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Potential and limits of land and soil for sustainable intensification of European agriculture

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ABSTRACT

Population and consumption growth causes a 50% greater demand for food and fiber in the next 35 years. This causes increasing pressure on agricultural production often accompanied by an increasingly degraded environment. To overcome this problem, the concept of “sustainable intensification” (SI) was introduced. The concept recognizes the need to simultaneously increase agricultural productivity and further reduce negative environmental impacts. So far, the importance of soil and its natural resilience was not included into the studies of SI. The aim of this study was to identify and localize arable soils with a high potential of recovery after disturbances (i.e. resilience) in Europe. Therefore, in a first step we attributed the new LUCAS 2009 topsoil data from 25 EU member states to the arable land in the Corine Land Use Cover 2006 data set as well as to the European digital soil map (ESDB). This resulted in the identification of 671,672 km^2, approximately two-thirds of the total arable land in Europe. In a second step, a recently established classification scheme based on 6 intrinsic soil and land indicators (i.e. soil pH, contents of soil organic carbon and clay plus silt, cation exchange capacity, soil depth, slope) was applied to the arable land. These six measured soil indicators try to comprise the main biochemical and physical soil properties influencing soil resilience. The results show that from a soil perspective, almost half (44%) of the investigated arable land cannot be recommended for SI. More than 3% of this area should be de-intensified in order to reduce environmental harm. 16% of the arable land can be recommended for SI with restrictions, whereas 40% of arable land has the potential for SI without impacting the delivery of goods and services provided by soils. The application of the presented classification scheme on a local study area (1.56 km^2) in Central Europe revealed clearly that for any final decisions on SI it is important to consider the heterogeneity of soil at the local scale. Our results of this and a previous study demonstrate that the presented classification scheme can be used on different scales including the local, regional and continental scale.

1. Introduction

to actual UN predictions, the world population will increase by more than 9 billion by 2050 causing a more than 50% greater demand for food (Alexandratos and Bruinsma, 2012). There is also a higher food demand due to higher consumption and a shift in diet to more meat, dairy and fish products (Godfray et al., 2010).

This higher demand can be fulfilled either by expanding cropland and harvested area, and/or by an intensification to increase crop yields (Pradhan et al., 2015). In the European Union (EU-27) agriculture is the dominant land use (accounting almost half of the land area) also impacting areas outside agricultural production (Stoate et al., 2009). The potential for additional agricultural land is much lower than previously assumed if constraints and trade-offs are taken into account (Lambin et al., 2013). Further, expansion of arable land (due to low yield agriculture) is associated with significant social and ecological costs. Avoiding a conversion of natural land to arable land has a benefit for biodiversity (Phalan et al., 2011) as well as to other important ecosystem services (Garnett et al., 2013).

Protecting natural land would only be possible with an increase of yields due to intensive agriculture to reach the future food demand. On a global scale, agricultural intensification increased the consumption of all fertilizers by fourfold (nitrogen fertilizers

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by sevenfold), caused a dramatic increase in the use of pesticides and led to a double amount of area under irrigation and agricultural machines in the last decade (Pretty, 2008).

A further increase of these factors would force eutrophication of groundwater and surface waters, habitat destruction accompanied by unprecedented ecosystem simplification, loss of ecosystem services, and species extinctions (Tilman et al., 2001).

To combine an intensive food production with avoiding these negative environmental impacts, the European Union decided to push its agriculture towards a "sustainable intensification" (Fischler and Pirzio-Biroli, 2014). The concept "sustainable intensification (SI) of agriculture" was introduced in 2009 by The Royal Society London who defined SI as a form of agricultural production where "yields are increased without adverse environmental impact and without the cultivation of more land" (The Royal Society London, 2009).

SI does not mean intensification by simply increasing the use of environmentally harmful agricultural inputs. The main objective of SI is to improve the resource efficiency of agriculture which can consequently lead to a further intensification by an increase of yield per hectare (Buckwell et al., 2014). SI in agriculture should minimize uses which cannot be reversed within 100 years or 4 human generations (e.g. like sealing, excavation, sedimentation, severe acidification, contamination, and salinization). This can be achieved by recognizing the importance and opportunities of appropriate agricultural production practices and management (Tilman et al., 2002; Mueller et al., 2012a,b; Pisante et al., 2012). These practices and management strongly vary and are depended on the conditions and the actual agricultural productivity and environmental performance of a special farm or system (Buckwell et al., 2014). The concept of SI should include the soils natural fertility (intensity aspect) and its ability to buffer possible negative environmental consequences (sustainability aspect).

A globally performed study by Blum and Eswaran (2004) showed that every soil has a different capacity to produce food which is one of its six soil ecosystem functions. These six soil ecosystem functions are (1) biomass production (2) chemical buffering, mechanical filtering and biochemical transformation of compounds between the soil surface and the groundwater, (3) gene reservoir, (4) physical basis for human infrastructure, (5) source of raw materials and (6) geogenic and cultural heritage (Blum, 2005). However, especially intensive land management often leads to tradeoffs and competitions between these functions (e.g. food production versus carbon sequestration or biodiversity loss) (Raudsepp-Hearne et al., 2010).

Since the green revolution the main focus of intensive agriculture was mainly on the productivity and the soils fertility to produce over long time periods (=performance) There was an increasing environmental awareness in the last decades but most of the existing intensively farmed agricultural land is not managed sustainably in Europe (Buckwell et al., 2014). The concept of natural soil resilience has to be considered for a sustainable land use (Blum and Santelices, 1994). Soil resilience is the capacity of a system to return to (a new) equilibrium after disturbance (Blum, 1994). Resilient soils have a high rate of recovery, a high elasticity, high buffering capacity, low malleability and may also be hysteretic because of intrinsic soil properties that influence the recovery path (Lal, 1997). Soil resilience is influenced by highly variable soil intrinsic properties (e.g. Blum and Eswaran, 2004). Compared to soil properties like poor soil nutrient status which can be overcome with an appropriate fertilization management (Pradhan et al., 2015), some of the intrinsic soil properties (e.g. soil depth and texture) cannot be changed by farmers. Resilience is based on functional soil characteristics like soil depth, texture, pH, CEC and contents of OM whereas agricultural performance depends on additive parameters like nutrient availability, biological activity and others which are normally reached by fertilization application and pH adjustment. In highly resilient soils the application of fertilizers and pesticides can be transformed into performance. In soils with low resilience, fertilizers and pesticides application leads to environmental pollution, e.g. of the groundwater.

A detailed review bringing together all important factors concerning SI was published by the RISE foundation in 2014 (Buckwell et al., 2014). In a case study a first draft of a classification scheme based on biogeochemical and physical soil processes was created. This scheme is based on the concept of resilience to define appropriate land for SI of agriculture in Europe. This scheme is based on six indicators including soil pH, contents of soil organic carbon (SOC) and clay plus silt, cation exchange capacity (CEC), soil depth and slope. It was further developed and used in a following study.

In Schiefer et al. (2015) the classification scheme was compared to a detailed survey on natural yield potentials (i.e. natural fertility) of soils in Germany described in Mueller et al. (2007, 2012a,b). This study showed that soils with high soil resilience (Schiefer et al., 2015) always overlapped with highly natural fertile soils (study by Mueller et al., 2007, 2012a,b). However, soils with a high fertility were not always highly resilient. This underlines the importance of including the concept of soil resilience in any SI study.

In this study our first objective was to test the applicability of the recently developed arable land classification scheme of soil resilience on the field (local) scale and to compare with soil fertility data.

Further, our second objective was to identify arable land in Europe with high soil resilience on the basis of the developed classification scheme (Schiefer et al., 2015) and new available soil data of a recent survey in the EU-25 (LUCAS 2009). Soil resilience defines the potential of arable land for sustainable agricultural production and therefore the limits for sustainable intensification (SI) (Buckwell et al., 2014). Consequently, recommendations can be given where cropping areas in EU-25 can be used predominately for SI and where arable land should be managed with precaution to control environmental risks.

Table 1
Soil and land indicators and its affected properties for a high soil resilience.

Soil and Land indicators	Biochemical and physical processes affected
(1) SOC[a]	Most physical, chemical and biological processes: increases water holding capacity, soil structure, aggregation filter transformation and buffer capacity and bulk density; represents a source of plant nutrients, source of energy for soil organisms;
(2) Clay + Silt	Formation of clay- humus complexes and aggregation; increases surface area of the soil and amount of plant available water; decreases the leaching potential;
(3) pH and (4) CEC[b]	Mobility and availability of nutrients; leaching potential; biodiversity
(5) Depth	Rooting depth; filter, buffer and transformation capacities; pollutant and nutrient storage;
(6) Slope	Erosion and loss of soil;

[a] SOC = Soil organic Carbon.
[b] CEC = Cation exchange capacity.