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A methodological approach for deriving regional crop rotations as basis for the assessment of the impact of agricultural strategies using soil erosion as example

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ABSTRACT

Regarding increasing pressures by global societal and climate change, the assessment of the impact of land use and land management practices on land degradation and the related decrease in sustainable provision of ecosystem services gains increasing interest. Existing approaches to assess agricultural practices focus on the assessment of single crops or statistical data because spatially explicit information on practically applied crop rotations is mostly not available. This provokes considerable uncertainties in crop production models as regional specifics have to be neglected or cannot be considered in an appropriate way.

In a case study in Saxony, we developed an approach to (i) derive representative regional crop rotations by combining different data sources and expert knowledge. This includes the integration of innovative crop sequences related to bio-energy production or organic farming and different soil tillage, soil management and soil protection techniques.

Furthermore, (ii) we developed a regionalization approach for transferring crop rotations and related soil management strategies on the basis of statistical data and spatially explicit data taken from so called field blocks. These field blocks are the smallest spatial entity for which agricultural practices must be reported to apply for agricultural funding within the frame of the European Agricultural Fund for Rural Development (EAFRD) program. The information was finally integrated into the spatial decision support tool GISCAME to assess and visualize in spatially explicit manner the impact of alternative agricultural land use strategies on soil erosion risk and ecosystem services provision. Objective of this paper is to present the approach how to create spatially explicit information on agricultural management practices for a study area around Dresden, the capital of the German Federal State Saxony.

1. Introduction

As part of climate change research, land use, land use changes and the regional consequences on landscape scale have received increasing attention. The agricultural sector represents worldwide one of the major land uses: about 38% of the global land (FAO-Stat, 2012) and over 40% of land in the European Union is in agricultural use (EuroStat, 2012). In Germany, the agricultural area amounts to 48% (FAO-Stat, 2012) and in Saxony to 49.6% (LfULG, 2011a). Even when focusing exclusively on arable farming, agricultural management practices are diverse and address, for instance, the question of optimal crop rotations, soil tillage techniques, and fertilizer management. These aspects play an eminent role, when intending to describe the impact of agricultural management on soil erosion risk and sustainable provision of ecosystem services and neglecting this information will provoke an over- or underestimation of the role impact of agricultural land use as such. Especially when coming to impact assessment at landscape scale, a need to harmonize the temporal dynamics of the different land use systems can be identified and agricultural land use classes must be defined that account better for inter-annual aspects and do not refer only to specific crops. In consequence, use of crop rotations would be more favorable for landscape scale related impact assessment (see e.g.,

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Leteinturier et al., 2006). Crop rotations drive the whole agricultural management, for example nutrient supply and efficiency (Smith et al., 2008), nutrient leaching (Broussard and Turner, 2009), suppression or promotion of pests and diseases and type and technique of soil tillage. Furthermore, a diverse and regionally adjusted crop rotation can split and lower the farm risks due to weather-related extreme events (Howden et al., 2007).

Still, most approaches on modeling agricultural land use and especially crop production focus on single crops and statistical data because more concrete or even spatially explicit information on crop rotations is often not available or highly aggregated in a manner that restricts the use of this information. However, already some models are available to derive crop rotations by so-called expert knowledge (e.g., Rode et al., 2009) or combinations of statistical data and expert knowledge (e.g., Schönhart et al., 2011; Castellazzi et al., 2008; Bachinger and Zander, 2007; Dogliotti et al., 2003; Stöckle et al., 2003). Crop rotations are used, for instance, in bio-physical process models or economic models on farm level (Janssen and van Ittersum, 2007; Renton and Lawes, 2009; Schuler and Sattler, 2010) to assess environmental impacts (e.g., Bechini and Stöckle, 2007; van Ittersum et al., 2008), whereas economic farm models optimize micro-economic or management aspects (Rounsevell et al., 2003; Dogliotti et al., 2003; Piorr et al., 2009). Auerbacher and Dabbert (2011) presented a method to bridge the gap between farm management models and bio-physical process models in generating crop rotations by using maximum entropy and Markov chains.

One of the main problems in using crop rotations in integrated land use modeling is the lack of empirical data (Schönhart et al., 2011). Therefore, the implementation is often based on selected case studies, farm surveys or expert and modeler knowledge (e.g., Belcher et al., 2004; van Ittersum et al., 2008; Rode et al., 2009), whereas the currently applied crop rotations, especially on regional scale, are unknown. Furthermore, the spatial scale of land use models varies from single farm level to catchment, sub-regional or regional level and it pursues different objectives (e.g., varying environmental impacts, economic benefits, management strategies and optimization, etc.).

Additionally, spatial allocation of crop rotations and cropping systems plays a fundamental role, but is also a weak point and source of uncertainty in deriving environmental impacts at regional scale (see e.g., Rounsevell et al., 2003; Castelazzi et al., 2007; Thenail et al., 2009; Dury et al., 2010; Leenhardt et al., 2010).

In consequence, models are faced to high uncertainty on crop rotations, related soil management and fertilizing practices as such and on their spatial location and are often forced to ignore regionally specific management practices that are not only driven by bio-geo-physical factors, but often by cultural heritage. However, reliable assessment of the impacts of different land use practices and their spatial constellation is requested to assess, plan, manage and control strategies to cope with climate change, migration processes and the threat of land degradation.

In this paper we present an approach how to combine data to derive regionally characteristic crop rotations with related tillage and soil protection measures to come to agricultural land use classes that can be used for assessing the impact of alternative agricultural land use patterns. We show how these agricultural land use classes can be scaled-up based on spatially explicit information at level of so called “field blocks” in which agricultural management practices have to be documented for agricultural funding within the frame of the European Agricultural Fund for Rural Development (EAFRD) program.

Our agricultural land use classes where subsequently integrated in to the spatial decision support tool GISCAME (Fürst et al., 2010a,b) and were used together with forest land use classes to explore potentials of an adapted land use to contribute to the mitigation of climate change effects (Fürst et al., 2011, 2012, 2013; Koschke et al., 2013).

2. Material and methods

2.1. Study area and agricultural sub-regions

The 4800 km^2 large study area is located around Dresden, the capital of the German Federal State Saxony, East Germany (Fig. 1). Pedogenic and climatic conditions vary over a gradient from dry lowland climate with diluvial sandy soils or loess soils in the north and middle to low mountain range climate with acidic brown soils in the south. Using environmental factors relevant for agricultural production, Winkler et al. (1999) divide Saxony in 12 agricultural sub-regions which reflect the bio-geo-physically driven diversity of agricultural land use practices (Fig. 1). The model region encloses parts of the sub-regions (1) Lausitzer Heide- und Teichgebiete, (2) Lausitzer Platte, Oberlausitzer Bergland, (3) Elbsandsteingebirge and Zittauer Gebirge, (4) Nördliche Erzgebirgsabdachung, (5) Erzgebirgskamm, (7) Mittelsächsisches Hügelland and (8) Mittelsächsische Platte.

A comparison to statistical data (LfULG, 2011b) of sub-region 3 (Elbsandsteingebirge), which was not used as input for the initial calculation of crop shares, is conducted for validating the results. Sub-region 3 was selected because it is the only sub-region which is completely present (a) in the model region and (b) in all available statistical data from agriculture (see chapter 3.3).

To create a level of information aggregation relevant for rural planning, these sub-regions are subsequently clustered into soil type regions (STR) which allow for concluding on major environmental factors and related risks for land degradation caused by agricultural land use (Winkler et al., 1999). To ensure compatibility with rural planning, our agricultural land use classification approach is based on the STR. Table 1 provides an overview on the three STR, which are relevant in our model region, namely diluvial soils region, loess soils region and deeply weathered bed rock soils region.

2.2. Methodological approach

To ensure compatibility with rural planning, our agricultural land use classification approach is based on the STR by Winkler et al. (1999).

2.2.1. Regional crop rotations

To derive our agricultural land use classes, we made some assumptions: to reduce complexity of agricultural management practices to a meaningful and processible level, we restricted our number of potential agricultural land use classes to 10 per STR, i.e., in sum we focused on providing 30 regionally characteristic agricultural land use classes for the later impact assessment. In addition, one “reference” crop rotation was integrated to represent the impact of perennial grass or fodder production on arable land (A1). Clovergrass was chosen as an example, because of its spatial representativeness in the model region.

This limitation to 30 + 1 additional agricultural management classes was a consensus with regard to the parallel integration of additional forest management classes (Fürst et al., 2011, 2012) and intended to provide a proper base for assessing the impact of different agricultural and forest land management strategies on the provision of ecosystem services in qualitative manner on a scale from 0 (no/worst provision of services) to 100 (highest possible provision of services). A more detailed classification resulting in an even higher number of classes would have provoked problems in