the economic value of overall ES resulting from organic farming (Sandhu et al., 2008, 2010, 2015). The lack of studies in this area could be the effect of criticism of the of economic valuation of ES as trying to put a “price tag” on nature and encourage us to think of them as property for utilitarian benefits, not for nature's own sake (Sagoff, 1996; McCauley, 2006). In addition, there are various approaches to estimate the economic valuation of ES; all of these approaches have their limitations and caveats that are yet unresolved (Ludwig, 2000; Spangenberg and Settele, 2010), and valuation methods in general are affected by uncertainty and technical issues in the valuation process. However, it would restrict the applicability of any study to exclude an economic valuation of ES on the abovementioned grounds. The combined economic valuation of both marketable and non-marketable ES is nowadays widely used and frequently advocated as an approach to provoke society to acknowledge the value of natural capital which is becoming scarce, and promote the conservation of non-marketable ES for sustainable development (Liu et al., 2010). Economic valuation of both marketable and non-marketable ES can estimate the value of the benefits derived by humans for ecosystems and assign the different services a uniform value (in dollar terms) for direct comparison (Costanza et al., 2014). Moreover, economic value of ES provide the information precisely to decision makers to help them better understand ecosystem benefits for humans in a more intuitive way, and thereby design policy tools for managing ES (Power, 2010; Ma et al., 2015; Rogers et al., 2015). Although monetary valuation of ES has its risks and may not reflect the plurality of ES values (Fanny et al., 2015), a large majority of policy- makers find economic valuation of ES useful and necessary for decision making, and most already use it as a tool to reveal nature's hidden economic values (Farber et al., 2002; Pascual et al., 2010; Marre et al., 2016). Whereas great caution should be taken before relying solely on monetary valuation of ES in developing countries where intrinsic ecological values and socio-cultural values could be very high (Fanny et al., 2015), this may be less problematic in the context of intensively managed European agroecosystems where most ES can be successfully translated to either market or non-market value, and non-use values such as biodiversity and ecological status are already integrated in the EU Habitat Directive (ECC, 1992) with the Natura 2000 Management Plans and in the EU Water Framework Directive (ECC, 2000) with the River Basin Management Plans. Furthermore, monetary valuation of both marketable and non-marketable ES is an effective way to educate policy-makers about the direct and indirect environmental benefits of different management practices, and thereby inform the process of integrating payment for ecosystem services in agricultural policy support schemes that support such management practices. In our study economic valuation of both marketable and non-marketable good and services have been performed. Marketable goods such as food, straw materials, fodder as provision ES are traded in agricultural markets directly. The monetary valuation of the marketable ES is based on the market price. However, there is no market for ES, and its market price therefore relies on the valuation of providing society with information on the relative level of resource scarcity, which is also affected by uncertainty over time. Therefore, we use the market price method in our study, since the market price can be a good indicator of the value of ES that is being studied (Baskaran et al., 2009; Pascual et al., 2010). The non-marketable ES which are not traded in the market were also monetized. For non-marketable ES, we used avoided cost method in our study, although this method ignores the intrinsic and other non-use values related to the natural process. This method is useful for providing the direct and indirect value of ES. Monetary valuation of non-marketable ES can provide insights and promote informed debate concerning trade-offs between economic and environmental benefits, which allows policy makers to design future support schemes for sustainable agriculture. If there are trade-offs between marketable and non-marketable value, there is a need for policy makers and farmers to take both into account for rational decision making. Moreover, economic valuation of ES can be integrated into existing policy documents (Sukhdev et al., 2010) to improve the balance amongst different ES. Whereas, numerous investigations reported effects of different managements practices on soil biological, physical, and chemical properties, as well as food productivity in conventional agricultural systems (Wada and Toyota, 2007; Mahmoodabadi and Heydarpour, 2014; Yang et al., 2015; Jia et al., 2016), little known is about how field management practices in relation to organic matter input affect ES delivery in organic farming systems. Therefore, we performed field measurements in a long-term organic cereal crop production system to determine the effects of different management practices on marketable and non-marketable ES, and to provide the basis for informing Danish policy makers and other stakeholder within organic farming on different strategies for future policies on sustainable agriculture. Therefore, our objectives are (1) to estimate the input and output of organic farming systems with different management practices (2) to quantify and value the total ES of organic cereal crop production systems (3) to elucidate how different management practices in relation to organic matter input affect the marketable and non-marketable ES values, and (4) to provide an objective basis for informed decision-making of suitable management practices for agro-ecosystems.

2. Materials and methods

2.1. Field site and experimental design

The study was made at Bakkegården, an experimental farm located in the municipality of Taastrup (55°40′N, 12°18′E), under the University of Copenhagen in Denmark. We used a long-term organic farming experiment according to EU organic farming standards initiated in 1999. The soil type was sand clay loam (USDA Soil Taxonomy System, (Møberg and Nielsen, 1986)) containing 22% clay, 22% silt, 55% sand. The air temperature and annual precipitation was 9.3 °C and 853 mm respectively in sampling year 2015. There were 12 fields under study in total, consisting of three separate organic farming