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Opportunities for sustainable intensification in European agriculture

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ABSTRACT

Sustainable agricultural intensification is needed to tackle food insecurity and global environmental change. Local environmental conditions determine the needs and potentials for increasing sustainability of agricultural practices. However, the potential for implementation also depends on socio-economic factors, as farmers need to adopt innovative farming practices, and consumer demand affects the economic feasibility. This study aims to map opportunities for sustainable intensification in Europe taking into account farmer characteristics, consumer behaviour, environmental pressures, and unexploited agronomic potentials. In areas identified as having high opportunities, we estimate the impacts of specific sustainable intensification measures on both intensification (in terms of calorie gains) and sustainability (in terms of resource savings). The study finds high spatial variation in opportunities for sustainable intensification across Europe. High opportunities for sustainable intensification are found on 34% of the arable area in Europe. In addition, the analysis shows that a combination of different measures can simultaneously improve food security and sustainability.

1. Introduction

Achieving global food security becomes increasingly challenging. On the consumer side, population grows and changes its consumption patterns. On the production side, increasing food production is limited by land availability for agricultural expansion and trade-offs related to intensification. According to medium estimates, cropland could potentially expand to less than double (a factor of 1.0–1.9 of) its size in 2005 (Eitelberg et al., 2015). This compares to a slightly higher projected increase (a factor of 1.6–2.0) in food demand in terms of calories until 2050 (Tilman et al., 2011; Valin et al., 2014). However, land assigned as ‘available’ is in reality already providing multiple functions besides food production (Verburg et al., 2013), such as the production of feed, fibre, fuel and timber, regulating ecosystem services like carbon sequestration, water purification and flood control, and habitat provision for flora and fauna. Furthermore, potentially available land is likely to be less productive than current agricultural areas. Therefore, recent increases in food production were attained by intensification rather than expansion (Foley et al., 2011). In spite of this intensification, there are still considerable yield gaps in many parts of the world (related to the efficiency within one crop cycle) (Mueller et al., 2012; Pradhan et al., 2015) as well as harvest gaps (related to the cropping frequency) (Ray and Foley, 2013; Yu et al., 2017) that could be closed.

However, intensification is often attained at the expense of environmental integrity. Most importantly, irrigation and fertilization drive water scarcity (Scherer and Pfister, 2016a), eutrophication (Scherer and Pfister, 2015a), and acidification (Tian and Niu, 2015). In some views, environmental sustainability and intensification seem incompatible and contradictory (Robinson, 2004; Garnett et al., 2013). That is why, in the past, nature protection was typically striven for by setting apart lands as protected areas (Mace, 2014). Such a strategy, however, cannot avoid the negative impacts of intensively used agricultural areas. Moreover, it is increasingly recognized that, in a human-dominated world, people and nature are interdependent and their demands must be tackled simultaneously (Mace, 2014). Consequently, many scientists emphasise the need for sustainable intensification of agriculture (Godfray et al., 2010; Foley et al., 2011; Tilman et al., 2011; Smith, 2013). Ideally, sustainable intensification implies more production on the same land area while reducing environmental impacts and maintaining ecosystem functioning. Pathways to sustainable intensification can be diverse and must be adapted to the location and context (Garnett et al., 2013; Buckwell et al., 2014). Measures range from agronomic development (e.g. no-tillage farming) and resource-use efficiency (e.g. deficit irrigation) at the farm scale to land use allocation (e.g. spatial targeting) and regional integration (e.g. diffusion of innovation) at the regional scale (Weltin et al., submitted). Trade-offs between intensification and sustainability may be unavoidable and, therefore, yield increases are not imperative to the concept. Instead, the concept of sustainable intensification can include conventional intensification at some locations and de-intensification or land

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reallocation at other locations in favour of environmental benefits. Still, overall output and sustainability over larger scales should increase without agricultural expansion (Garnett et al., 2013; Buckwell et al., 2014).

Studies related to sustainable intensification mostly focus on quantifying the opportunities of increasing production (Mueller et al., 2012). However, others have indicated that meeting the twin challenge of sustainable intensification would also require changes on the demand side (Foley et al., 2011; Smith, 2013; Davis et al., 2016a). Looking at the opportunity space from a demand and a supply perspective simultaneously is rarely done, with the notable exception of Pradhan et al. (2014). This study aims to map opportunities for sustainable intensification in Europe by considering both socio-economic and environmental factors. We focus on arable farming while acknowledging that similar challenges apply to pastoral farming. Europe is among the most densely populated world regions (Doxsey-Whitfield et al., 2015) and, as a result, faces a high land pressure. At the same time, Europe is rich in productive farmland and is among the largest food importers as well as exporters (Benton et al., 2011). The global importance of Europe as a consumer and producer makes it a relevant focus area for our study. Agriculture in Southern and Eastern Europe can still be intensified, while agriculture in Northern and Western Europe is already intensive (Pradhan et al., 2015). Still, the latter can improve sustainability and manage food demand. Next to determining areas of high opportunities, the objective of this study is to provide the first coarse estimate of the potential benefits of a set of measures for both agricultural production and sustainability in these areas.

2. Methods

2.1. Conceptual framework

The feasibility of sustainable intensification of crop production in Europe depends on both (1) socio-economic opportunities (Section 2.2) as the willingness of farmers and consumers to produce and buy sustainably intensified agricultural products, and (2) environmental opportunities (Section 2.3) as the necessities for reducing environmental impacts (e.g. water scarcity) or the existence of unexploited potentials (e.g. harvest gaps). After mapping the individual indicators for both types of opportunities across Europe, they were aggregated to obtain overall indices for socio-economic and environmental opportunities, respectively, following the aggregation procedures described in Sections 2.2 and 2.3. The opportunities of both aspects were mapped by means of an opportunity matrix for colour coding. The indicators were classified as low, moderate, or high if they are i) below the quantile Q_{25}, between Q_{25} and Q_{75}, or $> Q_{75}$ (default), or ii) below the quantile $Q_{33.3}$, between $Q_{33.3}$ and $Q_{66.7}$, or $> Q_{66.7}$ (alternative). Since there is considerable uncertainty in the choice of indicators and associated spatial data, we judged such a quantile representation as adequate for the type of information rather than more precise quantitative details. A special case is food waste, whose reduction at the consumption level is independent of the location of agricultural production and the behaviour of farmers. Therefore, only opportunities by consumers were considered in this case.

Within areas of the same identified opportunity category, the second part of the analysis aims to quantify the effects of implementing a set of sustainable intensification measures on (1) intensification in terms of calorie gains (or losses), and on (2) the environment in terms of resource savings (Fig. 1). For each measure, both aspects are considered. Due to the higher implementation feasibility, we emphasize areas with high opportunities with regards to both the environment and socio-economic characteristics as well as for areas with high opportunities with regards to one and moderate opportunities with regards to the other aspect. By not focusing on only high opportunities in both aspects, the effects of implementing sustainable intensification can be assessed more widely. As a reference for the analysis, we use the year 2010. When data for the reference year were not available, we used data closest to the reference year, with preference given to the more recent year (i.e. rather 2011 than 2009).

Due to the multitude of global environmental challenges (Steffen et al., 2015) and pathways towards sustainable intensification (Weltin et al., submitted), it is unfeasible to analyse all possible environmental opportunities and measures at continental scale. We focus on the three most vital resources: land (Eitelberg et al., 2015), water (Scherer and Pfister, 2016a), and soil (Keesstra et al., 2016). These resources are not only vital for ecosystems, but are also limiting for agricultural production providing food to humans. Like challenges and pathways, the determinants of pro-environmental behaviour are numerous and complex (Bamberg and Möser, 2007) and were, therefore, simplified based on the best information available. By balancing the available information and the complexity of modelling, this study aims to provide an overview of opportunities for sustainable intensification in Europe. It illustrates the potential for sustainable intensification and points to priority areas for more detailed assessments.

2.2. Socio-economic opportunities

To map socio-economic opportunities for sustainable intensification, we used spatial proxies for the adoption of innovation and sustainable practices among farmers and consumers, derived from a literature review. Farmers open to innovation and sustainability tend to be younger, be better educated and have larger farms (Genius et al., 2006; Passel et al., 2007; Koesling et al., 2008; Lobley et al., 2009; Gómez-Limón and Sanchez-Fernandez, 2010; Zagata and Sutherland, 2015; Degla et al., 2016; Pavlis et al., 2016). The type of tenure is important because farmers tend to adopt more sustainable practices on owned land than on rented land (Fraser, 2004; Kassie et al., 2015). If farmers own the land, they are more willing to invest (Kabubo-Mariara, 2007) and to participate in agri-environmental schemes (Walford, 2002).

Besides the role of consumers for demand-side measures, consumers might also influence farmers either through vendor-customer interactions (Hunt, 2007) or through social norms within the society (Fehr and Fischbacher, 2004) both belong to. Among consumers, potential for pro-environmental behaviour (including consumption) was found to be associated with various character traits and behaviours. First, post-materialistic attitudes favour pro-environmental behaviour (Inglehart, 1995; Franzen and Meyer, 2010; Salonen and Åhlberg, 2013). Post-materialism refers to a change of values emphasizing material needs and luxuries to emphasizing self-expression and life quality (Inglehart, 1995). Second, although environmental concerns might not be the main motivator to purchase organic food (Hughner et al., 2007; Kriwy and Mecking, 2012) or to be a vegetarian (Fox and Ward, 2008; Hoffman et al., 2013), both types of consumers still demonstrate pro-environmental attitudes. We used organic sales and a low or decreasing consumption of meat as proxies for the relative share of such consumers. Third, we approximated pro-environmental attitudes by affiliations with environmental NGOs and agreement to hypothetical donations for the environment.

The data sources for the parameters mentioned above are described in Table 1. Eurostat data (EC, 2016) are given as ordinal variables. In absence of more detailed information, the class reflecting the highest opportunity was assigned the value 1, while the class reflecting the lowest opportunity was assigned the value 0. Where only one additional categorical class exists, it was assigned the value 0.5. Where several other interval classes exist, the values were scaled between 0 and 1 depending on the mid-range value of the class compared to the two boundary values (Table A1-A4 in the Appendix). The continuous variables describing consumers were scaled to range from 0 to 1 based on their minima and maxima. In addition, pairwise Pearson correlation analysis were carried out to support the interpretation of the results.

In an intermediate step, socio-economic parameters were averaged