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Spatio-temporal analysis of crop rotations and crop sequence patterns in Northern Germany: potential implications on plant health and crop protection

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Abstract

Crop sequence patterns are considered as those schemes farmers apply within a single field to succeed crops over time, regardless of whether the same crop is grown continuously or a diverse rotation is used. This study aimed at identifying these patterns for a large and representative area in Northern Germany during a six-year period from 2005 to 2010. The analysis was carried out for the entire federal state of Niedersachsen (Lower Saxony) which has 1.8 million hectares of arable area.

Field data was obtained by the Integrated Administration and Control System (IACS), which was developed for the administration of the European agricultural direct payments. So far, German IACS has not been exploited in the light of agronomical practice. In total, the available data comprised about 990 000 records for each year, each representing a single field out of the study region. Throughout the analysis, different agronomic and temporal scopes resulted in a different number of fields being accessible for evaluation. Ten major arable crops and crop groups were considered for the study; 184 701 fields representing 645 870 ha of arable area could be analyzed to identify crop sequence patterns over the six years. Thus, 16 836 combinations of the 10 major crops occurring in time and space could be described. Thereof, 12 crop sequence patterns were found covering 55.6% of arable area. For 2010, 619 447 fields representing 1 730 564 ha of arable area, were analyzed with regard to their respective crops and pre-crops. Maize, winter wheat, sugar beet, oilseed rape and potatoes were studied with special emphasis. On average, 46.9% of maize area were cropped following maize as a pre-crop. For winter wheat, self-sequences were identified on 30.0% of arable area. Oilseed rape and sugar beet are generally grown in typical rotations. However, 24.6% of arable crop area were considered as having a pre-crop which might be disadvantageous for crop health.

Due to a rapid increase of maize area in the region, crop sequence patterns are undergoing a dramatic shift. It is concluded that a large proportion of arable area is potentially threatened by risks of pest and disease outbreaks as well as by economical over-reliance in a few cash crops. We demonstrate, that administrative data could offer many insights in agronomical trends and practices and should, therefore, be analyzed in more detail.

Key words: arable land use, pre-crop, crop health, maize, winter wheat, oilseed rape, sugar beet, potatoes

Introduction

Arable crops are grown by farmers in patterns according to time and space. A crop rotation could be described as "growing crops in a recurring sequence on the same field" (Thenail et al. 2009). The benefit of crop rotations is well accepted in traditional farming approaches as well as supported by scientific knowledge (Bennett et al. 2012, Koennecke 1967). Rotation patterns used by farmers can be motivated by regional, agronomical and socio-economic aspects. Regional aspects are due to conditions of soils, availability of water and nutrients and climate. So, different regions offer different patterns of crops being present in the landscape.

Crop rotation offers chances to farmers and the public. Since crop diversity is generally accompanied by spatial and genetic diversity of land use, crop rotations are drivers to enhance biodiversity on a landscape level. The benefits of crop rotations are various and could be described by:

- inclusion of breaking phases to decrease population dynamics of pests and weeds (Cardina et al. 2002, Liebman & Dyck 1993, Kirkegaard et al. 2008);
- providing better nutritional conditions for crop growth due to a suitable pre-crop (Soon & Clayton 2002, Stanger et al. 2008);
- optimizing farm income and labour allocation (Castellazzi et al. 2007, Fraser 2006);
- providing a key element of agroecology and biodiversity on farm and landscape level (Altieri 1999, McLaughlin & Mineau 1995).

On the other hand, crop rotations are underlying constraints which limit the maximum use of this agronomical instrument. In many cases, the specialization of farms does not allow for any desired number of crops as specific machinery and growing knowledge might not be available. Also sanitary reasons might constrain combinations of some crops. As an example, growing sugar beets in a dense sequence with maize and oilseed rape is disadvantageous due to promotion of *Rhizoctonia solani* or *Heterodera schachtii* respectively (Dobosz & Kornobis 2008, Rush & Winter 1990).

According to plant health and soil fertility, cropping designs containing more than one crop are normally built up by elements of crop sequences with a beneficial crop and an exploiting one (*sensu* Castellazzi et al. 2008). In many cases, these pairs of a crop, its pre-crop and their interactions are more important than the rotation as a whole. Therefore, crop rotation and crop sequence are terms that have to be clearly distinguished, but cannot be separated if rotations should be analyzed, since a rotation is always a composition of crop sequences. If so, could a continuous growing of the same crop be considered as a rotation or are at least two crops required? Some authors do not consider continuous cropping of the same crop as a rotation (e.g. Zentner et al. 2002), but others also describe monocultures as rotations (e.g. Stanger et al. 2008). Kirkegaard et al. (2008) therefore distinguish between the more dominant break crop effect and a probably less dominant rotation effect. To avoid semantic confusion, in this study, a preference is given to the term crop sequence pattern.

Though having many beneficial effects, classical crop rotation became fragmented and simplified during the last decades (Rabbinge & Van Diepen 2000). Reduction of crop diversity is induced by economic profitability of some crops and market preferences (Fraser 2006). Also due to agricultural policy, farmers are attracted to grow some crops that receive special support (Marsden 1998). In Germany this process could be described by the loss of crop diversity and increasing abundance of some major crops such as wheat and maize. Especially maize as a crop for fermentation use became attractive to farmers since national support of bioenergy was established in 2000. In recent German arable farming, the three crops wheat, maize and oilseed rape cover 58% of arable land (calculated by data of Destatis 2010). Obviously, the tools for designing crop rotations are limited due to limitation on economically preferable crops.

Renewed attention was spent to crop rotations with the unintended introduction of *Diabrotica virginifera* to German maize fields in 2007. Due to its biology, this pest is specialized to maize growing in a continuous sequence and, therefore, could be controlled by rotation practice (Gray et al. 2009). Since large proportions of maize in Europe are cropped in a self-sequence, the sanitary quality of rotational breaks became evident with the occurrence of this pest and with increasing abundance of maize. Furthermore, an impetus from agricultural policy to fostering rotations was made with the European directive establishing a framework for the sustainable use of pesticides within the European Union (EU 2009). Here, crop rotations were mentioned between others as a first key element for integrated crop protection. While integrated crop protection is scheduled to become a mandatory element of EU plant protection in 2014, crop rotations must play a more important role in the future.

Indeed, information is lacking to spatially describe and to understand the current status and driving forces of crop sequence patterns realized in production agriculture. This knowledge gap is crucial for policy, administration, extension and research, as well. Also for predicting future land use or generating rotation optimization models actual information might be valuable (e.g. Clavel et al. 2011, Rounsevell et al. 2005). The only one who has partial knowledge is the farmer himself, on the basis of his farmland. Many scientific approaches try to understand cropping patterns on a farm or landscape level (Castellazzi et al. 2007, Dury et al. 2012, Glemnitz et al. 2011, Mignolet et al. 2007, Thenail et al. 2009). This is justified, since decisions on farming systems are developed on the farm scale, which is strongly interacting with the landscape. However, up to now, information on what kind of crop rotations are really carried out by a large and representative number of farmers is lacking.

Traditionally, agricultural land use within a region is described by surveys carried out by authorities. Data obtained by this method are quite valid, but spatial explicity is lacking. Insights in agricultural structures are also limited. Most statistics rely on inquiries on cropped area by farm or community and result in proportions of overall land uses. So, applications to estimate real crop rotations are limited. To overcome these restrictions and to study real cropping patterns on arable land, other sources of information have to be exploited.

In this study, we have analyzed a new official data source being represented by the Integrated Administration and Control System (IACS), which was developed for the administration of the European agricultural direct payments (EU 2003). In Germany, this administrative system is called INVEKOS. Each farmer willing to receive direct payments has to offer information on field size and crops grown on each field in every year of participation. First attempts of studying this type of data were made by Leteinturier et al. (2006) in the Wallon region (Belgium) and Schönhart et al. (2011) in the Mostviertel region (Austria). Nitsch et al. (2012) demonstrated the informational surplus on the basis of grassland transition in Germany. In our study, we used IACS to investigate crop sequence patterns throughout an entire federal state of Germany.

Two objectives should be addressed by this investigation. These were:

i) identifying status and trends of crop rotations and crop sequence patterns from IACS data,
ii) analyzing chances and weaknesses of recent agricultural crop sequences in terms of crop health and crop protection.

Material and methods

Study region

The study is based on land use data of the German federal state of Niedersachsen (Lower Saxony). The region is covered by a wide range of agricultural land uses, such as arable farming, dairy grassland farming and diverse mixed farming. 42 000 farmers manage 2.6 Mio ha of land with an average of 61 ha per farm (LSKN 2012). Land use statistics are shown in Table 1. The study area is divided into 46 administrative districts and 1 047 communities, which could be considered as numerical repetitions and spatial variation, respectively.

Table 1: Agricultural land uses of the study region Niedersachsen in Northern Germany in 2010 (NMELVL 2010).

Crop/land use	Area	Proportion of arable area (%)
utilised agricultural area	2 577 017	–
grassland	693 042	–
arable area	1 863 849	100
thereof:		
maize (corn and silage)*	532 272	28.6
winter wheat*	430 181	23.1
winter rye/triticale*	199 564	10.7
winter barley*	164 486	8.8
oilseed rape*	130 039	7.0
potatoes*	112 594	6.0
sugar beet*	97 964	5.3
forage grass*	69 080	3.7
summer cereals*	49 672	2.7
pulses*	3 530	0.2
others	74 467	4.0

* considered as relevant arable crops in this study

Arable cropping patterns are heterogeneous within the region. As an example for identifying regional differences in land use, the cropping density of maize and winter wheat is displayed in Fig. 1. The north western part of the region is dominated by maize, mainly used as forage for dairy farming. The south eastern part is devoted to arable farming with high proportions of winter wheat and other marketable crops such as sugar beet and oilseed rape. The area between these two specialised parts of the region is represented by mixed farming with a higher diversity of crops. Maize for biofermentation is grown all over the federal state with special emphasis on this middle part.

Land use data

We analyzed administrative data for the years 2005 to 2010. Data were obtained from the IACS (integrated administration and control system), which was set up for the administration of EU direct payments (EU 2003). This data represents land use information which is generated by mandatory disclosure of farmers. Farmers have to provide field specific information on the actual land use until May 15 each year. This includes individual field identification, field size and specification of the crop utilized in the present year. Due to privacy issues, this data is not for public use up to now, and only specific scientific applications are feasible.

IACS datasets contained roughly 990 000 single entries per year, each entry representing information on agricultural land use for a single field. Spatial reference within IACS was obtained by individual geo-labelling of a so-called field block structure. A field block is defined as a spatial unit of arable land surrounded by fixed landscape structures such as tracks, forest borders, hedges or ditches. So, the field blocks reflect the landscape structure. A single field block contains one field or more, which, in course, may be

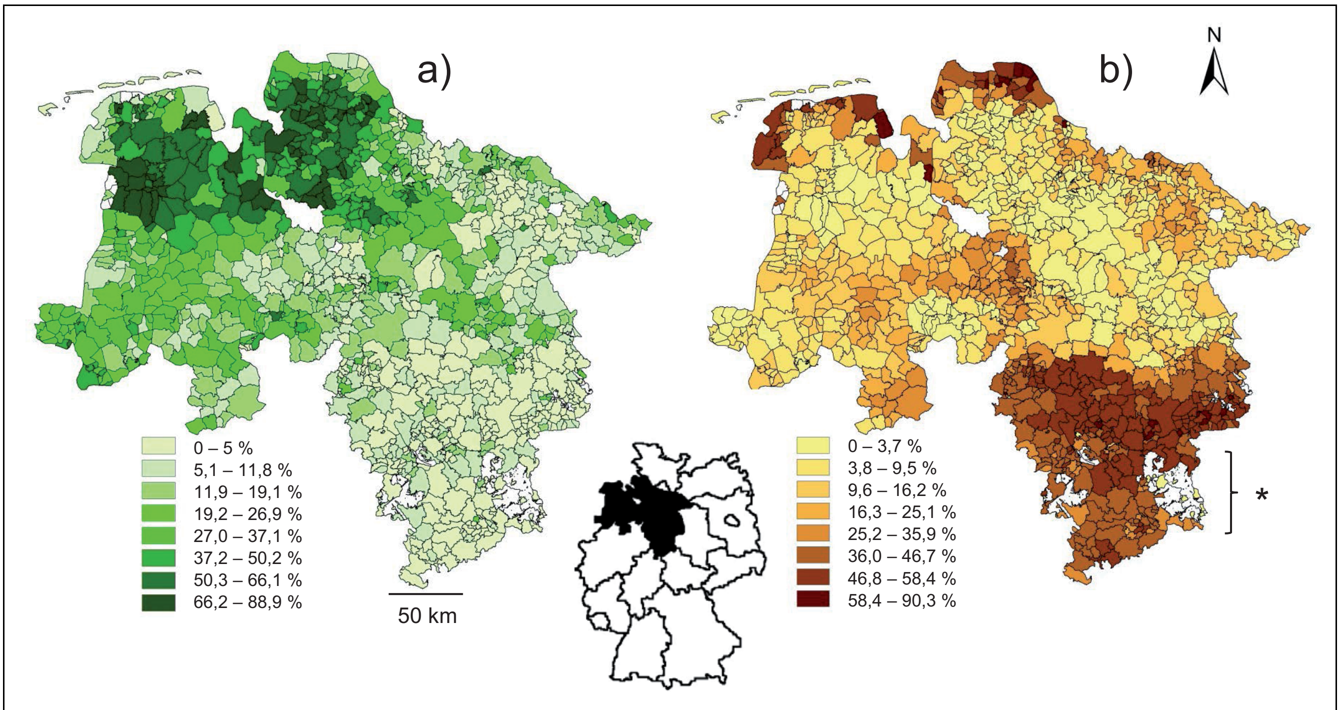

Fig. 1: Characterization of land use in the study region in Niedersachsen, Northern Germany. a) proportion of maize of arable area, b) proportion of wheat of arable area. Proportions are given for communities (n = 1 047), land use census LSKN 2010, * = mountain area, no arable land use).

cropped with different crops by different farmers. Spatial information for single fields is aggregated to the field blocks and identified by numerical coding. To summarize, each data row out of the 990 000 entries comprises these information: i) field block identifier, ii) running field number, iii) field size, iv) crop or other land use specified by an official numeric code. This coding was used for traceability of single fields and for analyses of land use. For each year, about 2.6 million ha of utilized arable area (arable land and grassland) were described in the data.

To study relevant arable land use, all data rows encoding land use other than arable crops were omitted from further calculation. Also set-aside was withdrawn from consideration, because it became less important with the end of being compulsory for European farmers. Thus, out of the different land uses, 10 crops and crop groups were selected representing relevant arable crops of the region (see also Table 1). These crops were maize, winter wheat, winter barley, rye/triticale, spring cereals, winter oilseed rape, sugar beet, potatoes, forage grass and pulses. However, pulses do just cover a small percentage of the region, but they were included as potentially valuable parts of crop rotations. For the analysis of crop sequences additionally set-aside and grassland was included, thus resulting in 12 potential pre-crops. Out of these relevant crops, crops of high agronomic and economic importance for rotation schemes were specified such as maize, winter wheat, oilseed rape, sugar beet and potatoes.

For the analysis, only those fields were considered, for which administrative identity and field size could be traced over all relevant years. So, a large number of data rows had to be rejected due to uncertainty of field identifiers or changing field size. However, this data reduction had no spatial bias and, therefore, did not affect the traceability and the representative status of the data. For the analyses of crop sequence patterns over six years, 184 701 fields, representing 645 870 hectares of arable area were available. Describing fields and their crops grown in 2010 with regard to their pre-crops (2009) a total amount of 619 447 fields could be analyzed, representing 1 730 564 ha. Spatial aggregation of selected variables was obtained on the basis of administrative communities and other territories (n = 1 047). Thirty-two extraordinary territories were omitted from land use analysis. These shapes contained administratively separated and remote areas (so-called "extra-community area") and had an extremely small amount of arable area (< 20 hectares). So, the remaining number of communities as been considered here was n = 1 015.

Crop sequence patterns

The number of relevant crops was calculated to describe the diversity of crops of major agronomical importance being present in the communities. Crops with a spatial share of more than 5% of arable land within the respective community were treated as relevant for the landscape in which the community falls. Crops with a share of less than 5% were not regarded to be relevant for regional agronomical practice. This proportion reflects the recent European threshold on farm crop diversity (EU 2011).

Crop sequence patterns here are considered as both rotational structures over the six year study period and crop sequences over a two year period. In a first step, crop combinations were detected. Therefore, traceable fields were grouped according to presence or absence of relevant crops by data sorting. Generalized six-year patterns were derived from the original data and their permutations to generate unique patterns where the respective year is of no importance. Real rotations in an agronomical sense were then identified according to repetitive patterns within the combinations.

In a second step, crop sequences of the most recent years 2009 and 2010 were calculated for 10 relevant crops and the 12 pre-crops, respectively. These patterns were interpreted in the light of phytopathological knowledge establishing the term critical crop sequences. All selected field data were summed up in the dimension hectar (ha) and, if necessary, calculated as a proportion of studied arable area (arable area = AA).

Data management, graphs and statistics

Raw data was stored and processed with MS Access® and MS Excel®. Summary- and univariate statistics were calculated from the data using Sigma Plot® and Statistica®. Regression analysis was carried out to reveal relations between the proportion of self-sequences of selected crops and their presence in the regional area. Regressions and box and whisker plots were drawn with Sigma Plot® while the box and whisker plots were displaying median and 95 percentile. Spatial data was processed and visualized with ArcView 3.2® and MicroImages TNTmips Pro 2010.

Results

Crop rotation diversity, described by the number of relevant crops that are grown in a community is characterized by strong regional variation (Fig. 2). In the north-western part of the study region a dominance of one or two relevant crops could be identified. The south eastern part of the region is described by three and four relevant crops. A central region is characterized by occurrence of five to ten relevant crops in the majority of the communities.

During the 6 years period of 2005 to 2010, a total of 16 836 combinations of crops were realized in the federal state on 645 870 hectares (Fig. 3). Displayed as a sum curve, it could be shown that the major proportion of combinations covers a small area of the region, whereas a small number of combinations already represent large proportions of the area.

Real crop sequence patterns and rotations were identified and the 12 most prevailing patterns are listed in Table 2. Patterns, dominated by wheat and maize covered the largest proportion of arable land due to their large amounts of cropped area. Important crop rotations *sensu stricto* are

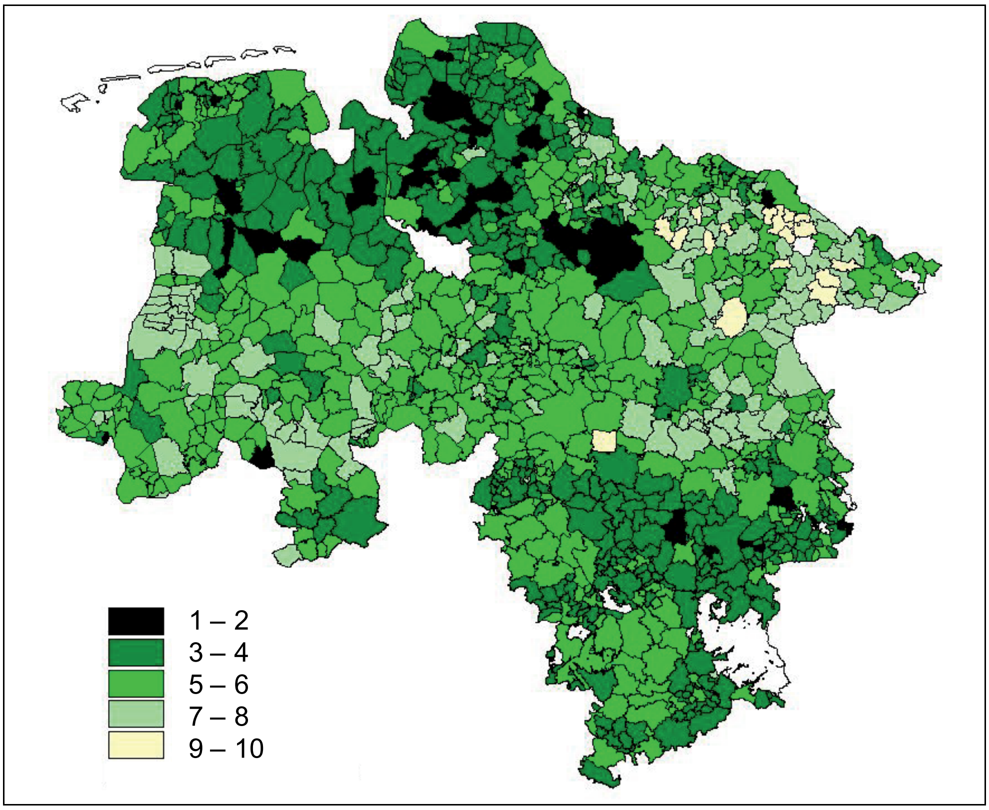

Fig. 2: Number of relevant crops in communities in Niedersachsen, Northern Germany (reference year 2010). Only crops with an area share of > 5% of arable area are considered as relevant.

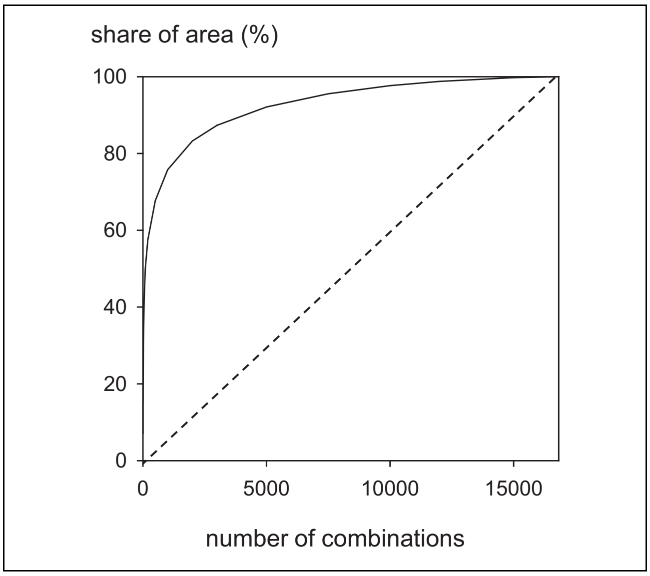

Fig. 3: Concentration of crop combinations cultivated on arable area in Niedersachsen, Northern Germany (2005 to 2010) displayed as a sum curve (solid line); dotted line represents 1:1 ratio.

Table 2: Most prevailing crop sequence patterns and rotations of major crops calculated for the six year period of 2005 to 2010 in Niedersachsen, Northern Germany (basis = 645 870 ha). All cereals are winter sown types. Rotations longer than six years could not be analyzed. AA: arable area.

Crop sequence pattern	Share of AA (%)	Cumulated share of AA (%)
wheat 4–5 times	14.8	14.8
maize 4–5 times	10.4	25.2
maize 3 times	9.1	34.3
continuous maize	7.1	42.2
sugar beet-wheat-wheat	3.5	45.7
oilseed rape-wheat-wheat-barley	2.4	48.1
oilseed rape-wheat-barley	2.3	50.4
oilseed rape-wheat-wheat	1.5	51.9
continuous forage grass	1.3	53.2
rye/triticale 5 times	1.0	54.2
continuous rye	0.4	54.6
continuous wheat	0.4	55.0

those with oilseed rape and sugar beet as major crops. Potatoes and spring sown cereals are not represented within these most important rotations. Fifty-five percent of arable land is cropped with these patterns. A dominance of either winter sown crops or spring sown crops was found for many fields. So, during the six year study period 36.4% of arable area was cultivated with winter crops in 5 to 6 out of the six years and 17.1% of arable area was devoted to spring sown crops in 5 to 6 years out of six.

In Fig. 4, biennial crop sequences of pre-crop and following crop are displayed for each of five major crops of high agronomic importance. The major proportion of pre-crops is

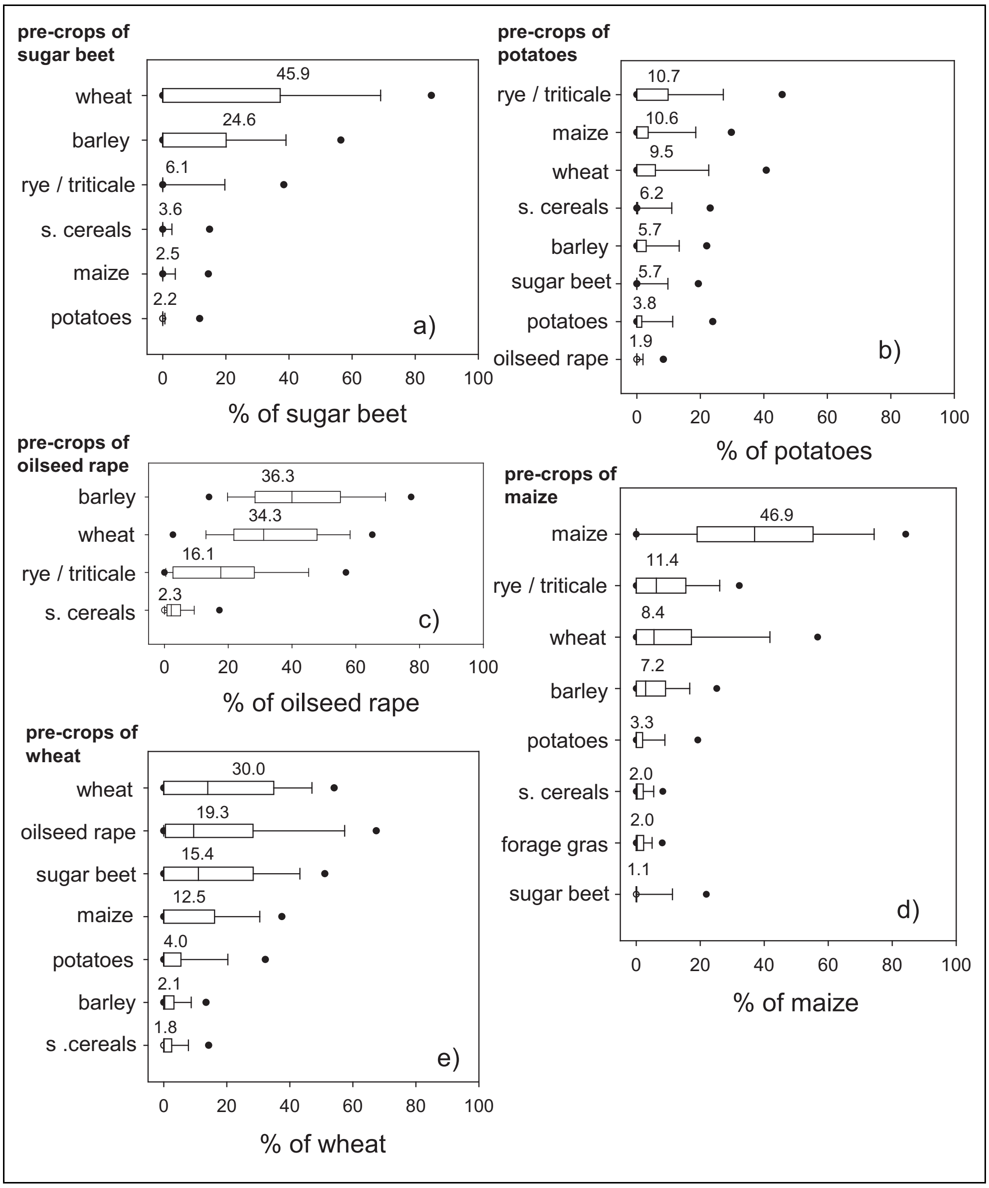

Fig. 4: Pre-crops of major regional arable crops in Niedersachsen, Northern Germany (2009/2010). Box and whiskers display proportions of the major crops which was grown following the specific pre-crops in the communities (n = 1 015). Dots show 95th percentile. Figures show arithmetic means calculated by overall data of the whole study region. a) sugar beet, b) potatoes, c) oilseed rape, d) maize, e) wheat. All pre-crops are listed, which represent an arithmetic mean > 1% of the overall area of the respective crop. If not otherwise stated, all cereals are winter types; s. = spring sown cereals.

described by just a small number of crops, whereas variation is high due to regional diversity. Maize, wheat and rye (see also Fig. 3) are the crops with a remarkable share of self-sequences. On overall average, 46.9% of maize area is grown in a self-sequence. Sugar beet and oilseed rape are mostly following winter wheat and winter barley. Potatoes have the most diverse patterns regarding their pre-crops.

Self-sequences were extensively studied for three crops maize, wheat and rye/triticale (Fig. 5). In each case, proportions of self-sequences increased with increasing share of this crops in a given community, but these patterns of increase differed crop specifically. Especially for maize, it could be shown that even in districts with low cropping density, already a high percentage of maize is grown in a self-sequence. Though, being cropped in similar density patterns in the communities (Fig. 5d), maize and wheat differ in their exposition to rotational self-sequences. Here, wheat and rye are treated more similarly by farmers (Fig. 5e).

Crop sequences built from pre-crop and following crop could interfere with crop growth and crop health due to enhancement of soil-borne diseases, pests and weeds. In Table 3, sequences that could be seen as disadvantageous based on expert knowledge were identified. In total, these sequences cover 24.6% of arable area.

Discussion

Germany´s agricultural administration is strictly organized by federal states. Therefore, many analyses of administrative data could only be carried out on a state level. We had the chance for taking a first look into regional IACS data. To our knowledge, no similar approach has been published for German agriculture before. So, neither does this study claim for a country-wide significance nor does the study region have to be seen as a worst case. However, the overall aim of the IACS database is not an agronomical purpose but a justified administration of field use in each single year. So, the agronomical traceability of each dataset over many years is yet not targeted as a goal and many fields get lost for

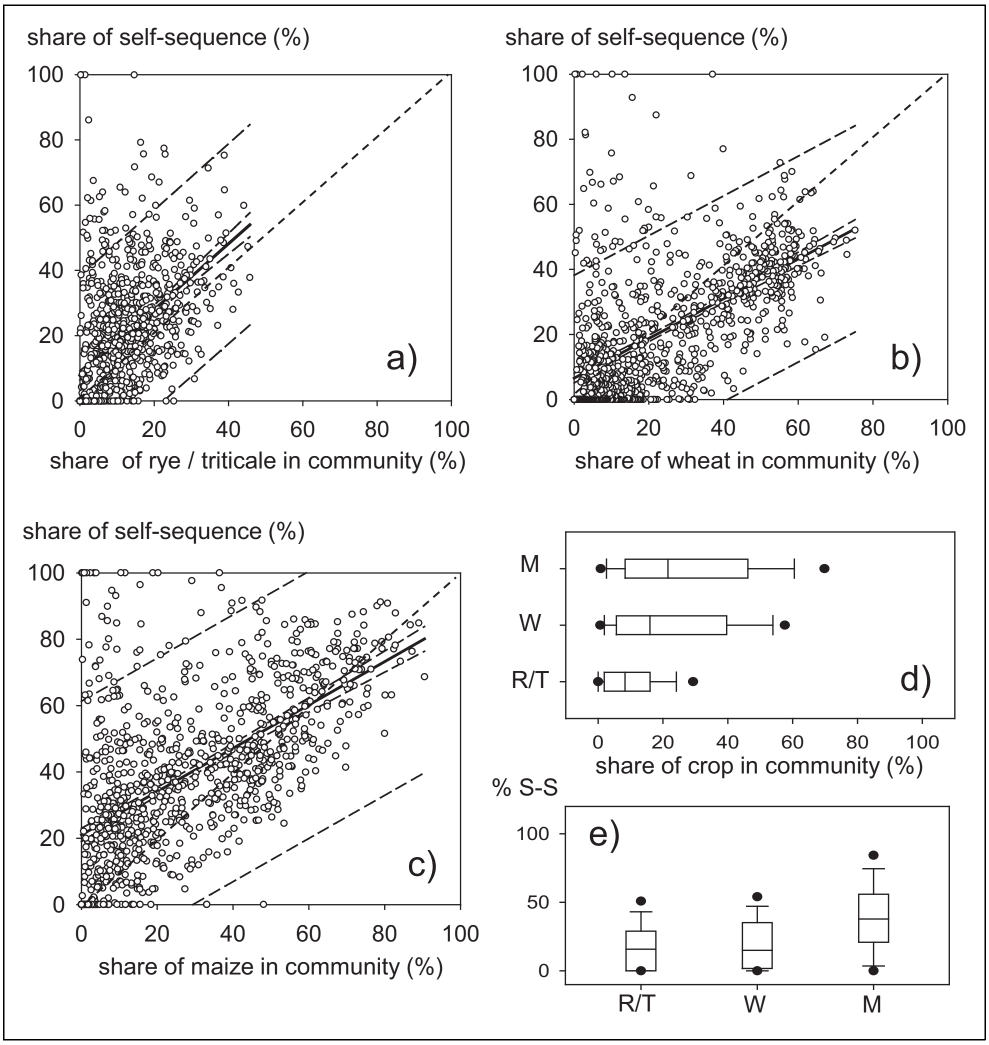

Fig. 5: Cropping area of three crops grown in a self-sequence (% S-S) in Niedersachsen, Northern Germany in relation to the crop density (2009/2010, n = 1 015 communities). Crop density is considered as share of land grown with the specific crop within a community´s arable area in 2010. Graphs show linear regression (solid line), 95% confidence interval (narrow), prediction interval (wide) and 1:1 line. Box and whisker plots show 95th percentils as dots. R/T: rye/triticale, W: winter wheat, M: maize. a) rye/triticale, $y = 7{,}805 + 1{,}009x$, $R^2 = 0{,}277$ ***; b) winter wheat, $y = 6{,}580 + 0{,}601x$, $R^2 = 0{,}357$ ***; c) maize, $y = 21{,}024 + 0{,}653x$, $R^2 = 0{,}338$ ***; d) share of crops in the communities; e) share of self-sequences.

analysis from one year to the next. This problem might be attributed to changes in agricultural structure due to restructuration of tenancies, reallocation of rural landscapes and loss of fields due to traffic or village growth. In our dataset, > 90% of the parcels could be re-identified from one year to the next. So, IACS offers valuable and viable insight into agricultural practice and land use (*sensu* Longueville et al. 2007, Leteinturier et al. 2006, Schönhart et al. 2011).

According to crop diversity, the north-western part of the study region is dominated by 1 to 2 relevant crops, which is characterized by a high share of maize in arable area. The south-eastern region is characterized by rotations of winter wheat associated with sugar beet or oilseed rape. Regional preferences of farmers for specific crops are generally attributed to soil conditions, livestock density and market contracts as regularly described by official statistics (LSKN 2007-2012).

The combinations of the available crops are manifold. In six years, about 17 000 combinations of land uses are present in the region. Further proceedings of data analyses showed that this diversity was narrowed to a dozen patterns which cover 55% of arable area. This uneven distribution of patterns rigorously shows limitations of cropping diversity. Schmit & Rounsevell (2006) already suggested poor land use diversity when they ordered proportions of actual crop area for an adjacent Belgian region. Schönhart et al. (2011) also showed extremely biased distributions of crop rotations on the basis of a crop rotation model in the Austrian Mostviertel region.

Within these combinations, sequence patterns, described by a crop and its preceding crop are also valid indicators to study the vulnerability of crop health. Rotational interactions between crops are most prominent during the transition phase (Kirkegaard et al. 2008, Krupinsky et al. 2006). This is true for combined sequences as well for self-sequences. On average, maize is predominantly grown in a self-sequence. However, even in regions with low density of maize, this crop is characterized by higher levels of self-sequences than wheat and rye. Farmers seem to treat maize preferentially as a continuous crop, even if maize area itself is not limited. Oilseed rape, sugar beet and potatoes are less problematic according to their pre-crops. Oilseed rape and sugar beet in particular could be seen as typical rotational elements.

It is a surprising result of this analysis, that classical crop rotations, such as those of oilseed rape or sugar beet only represent 10% of arable land. However, some more diverse and complex rotations of the region could not yet be identi-

Table 3: Critical crop sequences in Niedersachsen, Northern Germany (pre-crop – following crop) in the light of phytohygiene and plant health and the proportion of arable area cropped with these combinations in the study region during 2009 (pre-crop) and 2010 (following crop). "Critical" is referred to the potential of specific problems of phytopathology (see references), AA: arable area.

Crop sequence	% of AA	% of AA (cumul.)	Problem	References
maize – maize	13.3	13.3	problem weeds, *Diabrotica* sp.	Cardina et al. 2002, Meissle et al. 2010
wheat – wheat	6.7	20.0	grass weeds, take-all, leaf spots	Chauvel et al. 2001, Bailey et al. 2002, Kirkegaard et al. 1994
maize – wheat	2.8	22.8	*Fusarium* sp. (if without plough)	Oldenburg et al. 2007
maize – potatoes	0.64	23.4	*Rhizoctonia* sp.	Scholte 1992
barley – barley	0.55	24.0	basis and leaf diseases, virusses	Delogu et al. 2003, Villich 1993
potatoes – potatoes	0.23	24.2	nematodes, bacteria	Kapsa 2008
grassland – maize	0.13	24.4	*Agriotes* sp.	Parker & Howard 2001
maize – sugar beet	0.11	24.5	*Rhizoctonia* sp.	Führer Ithurrart et al. 2004, Kluth & Varrelmann 2010
set-aside – maize	0.04	24.5	*Agriotes* sp.	Parker & Howard 2001
rape – sugar beet	0.02	24.5	nematodes, volunteers	Märländer et al. 2003
sugar beet – sugar beet	0.02	24.5	nematodes	Märländer et al. 2003
oilseed rape – oilseed rape	0.02	24.6	*Sclerotinia* sp., *Verticilium* sp.	Johansson et al. 2006, Twengström et al. 1998
set-aside – potatoes	0.003	24.6	*Agriotes* sp.	Parker & Howard 2001
set-aside – sugar beet	0.003	24.6	*Agriotes* sp.	Parker & Howard 2001

fied with the available data. On the other hand, simplified crop sequences dominate nearly 50% of the current arable land use. Furthermore, many crop sequence patterns are dominated by repeated winter crops growing and others are dominated by spring sown crops. It could be shown, that such patterns, again, were found for roughly 50% of arable area. Under the viewpoint of selection pressure on weed populations, this segregation of spring and winter rotations bears the risk of boosting problematic weeds and has to be seen critical, as weed populations benefit from similar life-cycles of the crops (Froud-Williams 1988).

Some of the crop sequence patterns found in our study differ from findings of Leteinturier et al. (2006) in the Wallon region. In the Niedersachsen region, winter wheat and maize are grown in higher proportions after themselves as a pre-crop. Potatoes in our study region are more diverse according to their pre-crops than in Belgium. However, the information on potato cropping has to be read with some caution, since potato-fields were disproportionately lost from the data tracing, which might be due to changes of field size.

Recently, a strong land-use change occurs within some parts of the study region, due to an increased use of maize as a crop for biogas fermentation. During 2000 and 2010, the arable area of Niedersachsen cropped with maize increased from 291 000 ha to 531 880 ha, which is equivalent to 24 000 ha growth per year (LSKN 2010). Only from 2008 to 2010, the increase was 70 000 ha. These temporal dynamics of land use shift might narrow the chances for crop rotation diversity. This development might further narrow the potential of diverse crop rotations.

Conclusions

In terms of methodology, with this study a first large scale field survey on real crop rotations and crop sequences in Germany could be carried out, offering insights for policy, research and advisory service. However, on the basis of the current data as being available in our study, identifying crop sequence patterns of more than four years was hardly possible. In fact, the crop sequence pattern is not the only variable that indicates farming intensity, agronomical variable such as soil cultivation or intensities of fertilizer and pesticides have to be incorporated in further studies (see Mignolet et al. 2007, Herzog et al. 2006).

In terms of agronomical insights, it became evident, that classical crop rotations only play a minor role and the number of clearly defined rotations in a region is small and the proportion of other patterns is high, while occupying half of the arable land. So, a large number of farmers might not follow a strict rotation scheme rather than a random or spontaneous crop sequence pattern, characterized as a compromise between market incentives and some essential needs for rotational breaks. This leads to a high proportion of combinations being disadvantageous for crop health and accelerating pest outbreak. The dynamics of land use shift due to preference of growing maize and wheat must be seen as a driving force for this change of crop sequence patterns. As a consequence, it could not be denied that many crop sequences within the study region are too highly simplified and carry the risk of pest and disease outbreak as well as economical over-reliance in a few cash crops. Simplification occurs visibly in the landscape, such as the dominance of some crops, but could also occur as a "hidden" simplification, if winter and spring crop sequences are segregated from each other.

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References

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

Bennett AJ, Bending GD, Chandler D, Hilton S & Mills P, 2012. Meeting the demand for crop production: the challenge of yield decline in crops grown in short rotations. Biol Rev 87, 52-71.

Chauvel B, Guillemin JP, Colbach N & Gasquez J, 2001. Evaluation of cropping systems for management of herbicide-resistant populations of blackgrass (*Alopecurus myosuroides* Huds.). Crop Prot 20, 127-137.

Bailey KL, Gossen BD, Lafond GP, Watson PR & Derksen DA, 2002. Effect of tillage and crop rotation on root and foliar diseases or wheat and pea in Saskatchewan from 1991 to 1998: univariate and multivariate analyses. Can J Plant Sci 81, 789-803.

Cardina J, Herms CP & Doohan DJ, 2002. Crop rotation and tillage system effects on weed seedbanks. Weed Sci 50, 448-460.

Castellazzi MS, Perry JN, Colbach N, Monod H, Adamczyk K & Viaud V, 2007. New measures and tests of temporal and spatial pattern of crops in agricultural landscapes. Agric Ecosyst Environ 118, 339-349.

Castellazzi MS, Wood GA, Burgess PJ, Morris J, Conrad KF & Perry JN, 2008. A systematic representation of crop rotations. Agr Syst 97, 26-33.

Clavel L, Soudias J, Baudet D & Leenhardt D, 2011. Integrating expert knowledge and quantitative information for mapping cropping systems. Land Use Pol 28, 57-65.

Delogu G, Faccini N, Alberici R, Gianinetti A & Stanca AM, 2003. Soil-borne viruses of barley seriously affect plant growth and grain yield in a monocropping system. Cereal Res Com 31, 137-144.

DESTATIS (German federal authority for statistics), 2010. Data on agricultural land use. http://www.destatis.de/jetspeed/portal/cms/(current supply of data).

Dobosz R & Kornobis S, 2008. Population dynamics of sugar beet cyst nematode (*Heterodera schachtii*) on spring and winter oilseed rape crops. J Plant Prot Res 48, 237-245.

Dury J, Schaller N, Garcia F, Reynaud A & Bergez JE, 2012. Models to support cropping plan and crop rotation decisions. A review. Agronomy Sust Developm 32, 567-580.

DWD (German Weather Agency), 2009. Facts and Figures on German Climate. Internal communication, pdf-document.

EU (European Commission), 2003. Council 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.

EU (European Commission), 2009. Directive 2009/128/EC of the European Parliament and of the Council establishing a framework for Community action to achieve the sustainable use of pesticides. Official Journal of the European Union L 309/71.

EU (European Commission), 2011. Proposal for a regulation of the European Parliament and of the Council establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy. COM (2011) 625 final/2.

Fraser EDG, 2006. Crop diversification and trade liberalisation: Linking global trade and local management through a regional case study. Agric Hum Val 23, 271-281.

Führer Ithurrart ME, Büttner G & Petersen J, 2004. Rhizoctonia root rot in sugar beet (*Beta vulgaris ssp. altissima*) – Epidemiological aspects in relation to maize (*Zea mays*) as a host plant. J Plant Dis Prot 111, 302-312.

Froud-Williams RJ, 1988. Changes in weed flora with different tillage and agronomic management systems. In Altieri MA & Liebman M (ed.). Weed management in agroecosystems. Ecological approaches. CRC Press, Boca Raton, FL. 213-236.

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

Gray ME, Sappington TW, Miller NJ, Moeser J & Bohn MO, 2009. Adaptation and invasiveness of Western Corn Rootworm: Intensifying research on a worsening pest. Annu Rev Entomol 54, 303-321.

Johansson A, Goud JK & Dixelius C, 2006. Plant host range of *Verticillium longisporum* and microsclerotia density in Swedish soils. Eur J Plant Pathol 114, 139-149.

Herzog F, Steiner B, Bailey D, Baudry J, Billeter R, Bukácèk R, de Blust G, de Cock R, Dirksen J, Dormann CF, de Filippi R, Frossard E, Liira J, Schmidt T, Stöckli R, Thenail C, van Wingerden W & Bugter R, 2006. Assessing the intensity of temperate European agriculture with respect to impacts on landscape and biodiversity. Eur J Agron 24, 165-181.

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

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

Kirkegaard JA, Gardner PA, Angus JF & Koetz E, 1994. Effect of Brassica break crops on the growth and yield of wheat. Aust J Agric Res 45, 529-545.

Kluth C & Varrelmann M, 2010. Maize genotype susceptibility to *Rhizoctonia solani* and its effect on sugar beet crop rotations. Crop Prot 29, 230-238.

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

Krupinsky JM, Tanaka DL, Merrill SD, Liebig MA & Hanson JD, 2006. Crop sequence effects of 10 crops in the northern Great Plains. Agr Syst 88, 227-254.

Leteinturier B, Herman JL, 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.

Liebman M & Dyck E, 1993. Crop rotations and intercropping for wheat management. Ecol Appl 3, 98-122.

Longueville F de, Tychon B, Leteinturier B & Ozer P, 2007. An approach to optimise the establishment of grassy headlands in the Belgian Walloon region: A tool for agri-environmental schemes. Land Use Pol 24, 443-450.

LSKN (Landesbetrieb für Statistik und Kommunikationstechnologie in Niedersachsen), 2007-2012. Different statistical data obtained by online access and data-files sent on request. http://www.lskn.niedersachsen.de/live/live.php?&article_id=87564&navigation_id=25698&_psmand=40 (current access).

Märländer B, Hoffmann C, Koch HJ, Ladewig E, Merkes R, Petersen J & Stockfisch N, 2003. Environmental situation and yield performance of the sugar beet crop in Germany: Heading for sustainable development. J Agron Crop Sci 189, 201-226.

Marsden T, 1998. Agriculture beyond the treadmill? Issues for policy, theory and research practice. Prog Hum Geog 22, 265-275.

McLaughlin A & Mineau P, 1995. The impact of agricultural practice on biodiversity. Agric Ecosyst Environ 55, 201-212.

Mignolet C, Schott C & Benoit M, 2007. Spatial dynamics of farming practices in the Seine basin: methods for agronomic approaches on a regional scale. Sci Tot Environ 375, 13-32.

Meissle M, Mouron P, Musa T, Bigler F, Pons X, Vasileiadis VP, Otto S, Antichi D, Kiss J, Palinkas Z, Dorner Z, van der Weide R, Groten J, Czembor E, Adamczyk J, Thibord JB, Melander B, Cordsen Nielsen G, Poulsen RT, 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.

Nitsch H, Osterburg B, Roggendorf W & Laggner B, 2012. Cross compliance and the protection of grassland – Illustrative analyses of land use transitions between permanent grassland and arable land in German regions. Land Use Pol 29, 440-448.

NMELVL (Niedersächsisches Ministerium für Ernährung, Landwirtschaft, Verbraucherschutz und ländliche Entwicklung), 2010. Die Landwirtschaft in Zahlen. Online publication. http://www.ml.niedersachsen.de/live/live.php?&article_id=4974&navigation_id=1343&_psmand=7 (access on 21.03.2011).

Oldenburg E, Brunotte J & Weinert J, 2007. Strategies to reduce DON contamination of wheat with different soil tillage and variety systems. Mycotoxin Res 23, 73-77.

Parker WE & Howard JJ, 2001. The biology and management of wireworms (*Agriotes* spp.) on potato with particular reference to the U.K. Agric For Entomol 3, 85-98.

Rabbinge R & Van Diepen CA, 2000. Changes in agriculture and land use in Europe. Eur J Agron 13, 85-100.

Rounsevell MDA, Ewert F, Reginster I, Leemans R & Carter TR, 2005. Future scenarios of European agricultural land use. II. Projecting changes in cropland and grassland. Agric Ecosyst Environ 107, 117-135.

Rush CM & Winter SR, 1990. Influence of previous crops on Rhizoctonia root and crown rot of sugar beets. Plant Dis 74, 42-425.

Schmit C & Rounsevell MDA, 2006. Are agricultural land use patterns influenced by farmer imitation? Agric Ecosyst Environ 115, 113-127.

Scholte K, 1992. Effect of crop rotation on the incidence of soil-borne fungal diseases of potato. Europ J Plant Pathol 89, 93-101.

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

Soon YK & Clayton GW, 2002. Eight years of crop rotation and tillage effects on crop production and N fertilizer use. Can J Soil Sci 82, 165-172.

Stanger TF, Lauer JG & Chavas JP, 2008. The profitability and risk of long-term cropping systems featuring different rotations and nitrogen rates. Agron J 100, 105-113.

Thenail C, Joannon A, Capitaine M, Souchere V, Mignolet C, Schermann N, Di Pietro F, Pons Y, Gaucherel C, Viaud V & Baudry J, 2009. The contribution of crop-rotation organization in farms to crop-mosaic patterning at local landscape scales Agric Ecosyst Environ 131, 207-219.

Twengström E, Sigvald R, Svensson C & Yuen J, 1998. Forecasting sclerotinia stem rot in spring sown oilseed rape. Crop Prot 17, 405-411.

Villich V, 1993. Crop rotation with pure stands and mixtures of barley and wheat to control stem and root rot diseases. Crop Prot 12, 373-379.

Zentner RP, Wall DD, Nagy CN, Smith EG, Young DL, Miller PR, Campbell CA, McConkey BG, Brandt SA, Lafond GP, Johnston AM & Derksen DA, 2002. Economics of crop diversification and soil tillage opportunities in the Canadian prairies. Agron J 94, 216-230.