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Indicators for the definition of land quality as a basis for the sustainable intensification of agricultural production

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Abstract

Sustainable intensification (SI) is a concept for increasing agricultural production under sustainable conditions to meet the needs of the growing population of the world. To achieve this goal, the intrinsic potential of soils for SI has to be considered. This report aims at identifying indicators for arable soils in Germany, which have the best natural resilience and performance and therefore can be used for SI. Six intrinsic land and soil characteristics (organic C content, clay + silt, pH, CEC, soil depth and slope) were selected as indictors for defining the resilience and performance of land. New data from arable sites from LUCAS topsoil survey 2009 were used and attributed to arable land, applying the Arc Geographical Information System (ArcGIS). The results of this investigation reveal that 39% of the actual analyzed arable land can be recommended for SI in Germany. A comparison with the Muencheberg Soil Quality Rating shows that most of this land reflects the highest potential for agricultural yields. Approximately 61% of the analyzed agricultural land is not suitable for intensification, about 1.5% should be reduced in intensity with a possible conversion to avoid environmental harm. The most frequent limitation factor for SI is a too low cation exchange capacity in German soils.

Keywords: Agriculture; Soil resilience; Soil performance; Soil properties; Environmental protection

1. Introduction

By 2050, the world population will reach more than 9 billion people according to UN projections (Alexandratos & Bruinsma, 2012). Besides population growth, higher per-capita income will increase the demand for food (Godfray et al., 2010). The process of agricultural intensification, including the introduction of new crop varieties, the use of agro-chemicals, and fossil energy driven mechanization, has caused positive effects such as the growth of agricultural output, increasing consumer wealth (Schönhart, Schauppenlehner, Schmid, & Muhar, 2011). However, for future predictions there are serious concerns that the actual increase of yields will be too slow to meet the growing demand for food in many areas (Ray, Mueller, West, & Foley, 2013). Moreover, the ecosystems of the world that produce

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food, feed and fiber, are to a great extent degraded or used unsustainably (Montanarella & Vargas, 2012). The intensification of agriculture is accompanied by negative impacts on the quality of soil, water, air and biodiversity. On the contrary, studies show that high-yield farming can protect natural habitats from conversion to agriculture, and it therefore has less negative impacts on biodiversity than enlarged wildlife-friendly farming (Phalan, Balmford, Green, & Scharlemann, 2011).

A possible solution to meet the increasing food demand of future generations without harming the environment is sustainable intensification (SI). Garnett and Godfray (2012) define SI as “increasing yields per unit inputs” which means that (per area land) higher yields should be produced with less environmental impacts (per unit yield). In the sense of SI, any system which depends on non-renewable inputs is unsustainable. It cannot consistently and predictably deliver desired outputs, except by requiring the cultivation of more land, thus causing adverse and irreversible environmental impacts which threaten critical ecological functions (The Royal Society London, 2009).

Soils perform a variety of environmental, social and economic functions like (1) biomass production for different uses; (2) buffering, filtering and biochemical transformation; (3) gene reservoir; (4) physical basis for human infrastructure; (5) source of raw materials and (6) geogenic and cultural heritage (Blum, 2005). Sustainable land use has to harmonize the use of these six soil functions in space and time, minimizing uses which cannot be reversed within 100 years or 4 human generations (e.g. sealing, excavation, sedimentation, severe acidification, contamination, and salinization).

An environmental friendly intensification of agriculture cannot be implemented without considering the capacity of soils to fulfill additional ecological functions besides the provision of food and biomass. As food security is intimately related to soil security and sustainable agriculture (The Royal Society London, 2009), the resilience and performance of soil under intensification must be considered (Blum & Eswaran, 2004).

In this context, we only consider the three ecological functions: biomass production; filter, buffer and transformation processes and gene reserve (biodiversity).

In this sense, sustainable agriculture combines the concepts of resilience (the capacity of systems to return to (a new) equilibrium after disturbance) and performance (the capacity of systems to produce over long periods), thus addressing wider economic, social and environmental targets.

The main objective of this work is to identify the most important soil intrinsic indicators, which define the concept of soil resilience and performance according to the ecological functions provided by soil. The chosen indicators were applied in Germany and identified SI land categories compared to the Muencheberg Soil Quality Rating, thus allowing the SI scheme applicability for testing. Moreover, we analyzed the relationship between land suitability for SI and its agricultural yield potential.

2. Definition and identification of indicators for SI

Indicators provide information for understanding and managing land according to soil resilience and performance. Criteria for indicators reflect ecosystem processes and integrate physical, chemical, and biological properties and their sensitivity to management and climatic variations (Doran, Sarrantonio, & Liebig, 1996). Moreover, indicators must be easily measurable and understandable for specialists, as well as for politicians, decision makers and farmers at the grassroot level (Doran et al., 1996). To define the capacity of soil systems providing the above mentioned goods and services, no single indicator can cover all aspects, nor would it be feasible (or necessary) to analyze all possible influencing indicators (Kibblewhite, Ritz, & Swift, 2008).

The methodological concept of this study is based on the fact that fertile soils with specific characteristics have a high resilience against physical, chemical and biological disturbances and also show a high performance by producing a maximum amount of agricultural commodities if managed safely. We selected 6 specific land and soil characteristics, which indicate the resilience and performance of land based on available literature and expert knowledge.

The intensification of an environment friendly agricultural production by cropping should be avoided on sites located on slopes with a steepness above 25%. An increased erosion probability could cause irreversible soil losses. Generally, deep soils with a high clay and silt content retain nutrients and avoid the contamination of groundwater. Those soils also have a better water retention capacity and can therefore withstand periods of drought. An important factor concerning SI is soil organic matter (SOM) which is the basis of soil biology, also further influencing soil properties such as the filter, buffer, transformation and water holding capacity. Soil organic matter is defined as all