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Research Paper

Identifying crop rotation practice by the typification of crop sequence patterns for arable farming systems – A case study from Central Europe

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ABSTRACT

During the last decades crop rotation practice in conventional farming systems was subjected to fundamental changes. This process was forced by agronomical innovations, market preferences and specialist food processing chains and resulted in the dominance of a few cash crops and short-term management plans. Classical crop rotation patterns became uncommon while short rotations and flexible sequence cropping characterize the standard crop rotation practice. The great variety and flexibility in cropping management as a reaction to economic demands and climatic challenges complicate the systematization of crop rotation practice and make historical systematization approaches less suitable. We present a generic typology approach for the analysis of crop rotation practice in a defined region based on administrative time series data. The typology forgoes the detection of fixed defined crop rotations but has its focus on crop sequence properties and a consideration of the main characteristics of crop rotation practice: i) the transition frequency of different crops and ii) the appropriate combination of crops with different physical properties (e.g. root system, nutritional needs) and growing seasons. The presented approach combines these characteristics and offers a diversity-related typology approach for the differentiation and localization of crop sequence patterns. The typology was successfully applied and examined with a data set of annual arable crop information available in the form of seven-year sequences for Lower Saxony in the north-western part of Germany. About 60% of the investigated area was cropped with the ten largest crop sequence types, which represent the full range of crop pattern diversity from continuous cropping to extreme diversified crop sequences. Maize played an ambivalent role as driver for simplified rotation practice in permanent cropping on the one hand and as element of diversified sequences on the other hand. It could be verified that the less diverse crop sequence types were more strongly related to explicit environmental and socio-economic factors than the widespread diverse sequence types.

1. Introduction

Crop rotation has always been a cornerstone in annual cropping systems. However, farmers operate between different and often contrary objectives and demands for planning their crop cultivation. Market preferences, specialist food processing chains as well as political objectives forced the dense rotation of cash crops and short-term management plans in conventional farming systems (Fraser, 2006; Bennett et al., 2011; Bowman and Zilberman, 2013; van Zanten et al., 2014). This was supported by enormous progress in plant protection and plant breeding as well as technological advances during the last decades. In many parts of Europe these developments resulted in the dominance of a few crops and a reduction in crop diversity. Fixed cyclical crop rotations are increasingly being replaced by short sequences of two or three years (Leteinturier et al., 2006; Glemnitz et al., 2011). Hence, decreasing crop diversity is one characteristic of agricultural intensification which affects the biodiversity of agricultural landscapes and related ecosystem services in a negative way (Tscharntke et al., 2005). The repeated cultivation of the same crop with the same management practices has negative effects on the soil quality and increases the risk for an accumulation of harmful organisms like weeds, pests and diseases, which can result in yield decline (Karlen et al., 1994; Berzsenyi et al., 2000; Ball et al., 2005; Bennett et al., 2011).

Political measures to address these challenges are already implemented. Recently, the European Commission targeted the connection between intensive agricultural production and ecosystem services decline in its Biodiversity Strategy 2020 and in the Common Agricultural Policy (CAP) reform in 2014 (European Commission, 2011; Science for Environment Policy, 2015). The latter rewards the preservation of environmental public goods such as crop diversification in the direct payments (European Parliament, 2013). Another recent example of increasing political attention on crop rotation diversification is

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the EU members' efforts regarding the efficient use of plant protecting measures in accordance with the aim of integrated pest management and sustainable agriculture (Boller et al., 1997; European Commission, 2007a; European Parliament, 2009). The increase of functional diversity over a crop rotation course has been argued to reduce resource-competing crop–weed relations and is therefore an important measure of non-chemical weed management and integrated farming (El Titi et al., 1993; Blackshaw et al., 2007; Smith et al., 2009; Melander et al., 2013). Crop sequences with a high grade of structural and functional diversity have positive effects on the function of the agroecosystem and its capacity to generate ecosystem services (Altieri, 1999; Zhang et al., 2007). Further, the diversification of agricultural systems is considered as an adaptation for changing thermal and hydrological conditions in the future (IAASTD, 2009; Lin, 2011). However, a crop rotation classification focusing on both diversity properties − functional and structural diversity − is missing so far. We present a new crop sequence typology approach to close this gap. A crop sequence typology facilitates the detection and localization of crop rotation patterns which can help to estimate trends and locate risks in agricultural land use and to assess the vulnerability or resilience of an agricultural system (Abson et al., 2013). Together with the crop management system crop rotation is the key element to investigate land use intensity and describe cropping systems (Leenhardt et al., 2010; Glemnitz et al., 2011; Steinmann and Dobers, 2013). We demonstrate the potential of the presented typology to describe cropping systems by qualifying the diversity aspect of crop sequences in a study area and examine the linkage of the generated crop sequence types with landscape factors.

The typification of crop sequences by their diversity aspects depends strongly on the availability of crop data. Improvements in the collection and storage of spatially explicit and high-resolution crop data have made a comprehensive detection of crop rotation practice much easier. A recent example is the Integrated Administration and Control System (IACS) of the EU and its land parcel information system, which stores area-based annual crop information for administrative purposes. Beside this, the data offers a vast amount of information on current agricultural land use (Levavasseur et al., 2016). However, the crop rotation analysis from those data sets requires the development of methods for structuring large crop data sets in spatial and temporal dimensions. Administrative data usually store time series information on the presence of annual crops on a given parcel. A series of crop presence data represent sections or segments of rotations with a possible rotation start in the middle or at the end of the series. A further challenge is the trace of one rotation over time if the parcel boundaries within a field block change from one year to another. Hence, the analysis of these sequences for crop rotation questions requires appropriate treatment.

A well-known problem of recent studies which analyzed the crop rotation practice in a defined region from time series is the high number of different crop combinations and the relatively low occurrence of each combination type. Previous studies solve this by analyzing short individual sequences of two or three years (Leteinturier et al., 2006; Long et al., 2014). Although this method provides information on the relation of crop and previous crop, the real rotation pattern remains concealed.

Tools for crop rotation modelling and prediction based on agronomical rules or farm-scale decision-making processes are well established for integrated and organic farming systems at the regional and landscape scale (Rounsevell et al., 2003; Stöckle et al., 2003; Klein Haneveld and Stegeman, 2005; Bachinger and Zander, 2007; Schönhart et al., 2011). Although these studies are very important and the tools are also useful for the evaluation of crop rotation practices, they are only partly suitable for sequence typology. An important approach for the characterization of crop rotation practice in a defined region based on internal structure and cyclical pattern was presented by Castellazzi et al. (2008). The scientists studied crop sequences with a straight mathematical approach which describes rotations as probabilities of crop succession from the pre-crop to the main crop by using transition matrices of a Markov chain. This so-called first-order Markov model was also applied by other research groups for modelling spatial aspects of cropping systems (Salomon-Monviola et al., 2012; Aurbacher and Dabbert, 2011). A continued development of this approach was the implementation of second-order hidden Markov models, which allows modelling based on the pre-crop and the pre-pre-crop of the main crop (Le Ber et al., 2006; Mari and Le Ber, 2006; Xiao et al., 2014). The filtering of big data sets by this method requires though a fixed definition of the searched crop sequence concerning length, crop order and the frequency of crop occurrence (Xiao et al., 2014). These are limiting requirements for the mining of unstructured sequence data.

A historical example of a crop rotation typology in a classical sense was presented by Brinkmann (1950) for the seasonal arable cropping systems in Germany. For Brinkmann the main criterion to distinguish regional crop rotation types was the ratio of cereal crops and leaf crops within a rotation. Leaf crops were here defined as dicotyledonous crops with a high proportion of leaf surface like potato, legumes or sugar beet. The crops have positive impact on soil structure, soil fertility and serve as a break crop for cereals. However, this typology approach does not comply with recent crop rotation practice due to the increased role of comparably new crops in European cropping systems like maize. Maize is a symbol crop for the disregard of crop rotation rules and the practice of permanent cropping on the one hand a profitable spring crop with the potential to improve the pure winter crop rotations on the other hand. So, the presented typology approach complement the leaf crop-cereal crop distinction by the distinction of spring crops and winter crops to consider the special role of maize in the rotation practice and to complete the qualitative aspects in the typification. Typology approaches of the more recent past operate mainly with the quantitative and structural characteristics of crop rotations like the amount of different crops or the minimal return time of a crop (Leteinturier et al., 2006). This is a methodological reaction to the fact that farmers today face a complex decision-making process to draw up their cropping plan and react more often with the adaptation of crop sequence parts from one season to the next and the abandonment of planned crop rotations with a length of more than three years (Bennett et al., 2011; Dury et al., 2013). Our presented typology approach builds a bridge between the qualitative focus of historical crop rotation systematization and the quantitative perspective of most recent systematization approaches.

2. Materials and methods

2.1. Research area

Lower Saxony is a federal state in north-western Germany in Central Europe (DE9 in the European Nomenclature of Territorial Units for Statistics NUTS 1). The study area is characterized by a great variety of landscape types, with a marshy coastal area in the north and moraine deposits in the east and west, dissected by river plains which also formed the hilly uplands in the south. Fertile lowland with loessial soils stretches in the transition area from the moraine landscapes to the uplands. These regions are dominated by arable farming with cash crops such as sugar beet (*Beta vulgaris* subsp. *vulgaris*), oilseed rape (*Brassica napus*) and winter wheat (*Triticum aestivum* L.). The cultivation of maize (*Zea mays* L.) has increased in all parts of Lower Saxony during the last ten years but plays the biggest role in the western and northern parts, where it is linked with traditional structures of livestock farming and new structures of biogas production. These four crops are considered highly important for arable land use and crop sequence composition due to their proportion of the cropped area (maize, wheat; see Table 1) and their specific economic importance as cash crops (sugar beet, oilseed rape).

The observed area is located in a temperate climate zone with maritime influence in the northwestern part and a stronger continental character to the east. Annual precipitation ranges from 560 mm*yr^{-1} to 1200 mm*yr^{-1} with a mean of 750 mm*yr^{-1} (DWD, 2014) (Fig. 1).