Spatial analysis of crop rotation practice in North-western Germany

Dissertation

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Meinem geliebten Mann Carsten gewidmet,

der hierfür unzählige Stunden im Zug und einsame Abende in Kauf genommen hat.

Content

Introduction

Crop rotation means the systematic cultivation of different crops on the same land in a recurring sequence (Liebman and Dyck, 1993). This involves growing crops in a useful order considering crop-to-crop compatibilities and management processes. The principles of crop rotation are as old as arable land use itself and have already been scientifically described in the 19th century (e.g. Daubeny, 1845). A well-adapted crop rotation has positive effects on the soil fertility and all factors of the field ecosystem services like the water and nutrient cycle, humus content, and the diversity and density of yield supporting or reducing micro- and macro-organisms (Karlen et al., 1994). Variety of the weed flora and related species like invertebrates is strongly determined by the kind of crop and its order in a sequence and improves, therefore, phytosanitary conditions (Blackshaw et al., 2007; Smith et al., 2008; Melander et al., 2013). Changing the main crop and, consequently, the soil tillage and the residue regime has positive effects on the soil, such as diversified microorganism community, improvement of the soil aggregates stability, bulk density, and hydraulic properties (Blanco-Canqui and Lal, 2009; Tiemann et al., 2015). Short rotations may result in degradation of soil structure and fertility as well as force soil erosion (Bullock, 1992).

Even if crop rotation is a fundamental agricultural instrument for each farmer, the *green revolution* (1950-1970) with synthetic fertilizers and pesticides, high yielding crop varieties, and modern machinery seemed to replace the rules of crop rotation/effect (Bullock, 1992). The impact of these developments was enforced in the following decades by an enormous grew in the world agricultural trade and increased importance of economic drivers apart from the regional scale. The rotations became simplified and short. Today it is political consensus again that crop rotation serves as an instrument to reduce chemical inputs and grants sustain soil fertility (European Commission, 2010). Negative side effects of intensive agriculture, like soil degradation and resistant weeds, force the need to reintroduce crop rotation (Kay, 1990).

This dissertation was developed in the light of a significant increase of the Lower Saxonian maize acreage in a comparably short period of time, from about 355.000 ha in 2005 to about 610.000 ha in 2011, whereby one-third of the latter was maize for biogas production (NMELV, 2013). One reason for this development was the amendment of the Renewable Energy Act (EEG) in 2004, which included bonuses for energy plant production. The change of the crop rotation practice started a long time before, for the reasons mentioned above. The intensive livestock farms, which are located mainly in the North-western part of Lower Saxony, namely the Weser-Ems region, had high maize acreage of more than 30% already before the biogas plant developments. The historical as well as recent developments, lead to the question, whether there are still patterns of crop rotation detectible or not. What are the present crop rotation patterns in Lower Saxony? Since I am a geographer by training, including the spatial dimension in my analysis seemed natural. Are there regional patterns of crop rotation in Lower Saxony? And what are the driving forces for the formation of these patterns? The first step for answering these questions was to analyze the spatial crop distribution in one year. To use the crop statistic of one year is the most common way to derive crop rotation, usually quantified by the Shannon Index (e.g. Monteleone et al., 2018).

The first chapter of this thesis presents an alternative approach, the formation of regional crop clusters. This allows for comparing the spatial congruency of the crop clusters with clusters of site conditions, e.g. soil texture, arable farming potential, precipitation, and livestock density. The results of that one-year-analysis build the fundament for the detection of regional crop rotation patterns in a seven-year-analysis and enlightened the driving forces for these patterns, as explained in the second chapter. To answer this central question of my study was possible due to the lucky coincidence of having access to an enormous set of data. It included information on the main arable crop at field scale in Lower Saxony for the years 2005 to 2011 for which the farmers received direct payments from the European Union. The source of the data is the Integrated Administration and Control System (IACS), which helps farmers and authorities with the area-based administration of the yearly agricultural subsidies within the frame of the Common Agricultural Policy (CAP) (European Council Regulation 1593/2000 – European Commission, 2000). The agricultural reference parcels are registered in the Land Parcel Identification System (LPIS). IACS and LPIS were conceptualized in 1992 (European Council Regulation 3508/92 and Commission Regulation 3887/92 – European Commission, 1992) and further developed into a Geographic Information System that replaced the cadastre in 2005. LPIS with its high spatial and temporal resolution offers a valuable data source for land-use change and cropland dynamic studies, (e.g. Leteinturier et al., 2006; Schönhart et al., 2011, Levavasseur et al., 2016; Lüker-Jahns et al., 2016; Zimmermanns et al., 2016; Barbottin et al., 2018) and evaluation and monitoring approaches (Reiter & Roggendorf, 2007; Lomba et al., 2017). A first analysis of the LPIS data for Lower Saxony by Steinmann and Dobers (2013) identified a great variety of crop sequences. It concluded that most of the farmers tend to change their crop order highly dynamic. This goes in line with the conclusion for the European crop rotation practice that farmers seem to choose crops mainly depending on the preceding crop and not following any crop rotation pattern (European Commission, 2010).

The second chapter of this thesis presents a method to uncover crop rotation patterns by defining crop sequence types based on structural properties, like the number of crops and their transition rate in a sequence, and based on physical properties of the crops. These physical properties determine the functional role of a crop in an appropriate crop rotation.

The third chapter of this thesis uses this typification approach for a methodological excurse and relates the crop sequence types in the temporal dimension of crop rotation practice with the spatial dimension of crop pattern based on one-year crop data.

References

Barbottin, A., Bouty, C., Martin, P., 2018. Using the French LPIS database to highlight farm area dynamics: The case study of the Niort Plain. Land Use Policy 73, 281-289. DOI: 10.1016/j.landusepol.2018.02.012

Blackshaw, R. E., Andersson, R.L., Lemerle, D., 2007. Chapter 3: Cultural weed management. In: Upadyaya, M.K. and Blackshaw, R.E.: Non-Chemical weed management: Principles, concepts and technology. CAB International, Wallingford, UK, 35-48.

Blanco-Canqui, H., Lal, R., 2009. Crop residue removal impacts on soil productivity and environmental quality. Crit. Rev. Plant Sci. 28, 139-163.

Bullock, D.G., 1992. Crop rotation. Crit. Rev. Plant Sci. 11, 309-326.

Daubeny, C., 1845. Memoir on the rotation of crops, and on the quantity of inorganicmatters abstracted from the soil by various plants under different circumstances. Philos. Trans. R. Soc. Lond. 135, 179–252.

European Commission, 2010. Environmental Impacts of Different Crop Rotation in the European Union (Final Report 6 Sept. 2010).

Karlen, D.L., Varvel, G.E., Bullock, D.G., Cruse, R.M., 1994. Crop Rotations for the 21st Century. Advances in Agronomy 53, 1-45.

Kay, B. D. 1990. Rates of change of soil structure under different cropping systems. In: Stewart, B.E. (Ed.): Advances in Soil Science, Volume 12, Springer Verlag New York, 1-52. DOI: 10.1007/978-1-4612-3316-9

Leteinturier, B., Herman, J. L., de Longueville, F., Quintin, L., Oger, R., 2006. Adaptation of a crop sequence indicator based on a land parcel management system. Agric. Ecosyst. Environ. 112, 324-334.

Levavasseur, F., Martin, P., Bouty, C, Barbottin, A., Bretagnolle, V., Thérond, O., Scheurer, O., 2016. RPG Explorer: A new toll to ease the analysis of agricultural landscape dynamics with the Land Parcel Identification System. Comput. Electron. Agr. 127, 541-552.

Liebman, M., Dyck, E., 1993. Crop rotation and intercropping strategies for weed management. Ecol. Appl. 3, 92-122.

Lomba, A., Strohbach, M., Jerrentrup, J. S., Dauber, J., Klimek, S., McCracken, D. I., 2017. Making the best of both worlds: Can high-resolution agricultural administrative data support the assessment of High Nature Value farmlands across Europe?. Ecological Indicators 72, 118-130.

Lüker-Jahns, N., Simmering, D., Otte, A., 2016. Analysing data of the Integrated Administration and Control System (IACS) to detect patterns of agricultural land-use change at municipality level. Landscape Online 48, 1-24. DOI: 10.3097/LO.201648

Melander, B., Munier-Jolain, N., Charles, R., Wirth, J., Schwarz, J., van der Weide, R., Bonin, L., Jensen, P. K., Kudsk, P., 2013. European perspectives on the adoption of nonchemical weed management in reduced-Tillage systems for arable crops. Weed Technol. 27, 231-240.

Monteleone, M., Cammerino, A.R.B., Libutti, A., 2018. Agricultural “greening” and cropland diversification trends: Potential contribution of agroenergy crops in Capitanata (South Italy). Land Use Policy 70, 591-600. DOI: 10.1016/j.landusepol.2017.10.038

NMELV, 2013. Ergänzungen zur Broschüre: Die niedersächsische Landwirtschaft in Zahlen 2011 (Stand: November 2013). Niedersächsisches Ministerium für Ernährung, Landwirtschaft und Verbraucherschutz, Hannover.

Reiter, K., Roggendorf, W., 2007. Nutzbarkeit vorhandener Datenbestände für Monitoring und Evaluierung – am Beispiel des InVeKoS. In: Begemann, F., Schröder, S., Wenkel, K.-O., Weigel, H.-J. (Eds.): Monitoring und Indikatoren der Agrobiodiversität. Agrobiodiversität 27, 274-287.

Schönhart, M., Schmidt, E., Schneider, U. A., 2011. CropRota – A crop rotation model to support integrated land use assessments. Europ. J. Agron. 34, 263-277.

Smith, V., Bohan, D. A., Clark, S. J., Haughton, A. J., Bell, J. R., Heard, M. S., 2008. Weed and invertebrate community compositions in arable farmland. Arthropod-Plant Interactions 2, 21-30. DOI: 10.1007/s11829-007-9027-y

Steinmann, H.-H., Dobers, S., 2013. Spatio-temporal analysis of crop rotations and crop sequence patterns in Northern Germany: potential implications on plant health and crop protection. J. Plant Dis. Protect. 120 (2), 85–94.

Tiemann, L.K., Grandy, A.S., Atkinson E.E., Marin-Spiotta, E., McDaniel, M.D., 2015. Crop rotational diversity enhances belowground communities and functions in an agroecosystem. Ecol. Letters 18, 761-771.

Zimmermann, J.; González, A.; Jones, M. B.; O'Brien, P.; Stout, J. C.; Green, S. (2016): Assessing land-use history for reporting on cropland dynamics – A comparison between the Land-Parcel Identification System and traditional inter-annual approaches. Land Use Policy 52, 30-40.

Chapter 1

Linking arable crop occurrence with site conditions by the use of highly resolved spatial data

Abstract

Agricultural land use is influenced in different ways by local factors such as soil conditions, water supply and socioeconomic structure. We investigated at the regional and the field scale how strong the relationship of arable crop pattern and specific local site conditions is. At field scale a logistic regression analysis for the main crops and selected site variables detected for each of the analyzed crops its own specific character of crop-site relationship. Some crops have diverging site relations such as maize and wheat, while other crops show similar probabilities under comparable site conditions e.g. oilseed rape and winter barley. At the regional scale the spatial comparison of clustered variables and clustered crop pattern showed a slightly stronger relationship of crop combination and specific combinations of site variables compared to the view on the single crop-site relationship.

Introduction

In the last decades, European arable farming was characterized by modifications of cropping patterns and crop choice driven by an enormous progress in plant breeding, plant protection, fertilization and drainage techniques (Tilman et al., 2002; van Zanten et al., 2014). Also, market prices, farm subsidies and political incentives such as support of bioenergy crops influenced crop choice [Dury et al., 2013; Aouadi et al., 2015; Troost et al., 2015). Recent studies have shown that a few cash crops are preferentially grown both in time and space while other crops are neglected (Baaker et al., 2011; Steinmann and Dobers, 2013). In Northern Germany maize and winter wheat are cropped on more than 50 % of the arable area and in many regions only one to three relevant crops are grown (Steinmann and Dobers, 2013). On the other hand, a decreasing importance of regional site conditions such as soil conditions, water supply and climate for choosing a crop for a given site can be observed (Antrop, 2005; Baaker et al., 2013). Thus, the relationship between site conditions and farmers crop choice (hereafter referred to as crop-site relationship) seems to become weaker in modern farming.

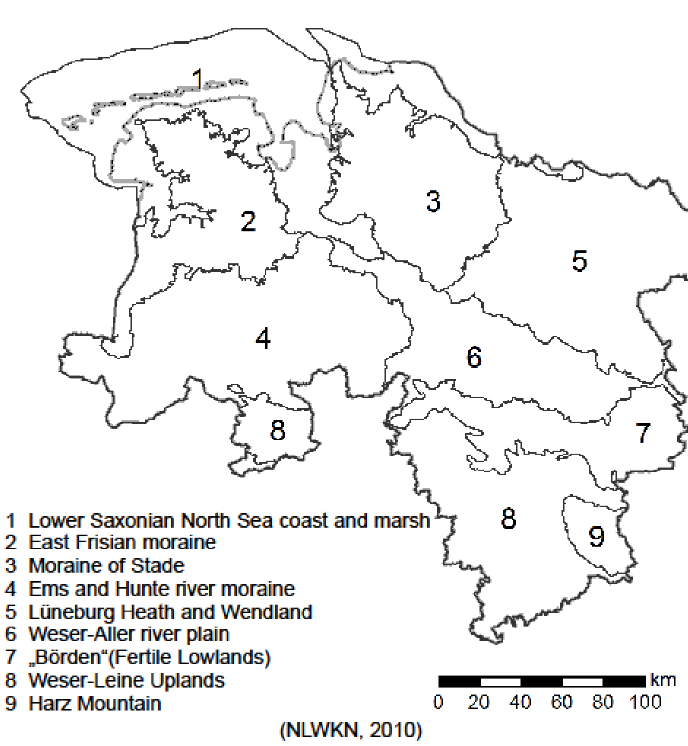
One initial objective of the Common Agricultural Policy (CAP) is to increase productivity. This policy, therefore, has been a major driver of land use change for many decades (Viaggi et al., 2013). The reform of 2003 introduced new rules of payments to farmers. Payments were decoupled from production to Single Farm Payment. At the same time, intervention prices for specific crops were maintained. National schemes on the promotion of renewable energy crops supported the intensive cultivation of crops for biomass production (EEG, 2004). All this resulted in a continuation of intensive arable production in many historically intensively managed regions (OECD, 2004; Tzanopoulos et al., 2012; Trubins, 2013). The latest reform of the CAP in 2013 implemented political instruments that are commonly named with the term “greening” (European Parliament, Reg. No 1307/2013) like crop diversification. However, there is lack of knowledge to which extend farmers do have enough options to diversify crop rotations. In a recent approach, it was shown on the basis of spatial data that some crop rotation patterns refer to site conditions, whereas others do explicitly not (Stein and Steinmann, 2018). To our knowledge, there is no spatial explicit information to which extent crop-site relationship still exist in recent landscapes. We present here a method to detect the relationship of crop cultivation and site conditions to improve the understanding and assessment of ecosystem services in the agricultural system.

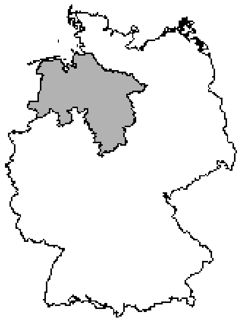
With the presented methods, a binary logistic regression and a k-means clustering, we analysed crop patterns in the landscape to understand to what extent crop choice still depends on site conditions. We had chosen the two methods to explore, first, how intensive the individual relationship between the single crop and the single site variable is. Second, we localized regions of relationship between the clustered sets of site variables and the clustered crop patterns. Our study combines site variables and crop data of the year 2011 for the German federal state Niedersachsen (Lower Saxony) which includes an exceptional variety of agricultural systems. These characteristics make the region a good example for other arable regions and for the estimation of future trends in agricultural land use.

Materials and Methods

Research area

Lower Saxony is characterized by various site conditions and a broad spectrum of agricultural land uses. The 2.6 million ha of farmland are cultivated by 41,730 farms with an average farm size of 61.8 ha (NMELV, 2013). During the last decade maize (*Zea mays* L.) became the most dominant crop followed by winter wheat (*Triticum aestivum* L.) and oilseed rape (*Brassica napus L.*) (Figure 1). The northwestern part is dominated by marshy land with maritime climate, a high proportion of permanent grassland and extensive cattle breeding in the north and livestock breeding in the west. The cropping proportion of maize on arable land is above average for the Lower Saxonian acreage in this region. In the eastern part sandy moraine soils with mixed farms are dominating. Arable farming characterizes the middle and south of Lower Saxony established on loessial soils in a hilly terrain influenced by subcontinental climate. The preferred crops under these conditions are sugar beet (*Beta vulgaris* subsp. *vulgaris*), oilseed rape and winter wheat.





Crop	Area in ha	Share in arable area
Maize	607,736	32%
Winter Wheat	393,922	21%
Winter Barley	138,599	7%
Winter Oilseed Rape	127,337	7%
Rye	113,436	6%
Potato	112,902	6%
Sugar Beet	101,921	5%
Forage	90,146	5%
Triticale	66,703	4%
Summer Cereals	52,546	3%

(NMELV, 2013)

Figure 1. Natural area classification of the German federal state of Niedersachsen (Lower Saxony NUTS 1 region DE9 (European Nomenclature of Territorial Units for Statistics)) and the acreage of the ten main crops or crop groups in 2011, forage includes.

Data characteristics and processing

Our analysis followed two complementary approaches to detect the characteristics and spatial distribution of specific crop-site relationship. In a first step a logistic regression analysis was processed that combines crop information at the field scale for the ten most commonly used crops in Lower Saxony with site variables such as soil, precipitation or livestock density to characterize the relationship between these and the crops at the field scale. This result is compared with the result from a k-means clustering process to localize spatial overlays of clustered crops and clustered site variables at the regional scale.

For the crop data at the field scale the Land Parcel Identification System (LPIS) was used, a yearly updated database which supports the administration of direct payments for European farmers as part of the Integrated and Control System (IACS). It was established in all member states of the European Union in 1992 and developed concurrently with political reform measures (European Parliament, Reg. No 1782/2003). In Germany the data are managed by the German Federal States’ institutions. The access is limited due to privacy protection reasons and special permission is required for scientific use. For this study information about the main agricultural land use type in 2011, the field size and individual field identification numbers were provided for the state Lower Saxony. The dataset was attributed to a GIS-geometry which comprises the boundaries for all agricultural parcels (about 990,000 records in total) (SLA, 2011). Due to a small amount of imprecise field identification, e.g. the assignment of one ID to more than one field, the IACS dataset had to be debugged for uncertainties. For the analysis only arable fields were included. Hence, with a loss of 15% due to imprecise field identification and intersection loss, the basic dataset of the analysis consists of 444,009 agricultural parcels.

To analyse the crop-site relationship it was necessary to find spatial variables which represent the site conditions of the investigated area in a suitable resolution and area-wide consistent availability. Official data from well-established public sources satisfied these requirements (Table 1). The variables were selected with the aim to represent the environmental site conditions in Lower Saxony. This North-western part of Germany is characterized by locally high densities of livestock husbandry and grassland farming (NMELV, 2011, Figure 2). Therefore, variables on animal production were included.

The data for cattle density, pig and poultry density, and the average farm size were extracted from agricultural census data at LAU-2 (Local Administrative Unit) scale (Figure 2). The relative biotope index was developed by the Julius Kühn-Institute, the German Federal Research Centre for Cultivated Plants, to estimate the biotope features in agricultural landscapes. The value for the relative biotope density was calculated using the locally observed density of linear biotope habitats (field margins and hedgerows) and patch biotopes (small woods and grassland patches) per estimated minimum biotope density at LAU-2 scale. The latter was extrapolated from the intensity of plant protection in the corresponding landscape type – the higher the intensity of plant protection applications, the higher is the need for biotopes (Gutsche and Enzian, 2002). The proportion of grassland refers to the area of grassland per arable area in a 1 x 1 km cell of a raster. The multi-annual precipitation sum (1981-2010, DWD, 2014) is available in 0.96 x 0.96 km raster format. The temperature was not regarded due to the low variation of the thermal regime in the study region. For the soil texture and slope information, the data of the European Soil Database were used which are available in so called Soil Typological Units (ESDAC, 2004). The arable farming potential was derived by the Lower Saxonian State Office for Mining, Energy and Geology (LBEG) based on soil and climate parameters (e.g. soil texture, bulk density, humus content, soil structure, water logging level) (Richter and Eckelmann, 1993). The higher the value of the arable farming potential is, the higher is the natural locally potential for biomass production of the soil. For the regression analysis all metric variables were transformed from metric values into interval values to facilitate the comparison of the variables' potential (Table 1). The classification of the intervals was implemented by a geometrical interval algorithm which minimizes the sum of squares of the number of elements per class to ensure approximately the same number of values in each range (ESRI, 2007).

Table 1. Site variables with their classes, units and source scale. Classification of the metric variables was implemented corresponding to the geometrical intervals.

Predictor variable	Classes	Unit	Source
Arable farming potential	1-7 Classes: 'extremely low' to 'extremely high'		(LBEG, 1996) 1: 50 000
Soil texture (Dominant surface textural class of the Soil)	1 Peat soil 2 Coarse (> 65% sand) 3 Medium (< 65% sand) 4 Medium fine (< 15 % sand) 5 Fine (>35% clay)		(ESDAC, 2004) 1: 1 000 000
Slope (Dominant slope class)	1 Level (< 8 %) 2 Sloping (8 - 15 %) 3 Moderately steep (>15 %)		(ESDAC, 2004) 1: 1 000 000
multi-annual precipitation sum (1981-2010)	1 560-676 2 677-746 3 747-806 4 807-878 5 879-1202	$mm*y^{-1}$	(DWD, 2014) 0.96 x 0.96 km
Relative biotope density		Observed Density/ Potential Density	(JKI, 2004) LAU 2
Grassland proportion	1 0.00-0.02 2 0.03-0.06 3 0.07-0.17 4 0.18-0.44 5 0.45-1.00	ha/ ha agric. area	Based on IACS-data 2011 1x1 km
Cattle density	1 0.00-0.10 2 0.11-0.29 3 0.30-0.65 4 0.66-1.32 5 1.33-2.93	Livestock unit/ha (agricultural area)	(LSKN, 2012) LAU 2
Pig/poultry density	1 0.00-0.02 2 0.03-0.09 3 0.10-0.30 4 0.31-0.99 5 1.00-3.21	Livestock unit/ha (agricultural area)	(LSKN, 2012) LAU 2
Average farm size	1 0-40 2 41-64 3 65-104 4 105-172 5 172-311	ha (agricultural area)	(LSKN, 2012) LAU 2

Due to the differences in format and spatial scales of the used datasets they were processed in relation to a reference scale. For the logistic regression the reference scale was the field scale. For the cluster process the information content of the variable polygons was attributed to a 1 x 1 km grid according to their spatial location and proportion. Grid cells with less than 10% of arable area within the grid cell area, i.e. less than 10 ha of arable area, were not included in the analysis. The merging of the attributed information was performed with the Spatial Join tool in ArcGIS®. For the small patched polygons of the arable farming potential the mean of all soil classes per quadrant was attributed. Furthermore, the grid surface permits the calculation of the crop area proportion (crop area per arable area in a 1 x 1 km grid cell) as metric variables. The crop area per grid cell is a sum of all fields which had their centroid within one grid cell.

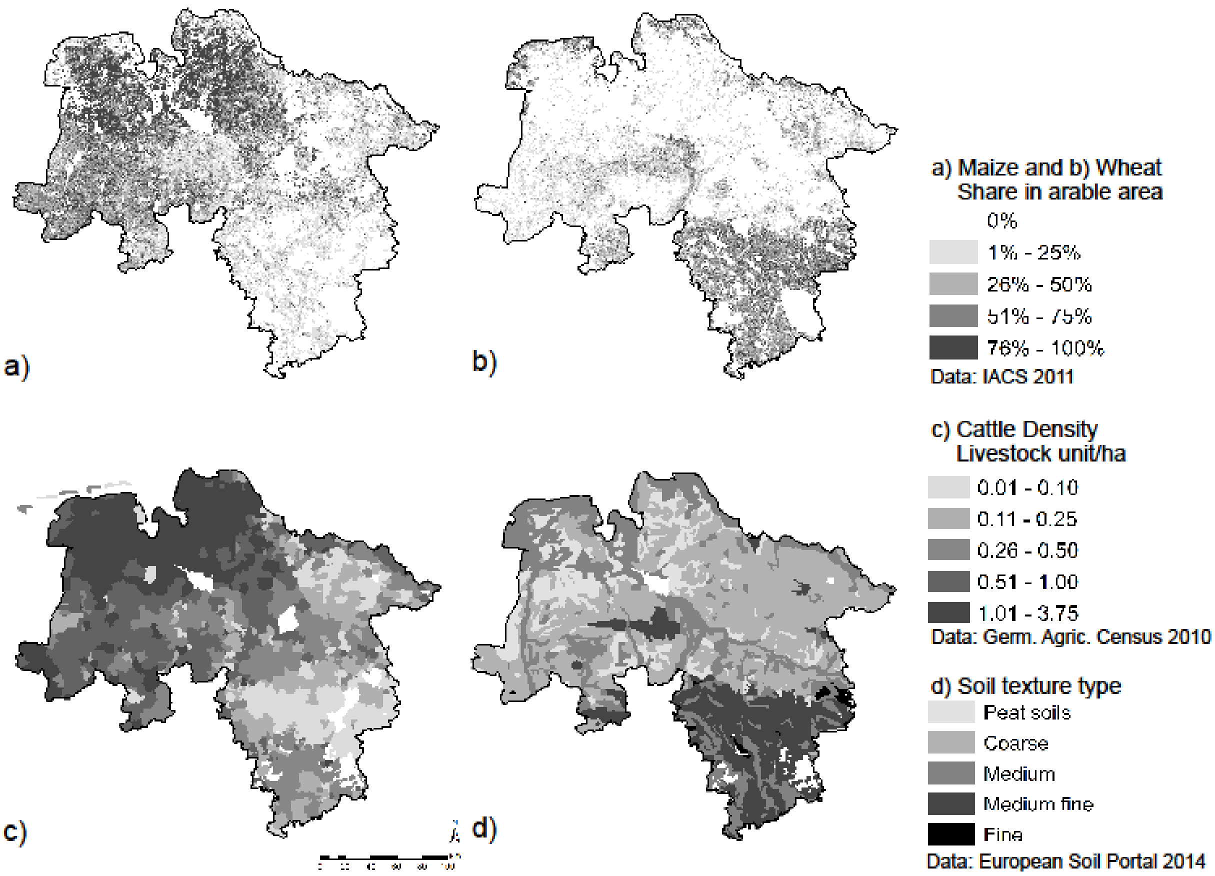


Figure 2. Exemplary mapping of the spatial distribution of two crops and two variables: a) Acreage of maize 2011; b) Acreage of winter wheat 2011; c) Cattle density per LAU-2 unit; d) Soil texture distribution.

Binary logistic regression (field scale)

Logistic regression is used instead of linear regression when the observed or measured response of interest is not continuous but binary to predict the likelihood of an event over the likelihood of non-occurrence (Tarpey, 2012). The cultivation of a crop on a specific field is such a binary event. Its likelihood under the occurrence of a specific site variable indicates the strength of its relationships to the cultivation site. If the site variable, e.g. cattle density, changes by one unit while all other variables stay stable, the likelihood of crop occurrence, e.g.

maize, is increased or decreased by the resulted value of the regression equation. This resulting value is larger or smaller than zero and can be larger than one. The two variables, arable farming potential and soil texture, have an ordinal scale and not a metric scale like all the other variables. Due to this, all characteristics of these two variables were analysed separately (Table 3). The first characteristic, peat soil for soil texture and very low arable farming potential, had the role of the reference value, the same role that zero had for the other variables.

The nine main crops of Lower Saxony were chosen for analysis plus one group containing all spring cereals. For each of the ten crop categories a binomial regression equation with a binary response variable, y ϵ {0, 1}, was defined to determine the probability of occurrence for each crop separately (Menard, 1995; Hosmer and Lemeshow, 2000). The regression analysis was performed by using the software CRAN-R version 3.1.0 (R Core Team, 2013). It uses a logarithmic function calculating the logit (π_i) for the ratio of the probability (*Pij*) that a field (*i*) is cultivated with a specific crop (*j*) or not (1 - *Pij*). Written in a logit equation as suggested by Fahrmeir et al. (2013):

$$\pi_i = P(y_i = 1) = \frac{\exp(\eta_i)}{1+\exp(\eta_i)},$$

containing the linear predictor

$$\eta_i = \beta_0 + \beta_1 x_{i1} + \ldots + \beta_k x_{ik} \ .$$

The predictor (π_i) represents the logarithmic odds (log odds), while the coefficient (β_k) for this variable (x_{ik}) is the expected change in these log odds. While holding the corresponding predictor variables constant, a one unit increase of the predictor variable causes the change of the probability corresponding to the coefficient value for having the subject crop (ESRI, 2007; Fahrmeir et al., 2013).

The likelihood ratio test with a null model for each crop resulted in a rejection of the null hypothesis for all crops. That means that the observed crop occurrence is more likely under the presented model than under the null model.

In contrast to the other variables, arable farming potential and soil texture are handled as factor variables. The coefficient of the first category acts as reference category with a value of zero.

We inspected the correlation effects between the site variables to identify the rate of correlation between the variables, e.g. cattle density and biotope density or soil texture and arable farming potential (Table 2). These effects are immanent for variables which characterize ecological and spatial phenomena (Kleinn et al., 1999). A high correlation of the variables is an expected effect and is therefore not considered in the equation. This decision is forced by the objective of the regression analysis which is not used as a predicting model but as a method to characterize the relationship between the crops and the site conditions.

Table 2. Correlation matrix of the site variables used in the logistic regression model.

	A. F. Pot.[1]	Soil texture	Slope	Precipit.	Biotope I[2]	Farm Size	CattleD[3]	PigPoulD[4]	GrassL[5]
A. F. Pot.	1								
Soil texture	0.617	1							
Slope	0.145	0.267	1						
Precipit.	-0.125	-0.093	0.117	1					
Biotope I	-0.503	-0.548	-0.227	0.350	1				
Farm Size	0.162	0.161	0.084	-0.421	-0.367	1			
CattleD	-0.439	-0.437	-0.190	0.501	0.665	-0.435	1		
PigPoulD	-0.207	-0.248	-0.161	0.248	0.227	-0.358	0.221	1	
GrassL	-0.242	-0.144	0.006	0.235	0.332	-0.154	0.388	-0.132	1

[1] Arable Farming Potential, [2] Biotope Index, [3] Cattle Density, [4] Pig/ Poultry Density, [5] Grassland proportion

Cluster analysis (regional scale)

A non-hierarchical k-means clustering with the Hartigan & Wong algorithm (Hartigan and Wong, 1979) was used to detect regional patterns of similarities for the site variables and for crops (Hartigan, 1975; Draper and Smith, 1998). This was realized with the software CRAN-R version 3.1.0 (R Core Team, 2013; R Documentation, 2015). The k-means clustering is a common method for identifying spatial units at the landscape scale (Schmidt et al., 2010; Caravalho et al., 2016; Ivadi et al., 2017). It was used in this paper to identify spatial units with consistent properties. The crop clusters and the site clusters were than compared in their spatial concordance.

The optimal number of classes, k, was found by comparing results of multiple runs with different number of classes and visualizing the grade of clustering in a map (Morissette and Chartier, 2013). The uncertainty of the initial random partition was adjusted by choosing the most frequent version of partition in ten runs. In a previous step a z-transformation of all variable values standardized the very different scales to improve the comparability of the results. The cluster analysis generated five site clusters (S1, S2, S3, S4, S5) and five crop clusters (C1, C2, C3, C4, C5).

Results

Site dependency at the field scale

The intensity of crop-site relationship is reflected in the coefficient value of the logistic regression analysis (Table 3). In general, the probability of crop appearance in the dataset depends stronger on soil variables than on other site variables. Arable farming potential and soil texture show a high likelihood of determine the occurrence or not-occurrence of a crop but vary in their direction of relationship.

There are linear relations between crop and site variables in different directions e.g. the increase of farming potential increases the probability for wheat but decreases the probability for forage cropping. Oil seed rape is an example for non-linear relations. It was cropped on fields with a middle and high arable farming potential with a much higher likelihood than on fields with an extremely high farming potential. The log odd results of sugar beet prove that soil variables can differ in their direction of influence and explain different aspects of crop-soil relationship. The ambivalent relationship of sugar beet cropping and soil texture is determined by historical production quotas rather than by soil conditions. The variables farm size, pig/poultry density, grassland density and biotope index have in general a low influence on the probability. Each of the analyzed crops has its own specific character of site dependencies. Some crops have diverging site relations such as maize and wheat, while other crops show similar probabilities under comparable site conditions e.g. oilseed rape and winter barley. This result will be examined further in the next section by identifying regions with convergent characteristics.

Table 3. The log odds values describe the likelihood of crop occurrence when the variable value changes by one unit, while all other variable stay stable. The positive/negative sign shows the direction of relationship; ref. is the reference category of the ordinal variables.

Variables	SBeet	WO Rape	Triticale	Potato	Rye	WBarley	WWheat	SCereal	Forage	Maize
Arab. Farm. Pot.										
Extremely Low	*ref.*	*ref.*	*ref.*	*ref.*	*ref.*	*ref.*	*ref.*	*ref.*	*ref.*	*ref.*
Very Low	-0.082	-0.142	-0.141	0.419	-0.359	-0.143	0.140	0.112	0.086	-0.097
Low	0.330	0.040	0.081	0.613	0.430	0.364	-0.116	0.133	-0.311	-0.187
Middle	0.729	0.484	-0.090	0.489	0.172	0.665	0.468	0.112	-0.564	-0.408
High	0.611	0.480	-0.508	-0.285	-0.530	0.547	0.831	0.283	-0.397	-0.726
Very High	1.025	0.440	-0.638	-0.014	-0.831	0.585	0.775	-0.122	-0.676	-0.693
Extremely High	1.136	-0.457	-1.198	-0.388	-1.796	0.354	0.763	-0.443	-1.000	-0.710
Soil Texture										
Peat soil	*ref.*	*ref.*	*ref.*	*ref.*	*ref.*	*ref.*	*ref.*	*ref.*	*ref.*	*ref.*
Coarse	0.727	0.445	0.137	-0.106	0.498	0.493	0.120	0.007	-0.015	-0.203
Medium	0.285	0.960	-0.075	-0.659	-0.160	0.511	1.077	0.026	0.023	-0.348
Medium Fine	0.480	1.043	-0.600	-1.312	-1.019	0.651	1.186	-0.837	-0.181	-0.549
Fine	0.225	0.861	-0.117	-2.576	-0.093	0.454	1.170	-0.111	-0.158	-0.114

Slope	-0.040	0.230	-0.146	-0.513	-0.269	0.254	0.159	-0.330	0.130	-0.493
Precipitation	-0.198	0.019	-0.213	-0.113	-0.285	0.018	0.021	0.092	0.078	0.093
Biotope Index	-0.278	-0.165	0.036	-0.003	0.205	-0.047	-0.240	-0.067	-0.037	0.173
Farm size	0.067	-0.026	-0.213	0.094	0.141	-0.304	-0.055	-0.060	-0.031	0.043
Cattle Density	-0.498	-0.323	-0.201	-0.145	0.391	-0.176	-0.034	-0.145	0.091	-0.176
Pig/ Poultry Density	-0.215	0.125	-0.033	-0.209	0.141	0.167	0.202	-0.209	-0.008	0.167
Grassland/ a. area	-0.192	-0.230	0.056	0.084	0.058	-0.008	0.002	0.084	0.221	-0.008

Statistical clustering and spatial projection

The nature of the relationship between site variables and the grown crop is examined in the regression analysis. With two statistical clustering processes – one for the site variables and one for the crop data – the characterization of crop-site relationship will be transferred into a spatial projection to visualize overlapping spatial patterns. The k-means clustering of the site variables formed five continuous regions which are characterized by their mean value in the defined clusters (Table 4).

Table 4. Mean values per cluster of the k-means clustering for site variables (S1, S2, S3, S4, S5 - corresponding map in Figure 3 a). Values are z-standardized and represent how strong the standard deviation differs from the mean value (μ=0.000). A small value shows no significant difference from the mean value. The positive and negative value represent the direction of deviation from the mean value in that cluster.

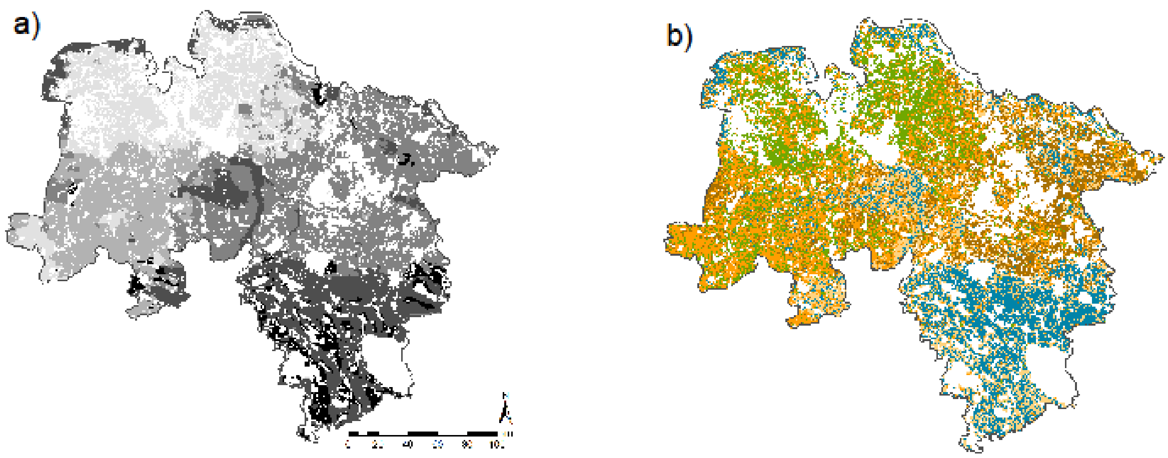
	S1	S2	S3	S4	S5	Mean	SD	Unit
A. F. Pot.	-0.520	-0.290	-0.254	0.530	**1.648**	3.63	1.14	middle
Soil texture	-0.545	-0.390	-0.453	**1.017**	**1.298**	2.52	0.94	medium
Slope	-0.278	-0.279	-0.269	**3.415**	-0.279	1.09	0.39	(< 8 %)
Precipit.	**0.422**	**-0.638**	0.276	**0.414**	-0.246	774.42	75.96	mm
Biotope I	1.030	-0.363	-0.159	-0.607	-0.703	1.68	1.19	oD/pD
Farm Size	-0.415	**0.321**	**-0.612**	0.205	0.318	69.59	29.77	ha
CattleD	**1.362**	-0.511	0.122	-0.680	-0.665	0.64	0.53	LU/ha Agric. A.
PigPoulD	-0.285	-0.244	**1.861**	-0.423	-0.306	0.38	0.54	LU/ha Agric. A.
GrassL	**0.408**	-0.356	-0.564	-0.314	-0.504	0.21	0.22	ha/ha Agric. A.

The site cluster S1 is characterized by a low farming potential and sandy soils which correlate with a higher than average cattle density, biotope density and grassland proportion. A quite different pattern of site conditions and crops characterizes the cluster S2: less humid climate and larger farm sizes. Cluster S3 has strong relations to farms which are smaller than average with a specialization in pig and poultry farming. The S4 and the S5 clusters have many similar characteristics but are distinguishable in the steeper slope and higher precipitation of the fifths cluster. The k-means clustering of the regional crop area proportion resulted in five clusters as well (C1, C2, C3, C4, C5). Each of these clusters have a characteristic composition of dominant crops (Table 5): The regional pattern of site conditions in cluster C1 is related with a much higher than average maize proportion of the crop clustering process. Cluster C2 is the only cluster which is not dominated by maize or wheat but by a mixture of other crops, mainly rye and potato. The C3 cluster is characterized by a mixture of maize, triticale and forage cropping. A composition of oilseed rape, winter wheat and winter barley is the distinct feature of the forth cluster C4. The most obvious characteristic of cluster C5 is a winter wheat proportion which is three times higher than the mean in Lower Saxony.

The transfer in a spatial projection of the clustering results reveals relationships between the site variables and the crop clustering on the one hand and distinctive differences on the other (Figure 3). Significant congruencies can be proved for the second site cluster S2 and the potato-rye-cluster C2. The second and third highest proportions of quadrants with spatial congruence were observed for the S5 with C5 and for the S1 with C1. The other two crop clusters have less than 50% spatial congruence with the site clusters.

Table 5. Mean values of the k-means clustering of crop data (corresponding map in Figure 3 b). The values represent mean ratios of the crop area per arable area of the related quadrant. Values in bold are significantly higher than the mean value of the certain crop and are considered as characteristic crops for the cluster type.

	C1	C2	C3	C4	C5	Mean	SD	Unit
SBeet	0.002	0.052	0.013	**0.098**	**0.090**	0.05	0.11	ha/ha Arab. A.
Potato	0.015	**0.184**	0.060	0.026	0.015	0.06	0.13	ha/ha Arab. A.
WO Rape	0.005	0.034	0.028	**0.222**	0.064	0.06	0.13	ha/ha Arab. A.
SCereal	0.018	0.094	0.040	0.030	0.021	0.04	0.10	ha/ha Arab. A.
Maize	**0.816**	0.120	**0.463**	0.092	0.070	0.34	0.31	ha/ha Arab. A.
Triticale	0.018	0.066	**0.062**	0.032	0.008	0.04	0.09	ha/ha Arab. A.
Rye	0.033	**0.218**	0.073	0.026	0.009	0.07	0.14	ha/ha Arab. A.
Forage	0.042	0.062	**0.090**	0.034	0.024	0.05	0.11	ha/ha Arab. A.
WWheat	0.021	0.044	0.074	**0.228**	**0.621**	0.21	0.25	ha/ha Arab. A.
WBarley	0.020	0.055	**0.072**	**0.177**	0.054	0.07	0.12	ha/ha Arab. A.
All others	0.008	0.071	0.025	0.035	0.022	0.03	0.08	ha/ha Arab. A.



Site clusters		Crop clusters: Maize	Rye-Potato-mixture	Maize-Triticale-Forage-WBarley	OSRape, WWheat, WBarley, Sugar Beet	WWheat, Sugar Beet
		C1	C2	C3	C4	C5
S1	Cattle farm., dense biotopes, wet climate, sandy soils, high share of grassland	56%	8%	26%	4%	5%
S2	Larger farm size, less wet climate, sandy soils	16%	73%	34%	35%	16%
S3	Pig/poultry farm., cattle farm., sandy soils, smaller farm size, low share of grassland	25%	13%	33%	6%	3%
S4	High A. Farm. Pot., mod. steep, wet climate, fine soils, less biotopes, larger farm size	0%	2%	2%	15%	15%
S5	Very high A. Farm. Pot., fine soils, less biotopes, low share of grassland	2%	4%	6%	40%	61%

Figure 3. Spatial projection of the statistical k-means clustering results and the proportion of congruent areas in percent: a) Site clustering (S1-S5) and description, b) Crop clustering (C1-C5). Only quadrants ≥ 10 ha of arable area are included.

Discussion

General Discussion

Agricultural crops do not grow randomly at a specific site. Their spatial occurrence reflects the sum of farmers' decisions as a product of site conditions and the political and economic framework. In the last decades many farmers, breeders and the plant protection industry focused on a few profitable crops. This was also a result of the market price development and the European agricultural policy and culture of yield-based subsidies. However, sustainable cropping systems rely on diverse cropping systems, among other factors (Smith et al., 2005; Storkey et al., 2019). In our study, we detect the strongest relationship of site variables, namely soil texture and arable farming potential, with crops at the most productive areas and the least productive areas. Crops like sugar beet, oil seed rape and winter wheat are characterized by a high probability to be cropped on sites with a high arable farming potential. The spatial congruence of site clusters (e.g. S5) with crop clusters (e.g. C5) confirmed the regression result referring to the relationship of very high farming potential and the combined cropping of sugar beet and winter wheat. This was supplemented reversely by the significant absence of single crops on soils with high farming potential, like rye and forage. Zimmermann and Britz concluded from their study of the use of agri-environmental measures by farmers in the EU, that those measures were most likely found on less productive sites during 2000-2009 (Zimmermann and Britz, 2016). The recent CAP 2014-2020 includes agri-environmental measures like crop diversification as obligatory requirement for the first pillar payments. Recent studies concerning the impact assessment of the CAP 2014-2020 show contrary results: a limited environmental impact of the new greening rules (Cortignani and Dono, 2019) and strong effects on the farmland use in high-intensive agricultural regions (Bertoni et al., 2018).

The spring cereals and forage crops are characterized by a weak crop-site relationship as well as maize and winter wheat which are the main arable crops with acreage of 32% and 21% of the arable area, respectively (NMELV, 2013). The economical preference, the high tolerance for the combination with other crops as well as the tolerance to short intervals in the rotation result in a dense cropping of maize and winter wheat in space and time (Steinmann and Dobers, 2013; Stein and Steinmann, 2018). Nevertheless, each of these two crops dominate regions which are characterized by contrasting conditions concerning the soil texture and arable farming potential, slope as well as grassland and livestock density.

The relationship of maize cropping and specific combinations of site conditions is strongly determined by the cultivation practice for this crop. Rotations with maize are characterized by very dense cropping up to permanent cropping on the one hand and maize as one part of very diverse rotations on the other hand (Stein and Steinmann, 2018). These rotation phenomena are common in regions with different site characteristics and geography. This is further confirmed by the result that the spatial congruency of site clusters and the crop cluster with dense maize cultivation (Figure 3, C1) was clearly distinguishable from their relationship to the cluster of maize cultivation in combination with other crops (C3). Whether maize cropping is allocated to cluster C1 or C3 has apparently consequences for ecosystem effects. While the spatially dense maize cultivation can have negative impacts on ecosystem services, the maize cultivation within the more diverse system of C3 can have a positive impact (Albert et al., 2016). As the identified areas with high maize acreage are only partly explainable by livestock farming, they may correspond with other factors like biogas production which are not represented by the explanatory data. The area cultivated with maize increased in Northwestern Germany from 2005 till 2011 by 67% (NMELV, 2013). The widespread cultivation of maize is an effect of the expansion of biogas production after the implementation of the national renewable energy law (EEG, 2004; LSKN, 2012).

Reflections on the methods used

For a realistic analysis of regional crop-site relationships the use of crop information at field scale is essential (Leteinturier et al., 2006; Schönhart et al., 2011). The yearly updated database of the LPIS is a valuable data source for agronomical and environmental analysis. The LPIS data have a high spatial resolution which allows for a precise intersection with other spatial information and yields precise answers to field scale questions. Area-wide crop information on field scale could also be useful for the validation of crop growth models especially for areas with a large diversity of cropping systems (Nendel et al., 2013; van Wart et al., 2013) and for modelling procedures when information concerning cropping practices is needed (Schönhart et al., 2011; Mitter et al., 2015; Tychon et al., 2001). The scientific use of LPIS data, e.g. for the prediction of the crop yield or for projecting changes in agricultural land use practice is becoming more and more important (Mitter et al., 2015; Tychon et al., 2001; Kandziora et al., 2013; Andersson et al., 2014; Levavasseur et al., 2016).

Two statistical methods were applied for the analysis of crop-site relationship: the logistic regression analysis and the k-means clustering, visualized by a map projection. Both approaches concern different levels and aspects of the relationship. The level of spatial similarities between the crop clusters and the site clusters supplemented the results of the logistic regression analysis and elucidated in parts the fuzzy picture of direct relationships. This underpins the need to include cropping patterns instead of single crop information in modelling approaches.

Not all the chosen variables have the expected potential to explain crop-site dependencies. The low influence of farm size, pig/poultry density, grassland density and biotope index on the probability of crop cultivation in comparison with the soil variables can be explained by their low tendency to form spatial pattern or cluster in Lower Saxony which is reflected in the high standard deviation values. In our analysis we focused on environmental variables instead of economic variables because most of the studies concerning the cropping-plan decision making process of farmers consider economical and sociological drivers (Dury et al., 2013; Huber et al., 2018). However, we could show the still high potential of soil variables as drivers for decision making, which is also confirmed by a study of Peltonen-Sainio et al. (2018). This study exposed also field size as a potent driver variable, which was not concerned in our study, because it is indirectly included in the biotope index.

The crop clustering process resulted in a much more scattered picture than the site cluster projection. The latter is based on variables with different spatial resolution ranging from the smaller scaled LAU 2 data to 1 km² resolved raster data that gave different degree of precision. However, the reason for the different degree of spatial clustering is not only caused by the spatial resolution of the data sources. While the site clusters are a product of natural conditions, the crop clusters are a result of both, site conditions and socio-economic factors, e.g. market prices and subsidies. That supports flexibility of the farmers in the crop choice and therefore the fragmentation of crop clusters especially in the center of Lower Saxony (# 3, 5, 6 referring to Figure 1) with medium arable farming potential, sandy soils and a higher variation of farm types in this area than in other regions.

Conclusion

The relationship of site conditions and crop cultivation at the field scale is generally weak but detectible for some crops. One reason is that modern cropping practice enables the farmer to override the relationship of crop and site to a large extent. However, this does not apply to all crop-site relationships. In arable regions with productive soils the crop-site relationship is stronger. This comes along with specialization of the farming systems to a few cash crops, mainly the most profitable crops like sugar beet and winter wheat. On the other hand, a stronger relationship of crop and site at the regional scale was also detected for clusters with less productive soils and the crop cluster with dominant maize cultivation. Economic reasons and policy-based incentives, such as support for bioenergy crops may have enforced this allocation. Farming practice and agricultural policy must face the chances but also the risks of this development.

In regions with less fertile soils and mixed farming structure, the farmers cultivation practice is much more diverse. The site clusters are not dominated by one crop cluster but by a side-by-side of crop clusters with up to four dominating crops. The chance for crop rotation diversification is higher in these multiform regions but in the rather monotonous regions diversification efforts would be much more crucial.

References

Albert, Ch., Hermes, J., Neuendorf, F., von Haaren, Chr., Rode, M., 2016. Assessing and Governing Ecosystem Services Trade-Offs in Agrarian Landscapes: The Case of Biogas. Land, 5 (1), 1. DOI : 10.3390/land5010001

Andersson, G. K. S., Ekroos, J., Stjernman, M., Rundlöf, M., Smith, H. G., 2014. Effects of farming intensity, crop rotation and landscape heterogeneity on field bean pollination. Agr. Ecosyst. Environ. 184, 145-148.

Antrop, M., 2005. Why landscapes of the past are important for the future. Landscape and Urban Planning 70 (1/2), 21-34.

Aouadi, N., Aubertot, J.N., Caneill, J., Munier-Jolain, N., 2015. Analyzing the impact of the farming context and environmental factors on cropping systems: A regional case study in Burgundy. Eur. J. Agron. 66, 21-29.

Bakker, M. M., Hatna, E., Kuhlman, T., Mücher, C. A., 2011. Changing environmental characteristics of European cropland. Agr. Syst. 104 (7), 522-532.

Bakker, M. M., Sonneveld, M. P. W., Brookhuis, B., Kuhlman, T., 2013. Trends in soil–land-use relationships in the Netherlands between 1900 and 1990. Agr. Ecosyst. Environ. 181, 134-143.

Bertoni, D., Aletti, G., Ferrandi, G., Micheletti, A., Cavicchioli, D., 2018. Farmland use transition after the CAP greening: A preliminary analysis using Markov chains approach. Land Use Policy 79, 789-800.

Caravalho, M.J., Melo-Goncalves, P., Teixeira, J.C., Rocha, A., 2016. Regionalization of Europe based on a K-Means Cluster Analysis of the climate change of temperatures and precipitation. Physics and Chemistry of the Earth Parts A/B/C 94, 22-28.

Cortignani, R., Dono, G., 2019. CAP’s environmental policy and land use in arable farms: An impacts assessment of greening practices changes in Taly. Sc. of the Total Environment 647, 516-524. DOI: 10.1016/j.scitotenv.2018.07.443

Draper, N. R., Smith, H., 1998. Applied regression analysis. 3rd Ed. Wiley, New York.

Dury, J., Garcia, F., Reynaud, A., Bergez, J.-E., 2013. Cropping-plan decision-making on irrigated crop farms: A spatio-temporal analysis. Eur. J. Agron. 50, 1-10.

DWD (Deutscher Wetterdienst), 2014. Multi-annual precipitation sum (1981-2010). Online download via WebWerdis (accessed 06-03-2014).

EEG, 2004. Erneuerbare-Energien-Gesetz (Renewable Energies Act) of 21 July 2004 (Federal Law Gazette I p. 1918), last amended by Art. 1 Act of 7 November 2006 (Federal Law Gazette I p. 2550).

ESRI, 2007. ArcGIS 9.2 Desktop Help: Geometrical Interval. http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?topicname=geometrical_interval (accessed 22-03-2015).

European Parliament and Council, 2003. Regulation (EC) No 1782/2003 establishing common rules for direct support schemes under the common agricultural policy and establishing certain support schemes for farmers. Official Journal of the European Union (L 270/1-69), ELI: http://data.europa.eu/eli/reg/2003/1782/oj.

European Parliament and Council, 2013. Regulation (EU) No 1307/2013 establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy and repealing Council Regulation (EC) No 637/2008 and Council Regulation (EC) No 73/2009. Official Journal of the European Union (L 347/ 608-669), ELI: http://data.europa.eu/eli/reg/2013/1307/oj

ESDAC (European Soil Data Centre), 2004. The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN.

Fahrmeir, L., Kneib, T., Lang, S., Marx, B., 2013. Regression: Models, Methods and Applications. Springer, Berlin.

Gutsche, V., Enzian, S., 2002. Quantifizierung der Ausstattung einer Landschaft mit naturbetonten terrestrischen Biotopen auf der Basis digitaler topographischer Daten. Nachrichtenbl. Deut. Pflanzenschutzd. 54 (4), 92-101.

Hartigan, J. A., 1975. Clustering algorithms. John Wiley & Sons (Wiley series in probability and mathematical statistics).

Hartigan, J. A., Wong, M. A., 1979. Algorithm AS 136: A K-Means Clustering Algorithm. J. R. Stat. Soc. Series C 28/1, 100-108.

Hastie, T., Tibshirani, R., Friedmann, J., 2001. The Elements of Statistical Learning: Data Mining, Inference and Prediction, second ed. Springer.

Hosmer, D. W., Lemeshow, S., 2000. Applied Logistic Regression, second ed. Wiley, New York.

Huber, R., Bakker, M., Balmann, A., Berger, T., Bithell, M., Brown, C., Gret-Regamey, A., Xiong, H. et al., 2018. Representation of decision-making in European agricultural agent-based models. Agricultural Systems 167, 143-160. DOI: 10.1016/j.agsy.2018.09.007

Javadi, S., Hashemy, S.M., Mohammadi, K., Howard, K.W.F., Neshat, A., 2017. Classification of aquifer vulnerability using K-means cluster analysis. Journal of Hydrology 549, 27-37.

JKI (Julius Kühn-Institut) (Eds.), 2004. Verzeichnis der regionalen Kleinstrukturen des Landes Niedersachsen auf Gemeindebasis. Kleinmachnow.

Kandziora, M., Burkhard, B., Müller, F., 2013. Mapping provisioning ecosystem services at the local scale using data of varying spatial and temporal resolution. Ecosystem Services 4, 47-59.

Kleinn, Ch., Jovel, J., Hilje, L., 1999. A model for assessing the effect of distance on disease spread in crop fields. Crop Prot. 18 (9), 609-617.

Leteinturier, B., Herman, J. L., de Longueville, F., Quintin, L., Oger, R., 2006. Adaptation of a crop sequence indicator based on a land parcel management system. Agr. Ecosyst. Environ. 112 (4), 324-334.

Levavasseur, F., Martin, P., Bouty, C, Barbottin, A., Bretagnolle, V., Thérond, O., Scheurer, O., 2016. RPG Explorer: A new toll to ease the analysis of agricultural landscape dynamics with the Land Parcel Identification System. Computers and Electronics in Agriculture 127, 541-552.

LBEG (Landesamt für Bergbau, Energie und Geologie), 1996. Bodenübersichtskarte 1:50 000 (BÜK 50) von Niedersachsen. Standortbezogenes natürliches ackerbauliches Ertragspotenzial. Hannover.

LSKN (Landesbetrieb für Statistik und Kommunikationstechnologie Niedersachsen), 2012. Statistische Berichte Niedersachsen. Landwirtschaftszählung 2010, Brochure 1/A (Landuse) and 4 (Livestock). Hannover.

Menard, S., 1995. Applied Logistic Regression Analysis, second ed. Sage University Paper.

Mitter, H., Heumesser, Ch., Schmid, E., 2015. Spatial modeling of robust crop production portfolios to assess agricultural vulnerability and adaptation to climate change. Land Use Policy 46, 75-90.

Morissette, L., Chartier, S., 2013. The k-means clustering technique: General considerations and implementation in Mathematica. The Quantitative Methods for Psychology 9 (1), 15–24.

Nendel, C., Wieland, R., Mirschel, W., Specka, X., Guddat, C., Kersebaum, K. C., 2013. Simulating regional winter wheat yields using input data of different spatial resolution. Field Crops Res. 145, 67-77.

NLWKN (Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten-und Naturschutz), 2010. Naturräumliche Regionen in Niedersachsen. Extract from the Geobasisdata, map basis: TK1000/ Niedersächsische Vermessungs- und Katasterverwaltung (Eds.).

NMELV (Niedersächsisches Ministerium für Ernährung, Landwirtschaft und Verbraucherschutz) (Eds.), 2013. Ergänzungen zur Broschüre: Die Niedersächsische Landwirtschaft in Zahlen 2011 (Stand: November 2013). Hannover. Available online: http://www.ml.niedersachsen.de/download/83668/Die_niedersaechsische_Landwirtschaft_in_Zahlen_2011_-_Ergaenzung_11-2013.pdf (accessed on 04-05-2016).

OECD, 2004. Analysis of the 2003 CAP Reform. Paris. Available online: https://www.oecd.org/tad/32039793.pdf (accessed 20-03-2019).

Peltonen-Sainio, P., Jauhiainen, L., Sorvali, J., Laurila, H., Rajala, A., 2018. Field characteristics driving fram-scale decision-making on land allocation to primary crops in high latitude conditions. Land Use Policy 71, 49-59. DOI: 10.1016/j.landusepol.2017.11.040

R Core Team, 2013. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria (online access: http://www.R-project.org).

R Documentation, 2015. K-Means Clustering. Package 'stats' version 3.3.0. R Foundation for Statistical Computing, Vienna, Austria (2015). https://stat.ethz.ch/R-manual/R-devel/library/stats/html/kmeans.html (accessed 12-02-2015).

Richter, U., Eckelmann, W., 1993. Das Ertragspotential ackerbaulich genutzter Standorte in Niedersachsen - Beispiel einer Auswertungsmethode im Niedersächsischen Bodeninformationssystem NIBIS. Geol. Jb. F 27, 197-205.

Schönhart, M., Schmid, E., Schneider, U. A., 2011. CropRota – A crop rotation model to support integrated land use assessments. Europ. J. Agron., 34 (4), 263-277.

SLA (Niedersächsisches Servicezentrum für Landentwicklung und Agrarförderung), 2011. Digitale Feldblockkarte Niedersachsens (DFN). Digital map.

Smith, R.G., Gross, K.L., Robertson, G.P., 2008. Effects of Cropping Diversity on Agroecosystem Function: Crop Yield Response. Ecosystems 11, 355-366. DOI: 10.1007/s10021-008-9124-5

Stein, S., Steinmann, H.-H., 2018. Identifying crop rotation practice by the typification of crop sequence patterns for arable farming systems – A case study from Central Europe. Europ. J. Agron., 92, 30-40, DOI: https://doi.org/10.1016/j.eja.2017.09.010.

Steinmann, H.-H., Dobers, S., 2013. Spatio-temporal analysis of crop rotations and crop sequence patterns in Northern Germany: potential implications on plant health and crop protection. J. Plant Dis. Protect. 120 (2), 85–94.

Storkey, J., Bruce, T.J.A., McMillan, V.E., Neve, P., 2019. Chapter 12 – The future of sustainable crop protection relies on increased diversity of cropping systems and landscapes. Agroecosystem Diversity. Academic Press, 199-209. DOI: 10.1016/B978-12-811050-8.00012-1

Tarpey, T., 2012. Generalized Linear Models. http://www.wright.edu/~thaddeus.tarpey/ES714glm.pdf (last update at: 28-05-2012) (accessed 10-06-2015).

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., Polasky, S., 2002. Agricultural sustainability and intensive production practices. Nature 418 (6898), 671-677.

Troost, Ch., Walter, T., Berger, T., 2015. Climate, energy and environmental policies in agriculture: Simulating likely farmer responses in Southwest Germany. Land Use Policy 46, 50-64.

Trubins, R., 2013. Land-use change in southern Sweden: Before and after decoupling. Land Use Policy 33, 161-169.

Tychon, B., Buffet, D., Dehem, D., Eerens, H., Oger, R., 2001. The Belgium crop growth monitoring system. 2nd International Symposium: Modelling Cropping Systems. Florence, Italy (16-07-2001).

Tzanopoulos, J., Jones, P.J., Mortimer, S.R., 2013. The implications of the 2003 Common Agricultural Policy reforms for land use and landscape quality in England. Landscape and Urban Planning 108, 39-48.

van Wart, J., Kersebaum, K. C., Peng, S., Milner, M., Cassman, K. G., 2013. A protocol for estimating crop yield potential at regional to national scales. Field Crops Res. 143, 34-43.

van Zanten, B.T., Verburg, P.H., Espinosa, M., Gomez-y-Paloma, S., Galimberti, G., Kantelhardt, J., Kapfer, M., Lefebvre, M., Manrique, R., Piorr, A., Raggi, M., Schaller, L., Targetti, S., Zasada, I., Viaggi, D., 2014. European agricultural landscapes, common agricultural policy and ecosystem services: a review. Agron. Sustain. Dev. 34, 309-325.

Viaggi, D., Gomez y Paloma,S., Mishra, A., Raggi, M., 2013. The role of the EU Common Agricultural Policy: Assessing multiple effects in alternative policy scenarios. Land Use Policy 31, 99-101. DOI: 10.1016/j.landusepol.2012.04.019

Zimmermann, A., Britz, W., 2016. European farm’s participation in agri-environmental measures. Land Use Policy 50, 214-218. DOI: 10.106/j.landusepol.2015.09.019

Xiao, Y., Mignolet, C., Mari, J.-F., Benoît, M., 2014. Modeling the spatial distribution of crop sequences at a large regional scale using land-cover survey data: A case from France. Comput. Electron. Agr. 102, 51-63.

Chapter 2

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

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.

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 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 (Salmon-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 number 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.

Materials and methods

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 (Figure 4). 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 6) 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).

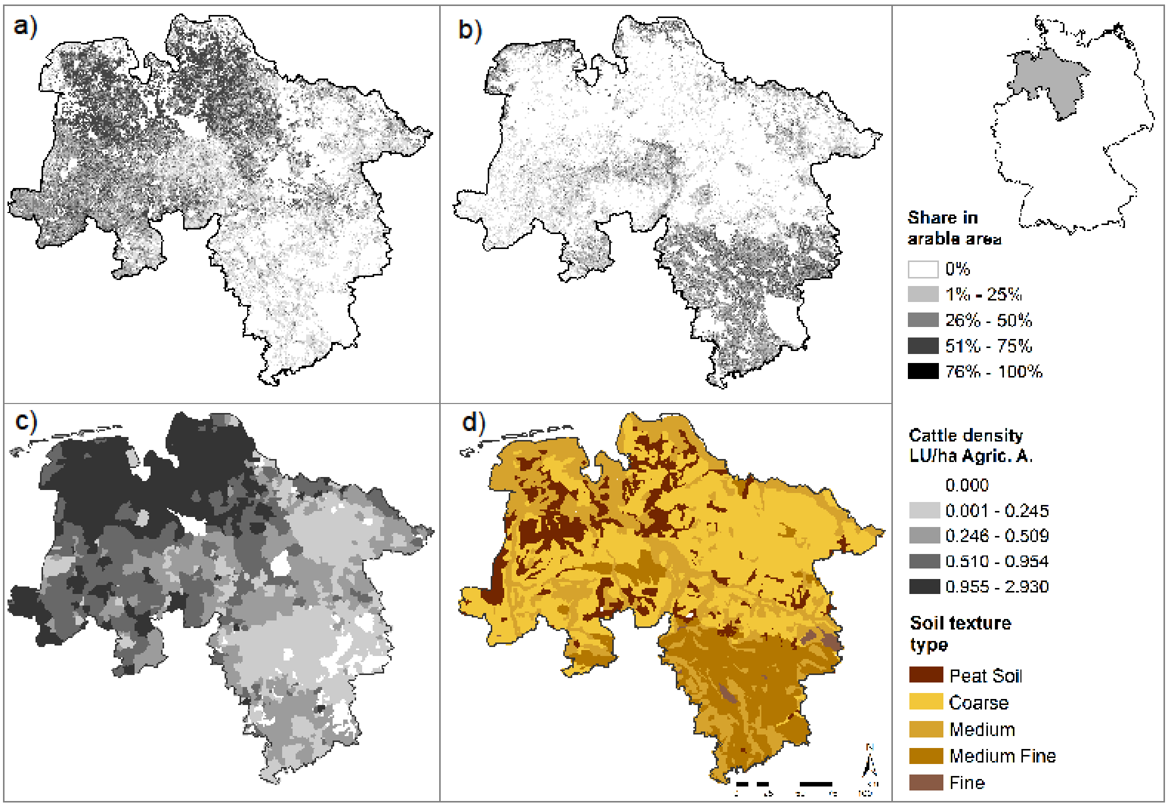


Figure 4. Selected maps of characteristic distribution pattern in Lower Saxony: a) Share of maize acreage per arable area (IACS, 2011); b) Share of winter wheat acreage per arable area (IACS, 2011); c) Cattle density per grid cell (LSKN, 2012); d) Soil texture c class distribution (European Soil Portal, 2014).

Data and data processing

The Integrated Administration and Control System (IACS) was implemented by each member state of the EU since the subsidies are based on the farming area to verify the correct sharing of the European Agricultural Guarantee Fund (European Commission, 2007b). It records and stores high-resolution land use data using a Land Parcel Identification System (LPIS), a GISsupported identification system which replaced the cadastral system with the reform in 2005 and facilitated the spatially explicit land use data analysis. However, an analysis of individual areas over a series of years needs to consider specific peculiarities. The identification of the individual land use unit is realized by an individual code which does not allow any conclusion on the corresponding farm due to privacy issues. An individual ID ensures the explicit localization of each land use unit, aside from small inconsistencies in the data frame each year like duplicates (1.5% in 2011 for the observed region). It has to be mentioned that the definition of the smallest spatial land use unit is not uniform in the EU member states (Kay and Milenov, 2008). In Germany, as well as in some other European countries (e.g. France, Czech Republic), the physical field block or farmer block framed by stable physical landscape elements is the reference scale which can be identified by a fixed individual IACS code (so-called field block identifier). Each block contains one or several so-called parcels of agricultural land use, defined as a unit of one main crop for one cropping period and numbered consecutively each year. The challenge for sequence analysis is the potential change of the parcels' shape and number in each growing season and the related change of the parcels ID number in that block. So, the longer the observed time series is, the greater is the loss of clear identifiable parcels due to changing parcel sizes.

Table 6. Share of cultivation area on arable area per year of the investigated fields and the average deviation [$\bar{z} = \frac{1}{n}\sum_{i=1}^{n} z_i \text{ when } z_i = (x_i) - (y_i)$] of the sequence crop area proportion [x_i] from the actual crop area proportion [y_i] in Lower Saxony (n= 122,956 records with 371,711 ha in total).

Crop	Acronym	Quality	2005	2006	2007	2008	2009	2010	2011	$\bar{z}$
Maize	MA	C / S	22.9%	23.5%	24.3%	26.7%	26.5%	29.4%	32.1%	1.9%
Winter Wheat	WW	C / W	26.5%	25.9%	24.5%	26.1%	26.2%	26.3%	24.7%	3.3%
Winter Barley	BA	C / W	11.6%	13.8%	12.5%	11.6%	11.9%	10.5%	9.5%	-0.4%
Oilseed Rape	OR	L / W	5.4%	6.3%	7.4%	7.5%	8.1%	8.6%	7.8%	1.1%
Rye	RY	C / W	5.8%	6.1%	7.3%	7.3%	7.7%	6.5%	6.3%	1.9%
Sugar Beet	SB	L / W	6.0%	4.7%	5.6%	5.6%	5.3%	5.4%	5.6%	0.1%
Triticale	TR	C / W	5.5%	4.7%	4.3%	4.4%	4.6%	4.6%	4.0%	-0.8%
Spring Cereals	SC	C / S	4.5%	3.9%	3.4%	4.2%	3.2%	2.5%	3.4%	0.4%
Potato	PO	L / S	3.5%	3.2%	3.2%	3.2%	3.2%	2.9%	2.9%	-0.6%
Arable Grass[a)]	GR	C / W	2.4%	2.6%	2.5%	2.7%	2.7%	2.6%	2.8%	-0.5%
Legumes	LE	C / S	0.5%	0.6%	0.5%	0.5%	0.5%	0.5%	0.5%	-0.8%
Vegetables	VE	C / S	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%	-0.2%

[a)] Arable Grass = annual or multi-annual (max. 5 yr.) cultivation of fodder grass on arable fields
[C] = Cereal crop
[L] = Leaf crop
[S] = Spring sown crop
[W] = Winter sown crop

The Lower Saxon LPIS stores crop and land use information for about 900,000 parcels per year; half of these records represent arable parcels (about 1.6 million hectares of arable area in total), whereas the rest comprises grassland, vegetables and other agricultural uses. For the year 2011 we used an administrative digital map of the parcels location which facilitates a spatially explicit traceability for a sufficient number of parcels. So, for the seven-year time series (2005–2011) 34% of all parcels were located precisely by the consistent identification code due to stable parcel size and proportion within the field block. For crop sequence analysis only complete seven-year sequences of arable cropping were involved. This was the case for 24% of the arable parcels (122,956 records). These parcels were considered as a representative sample for probing spatial distribution since they resemble the complete area. Nevertheless, some crops were slightly overrepresented while others are less represented in the sample sequences per year in comparison with the total acreage per year (Table 6) depending on the parcels' shape stability.

Crop Sequence Typology

The temporal distance of replanting the same crop or crops of similar physical and physiological properties as well as the appropriate combination of crop growing seasons are the main characteristics of crop rotation practice (Karlen et al., 1994). Our approach combines these characteristics and differentiates the crop sequences by their pattern of these properties. The result is a typology of crop sequences according to their grade of diversity, which enables an analysis and interpretation of land use structures. The analysis of crop sequences instead of crop rotations was owed to the fact that the data set represented a time frame showing incomplete rotation cycles. The concept of 'crop sequences' implies the order of crops, distances and frequencies of appearance in a fixed time period (Leteinturier et al., 2006). This concept is related to the definition of crop rotations as the practice of "sequentially growing a sequence of plant species on the same land" (Karlen et al., 1994). This principle of 'crop sequences' is used in the following. We analyzed a period of seven years, from 2005 till 2011, to ensure the inclusion of four-year sequences, which are typical for many regions. All sequences with more than two years of fallow or temporary grass were defined as crop livestock systems, instead of cropping systems, and were not included in the typology. This follows the classic differentiation approach of crop rotations in crop-livestock systems and cropping systems (Andreae, 1952; Brinkmann, 1950), based on the amount of temporary extensive farming in rotation with arable crop farming. The approach was applied for the seven-year period but could be adjusted to longer time series.

The differentiation of crop rotation practice focusses on two categories of diversity: the structural diversity represented by the number of transitions versus the crop number and the functional diversity described by the feature leaf crop proportion and spring crop proportion per sequence. The classification of crops into leaf crops and cereal crops is an essential part of traditional crop rotation systematization approaches and is related to the physiological differences of monocots and dicots concerning the leaf surface, the root system and harvest residues with specific effect on the soil structure and humus content (Brinkmann, 1950; Koennecke, 1967). We complemented this classical approach by an additional differentiation of the crops in spring-sown and autumn-sown/winter-sown crops which is related to their different role in crop rotations. A combination of spring and winter crops in a sequence has positive effects on grass weed management (e.g. *Alopecurus myosuriodes* in winter-sown cereals or *Avena fatua* in spring-sown cereals). So, a balanced ratio of spring-sown crops and winter-sown crops has the function to interrupt the accumulation of weed communities with specific seasonal growth periods (Liebman and Dyck, 1993). Further, the combination of spring-sown with winter-sown crops also has positive effects on soil quality due to variations in the duration of the soil regeneration period and soil cover.

The two aspects of diversity were detected in two processing steps. In a first step the structural diversity was addressed by dividing the dataset into groups according to the sum of transitions and the sum of crops per sequence (Figure 5). In our data the maximum sum of different crops in a seven-year sequence was seven. For longer time series the maximum sum of possible crops in a defined area or time frame could be set. The sum of transitions was expressed by the sum of crop changes in a sequence, which is maximum the sequence length minus one. Sequences with a high transition rate and more than two-third of the defined maximum crop sum were considered as highly diverse and were summarized in one group. As applied in Figure 6 we merged the transition groups to reduce this feature to units of two transitions. Sequences with only one crop were defined as continuous cropping (CC in Figure 5 and type A in Figure 6). Generally, sequences with less than three crops are considered as simple structured sequences (A, B, C, D), sequences with three crops as moderate structured (E, F) and with more than three as diverse structured sequences (G, H, I). Depending on the sum of different crops, all combination are not possible, e. g. it is not possible to grow four different crops with less than three transitions from one kind of crop to the next (A-B-C-D-D-D-D) in a 7-year-sequence. The types resulting from the first step were named “main types” marked with capital letters.

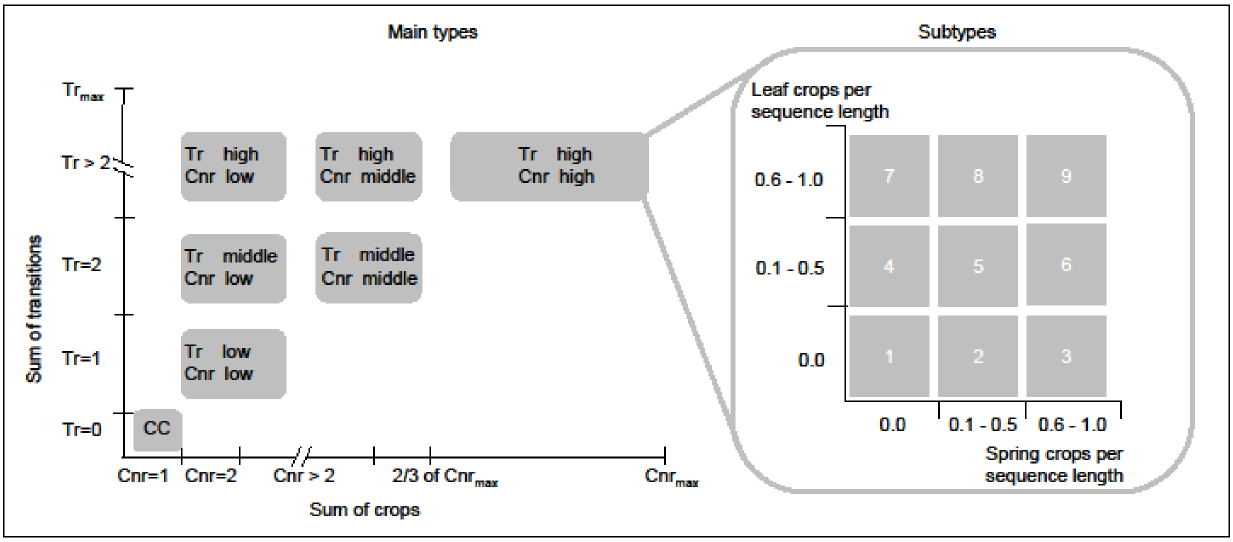


Figure 5. Typification scheme for crop sequences and its two diversity categories separated by their structural and functional diversity features. The main type (left side) concerns the sum of transitions [Tr] and the sum of different crops [Cnr] while continuous cropping (CC) is the lowest possible range. The right side of the figure distinguishes in a second step nine subtypes out of each main type by the proportion of leaf crops per sequence and the proportion of spring crops per sequence.

The second step addressed the functional aspects of crop pattern diversity depending on the amount of leaf crops and spring-sown crops. The types of this second step were considered as subtypes and marked with numerals from 1 to 9. According to Baeumer (1990) three assorted characteristics were specified according to the proportion of spring crops x: i) pure winter crop rotation ($x = 0$), ii) rotation with moderate spring crop amount ($0 < x \leq 0.5$), iii) spring crop dominated rotation ($x > 0.5$). In the case of sequences with odd numbers the ratio of 0.5 has to be rounded up (here ≤ 0.5 is equal to ≤ 4 in seven years), as otherwise the rotation A-B-A-B-A-B-A would not be considered the same as B-A-B-A-B-A-B. The categorization according to ‘leaf crop amount’ is based on rotation rules recommended by Baeumer (1990) to cultivate a maximum leaf crop ratio of 0.33. A leaf crop ratio of more than 0.33 increases the risk for the accumulation of soil-born pests, e.g. nematodes like *Globodera* (Kapsa, 2008). Sequences with an odd number of years may contain incomplete three-year or four-year rotations, which increase the real proportion. Hence, the maximum recommended leaf crop proportion (y) for these odd sequences is a rounded proportion of 0.5 instead of 0.33 (here $y \leq 0.5$ is equal to ≤ 3 in seven years). This results in the following division: i) no leaf crop ($y = 0$), ii) rotation with moderate leaf crop ratio ($0 < y \leq 0.5$), iii) leaf crop dominated rotation ($y > 0.5$). A matrix of both features spring crop amount (columns) and leaf crop amount (rows) splits each of the nine main types in nine sub-types, in the following considered as crop sequence types (CST). Not all crop sequence types could be observed in the data set. Of the 73 CSTs, the ten types with the greatest proportion of the investigated area were selected for further analysis.

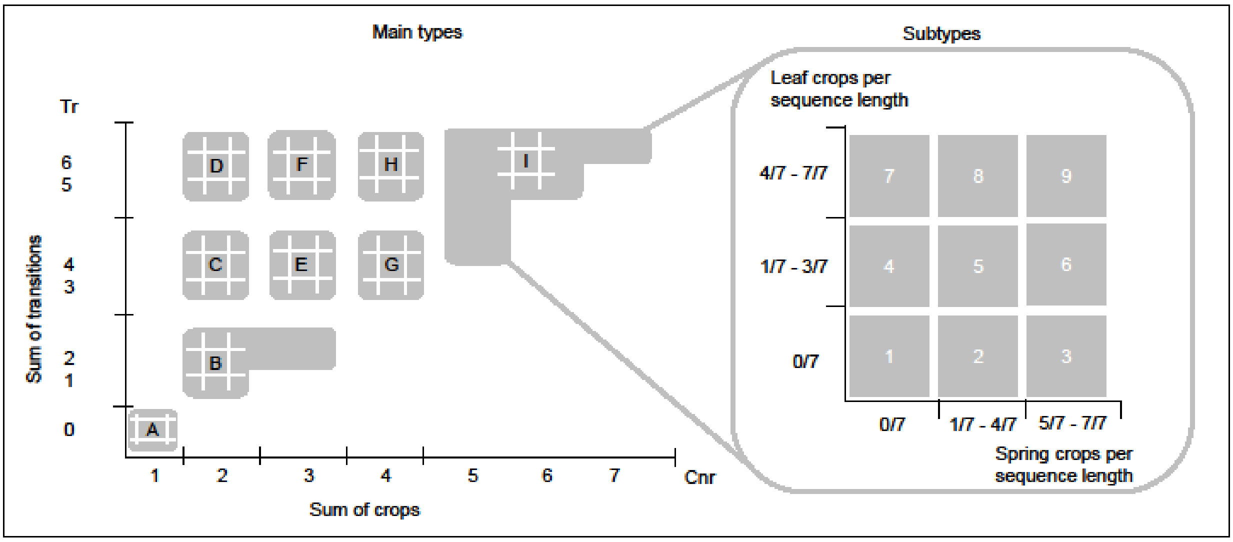


Figure 6. Application of the typification scheme for seven-year crop sequences. The left side of the figure presents the sum of transitions per sequence (Tr) on the y-axis and on the x-axis the sum of crops per sequence (Cnr) resulting in nine main types A - I. The right side of the figure concerns the amount of leaf crops on the y-axis and spring crops on the x-axis which form the nine subtypes 1–9.

The schema of the main types reflects the grade of diversity in a linear way in proportion to sum of transition and sum of crops per sequence while in schema of the subtypes the diversity decreases circular from the center to the edge. In the following we denote simple crop sequences as sequences with a low structural diversity and unbalanced amounts of winter sown crops in proportion to spring sown crops or cereal crops in proportion to leaf crops, e.g. pure maize sequences (A3) or sequences with a very high share of winter wheat (C5). The second example shows that a low structural diversity outweighs a high functional diversity. These types of sequences entailed a higher risk for pests and diseases and are therefore stronger dependent on plant protection products.

Landscape variables

To determine the role of location factors of the defined crop sequence types we studied the linkage of CSTs and specific site conditions. We selected spatial variables which represent the environmental and agro-economic attributes of the investigated area in a suitable resolution and area-wide consistent availability. Official data from public sources were obtained to meet these criteria (Table 7). The environmental conditions were characterized by the variables soil texture, slope and average annual precipitation. The average annual temperature was not considered due to the low variation of the thermal regime in the study region. The agro-economic characteristics were represented by the spatial density of livestock farming (livestock unit/ ha agricultural area), which was extracted from agricultural census data on LAU-2 (Local Administrative Unit) scale. With regard to the different land use patterns connected with cattle farming and pig and poultry farming, the livestock data were separated into two variables. These two variables – cattle density and pig/poultry density – were subdivided into five classes according to the quartiles of the frequency distribution and one class for no occurrence of livestock farming per LAU-2 area.

Table 7. Selected variables characterizing the arable landscape, their units, scales and data sources.

Predictor variable	Unit	Scale	Source
Soil texture (Dominant surface textural class of the soil)	1 peat soil 2 coarse (> 65% sand) 3 medium (< 65% sand) 4 medium fine (< 15% sand) 5 fine (>35% clay)	1: 1 000 000	European Soil Portal, 2004
Slope (Dominant slope class)	1 level (< 8%) 2 sloping (8–15%) 3 moderately steep (>15%)	1: 1 000 000	European Soil Portal, 2004
Average annual precipitation (1981–2010)	$mm*y^{-1}$	0.96 x 0.96 km	DWD, 2014
Cattle density	Livestock unit/ha (agricultural area)	LAU 2	LSKN, 2012
Pig/poultry density	Livestock unit/ha (agricultural area)	LAU 2	LSKN, 2012

The information of these landscape data was assigned to the parcels according to the parcel's centroid position in space and merged by the ArcGIS® tool Spatial Join. The relationship between the chosen variables and the crop sequence types was analyzed by a coefficient of variation which is closely related to the Chi-squared test without squaring and summation. The result is a value which represents the deviation from the overall mean per variable class. It is calculated as the deviation of the observed frequencies (obs = observed) from the expected frequencies (rand = random), computed as 100*(obs-rand)/rand.

Table 8. Correlation Matrix of the landscape variables used.

	Soil texture	Slope	Precipit.	CattleD	PigPoulD
Soil texture	1				
Slope	0.267	1			
Precipit.	-0.093	0.117	1		
CattleD	-0.437	-0.190	0.501	1	
PigPoulD	-0.248	-0.161	0.248	0.221	1

The correlations among the landscape variables show relations of various intensities (Table 8). High positive correlations, e.g. between cattle density and precipitation or negative correlation between cattle density and soil texture were validated by the results of the analyzed CST-landscape-relationship.

Results

Application of crop sequence types

The crop sequence types approach was applied for the crop sequence data of Lower Saxony in north-west Germany. We found that the nearly all forms of structural diversity, represented by the main types of the typification, where cropped in significant extent (Table 9). Both very simple sequence types and very diverse types occurred on large proportions of arable land. The sequences with only one or two crops (A, B, C, D) were detectable on 31.4% of the arable area. The main type F, which includes three crops that are combined in a very diverse way, represents the biggest share of land use (24% of the arable area).

Table 9. The share in arable area in percent of the nine crop sequence types (CST) in letters A–I of the main types and the 9 CSTs of the sub types in numerals from 1–9. Some combinations were not cropped in the observed period (-).

CST	Subtype									
Main type	1	2	3	4	5	6	7	8	9	∑
A	0.6	-	8.1	-	-	-	-	-	<0.1	8.7
B	0.4	0.7	5.2	0.8	0.6	0.5	<0.1	<0.1	0.1	8.2
C	0.3	0.8	2.6	2.2	4.6	0.3	<0.1	<0.1	0.1	10.7
D	0.3	1.1	1.6	0.2	0.3	0.1	<0.1	<0.1	0.2	3.8
E	0.3	1.6	2.8	3.7	5.2	1.1	<0.1	<0.1	0.1	14.9
F	0.4	5.1	1.8	7.8	6.2	1.7	<0.1	0.3	0.7	24.0
G	<0.1	0.7	0.6	0.7	1.8	0.6	<0.1	<0.1	<0.1	4.4
H	0.1	2.7	0.8	2.1	9.6	2.0	<0.1	0.3	0.9	18.4
I	<0.1	0.6	0.1	0.2	4.1	1.1	-	0.3	0.4	6.8
∑	2.3	13.4	23.6	17.6	32.4	7.5	<0.1	0.9	2.4	100.0

However, this high structural diversity is no guarantee for the functional diversity of a sequence. The main type F contained three subtypes of the ten most frequently cropped sequence types (Table 10) showing a great heterogeneity regarding the functional diversity aspects: F4 without any spring-sown crop, F2 without any leaf crop and F5, characterized by a moderate leaf crop amount and a moderate number of spring crops. Under functional aspects, this type contains the most diverse crop sequence types. In Lower Saxony 39.3% of the area was cultivated without any leaf crop (subtypes 1, 2, 3) since maize replaced the leaf crops in crop sequences in the previous years. A proportion of more than 0.5 leaf crops in a sequence was rare in the observed data set.

Table 10. The ten largest crop sequence types and their share in arable area (AA), sequence examples. BA = Winter Barley; MA = Maize; OR = Oilseed Rape; PO = Potato; RY = Rye; SA = Set-aside; SB = Sugar Beet; SC = Summer Cereals; TR = Triticale; WW = Winter Wheat.

Crop Sequence Type	Share in AA	Diversity	Sequence examples (according to crop rotations)
H5	9.6%	high	OR - WW - [WW] - MA - WW - BA
			OR - WW - BA - MA/SC - WW - BA
			SB - WW - [WW] - BA - OR - WW - BA
A3	8.1%	low / only cereals	MA - MA - MA - MA - MA - MA - MA
F4	7.8%	medium / only winter crops	OR - WW - [WW] - BA
			OR - WW - BA - OR - WW - WW
F5	6.2%	medium	SB - WW - WW - [BA] - SB - WW - BA/WW
			OR - WW - [MA] - WW - OR - WW - MA/WW
			PO - RY/WW - TR/BA
E5	5.2%	medium	SB - WW - WW - BA
			SB - WW - WW - [WW] - OR - WW - WW
B3	5.2%	low / only cereals	RY/BA/TR/SC/WW - MA - MA - MA - MA - MA - MA
F2	5.1%	medium / only cereals	MA/SC - WW - BA - [MA - WW - [WW]]
			MA - TR - BA
C5	4.6%	low	SB - WW - WW - [WW]
I5	4.1%	high	OR - WW - [WW] - MA/SC - WW/TR - BA
			OR - WW - BA/TR/RY - MA/SC -WW - BA - [SA]
			SA - WW - BA - OR - WW - MA - WW
E4	3.7%	medium / only winter crops	OR - WW - WW - [WW] - BA - [BA]
Total	59.6%		
			[ ] marks the flexible inclusion of crops / signifies “or”

The ten crop sequence types with the largest share of arable area were characterized in detail (Table 10). About 60% of the investigated area in Lower Saxony was cropped with these ten sequence types during the years 2005-2011. Nearly every range of diversity was represented here, from continuous cropping types to extremely diverse types. The most common CST was H5 with a high grade of diversity in its sequence structure. The second most common CST was A3, representing continuous cropping of cereal spring crops (here maize). So, the two most common sequence types represent the two poles of the diversity range, from very simple to very diverse.

Table 11 shows to which extent the most important crop sequence types are composed of the four most important crops of the study region. The upper part of the table shows the occurrence of the given crop in the respective crop sequence type based on all parcels cropped with this CST while the lower part gives the proportion of the specific crop in the sequences, where the crop was cultivated at least once in the observed time. The highest possible value is 1.00, which stands for continuous cropping. Maize dominated the simple sequence types A3 and B3 and was cropped in nearly all parcels of this CST, but also played an important role in the very diverse sequence types H5 and I5. All CSTs without continuous maize cropping are characterized by a strong presence of winter wheat, both in the area proportion and proportion per sequence. The mean area proportion of 0.61 calculated over all CSTs underlines the important role of winter wheat in Lower Saxon crop cultivation.

Table 11. Crop proportions of the four main crops in Lower Saxony in the ten largest crop sequence types ranging from very simple (A3 – continuous summer cereal cropping) to very diverse (I5). The values of the upper part indicate the share of arable area in the total arable area of the respective CST where the named crop was cultivated at least once in 2005–2011. For example, Winter Wheat was cropped at least once in seven years on 24% of the total area of the CST B3. That means the other 76% represent areas with combination of maize and other cereal crops but without Winter Wheat cropping. The lower part of the table shows the average proportion of the crop in the respective sequences for those fields where the individual crop was cultivated at least once in 2005–2011. So, if Winter Wheat is cultivated at least once in seven years in the sequence of type B3, its mean crop proportion in a seven-year sequence was about 20%. The mean represents these values for the total data set.

CST	A3	B3	C5	E4	E5	F2	F4	F5	H5	I5	Mean
Proportion of crop area in total CST area											
Maize	0.99	0.99	0.00	0.00	0.20	0.91	0.00	0.22	0.52	0.65	0.53
Winter Wheat	0.00	0.24	0.97	0.92	0.89	0.54	0.93	0.88	0.81	0.76	0.61
Sugar Beet	0.00	0.00	0.96	0.00	0.76	0.00	0.00	0.71	0.37	0.31	0.24
Oilseed Rape	0.00	0.00	0.00	1.00	0.35	0.00	1.00	0.31	0.73	0.79	0.35
Mean crop proportion per sequence											
Maize	1.00	0.79	0.00	0.00	0.21	0.34	0.00	0.26	0.20	0.18	0.52
Winter Wheat	0.00	0.18	0.68	0.57	0.61	0.36	0.41	0.48	0.37	0.25	0.42
Sugar Beet	0.00	0.00	0.32	0.00	0.21	0.00	0.00	0.28	0.19	0.16	0.24
Oilseed Rape	0.00	0.00	0.00	0.21	0.17	0.00	0.28	0.20	0.19	0.17	0.21

The two dominant leaf crops in Lower Saxony, sugar beet and oilseed rape, were cropped in sequence types with medial diversity. These crops had distinctive occurrence in CSTs C5 and E4 and were both rotational parts in CSTs F5, H5 and I5. On average, the maximum recommended proportion of 33% was not exceeded in any of these sequence types.

Figure 7 visualizes the spatial distribution based on the example of four CSTs. Simple CSTs (A3) occupied a more distinct area and dominated the landscape, as indicated by the high density of dots representing individual parcels. Diverse CSTs (I5) were more widely distributed and characterized by a looser pattern of parcels. CSTs of medium diversity were cropped in distinct areas with either looser (F2) or dense (F4) distribution patterns.

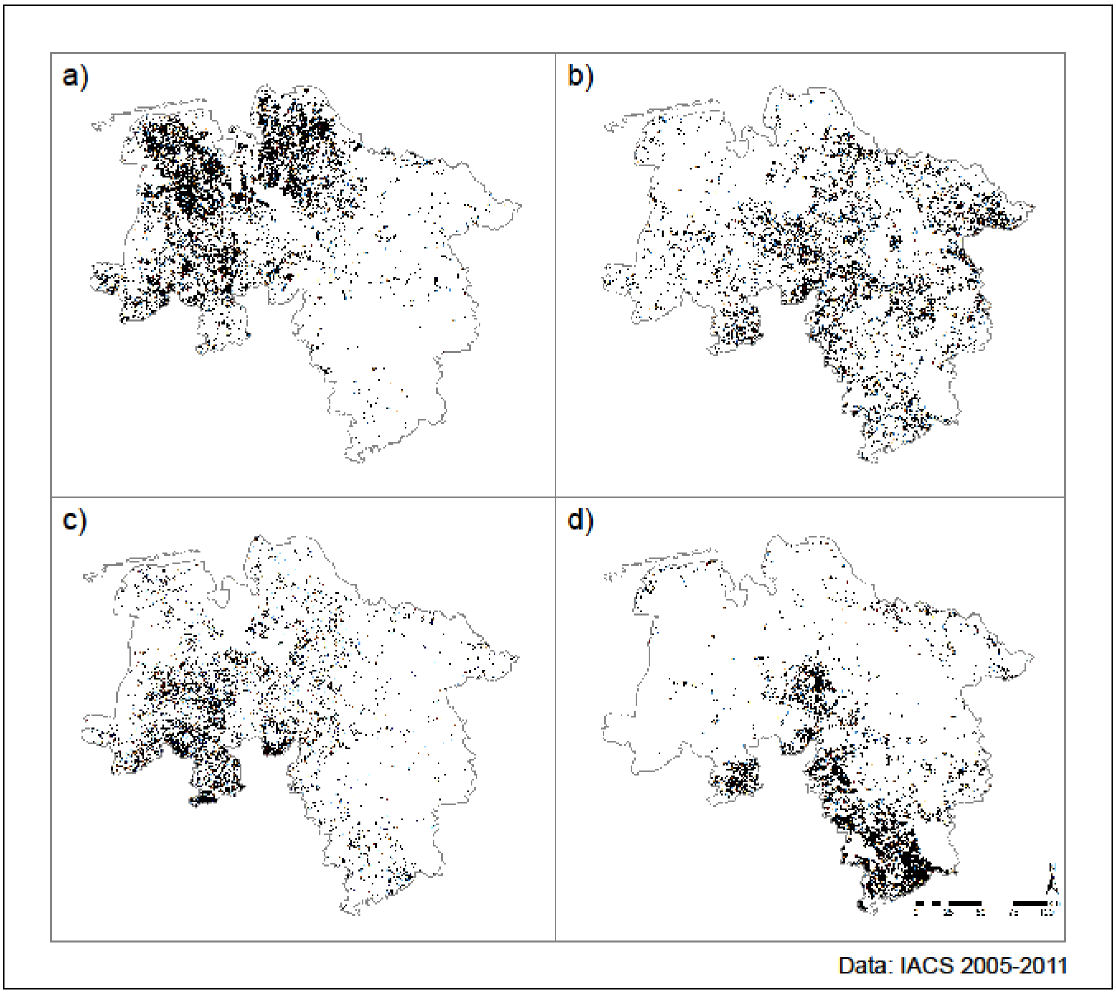


Figure 7. Occurrence of a) CST A3 (continuous maize cropping), b) CST I5 (most diverse crop sequence type), c) CST F2 (e.g. MA - WW - BA - MA - WW - WW) and d) CST F4 (e.g. OR - WW - BA - OR - WW - WW) in Lower Saxony where each dot on the map represents one field.

Relationship to landscape factors

An example of the application of the crop sequence typification is the analysis of the interaction of crop sequence pattern with agri-environmental site conditions.

Table 12 describes the relationship of the most frequent crop sequences and their associated landscape factors. The stronger the deviation from zero, the stronger was the deviation of the observed sequence frequency from the expected frequency. High or low values implicate preference or avoidance of the landscape factors and their grades in the observed time frame 2005–2011. The CSTs with the highest maize proportion (A3, B3 and F2) were grown to some extent under similar conditions, but some distinctions were visible. The sequence type for continuous summer cereal (here maize) cropping (CST A3) was strongly related to leveled regions with peaty soils, humid climate and intensive cattle farming. This resulted in a regional concentration of this sequence type (Figure 7 a). The spatial relationship of the three landscape variables was already reflected in the correlation matrix (Table 8). CSTs B3 and F2 were cropped under similar conditions concerning the slope and precipitation but were more frequently cropped on coarse soils. While parcels with dense summer cereal cropping combined with one other crop (CST B3) were linked with intensive cattle farming and partly with intensive pig and poultry farming, the diversified maize-cereal cropping (CST F2) was characteristic for regions with intensive pig and poultry farming outside the peaty soil regions.

Table 12. Deviation of observed CST frequencies from expected CST frequencies in percent characterizing the relation between the most frequent crop sequence types and attributed landscape variables.

Variable	CS Type	A3	B3	C5	E4	E5	F2	F4	F5	H5	I5	All others
Texture	peat soil	19.2	11.6	-10.2	-10.0	-7.4	-0.9	-10.2	-7.3	-6.8	-4.1	0.5
	coarse	5.1	10.8	-33.3	-29.1	-21.7	16.7	-29.3	-17.1	-6.2	7.6	7.2
	medium	-2.5	-2.7	-8.3	13.4	0.4	-5.6	13.1	-4.0	-0.9	-1.6	-0.1
	med. fine	-21.0	-19.0	51.4	24.5	27.6	-9.6	25.5	27.7	13.5	-1.7	-7.5
	fine	-0.7	-0.6	0.3	1.2	1.0	-0.5	0.9	0.7	0.4	-0.2	-0.1
Slope	level	9.2	8.1	-4.5	-16.4	-2.5	4.4	-23.8	-2.7	-3.3	0.3	2.4
	sloping	-4.8	-4.3	-1.8	6.5	-0.3	-2.6	15.0	0.5	2.3	0.7	-1.2
	mod. steep	-4.4	-3.8	6.2	9.9	2.8	-1.8	8.8	2.2	1.0	-1.0	-1.2
Precipitation	500–600	-0.9	-0.5	0.3	-0.3	0.8	-0.7	-0.4	1.0	1.0	1.7	-0.2
(mm*y^{-1})	601–700	-14.2	-11.8	35.2	-0.1	25.4	-8.5	-4.7	23.9	7.8	8.0	-2.4
	701–800	-6.9	-3.1	-2.5	2.7	-3.0	-1.9	2.2	-1.3	3.2	4.8	0.9
	801–900	24.9	17.9	-29.8	-6.2	-21.0	11.0	-7.3	-21.7	-13.7	-15.1	2.4
	901–1200	-3.0	-2.6	-3.3	3.9	-2.3	0.1	10.1	-1.9	1.7	0.6	-0.7
Cattle dens.	0.000	-1.6	-1.5	11.1	0.8	7.5	-1.5	-0.6	3.6	0.2	-0.7	-0.8
(LU/ha agric. a.)	0.001–0.245	-22.0	-19.5	51.5	17.2	29.9	-17.7	16.4	30.8	11.7	5.3	-5.2
	0.246–0.509	-17.9	-12.9	-15.2	12.4	-4.2	1.7	18.6	-2.2	11.9	12.8	-0.8
	0.510–0.954	-1.7	8.0	-23.1	-11.2	-15.8	17.0	-11.8	-12.2	-6.8	-2.9	4.8
	0.955–2.930	43.1	25.9	-24.3	-19.2	-17.3	0.6	-22.6	-20.0	-17.1	-14.4	2.0
Pig/poultry dens.	0.000	-0.4	-0.7	6.2	0.2	3.5	-1.1	-0.4	1.8	0.1	0.0	-0.5
(LU/ha agric. a.)	0.001–0.045	8.0	-2.1	30.0	6.6	18.3	-14.5	3.6	15.3	0.9	-3.6	-4.7
	0.046–0.160	-4.9	-9.0	6.7	16.1	8.0	-13.0	15.0	6.9	5.5	5.2	-2.6
	0.161–0.556	-1.2	3.0	-19.3	-7.0	-11.0	2.6	-3.6	-10.0	-1.6	5.7	3.1
	0.557–3.211	-1.5	8.8	-23.6	-15.9	-18.7	26.1	-14.6	-14.1	-4.8	-7.3	4.7

Sequence types with moderate leaf crop and spring-sown crop amount but different grades of structural diversity were represented in CSTs C5, E5, F5, H5 and I5. Their linkage with landscape factors was obviously determined by the presence of sugar beet in the sequence. The CST C5, with a lower structural diversity, and the sequence types E5 and F5, with a higher structural diversity (for comparison see Table 10), were cropped under the same site conditions - more frequently in regions with medium-fine soil texture, an annual precipitation of 600–700 mm and low density of livestock farming - but the characterization of the crop sequence types by the landscape-related variables was much more explicit in the simple structured sequences than in the diverse sequences. The last applies also to other CSTs.

The most diverse sequence types H5 and I5 were associated with a moderate humid climate and a medium-high livestock density. The preferences in soil texture were different and showed regional distribution on coarse (CST I5) and medium-fine soils (CST H5). The CST I5 was distributed in nearly every part of Lower Saxony with no significant regional concentration (Figure 7 b).

Discussion

The typification and its applicability

So far a lot of approaches and methods exist for assessing crop rotation management, even with the combined use of structural and functional characteristics. This approach of a crop rotation typification is explicitly different from those that aim to evaluate crop rotations, e.g. by a qualitative index. The crop sequence indicator presented by Leteinturier et al. (2006) based on the Indigo method (Bockstaller and Girardin, 1996) is such an approach for assessing the crop sequence composition as well as its quality. However, the translation of the rotation properties into coefficients and their merger into a single value entails the risk of information loss. So, the presented typology exposes the differences in cropping pattern and allows at the same time the diversity of crop rotation practice to be determined and located. For example, regions with a high amount of simple crop sequences and hotspots of vulnerability could be identified.

In recent arable cropping the integration of a leaf crop in the crop rotation is not obligatory at all. In Lower Saxony 39% of the area was cultivated without any leaf crop. Maize has characteristics of leaf crops concerning the high amount of residues at the parcel and the connected influence on the humus balance. The crop took the rotation place of leaf crops in areas of the observed region which are characterized by a low leaf crop amount (Bennetzen and Hake, 2009). This is due to external market factors (biogas production) on the one hand

and specific characteristics of maize on the other hand like its high tolerance of short rotational breaks and lower demands on soil quality compared with leaf crops like oil seed rape (for details see the following section Simplicity and diversity).

A few limitations of the typology were found. The use of catch crop cultivation in Lower Saxony could not be included in the study, since it was not part of the IACS data. It is undeniable that this information would made the picture more complete. Furthermore, the differentiation by sowing season limits the application of the typology approach to annual cropping in temperate climate zones and excludes intercropping systems. Nevertheless, most arable cultivation takes place in temperate climatic zones. So, the typology covers a wide range of applications.

For this typology approach only crop sequences were processed which were clearly identifiable over the observed time span due to constant number and size of parcels in the field block. However, methods exist to deal with that problem. Levavasseur et al. (2016) devised a tool which computes crop sequences using defined change rules in an algorithm. This tool allows the tracing of crop sequences when no spatial geometry is available and has shown good results in areas with small farm blocks. The facts that the observed crop area in Lower Saxony is characterized by complex field blocks with a high number of parcels and that an explicit spatial geometry for the year 2011 for all parcels was available for our study as well as the large data volume, caused the preference of the spatially precise sequence analysis instead of the maximum data exploitation. The latter would have been gone at the expense of accuracy.

Simplicity and diversity

The recent picture of crop rotation practice in Lower Saxony is characterized by a high rate of simplified cropping patterns especially in regions of intensive livestock farming as well as intensive cash crop production under favorable cultivation conditions. This could be shown clearly by demonstrating the proportions of simple CSTs. However, there was still a significant proportion of diverse crop sequences in arable cropping practice. These diverse sequence patterns are widely distributed across the study region on sites with different properties. This widespread distribution without significant dependency on specific site conditions is due to the high variety of crops summarized in one type.

Since the introduction of maize in the 1970s, this crop has been playing an important role in the crop rotation practice of Lower Saxony. It is a cornerstone of feed production in the regions of intensive livestock farming and it has become the main energy crop for biogas production. The latter is a result of the support policy for renewable energy production in Germany by the implementation of a national renewable energy law (EEG, 2004). Nearly one quarter of the arable area in Lower Saxony is cultivated with more than 50% maize ratio in the crop sequence. This fact reveals the level of disregard of crop rotation rules and the level of instability in the regional cropping systems. In dense maize rotations the demand for nutrients is higher in order to realize dense maize cropping over several years. Kleijn and Verbeek (2000) observed in their study on sandy soils in the Netherlands that maize-dominated crop rotations were managed with a significantly higher input of nutrients than other rotations under the same conditions. Dense maize cultivation increases the risk of arthropod pests like the European corn borer (*Ostrinia nubilalis*) and the Western corn rootworm (*Diabrotica virgifera virgiferia*). The most common answer to weeds, arthropod pests and fungal diseases in maize production is currently the application of pesticides. According to the goals of Integrated Pest Management, diversified cultivation is one important option to reduce the input of pesticides combined with other measures (Meissle et al., 2010; Andert et al., 2016). Despite its negative role in simple structured crop sequences, maize is a key component of many very diverse sequences and can play an important role in interrupting the continuous cropping of winter-sown crops and the corresponding accumulation of adapted weeds in several regions. So, maize cropping is not only a threat to modern arable cropping, but also an opportunity for building diverse crop sequence patterns.

Maize is a cereal that takes the functional role of a leaf crop like oilseed rape in the cereal rotations of the livestock farming regions. This is reflected, for example, in the comparison of the CSTs F2 (e.g. MA - WW - BA [- MA - WW - WW]) and F4 (e.g. OR - WW - BA [- OR - WW - WW], abbreviations see Table 1). Both sequence types are characterized by a high transition rate and three crops in the sequence. While the sequences of CST F2 are cultivated without any leaf crop, the sequences of type F4 are pure winter-sown crop sequences with a leaf crop proportion up to 0.33 per sequence. In Lower Saxony these two types of crop sequences show a very similar structure, distinguished only by the supporting crop which is cultivated in combination with the winter wheat and other winter cereals – maize in CST F2 and oilseed rape in CST F4. As can be seen in the analysis of the relationship to the chosen landscape variables (Table 12), the maize sequence F2 is related to coarse soil texture on level sites in pig and poultry farming regions. In contrast, the oilseed rape sequence F4 is principally cultivated in hilly humid regions characterized by medium-fine soil structure and a low density of livestock farming. The site-condition-dependent preferences of the two sequence types are reflected in their spatial distribution in Lower Saxony (Figure 7). So, maize takes the place of oilseed rape in sites where the conditions do not provide a high yield of the leaf crop and where the economic infrastructure allows or even requires the cultivation of maize.

Winter wheat was the most distributed crop in the Lower Saxon crop sequences during the observed time span. The repeated cultivation of wheat for three years is fraught with risk for yield instability and higher direct costs for fungicides and N fertilization. This is not only a topic of the pure cereal rotations but potentially in future also for sequences with a very high crop proportion of winter wheat, e.g. in high-yield regions with sugar beet cultivation (e.g. SB-WW-WW-WW in CST C5). The integration of leaf crops like oilseed rape or grain legumes in the rotation can offer an alternative. For the combination of two leaf crops with the same risks for pathogenic organisms the problem of soil-borne pathogens must be considered. The high attractiveness of oilseed rape as part of diverse rotations as well as of wheat-oriented rotations can be attributed to its high profitability (Berry and Spink, 2006). As an effective break for wheat, oilseed rape is an essential rotation crop in regions where wheat is the most profitable crop (Kirkegaard et al., 2008). The cultivation of legumes widely lost its role in the investigated area, except for organic farming. This is a consequence of decades of loss of legumes importance for soil fertilization and animal nutrition due to cost effectiveness. In seven years only 2% of the investigated area was cropped with legume in at least one year (8033 ha). Per year the amount is stable at about 0.7% of the arable area. Stronger efforts in the development of appropriate plant breeding and protection for legumes are necessary to make these crops more attractive for farmers. It is a question for the future if the recent greening efforts for the European agricultural policy will enhance the legumes role in the European crop rotation systems.

Conclusion

The presented crop sequence typology is a generic method for analyzing comprehensive crop sequence data sets of a defined area and time span to distinguish rotation practices by their rotation structure and composition of crops with specific functions. It is applicable for pattern search in a wide range of agricultural systems in temperate zones and for data with different crop sequence lengths. The typification approach is inspired by existing historical crop rotation systematizations but foregoes the principle of fixed rotation cycles to meet the recent farming practice of flexible, short-term cropping plans. The application of the typology for a data set of seven-year sequences in the arable area of north-western Germany showed a refined picture of recent crop rotation practice. The ten most common sequence types cover the full range of diversity. Diversified farming systems, which are generally more resilient to climate change variabilities and promote ecosystem services, are still common in the observed farming region. Agronomic research and extension service should further develop this potential by strengthening farming system approaches and helping farmers adapt cropping patterns to future demands. For agricultural policy and land use planning the findings might help to adjust measures to improve cropping diversity, as it becomes possible to locate simplicity and complexity on a finer scale. Regarding maize, which was proven as a crop of both very simple and very diverse sequences, it could be shown that the crops' value for a sustainable land use depends strongly on its intensity of cultivation.

References

Abson, D. J., Fraser, E. D. G., Benton T. G., 2013. Landscape diversity and the resilience of agricultural returns: a portfolio analysis of land-use patterns and economic returns from lowland agriculture. Agriculture & Food Security 2:2. DOI: 10.1186/2048-7010-2-2.

Altieri, M. A., 1999. The ecological role of biodiversity in agroecosystems. Agric. Ecosyst. Environ. 74, 19-31.

Andert, S., Bürger, J., Stein, S., Gerowitt, B., 2016. The influence of crop sequence on fungicide and herbicide use intensities in North German arable farming. Eur. J. Agron. 77, 81-89.

Andreae, B., 1952. Fruchtfolgen und Fruchtfolgesysteme in Niedersachsen. Bren, W. Dorn.

Aurbacher, J., Dabbert, S., 2011. Generating crop sequences in land-use models using maximum entropy and Markov chains. Agr. Syst. 104, 470-479.

Bachinger, J., Zander, P. 2007. ROTOR, a tool for generating and evaluating crop rotations for organic farming systems. Eur. J. Agron. 26, 130-143.

Baeumer., K., 1990. Gestaltung der Fruchtfolge. In: Dierks, R. And Heitefuß, R., 1990. Integrierter Landbau. BLV, München.

Bakker, M. M., Hatna, E., Kuhlman, T., Mücher, C. A., 2011. Changing environmental characteristics of European cropland. Agr. Syst. 104 (7), 522-532.

Ball, B. C., Bingham, I., Rees, R. M., Watson, C. A., Litterick, A., 2005. The role of crop rotations in determining soil structure and crop growth conditions. Canadian Journal of Soil Science 85, 557-577.

Bennett, A. J., Bending, G. D., Chandler, D., Hilton, S., Mills, P., 2011. Meeting the demand for crop production: the challenge of yield decline in crops grown in short rotations. Biol. Rev. 87, 51-72. DOI: 101111/j.1469-185X.2011.00182.x

Bennetzen, J. L., Hake, S. C., (ed.) 2009. Handbook of Maize: Its Biology. Springer.

Berry, P. M., Spink, J. H., 2006. A physiological analysis of oilseed rape yields: Past and future. The Journal of Agricultural Science 144 (9), 381-392.

Berzsenyi, Z., Gyorffy, B., Lap, D., 2000. Effect of crop rotation and fertilization on maize and wheat yields and yield stability in a long-term experiment. Eur. J. Agron. 13 (2-3), 225-244.

Blackshaw, R. E., Andersson, R.L., Lemerle, D., 2007. Chapter 3: Cultural weed management. In: Upadyaya, M.K. and Blackshaw, R.E.: Non-chemical weed management: Principles, concepts and technology. CAB International, Wallingford, UK, pp. 35-48.

Bockstaller, C., Girardin, P., 1996. The crop sequence indicator: a tool to evaluate crop rotations in relation to the requirements of Integrated Arable Farming Systems. Aspects Appl. Biol. 47, 405-408.

Boller, E. F., Malavolta, C., Jörg, E., 1997. Guidelines for integrated production of arable crops in Europe. IOBC Technical Guideline III. Bull. OILB Srop 20 (5), 5-19. ISBN 92-9067-090-8.

Bowman, M. S., Zilberman, D., 2013. Economic factors affecting diversified farming systems. Ecol. Soc. 18 (1), 33. DOI: 10.5751/ES-05574-180133.

Brinkmann, T., 1950: Das Fruchtfolgebild des deutschen Ackerbaues. Bonner Universitätsbuchdruckerei, Bonn.

Castellazzi, M. S., Wood, G. A., Burgess, P.J., Morris, J., Conrad, K. F., Perry, J. N., 2008. A systematic representation of crop rotations. Agr. Syst. 97, 26-33.

Dury, J., Garcia, F., Reynaud, A., Bergez, J.-E., 2013. Cropping-plan decision-making on irrigated crop farms: A spatio-temporal analysis. Eur. J. Agron. 50, 1–10.

DWD (Deutscher Wetterdienst), 2014. Long-term average annual precipitation (1981-2010). Online download via WebWerdis [accessed 06-03-2014].

EEG, 2004. Erneuerbare-Energien-Gesetz (Renewable Energies Act) of 21 July 2004 (Federal Law Gazette I p. 1918), last amended by Art. 1 Act of 7 November 2006 (Federal Law Gazette I p. 2550).

El Titi, A., Boller, E. F., Gendrier, J. P., 1993. Integrated production. Principles and technical guidelines. IOBC/WPRS Bull. 16, 13-38.

European Commission, 2007 a. Thematic strategy on the sustainable use of pesticides. Communication of the Commission of 12 July 2006 [COM(2006) 372]. URL: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=URISERV%3Al28178 [accessed 18-04-2016].

European Commission, 2007 b. Managing the agricultural budget wisely. Fact Sheet, European Communities. URL: http://ec.europa.eu/agriculture/sites/agriculture/files/cap-funding/audit/pdf/2007_en.pdf [accessed 06-12-2016].

European Commission, 2008. Agriculture: Member States agree in principle to abolish obligatory set-aside. Press Release IP/08/1069, Brussels, 1 July 2008.

European Commission, 2011. Our life insurance, our natural capital: an EU biodiversity strategy 2020. COM/2011/0244.

European Parliament, 2009. Directive 2009/128/EC of the European parliament and of the council of 21 October 2009. Official Journal of the European Union (L 309/71).

European Parliament, 2013. Regulation (EU) No 1307/2013 of the European parliament and of the council of 17 December 2013. Official Journal of the European Union (L 347/608).

European Soil Portal, 2014. The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN.

Fraser, E.D.G., 2006. Crop diversification and trade liberalization: linking global trade and local management through a regional case study. Agric. Hum. Values 23, 271–281.

Glemnitz, M., Wurbs, A., Roth, R., 2011. Derivation of regional crop sequences as an indicator for potential GMO dispersal on large spatial scale. Ecol. Ind. 11, 964-973.

IAASTD (International Assessment on Agricultural Knowledge, Science and Technology for Development), 2009. Global Report. Chapter 6: Options to enhance the impact of AKST on development and sustainability goals. Island Press. URL: http://www.unep.org/dewa/agassessment/reports/IAASTD/EN/Agriculture%20at%20a%20Crossroads_Global%20Report%20(English).pdf [accessed 12-11-2015].

Kapsa, J. S., 2008. Important Threats in Potato Production and Integrated Pathogen/Pest Management. Pot. Res. 51, 385-401.

Karlen, D.L., Varvel, G.E., Bullock, D.G., Cruse, R.M., 1994. Crop Rotations for the 21st Century. Advances in Agronomy 53, 1-45.

Kay, S., Milenov, P., 2008. Status of the implementation of LPIS in the EU Member States. Fact Sheet, European Commission. URL: http://ies-webarchive-ext.jrc.it/mars/mars/content/download/995/6112/file/LPIS_study_MS_8203.pdf [accessed 05-12-2015].

Kirkegaard, J., Christen, O., Krupinsky, J., Lyzell, D., 2008. Break crop benefits in temperate wheat production. Field Crop Res. 107, 185-195.

Kleijn, D., Verbeek, M., 2000. Factors affecting the species composition of arable field boundary vegetation. Appl. Ecol. 37, 256-266.

Klein Haneveld, W. K., Stegeman, A. W., 2005. Crop succession requirements in agricultural production planning. European Journal of Operational Research 166 (2), 406-429.

Koennecke, G., 1967. Fruchtfolgen. VEB Deutscher Landwirtschaftsverlag, Berlin.

Le Ber, F., Benoît, M., Schott, C., Mari, J.-F., Mignolet, C., 2006. Studying crop sequences with CarrotAge, a HMM-based data mining software. Ecol. Modelling 191, 170-185.

Leenhardt, D., Angevin, F., Biarnès, A., Colbach, N., Mignolet, C., 2010. Describing and locating cropping systems on a regional scale. A review. Agron. Sustain. Dev. 30 (1), 131–138.

Leteinturier, B., Herman, J. L., de Longueville, F., Quintin, L., Oger, R., 2006. Adaptation of a crop sequence indicator based on a land parcel management system. Agric. Ecosyst. Environ. 112, 324-334.

Levavasseur, F., Martin, P., Bouty, C, Barbottin, A., Bretagnolle, V., Thérond, O., Scheurer, O., 2016. RPG Explorer: A new toll to ease the analysis of agricultural landscape dynamics with the Land Parcel Identification System. Comput. Electron. Agr. 127, 541-552.

Liebman, M., Dyck, E., 1993. Crop rotation and intercropping strategies for weed management. Ecol. Appl. 3, 92-122.

Lin, B. B., 2011. Resilience in agriculture through crop diversification: Adaptive management for environmental change. BioScience 61 (3), 183-193.

Long, J. A., Lawrence, R. L., Miller, P. R., Marshall, L. A., 2014. Changes in field-level cropping sequences: Indicators of shifting agricultural practices. Agric. Ecosyst. Environ. 189, 11-20.

LSKN (Landesbetrieb für Statistik und Kommunikationstechnologie Niedersachsen), 2012. Statistische Berichte Niedersachsen. Landwirtschaftszählung 2010, Brochure 1/A (Landuse) and 4 (Livestock). Hannover.

Mari, J.-F., Le Ber, F., 2006.Temporal and spatial data mining with second-order hodden markov model. Soft. Comput. 10, 406-414.

Meissle, M., Mouron, P., Musa, T., Bigler, F., Pons, X., Vasileiadis, V. P., Otto, S., Antichi, D., Kiss, J., Pálinkás, Z., Dorner, Z., van der Weide, R., Groten, J., Czembor, E., Adamczyk, J., Thibord, J.-B., Melander, B., Cordsen Nielsen, G., Poulsen, R. T., Zimmermann, O., Verschwele, A.& Oldenburg, E., 2010. Pests, pesticide use and alternative options in European maize production: current status and future prospects. J. Appl. Entomol. 134, 357-375.

Melander, B., Munier-Jolain, N., Charles, R., Wirth, J., Schwarz, J., van der Weide, R., Bonin, L., Jensen, P. K., Kudsk, P., 2013. European perspectives on the adoption of nonchemical weed management in reduced-tillage systems for arable crops. Weed Technol. 27, 231-240.

Rounsevell, M.D.A., Annetts, J.E., Audsley, E., Mayr, T., Reginster, I., 2003. Modelling the spatial distribution of agricultural land use at the regional scale. Agric. Ecosyst. Environ. 95 (2-3), 465-479.

Salomon-Monviola, J., Durand, P., Ferchaud, F., Oehler, F., Sorel, L., 2012. Modelling spatial dynamics of cropping systems to assess agricultural practices at the catchment scale. Computers and Electronics in Agriculture 81, 1-13.

Schönhart, M., Schmidt, E., Schneider, U. A., 2011. CropRota – A crop rotation model to support integrated land use assessments. Europ. J. Agron. 34, 263-277.

Science for Environment Policy, 2015. Ecosystem Services and the Environment. In-depth Report 11 produced for the European Commission, DG Environment by the Science Communication Unit, UWE, Bristol. Available at: http://ec.europa.eu/science-environment-policy [accessed 03-10-2015].

Smith, R.G.; Mortensen, D.A.; Ryan, M.R., 2009. A new hypothesis for the functional role of diversity in mediating resource pools and weed-crop competition on agroecosystems. Weed Research 50, 37-48.

Steinmann, H.-H., Dobers, S., 2013. Spatio-temporal analysis of crop rotations and crop sequence patterns in Northern Germany: potential implications on plant health and crop protection. J. Plant Dis. Protect. 120 (2), 85-94.

Stöckle, C. O., Donatelli, M., Nelson, R. 2003: CropSyst, a cropping systems simulation model. Eur. J. Agron. 18, 289-307.

Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., Thies, C., 2005. Landscape perspectives on agricultural intensification and biodiversity—ecosystem service management. Ecol. Lett., 8, 857-874.

van der Zanden, E., Levers, C., Verburg, P. H., Kuemmerle, T., 2016. Representing composition, spatial structure and management intensity of European agricultural landscapes. A new typology. Landscape and Urban Planning 150, 36-49.

van Zanten, B.T., Verburg, P.H., Espinosa, M., Gomez-y-Paloma, S., Galimberti, G., Kantelhardt, J., Kapfer, M., Lefebvre, M., Manrique, R., Piorr, A., Raggi, M., Schaller, L., Targetti, S., Zasada, I., Viaggi, D., 2014. European agricultural landscapes, common agricultural policy and ecosystem services: a review. Agron. Sustain. Dev., 34, 309-325.

Zhang, W., Ricketts, T.H., Kremen, C., Carney, K., Swinton, S.M., 2007. Ecosystem services and dis-services to agriculture. Ecol. Econ., 64 (2), 253-260.

Xiao, Y., Mignolet, C., Mari, J.-F., Benoît, M., 2014. Modeling the spatial distribution of crop sequences at a large regional scale using land-cover survey data: A case from France. Comput. Electron. Agr. 102, 51-63.

Chapter 3

Annual crop census data does not proper represent actual crop rotation practice

Abstract

Crop rotation is often used as a criterion for assessing farming systems. The most common technique to derive the crop rotation practice is to use the crop statistic of one year. With the data of the actual crop rotation for the years 2005 till 2011 for the German federal state Lower Saxony we compare the spatial crop pattern of one year with the temporal crop sequences of the seven years. We grouped the crops depending on whether it is a leaf crop or a cereal crop or a spring sown crop or a winter crop in crop sequence types. This is based on the perception of former literature that today farmers often do not follow fixed crop rotations but more flexible patterns according to the function of the crop in a crop sequence. The comparison of the temporal and the spatial dimension of the crop sequence types showed that the derived crop sequence types of the spatial one-year statistic overstate the very heterogenous crop sequences and understate the less heterogeneous crop sequences.

Introduction

The interaction of spatial heterogeneity of landscape elements and the function and biodiversity of ecosystems is a key concept of landscape ecology (Wiens, 2002; Turner, 2005). The temporal dimension of landscape elements is fundamental as well in understanding these interactions (Reynolds-Hogland and Mitchell, 2007). The organization of agricultural practices by the farmers in space and time causes spatio-temporal heterogeneity of the agricultural landscape and the agro-ecosystems. It is a result of the factors that the farmer must consider like prevailing production condition (e.g. soil, water supply, climate), agronomic rules, market demands and suppliers as well as political requirements. The result is a side-by-side of different field works during the seasons. This spatio-temporal pattern at the field level, which is not detectable by a one-shot view, is what Vasseur et al. (2013) defined as the “hidden” heterogeneity. The hidden heterogeneity considers the temporal dimension of agricultural cropping as it is caused by crop rotation. This temporal aspect is highly important for agro-ecological studies, for example pollination ecology or insect-pest and antagonists’ ecology. Vasseur et al. (2013) analyzed the intra-annual dynamics of a field as carabid habitat. The temporal heterogeneity and the side-by-side of different agricultural practices during the year requires nevertheless the heterogeneity of crops in space. The simplest approach for the detection of the spatial heterogeneity of agricultural land use is to use the total number of crops or land use types and define an index like the Shannon index (e.g. Monteleone et al. 2018). But the type of crop and its physiological properties have different or similar functions depending on the context, e.g. the plant height and density or seed-producing potential means less or more benefit of the cover type for bird species. Fahrig et al. (2011) define functional cover types depending on the resource benefit of the landscape cover for the individual animals, called the *concept of functional landscape heterogeneity*. It means the measurement of heterogeneity based on the expected functions. Crop rotation is an important agricultural instrument to maintain soil functions like water and nutrient use efficiency. A proper crop rotation has the potential to reduce the risk of accumulating yield-reducing weeds and pests and therefore to minimize the use of pesticides (Karlen et al., 1994). We distinguished in this study the arable crops concerning their function in the crop rotation as leaf crops versus cereal crops (dicot crops versus monocot crops) and spring sown crops versus autumn sown crops (in the following named winter crops). The crop rotational function of these crop classification concerns the different effects of the crops on the weed community and the potential of weed accumulation (Bianchi et al., 2006). Weeds with specific seasonal growth periods may occur in strong concentration in crop rotations with high share of crops with the same growing season, like winter sown crops or spring sown crops (e.g. *Alopecurus myosuriodes* in winter sown cereals). Alternating spring and winter sown crops in a crop rotation have positive effects for the prevention of weed accumulation (Liebman and Dyck, 1993) as well as soil borne pathogens. There are several effects of crop rotation on soil properties in theory. A higher crop diversity and the placement of the soil cover period in different seasons has positive effects on the soil microbial activity which influences the aggregate stability of soil organic matter (McDaniel et al., 2014; Smith et al., 2014; Tiemann et al. 2015). An improved soil aggregate stability by crop rotation resulted in a greater water stability compared to farming systems without diverse crop rotations (Karlen et al., 1994). Crops with high rooting densities or rooting depth improve the water infiltration and deposition of organic material and support other crops with less rooting density.

This study compared the temporal and spatial heterogeneity of the arable crops concerning their functional characteristics as crop rotation elements. Steinmann and Dobers (2013) determined for agricultural practice in North-western Germany that most of the farmers tend to change their crop order very dynamic. The result is a great variety of crop sequences which seemed to have little in common with the actual definition of crop rotation. The aggregation of the crops in groups related to their function within a crop rotation exposed patterns of temporal sequences (Stein and Steinmann, 2018). We hypothesized that these patterns are significantly different in the spatial and temporal dimension. This would include the question if the land use statistics of one year can represent the actual crop rotation practice.

Materials and Methods

Research area

The study area is in Central Europe, in the North-western part of Germany, namely Lower Saxony (DE9 in the European Nomenclature of Territorial Units for Statistics NUTS 1). Lower

Saxony is characterized by a great variety of landscape types and types of farming. The main cash crops are maize (*Zea mays* L.), winter wheat (*Triticum aestivum* L.), sugar beet (*Beta vulgaris* subsp. *vulgaris*) and oilseed rape (*Brassica napus*). Typical crop rotations in Lower Saxony are Oilseed rape - Winter wheat - Barley, Maize - Winter wheat - Winter wheat, Sugar beet - Winter Wheat - Winter wheat and rotations with a high share of maize, depending on the region (Stein and Steinmann 2018). The study area is influenced by a temperate climate with annual precipitation ranges from 560 mm*yr^{-1} to 1200 mm*yr^{-1} with a mean of 750 mm*yr^{-1} (DWD, 2014).

Spatial and temporal crop sequences

We analyzed sequences of crops covering a time period of seven years, from 2005 till 2011. The data handling and method is based on the pre-work of Stein and Steinmann (2018). The data has been obtained from the Integrated Administration and Control System (IACS) which records and stores high-resolution land use data using a Land Parcel Identification System (LPIS). It was installed in all member states of the European Union to control and administrate the farming subsidies of the European Agricultural Guarantee Fund (European Commission, 2007). Each land use unit in the LPIS has an individual ID for clear identification of the data object and the attributed information of main crop for one cropping period. The data have some characteristics which have to be taken into account for the data usability. There are small inconsistencies in the data frame each year like duplicates (1.5% in 2011 for the observed region). For scientific analysis the provided data give no indication about the corresponding farm due to privacy issues. For our analysis of crop data, we calculate with a 2 km x 2 km grid of reference areas.

The smallest land use unit in the LPIS is not consistent in the EU. Each country defines its own smallest unit which can be a field block, a land parcel or a field. In Germany there are also different systems used in each federal state. In Lower Saxony the LPIS defines the smallest agricultural land use unit as a field parcel within a field block which is framed by stable physical landscape elements. While the field block ID never changes, the land use unit ID may change with changing field size and number of field parcels within the field block. So, for analysis of crop sequences over several years only land use units with unchanging field size and therefore with a consistent ID were usable. This applies to about a quarter of all arable land use units which are about 371.600 ha in sum. The statistic calculation included the main crop information of the years 2005 to 2011. The number of land use units per 2 km x 2 km grid cell ranges from one to 120 with a mean of 11 units. Grid cells with less than 11 land use units (56 % of the grid cells) were excluded to prevent a statistical bias by small populations. We distinguished spatial crop pattern and temporal crop sequences. The temporal crop sequences are the main crops of the seven years between 2005 and 2011 while the spatial crop pattern are the main crops of all land use units of one grid cell in the year 2011.

Sequences with more than two years of fallow or temporary grass were not included in the analysis because we assumed that these are farming systems with a focus on extensive grassland cultivation instead of arable farming. This assumption is based on the differentiation approach of crop rotations in crop-livestock systems and cropping systems (Andreae, 1952; Brinkmann, 1950).

Typification

A pre-step of analyzing the functional diversity of the crop sequences and crop pattern was the typification of the sequences according to their proportion of leaf crops and spring sown crops (Stein & Steinmann, 2018; Figure 8). Based on the cultivation advices after Baeumer (1990) we distinguished the three groups of spring crop sequences i) pure winter crop rotation ($x = 0$), ii) rotation with moderate spring crop amount ($0 < x \leq 0.5$), iii) spring crop dominated rotation ($x > 0.5$) and the three groups of leaf crop sequences i) no leaf crop ($y = 0$), ii) rotation with moderate leaf crop ratio ($0 < y \leq 0.5$), iii) leaf crop dominated rotation ($y > 0.5$). A combination of these groups in a matrix result in nine different types of crop sequences (Stein and Steinmann, 2018).

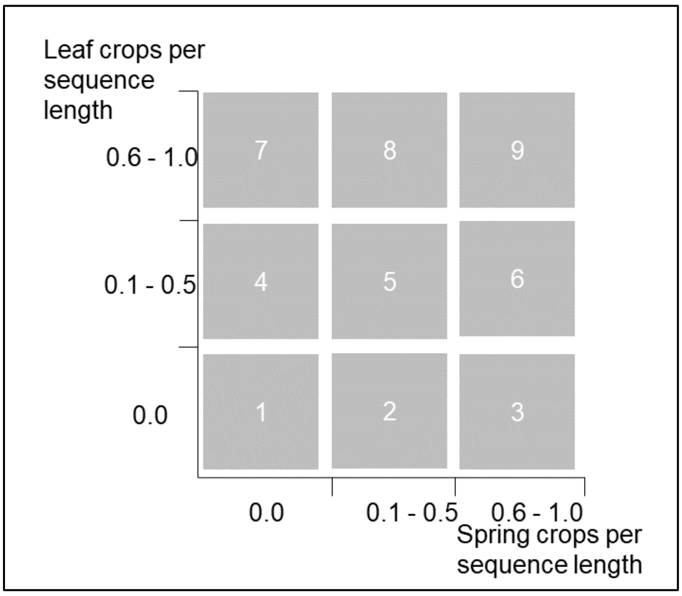


Figure 8. Matrix of crop sequence types derived from the amount of land use units with leaf crops and spring crops (after Stein & Steinmann, 2018).

The temporal crop sequences were assigned to the types by their leaf crop and spring crop amount in the years 2005 and 2011 per land use unit (Figure 9). The spatial crop pattern types were derived from the amount of leaf crops and spring crops of the land use units in one grid cell in 2011.

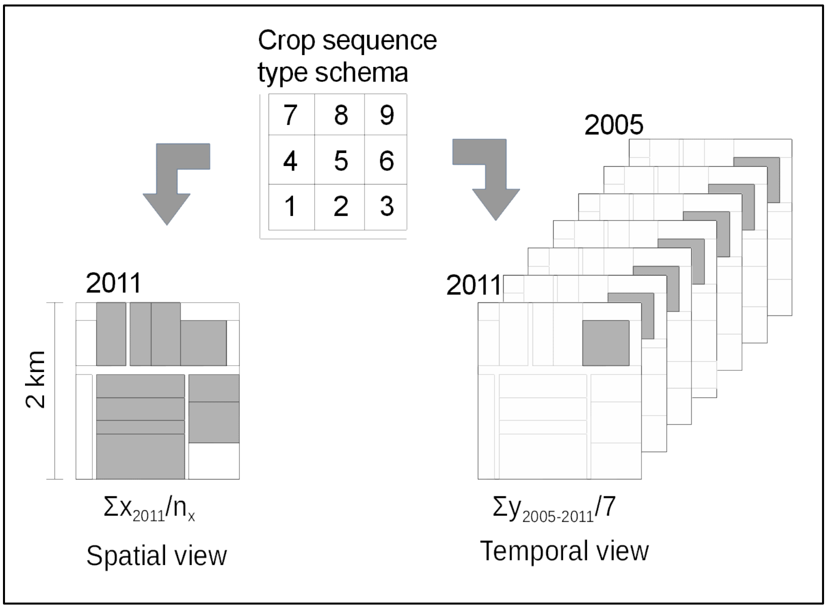


Figure 9. The comparison of the temporal and the spatial data.

Results

The comparison of the distribution among the nine types of the spatial crop occurrence (2011) and the temporal crop sequences (2005-2011) showed parallels but also notable differences (Table 13). One central result is that 40.4% of the land use units have the same type in the years 2005-2011 and in 2011.

Table 13. Proportional occurrence of crop sequence type 1-9 in the land use units for the year 2011 and the years 2005-2011.

	2005-2011									
2011	1	2	3	4	5	6	7	8	9	
1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0	0	0	0.002
2	0.005	0.031	0.026	0.006	0.009	0.002	0	0	<0.001	0.079
3	0.004	0.047	0.148	0.002	0.010	0.007	0	0	<0.001	0.219
4	0.002	0.003	<0.001	0.037	0.047	0.001	<0.001	<0.001	<0.001	0.091
5	0.014	0.061	0.034	0.133	0.166	0.022	<0.001	0.003	0.006	0.440
6	0.002	0.026	0.060	0.004	0.020	0.018	0	<0.001	0.004	0.134
7	<0.001	<0.001	0	0.003	0.004	<0.001	<0.001	<0.001	<0.001	0.008
8	<0.001	<0.001	<0.001	0.004	0.010	0.002	0	<0.001	0.002	0.021
9	<0.001	<0.001	<0.001	<0.001	0.001	0.002	0	<0.001	0.002	0.007
	0.028	0.169	0.270	0.190	0.267	0.055	<0.001	0.005	0.015	

In both typification groups the first type (no spring crops and no leaf crops) is uncommon in Lower Saxony. The same applies for the types 7, 8 and 9 (more than 50% leaf crops). The differences between the two dimensions, spatial and temporal, were highest for the types 2, 4 and 5. The frequencies for type 5, which is with moderate amounts of leaf crops and spring crops the most heterogeneous crop type, are much higher in the spatial crop pattern (44%) than in the temporal (26.7%). At the same time the frequencies of spatial pattern without any leaf crop (type 1-3) was lower for the year 2011, 30%, than the respective group of temporal sequences, 47%. In particular, the group of type 2 (no leaf crops, moderate amount of spring crops), was more than twice as high in the year 2011 as it was in the years 2005-2011. Further, the frequency of crop sequences or pattern without any spring crop (type 1, 4 and 7) is more than twice as much for the temporal sequences than for the spatial pattern (22% versus 10%), mainly due to the different frequency of type 4. The type 3 (no leaf crops, more than 50% of spring crops) represents in Lower Saxony mainly the maize dominated crop sequences and crop pattern. It was slightly more frequent in the temporal dimension than in the spatial dimension but fitted better than the other types did. This can be attributed to the high spatial dominance of maize on the arable fields in the North-western part of the country.

Overall, the spatial crop situation showed higher frequencies for heterogeneous crop pattern and lower frequencies for uniform crop pattern than the temporal crop situation. The one-year data overstate the more heterogenous crop pattern compared to the actual crop rotation practice. This overestimation on the one site gains more weight in front of the underestimation of the less heterogenous crop pattern.

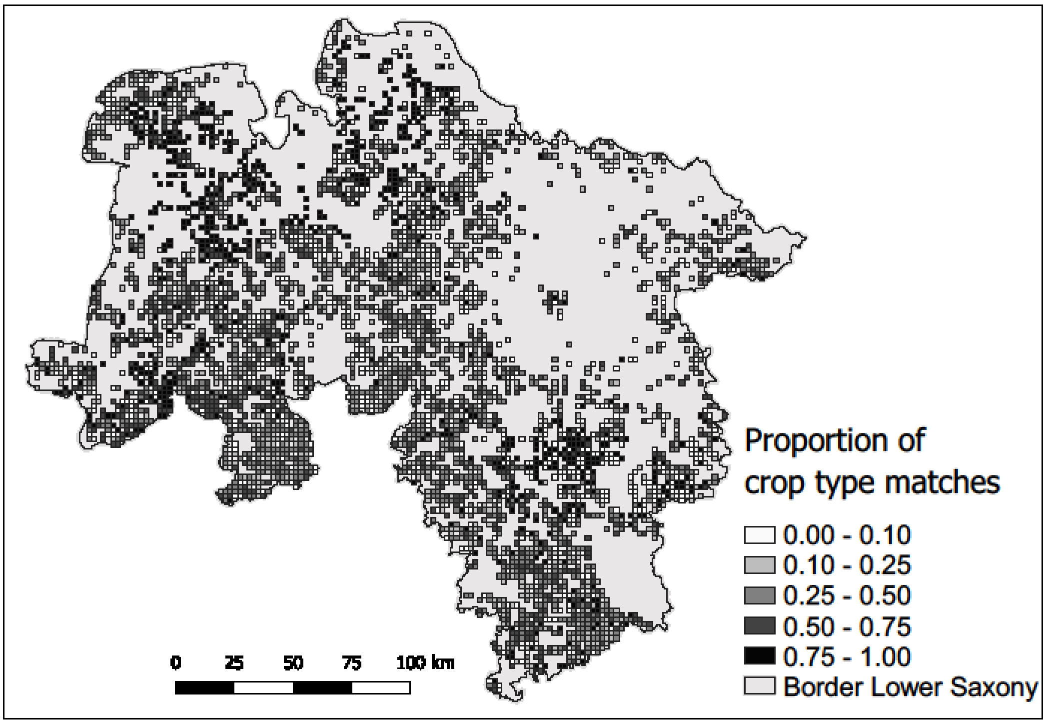


Figure 10. The proportion of matching temporal crop sequence types (2005-2011) per spatial crop pattern type (2011) in the corresponding 2 x 2 km grid cell in Lower Saxony.

Figure 10 shows that in Lower Saxony both assessment approaches, the spatial and the temporal, matches very well in the northwestern part and in the southeastern part of the area. In the mixed farming region of the Geest in the center of the state, the matching rate is very low due to a higher heterogeneity of the actual crop rotations. This suggests that the mismatching of the actual (temporal) and derived (spatial) crop sequences has a spatial dimension which concerns mostly the heterogeneous regions.

Discussion

Crop diversification was one of the main topics of the Common Agricultural Policy (CAP) reform in 2014 and is now a requirement for the direct payments (European Parliament, 2013). The regulation defines the number of necessary crops for the agricultural area of the farm for the specific year to assess the crop diversity. The assessment procedure of using the spatial crop information of one year instead of crop data per field over several years approximates the actual crop rotation. We compared the spatial crop pattern with the actual crop sequences. About 60% of the land use units did not match. On a side note, this mismatching would be even higher if we would have taken the actual crop species and not the grouped types. The most interesting fact is that this mismatching is not evenly distributed over the functional types. The spatial assessment pretends a heterogeneous crop situation that is not verifiable by the actual temporal assessment. So, the land use statistic of one year could not fully represent the actual crop rotation or has to be used with limitations. This applies with variant degree to the survey area, which showed regions with adequate comparability as well as regions with an overestimation of heterogeneity (Figure 10). Taking the results of Stein & Steinmann (2018) into account, the areas of high comparability are congruent with the areas where a high density of less diverse crop rotation types were found. If other factors may have an influence on the congruence of temporal and spatial crop heterogeneity, ought to be subject of future scientific analysis.

Fahrig et al. 2011 used the term of functional diversity with regard to the landscape ecology perspective and defined cover types in the spatial dimension by their functional properties depending on the requirements of a species in classes ‘dangerous’, ‘beneficial’ and ‘neutral’. These classes implicate an evaluation of the usefulness of the landscape patches for the single species. An evaluation like this was not the goal of our analysis, which focused on grades of heterogeneity.

We distinguished in our analysis the cover types by their function for crop rotation and soil cultivation. For the belowground perspective of agricultural land use and their function for soil communities the temporal dimension with the change of crop, soil tillage and plant input is much more relevant (Tiemann et al., 2015). We focused on two properties of the arable crops, dicot crops versus monocot crops and the sowing seasons, autumn and spring. Furthermore, there are other properties of crops which influence soil organic matter (SOM) stocks, water infiltration and microbial community, e.g. the growing density (row crops versus cereal crops). The distinction of leaf crops and cereal crops aims at crop properties like crop’s rooting depth and input of plant residues which are important for the aboveground-belowground interactions (McDaniel et al., 2014). The ratio of cereal versus leaf crops as well as the variation of planting date have furthermore relevance for the pest regulation. Rotations with predominantly cereal crops may risk a weed infestation (Zemanek et al. 1985; Liebman and Dyck, 1993). The variation of the planting date in association with other management strategies (e.g. tillage) is a measure to control weeds (Hakansson, 1982). Furthermore, the high ratio of cereal crops may affect the soil health and soil functions negatively (Karlen et al., 1994).

The same crop type can be managed with different intensity – e.g. conventional, low input, organic and no-till – which can have an effect on the SOM fractions and the C pool (Grandy and Robertson, 2007). This cannot be displayed by the data we used.

The share of silage maize in the arable area of Lower Saxony has almost doubled in the observed time period, from 15% in 2005 to 27% in 2011. This increase is linked with an expansion of bio-energy plants and supporting political measures and is concentrated in Lower Saxony mainly on regions in the North-western part where it is linked with established structures of intensive livestock farming. The match of temporal crop sequence types and spatial crop pattern is for these regions of homogenous maize cropping very high. For the mixed farming regions of the Geest we have a very low matching rate due to higher cropping diversity. So, the method of the derived crop rotations based on one-year statistics represent a false picture mostly for the mixed farming regions.

Conclusion

The comparison of the temporal with the spatial arrangement of crops showed specific inconsistencies by the comparison of the leaf crop amount and the spring sown crop amount in a crop sequence or a spatial crop pattern respectively. The spatial view of the main crops of one single year gives more weight to the most heterogeneous crop pattern types and less weight to the least heterogeneous types than it could be proven by the actual crop sequence types of the temporal view. This particularly applies in areas with a diverse cropping structure. In future, the method of deriving crop rotation practice by the spatial crop arrangement of one year, e.g. by taking official statistics, has to be under review.

References

Andreae, B., 1952. Fruchtfolgen und Fruchtfolgesysteme in Niedersachsen. Bren, W. Dorn.

Baeumer., K., 1990. Gestaltung der Fruchtfolge. In: Dierks, R. And Heitefuß, R., 1990. Integrierter Landbau. BLV, München.

Bianchi, F.J.J.A., Booji, C.J.H., Tscharntke, T., 2006. Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proc. R. Soc. B, 273, 1715-1727.

Brinkmann, T., 1950: Das Fruchtfolgebild des deutschen Ackerbaues. Bonner Universitätsbuchdruckerei, Bonn.

Cushman, S. A., McGarigal, K., Neel, Mc C., 2008. Parsimony in landscape metrics: strength, universality, and consistency. Ecol. Indic., 8, 691–703 http://dx.doi.org/10.1016/j.ecolind.2007.12.002

DWD (Deutscher Wetterdienst), 2014. Long-term average annual precipitation (1981-2010). Online download via WebWerdis [accessed 06-03-2014].

European Commission, 2007. Managing the agricultural budget wisely. Fact Sheet, European Communities. URL: http://ec.europa.eu/agriculture/sites/agriculture/files/cap-funding/audit/pdf/2007_en.pdf [accessed 06-12-2016].

European Parliament, 2013. Regulation (EU) No 1307/2013 of the European parliament and of the council of 17 December 2013. Official Journal of the European Union (L 347/608).

Fahrig, L., Baudry, J., Brotons, L., Burel, F.G., Crist, T.O., Fuller, R.J., Sirami, C, Siriwardena, G.M., Martin, J.-L., 2011. Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecology Letters 14, 101-112.

Grandy, A., Robertson, G., 2007. Land-Use Intensity Effects on Soil Organic Carbon Accumulation Rates and Mechanisms. Ecosystems, 10(1), 59-74.

Hakansson, S., 1982. Multiplication, growth and persistence of perennial weeds. Pages 123-135 in: Holzner, W. and Numata, M. (Eds.). Biologyand ecology of weeds. Dr. W. Junk, The Hague, The Netherlands.

Karlen, D.L., Varvel, G.E., Bullock, D.G., Cruse, R.M., 1994. Crop Rotations for the 21st Century. Advances in Agronomy 53, 1-45.

Laisch, A., Blaschke, T., Haase, D., Herzog, F., Syrbe, R.-U., Tischendorf, L., Walz, U., 2015. Understanding and quantifying landscape structure – A review on relevant process characteristics, data models and landscape metrics. Ecological Modelling 295, 31-41.

Liebman, M., Dyck, E., 1993. Crop rotation and intercropping strategies for weed management. Ecol. Appl. 3, 92-122.

McDaniel, M.D., Tiemann, L.K., Grandy, A.S., 2014. Does agricultural crop diversity enhance soil microbioal biomass and organic matter dynamics? A meta-analysis. Ecol. Appl., 24, 560-570.

McGarigal, K., Marks, B. J., 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. Pacific Northwest Research Station, Portland, Or. (USA), General Technical Report PNW-GTR-351.

McGarigal, K., Cushman S. A., 2005. The gradient concept of landscape structure. In: J. Wiens, M. Moss (Eds.), Issues and Perspectives in Landscape Ecology, Cambridge University Press, Cambridge, 112-119.

Monteleone, M., Cammerino, A.R.B., Libutti, A., 2018. Agricultural “greening” and cropland diversification trends: Potential contribution of agroenergy crops in Capitanata (South Italy). Land Use Policy 70, 591-600. DOI: 10.1016/j.landusepol.2017.10.038

Reynolds-Hogland, M.J., Mitchell, M.S., 2007.Three axes of ecological studies. In: Bissonette, J.A., Storch, I. (Eds.), Temporal Dimensions of Landscape Ecology. Springer, USA, 174-194.

Smith, A.P., Marin-Spiotta, E., De Graaf, M.A., Balser, T., 2014. Microbial community structure varies across soil organic matter pools during tropical land cover changes.Soil Biol. Biochem. 77, 292-303.

Steinmann, H.-H., Dobers, S., 2013. Spatio-temporal analysis of crop rotations and crop sequence patterns in Northern Germany: potential implications on plant health and crop protection. J. Plant Dis. Protect. 120 (2), 85-94.

Stein, S., Steinmann, H.-H., 2018. Identifying crop rotation practice by the typification of crop sequence patterns for arable farming systems – A case study from Central Europe. Europ. J. of Agronomy, 92, 30-40.

Tiemann, L.K., Grandy, A.S., Atkinson E.E., Marin-Spiotta, E., McDaniel, M.D., 2015. Crop rotational diversity enhances belowground communities and functions in an agroecosystem. Ecol. Letters, 18, 761-771.

Turner, M.G., 1989. Landscape ecology: the effect of pattern on process. Annu. Rev. Ecol. Syst., 20, 171–197.

Turner, M.G., 2005. Landscape ecology: what is the state of science? Ann. Rev. Ecol. Syst. 36, 319-344.

Vasseur, C., Joannon, A., Burel, F., Meynard, J.M.Baudry, J., 2013. The cropping mosaic system: How does the hidden heterogeneity of agricultural landscapes drive arthropod populations? Agriculture, Ecosystems and Environment 166, 3-14.

Wiens, J. A., 2002. Central concepts and issues of landscape ecology. In: Gutzwiller, K. J. (Ed.), Applying Landscape Ecology in Biological Conservation. Springer, New York, 3-21.

Zemanek, J., Mikulka, J., Ludva, L., Ludvova, A., 1985. The effect of longterm application of herbicides on weed infestationand crop yieldsat the research station, Hnevceves. Annals of the Research Institute for Crop Production Prague-Ruzyne 23, 99-118.

General Discussion

The main goal of my studies was to detect regional patterns of crop rotation practice in Lower Saxony. The typification approach, presented in detail in the second chapter, focused on the different functions of crops that support sustainable farming and serve the main goal of any farmer, a sufficient and stable yield. It groups the seven-year crop sequences in types of more and less diverse sequences, assuming that a diverse crop rotation has positive effects on the ability of agroecosystems to generate ecosystem services (Altieri, 1999, Zhang et al., 2007). Nevertheless, this assumption must be discussed. Generally, the *rotation effect* is expected to increase yield due to improvements in soil structure and pest suppression as benefits from rotation (Tiemann et al., 2015). Especially proving the direct linkage of crop rotation, soil structure, and crop yield is not trivial (Karlen et al., 1994). Even if meta-analyses have shown a positive effect of crop rotation on soil carbon and nitrogen, the soil structure, and the soil microorganisms community (Ball et al., 2005; McDaniel et al., 2014; Venter et al., 2016), these effects are difficult to separate from the impact of soil management, like tillage or fertilizer application. The inclusion of legumes in crop rotations has the potential to enhance microbial and enzyme activity in soil (Borase et al., 2020). However, during the observed period of time, legume cropping was only present in 0.5 % of the fields in Lower Saxony.

The impact of crop rotation on weed density and weed diversity is also hard to prove. While Liebman and Dyck (1993) showed a smaller impact of crop rotation than other measures for weed control like herbicides and soil cultivation, other studies proved that the crop rotation practice is an essential tool for any farmer influencing weed populations (Fried et al., 2008; de Mol et al., 2015). However, Ulber et al. (2009) could not prove a connection between high crop diversity and a high weed species richness for winter wheat stands in conventional cropping systems. Crop rotation was found to have the strongest effect on weed density only in combination with chemical weed management. This was also confirmed by studies of Bàrberi et al. (1997) and Doucet et al. (1999), who suggested the combination of both as an effective tool in integrated weed management. Also, the presence of cover crops has a stronger effect on weed communities than crop rotation in general (Smith and Gross, 2007). Nevertheless, it is essential for the assessment of crop rotation effect to distinguish between weed density and weed diversity. Moreover, Glemnitz and Hufnagel (2009) recommend addressing the functional groups of weeds for ecological evaluation of crop rotations. Functional diverse weed communities as an implication of functional diverse crop rotations differ in their effect on and the use of soil resources and compete less with the crop (Liebman & Dyck, 1993). So even a potentially higher weed abundance in diverse crop rotations has no yield-reducing effect, and an increase in weed diversity is a factor for less resource niche overlap and contributes to reduced specific yield loss due to weeds (Jolliffe, 1997; Smith, et al., 2009). Sequences of crops with similar character and management, such as cereals, have a lower diversity of weeds between the crops (Smith et al., 2008). So, the dense cultivation of winter cereals in Lower Saxonian regions with fertile soils potentially accumulate a range of problems for future cropping.

The same applies to the geographical clusters of dense maize cropping on less productive soils and in regions where intensive livestock farming is established. The comparably small share of arable area in regions dominated by grassland is used by farmers for the production of fodder with high energy potential, mainly maize. Here, we observe a high concentration of one kind of crop in time and low concentration in space. The Renewable Energy Act in 2004 caused an increase of maize cropping for bioenergy production not only in these regions, but there the problem of a high share of maize in rotations is also more severe because of the lack of alternative areas. A high share of maize in the rotation is also typical for mixed farming regions with less productive soils, e.g. the districts Diepholz or the Heide regions Lüneburg, Rotenburg, and Celle, where biogas production caused an increase of maize in the rotation. These are the same regions where little consistency among the spatial heterogeneity of the crops and their actual rotation heterogeneity was found (see chapter three). The dense maize cropping on several fields was spatially arranged with other crop rotations simulating a heterogeneity in space, which concealed the actual disregard of crop rotation rules on these fields. Increased maize cultivation for energy production may have negative effects on farmland wildlife (Gevers et al., 2011) and increases the risk of arthropod pests. However, maize is not only a crop of less diverse rotations. As it was analyzed in the second chapter, maize was often the only spring-sown crop in crop sequences that would be otherwise entirely assembled with winter-sown crops. So, the inclusion of maize in winter crop rotations could mean a useful break.

Crop rotation is strongly linked with soil tillage. The tendency of the last decades to reduce tillage intensity and use conservation tillage instead is only possible with an increase of herbicides and fertilizers if it is coupled with short crop rotations. Diversification of crop rotations accompanied by the use of catch crops and perennial species bare the potential for reducing the use of plant protection products by increasing the effect of biological control of pests through natural enemies (LLG, 2014; Dunbar et al., 2016). This would be in line with the goals of Integrated Pest Management (Meissle et al., 2010; Andert et al., 2016), which is also recommended by the European Commission (Article 14 of Directive 2009/128/EG).

Crop rotation diversification also has the potential to increase the resilience of agricultural systems by reducing risks from climate-change-related weather extremes (Bowles et al., 2020). A broader portfolio of crops may, in the future, increase the stability of the total yield at the national level in the face of limited water resources (Renard and Tilman, 2019).

The results of the present study showed that most of the Lower Saxonian farmers are still following crop rotation rules, albeit in a flexible way and, in some regions, to a reduced extent. Within a rotation, the crops may be exchanged flexibly according to their function within the rotation, which requires a method for selecting crops by their role within the rotation to identify crop rotation patterns. This was already recognized by Brinkmann (1950), who distinguished the crops in leaf crops and cereal crops. Further differentiation in spring-sown crops and winter-sown crops, presented in this study (chapter three), is an important extension of this approach. It has to be mentioned that this recognition is a result of the cropping circumstances in Lower Saxony with its high share of maize cultivation. However, even if the presented typification method is strongly influenced by the research area and its crop portfolio, it is, in general, applicable to other arable areas with one main crop per year.

The analysis of the crop-site interaction (as reported in chapters one and two) showed that the farmers in Lower Saxony cultivate their crops still considering site conditions, especially soil characteristics. The regional features of the crop-site interactions, especially of the crop patterns, are very stable (Andreae, 1952). This mitigates the apprehension that modern agriculture is more or less independent from the given site conditions (Antrop, 2005; Bakker et al., 2013). The present study used site variables that are very stable over time. The results may vary with short-term variables like market prices. But the subject of crop rotation is a long-term one, fundamental for agricultural production in history and, hopefully, in the future.

References

Altieri, M. A., 1999. The ecological role of biodiversity in agroecosystems. Agric. Ecosyst. Environ. 74, 19-31.

Andert, S., Bürger, J., Stein, S., Gerowitt, B., 2016. The influence of crop sequence on fungicide and herbicide use intensities in North German arable farming. Eur. J. Agron. 77, 81-89.

Andreae, B., 1952. Fruchtfolgen und Fruchtfolgesysteme in Niedersachsen. Bren, W. Dorn.

Antrop, M., 2005. Why landscapes of the past are important for the future. Landscape and Urban Planning 70 (1/2), 21-34.

Bakker, M. M., Sonneveld, M. P. W., Brookhuis, B., Kuhlman, T., 2013. Trends in soil–land-use relationships in the Netherlands between 1900 and 1990. Agr. Ecosyst. Environ. 181, 134-143.

Ball, B. C., Bingham, I., Rees, R. M., Watson, C. A., Litterick, A., 2005. The role of crop rotations in determining soil structure and crop growth conditions. Canadian Journal of Soil Science 85, 557-577.

Bàrberi, P., Silvestri, N., Bonarie, E., 1997. Weed communities of winter wheat as influenced by input level and rotation. Weed Research 37, 301-313.

Borase, D.N., Nath, C.P., Hazra, K.K., Senthilkumar, M. Singh, S.S., Praharaj, C.S., Singh, U., Kumar, N., 2020. Long-term impact of diversified crop rotations and nutrient management practices on soil microbial functions and soil enzymes activity, Ecological Indicators, 114, 106322; DOI: 10.1016/j.ecolind.2020.106322.

Bowles, T.M., Mooshammer, M., Socolar, Y., Calderón, F., Cavigelli, M.A., Culman, S.W., Deen, W., Drury, C.F., Garcia y Garcia, A., Gaudin, A.C.M., Harkcom, W.S., Lehman, R.M., Osborne, S.L., Robertson, G.P., Salerno, J., Schmer, M.R., Strock, J., Grandy, A.S., 2020. Long-Term Evidence Shows that Crop-Rotation Diversification Increases Agricultural Resilience to Adverse Growing Conditions in North America. One Earth, 2 (3), 284-293.

Brinkmann, T., 1950: Das Fruchtfolgebild des deutschen Ackerbaues. Bonner Universitätsbuchdruckerei, Bonn.

De Mol, F., von Redwitz, C., Gerowitt, B., 2015. Weed species composition of maize fields in Germany is influenced by site and crop sequence. Weed Research 55, 574-585, DOI: 10.1111/wre.12169.

Doucet, C., Weaver, S.E., Hamill, A.S., Zhang, J., 1999. Separating the effects of crop rotation from weed management on weed density and diversity. Weed Science, 47,729-735.

Dunbar, M.W., Gassmann, A.J., O'Neal, M.E., 2016. Impacts of Rotation Schemes on Ground-Dwelling Beneficial Arthropods. Environmental Entomology 45 (5), 1154-1160.

Fried, G., Norton, L.R., Reboud, X., 2008. Environmental and management factors determining weed species composition and diversity in France. Agriculture, Ecosystems and Environment 128, 68-76.

Gevers, J., Hoye, T. T., Topping, C. J., Glemnitz, M., Schröder, B., 2011. Biodiversity and the mitigation of climate change through bioenergy: impacts of increased maize cultivation on farmland wildlife. Global Change Biology Bioenergy 3, 6, 472-482.

Glemnitz, M., Hufnagel, J. (2009) Weed species diversity in energy cropping systems: potentials and threats. In: 3rd Workshop of the EWRS Working Group "Weeds and Biodiversity": Lleida, Spain 12 - 13 March 2009. Lleida, p. 17.

Jolliffe, P.A. (1997) Are mixed populations of plant speciesmore productive than pure stands? Oikos 80, 595-602.

Liebman, M., Dyck, E., 1993. Crop rotation and intercropping strategies for weed management. Ecol. Appl. 3, 92-122.

LLG - Landesanstalt für Landwirtschaft, Forsten und Gartenbau Sachsen-Anhalt, 2014. Fruchtfolgen – gestern – heute – morgen. Bernburg.

McDaniel, M.D., Tiemann, L.K., Grandy, A.S., 2014. Does agricultural crop diversity enhance soil microbioal biomass and organic matter dynamics? A meta-analysis. Ecol. Appl., 24, 560-570.

Meissle, M., Mouron, P., Musa, T., Bigler, F., Pons, X., Vasileiadis, V. P., Otto, S., Antichi, D., Kiss, J., Pálinkás, Z., Dorner, Z., van der Weide, R., Groten, J., Czembor, E., Adamczyk, J., Thibord, J.-B., Melander, B., Cordsen Nielsen, G., Poulsen, R. T., Zimmermann, O., Verschwele, A.& Oldenburg, E., 2010. Pests, pesticide use and alternative options in European maize production: current status and future prospects. J. Appl. Entomol. 134, 357-375.

Renard, D., Tilman, D., 2019. National food production stabilized by crop diversity. Nature 571, 257-260.

Smith, R.G.; Mortensen, D.A.; Ryan, M.R., 2009. A new hypothesis for the functional role of diversity in mediating resource pools and weed-crop competition on agroecosystems. Weed Research 50, 37-48.

Tiemann, L.K., Grandy, A.S., Atkinson E.E., Marin-Spiotta, E., McDaniel, M.D., 2015. Crop rotational diversity enhances belowground communities and functions in an agroecosystem. Ecol. Letters, 18, 761-771.

Ulber L., Steinmann H.H., Klimek S. & Isselstein J. (2009) An on-farm approach to investigate the impact of diversified crop rotations on weed species richness and composition in winter wheat. Weed Research, 49, 534-543

Venter, Z.S., Jacobs, K., Hawkins, H.-J., 2016. The impact of crop rotation on soil micrbial diversity: A meta-analysis. Pedobiologia 59 (4), 215-223.

Zhang, W., Ricketts, T.H., Kremen, C., Carney, K., Swinton, S.M., 2007. Ecosystem services and dis-services to agriculture. Ecol. Econ., 64 (2), 253–260.

Summary

The aim of the present study was to detect patterns of crop rotation in an agricultural region in the North-western part of Germany. It was analysed if and how the spatial distribution of the crop rotation patterns depends on selected ecological and economical site variables. The question arises in the light of the fast increase of maize acreage due to a booming biogas production. This was a data-based study using crop information of all arable fields in Lower Saxony which were funded with direct payments of the European Union agricultural fund during the years 2005 till 2011. Information about the related farm was not included. For the spatial localization only the digital field map of the year 2011 was available. Due to that, fields which changed their size and frame and so changing their identification number were not detectable over all seven years. However, about 24% of the arable parcels (122,956 records) could be used for complete seven-year sequence analysis. In a first step, before analysing crop rotations, the field data of the year 2011 were used to enlighten the relationship of crops with selected site variables. A logistic regression analysis was used to build spatial clusters of crop patterns which were compared with clusters of the following site variables: arable farming potential, soil texture, slope, precipitation, biotope density, grassland proportion, cattle density, pig and poultry density and farm size. The comparison showed a stronger relationship of clustered crop pattern with clustered site pattern than the single crop-site relationship. Maize and Winter wheat showed the clearest relation to site variables, especially the soil variables, but with diverging preferences.

To reveal crop rotation patterns out of the wealth of crop sequences a typification method was developed. This typification approach allows to group the crop sequences in two steps, i) by their number of different crops and their number of transitions from one crop to another, ii) by their amount of leaf crops and their amount of spring sown crops. The first step addressed the structural aspects of the sequences and the second addressed the arable functions of the crops in a rotation. The ten largest groups of crop sequence types derived by this method were cropped on 60% of the investigated arable area. Among these ten types we found types of low structural and functional diversity as well as the most diverse types in significant extent. The largest type group (9.6%) contains crop sequences with four crops and 6-5 transitions in seven years as well as 1-3 leaf crops and 1-4 spring crops. The second largest type group represents sequences which were permanently cropped with one cereal spring sown crop (8.1%), this was maize here, actually. So, in Lower Saxony we found both ends of the scale in a significant amount, the highly diverse crop sequences as well as the sequences of continuous maize cropping. Maize dominated the most simple sequences but played also an important role for the most diverse sequences and for the diversification of pure

winter crop stands. In the Geest region in Lower Saxony a number of rotation pattern with pure cereal crop sequences showed that maize took the role of the winter leaf crop (Oil seed rape) in the rotation, e.g. Maize-Winter Wheat-Winter Barley. One third of the arable area was cropped with sequences with a moderate amount of leaf crops (1-3) and spring crops (1-4), but nearly 40% showed any leaf crop and 20% any spring crop. So, Lower Saxony showed a pleasingly high amount of diverse crop sequences on the one hand but on the other hand we had nearly one third of the arable area cropped with only one or two crops, which is alarming. The latter were strongly linked with a high cattle density and peaty soils. Generally, the ten largest types showed specific relationships with the site variables and a spatial distribution related to the distribution of the soil conditions in Lower Saxony. This allows the conclusion that the crop rotation practice in Lower Saxony is related to the site condition in the respective regions.

The spatial distribution of the clustered crop patterns of one year showed concordance at the first view with the crop sequence patterns of the seven years. So, the third part of the study examined the spatial congruency of the seven-year sequence data with the field data from one year in a defined area around that sequence. All arable fields in one 2x2 km quadrant of a raster were compared with the temporal crop sequences within this quadrant, according to their amount of leaf crops and spring crops (equivalent to the second typification step). This analysis showed an overestimation of the amount of the diverse crop sequence types and an underestimation of the amount of simple crop sequence types in the one-year field data in comparison with the actual crop sequences. This applies in particular for regions with heterogenous crop patterns. So, the one-year crop statistic, which is commonly used to derive the actual crop rotations, is not a proper data source in any case.

Summarizing the results of the data analysis it can be stated that most of the farmers in Lower Saxony grow their crops in patterns which are inspired by crop rotation rules and used in relation to the site conditions. Regions with less fertile soils and mixed farming are more heterogenous than regions with very low or very high profitable soils. There is the dense maize cropping of the livestock farming regions as well as the pure winter cereal rotations in the coast regions which may lead to phytosanitary problems in the future if no measures of diversification are implemented. Due to biogas production, the dense maize rotations are no longer only an issue for intensive livestock farming regions. It is important to strengthen the development and market conditions for neglected crops, especially legumes and summer cereals, to enhance the diversification of crop rotations in future.

Zusammenfassung

Das Ziel dieser Arbeit war der Nachweis von Fruchtfolgemustern in einer landwirtschaftlich geprägten Region im Nordwesten Deutschlands. Hierbei wurde untersucht ob und wie die räumliche Verteilung von Fruchtfolgemustern im Zusammenhang mit ausgewählten ökologischen und ökonomischen Landschaftsvariablen stehen. Diese Fragen kamen vor dem Hintergrund einer rasch angestiegenen Maisanbaufläche als Folge einer erhöhten Biogasproduktion auf. Dies ist eine Daten-basierte Analyse, welche die Anbaudaten aller Ackerflächen in Niedersachsen nutzt, die in den Jahren 2005 bis 2011 durch Direktzahlungen aus dem Agrarfonds der Europäischen Union gefördert wurden. Informationen über die dazugehörigen Betriebe waren nicht enthalten. Für eine räumliche Verortung der Felder war lediglich die digitale Schlagkarte des Jahres 2011 verfügbar. So konnten Felder, welche ihren Feldzuschnitt oder die Größe und somit ihre ID-Nummer änderten, nicht über alle sieben Jahre hinweg zurückverfolgt werden. Trotz allem konnten 24% der Ackerflächen (122,956 Datensätze) für eine komplette siebenjährige Sequenzanalyse genutzt werden. In einem ersten Schritt, noch vor der Auswertung der Fruchtfolgen, wurden die Anbaudaten von 2011 herangezogen, um den Zusammenhang von Feldfrüchten mit ausgewählten Landschaftsvariablen zu beleuchten. Mittels einer logistischen Regressionsanalyse wurden Räume von Fruchtkombinationen definiert und mit Räumen von kombiniert auftretender Landschaftsvariablen verglichen, im Folgenden: Ackerbauliches Ertragspotenzial, Bodentextur, Hangneigung, Niederschlag, Biotopdichte, Graslandanteil, Rinderdichte, Schwein- und Geflügeldichte sowie Betriebsgröße. Der Vergleich zeigte einen stärkeren Zusammenhang zwischen Feldfruchtkombinationen und Variablenkombinationen als zwischen einzelnen Feldfrüchten und einzelnen Variablen. Mais und Winterweizen zeigten den deutlichsten Zusammenhang zu den Landschaftsvariablen, insbesondere zu den Bodenvariablen, aber mit gegensätzlicher Präferenz.

Um Fruchtfolgemuster aus der Fülle an Fruchtsequenzen herauszulesen, wurde eine Typisierungsmethode entwickelt. Dieser Typisierungsansatz ermöglichte eine Gruppierung der Fruchtsequenzen in zwei Schritten, i) entsprechend ihrer Anzahl verschiedener Früchte und ihrer Fruchtwechselanzahl, ii) nach ihrem Anteil an Blattfrüchten und ihrem Anteil an Sommerungen. Der erste Schritt bezieht die strukturellen Aspekte der Fruchtsequenzen ein, während der zweite Schritt die ackerbaulichen Funktionen der Feldfrüchte innerhalb der Fruchtfolge adressiert. Die zehn größten Gruppen der Fruchtsequenztypen, die sich auf diese Weise ableiten ließen, wurden auf 60% der untersuchten Ackerfläche angewandt. Unter diesen zehn Typen befanden sich in signifikantem Umfang sowohl Typen mit geringer struktureller und funktionaler Diversität als auch Typen der höchsten Diversitätsgruppen. Die

größte Typengruppe enthielt Fruchtsequenzen mit vier Früchten und 5-6 Fruchtwechseln in sieben Jahren sowie 1-3 Blattfrüchten und 1-4 Sommerungen (9,6%). Die zweitgrößte Typengruppe entspricht Sequenzen die permanent mit einem Sommergetreide bebaut (8,1%), in diesem Fall Mais. In Niedersachsen finden sich also beide Extreme in bedeutender Menge, die sehr diversen Fruchtsequenzen ebenso wie Sequenzen mit Mais im Daueranbau. Mais dominiert die einfachsten Fruchtsequenzen, spielt jedoch auch eine wichtige Rolle in den sehr diversen Sequenzen und für die Diversifizierung von reinen Winterungsfolgen. In der niedersächsischen Geest zeigen einige Fruchtfolgemuster aus reinen Getreidesequenzen, dass Mais die Funktion der Winterblattfrucht (hier Winter-Raps) in der Fruchtfolge übernommen hat, z. B. Mais-Weizen-Gerste. Ein Drittel der Ackerflächen wurde mit Sequenzen bestellt die eine moderate Menge an Blattfrüchten (1-3) und Sommerungen (1-4) enthielten, aber fast 40% wurden ganz ohne Blattfrucht und 20% ohne Sommerung bebaut. Niedersachsen zeigt also einerseits einen erfreulich hohen Anteil an diversen Fruchtsequenzen, andererseits wurden nahezu ein Drittel der Ackerfläche mit nu rein oder zwei Früchten in Sieben Jahren bestellt, was alarmierend ist. Letztere stehen in starkem Zusammenhang mit einer hohen Rinderdichte und Moorböden. Im Allgemeinen zeigten die zehn größten Typengruppen spezifische Zusammenhänge mit Landschaftsvariablen und eine räumliche Verteilung, die der Verbreitung der Bodenverhältnisse in Niedersachsen folgt. Dies legt den Schluss nahe, dass die Fruchtfolgepraxis in Niedersachsen in Zusammenhang mit den Landschaftsbedingungen der entsprechenden Region steht.

Die räumliche Verteilung der geclusterten Fruchtmuster eines Jahres zeigen auf den ersten Blick Übereinstimmungen mit den Fruchtsequenzmustern der sieben Jahre. Aus diesem Grund widmet sich der dritte Teil der Studie der räumlichen Übereinstimmung der Sieben-Jahres-Sequenzdaten mit den Felddaten eines Jahres in einem definierten Areal rund um diese Sequenz. Alle Ackerflächen in einem 2 x 2 km Quadranten eines Rasters wurden mit den zeitlichen Fruchtsequenzen innerhalb dieses Quadranten in Bezug auf ihren Blattfrucht- und Sommerungsanteil verglichen (äquivalent zum zweiten Typisierungsschritt). Diese Auswertung ergab eine Überschätzung der Menge der diversen Fruchtsequenztypen und eine Unterschätzung des Anteils einfacher Fruchtsequenztypen in den einjährigen Daten gegenüber den tatsächlichen Fruchtsequenzen. Dies gilt insbesondere für Regionen mit heterogenen Fruchtmustern. Demnach ist die einjährige Anbaustatistik, welche im Allgemeinen herangezogen wird, um Fruchtfolgen abzuleiten, nicht in jedem Fall hierfür geeignet.

Die Ergebnisse führen zu dem Schluss, dass die Mehrheit der Landwirte in Niedersachsen beim Anbau ihrer Feldfrüchte einem Muster folgen, welches sich an Fruchtfolgeregeln und den Anbaubedingungen orientiert. Regionen mit Böden mit mittlerem

Ertragspotenzial und gemischtwirtschaftlichen Betrieben sind hierbei heterogener als Regionen mit ertragsarmen und Regionen mit ertragsreichen Böden. Sowohl die dichten Maisfruchtfolgen der Viehhaltungsregionen als auch die reinen Wintergetreidefolgen der Küstenregionen können zukünftig zu phytosanitären Problemen führen, wenn keine Maßnahmen zur Diversifizierung erfolgen. Als Folge der Biogasproduktion sind enge Maisfruchtfolgen nicht mehr allein ein Thema der Viehhaltungsregionen. Umso wichtiger ist es zukünftig die Züchtung vernachlässigter Feldfrüchte zu intensivieren und Marktbedingungen, insbesondere für Leguminosen und Sommergetreide, zu verbessern, um die Fruchtfolgediversifizierung zu fördern.

List of Publications

as to Mai 2020

Peer-reviewed journal articles

Stein, S., Steinmann, H.-H. (2020): Annual crop census data does not proper represent actual crop rotation practice. *Manuscript*

Stein, S., Steinmann, H.-H., Isselstein, J. (2019). Linking arable crop occurrence with site conditions by the use of highly resolved spatial data. Land MDPI, Open Access Journal, 8 (4), 1-14.

Stein, S., Steinmann, H.-H. (2018): Identifying crop rotation practice by the typification of crop sequence patterns for arable farming systems – A case study from Central Europe. European Journal of Agronomy 92, 30-40.

Andert, S.; Bürger, J.; Stein, S.; Gerowitt, B. (2016): The influence of crop sequence on fungicide and herbicide use intensities in North German arable farming. European Journal of Agronomy 77, 81-89.

Talks

Stein, S., Steinmann, H.-H. Fruchtfolgemuster in Niedersachsen – Ein Typisierungsansatz anhand quantitativer und qualitativer Merkmale. Institut für Zuckerrübenforschung, Göttingen, 19. März 2018, *invited talk*.

Stein, S.; Steinmann, H.-H. (2014): The situation of current crop rotations in Northern Germany: Risks and chances for future farming systems. IFSA Conference, Berlin, 1.-4. April 2014.

Stein, S.; Steinmann, H.-H. (2014): Der Einfluss von regionalen Faktoren auf die Wahl von Feldfrüchten und Fruchtfolgen. Mitt. Ges. Pflanzenbauwiss. 26, S. 48-49, Tagung der Gesellschaft für Pflanzenbauwissenschaften e.V., Wien, 16.-18. September 2014.

Stein, S.; Steinmann, H.-H. (2014): Aktuelle Fruchtfolgen und ihre Interaktion mit Region und Agrarstruktur. Julius-Kühn-Archiv: 447, 59. Deutsche Pflanzenschutztagung, Freiburg, 23.-26. September 2014.

Posters

Stein, S.; Steinmann, H.-H. (2018): Functional and structural diversity aspects of crop sequence typification approach. Landscape 2018 – Frontiers of agricultural landscape research, Berlin, 12-16.03.2018.

Stein, S.; Steinmann, H.-H. (2015): Temporal and spatial aspects of maize cropping in Northwestern Germany. Deutscher Kongress für Geographie, Berlin, 1.-6. Oktober 2015.

Further publications

Stein, S., Steinmann, H.-H.: Fruchtfolgen in der Landwirtschaft: Einheitsbrei oder doch noch Vielfalt? Natur und Landschaft. 2017-11-03.

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