Original papers

RPG Explorer: A new tool to ease the analysis of agricultural landscape dynamics with the Land Parcel Identification System

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ABSTRACT

In the early 2000s a Land Parcel Identification System (LPIS) was set up by each member state of the European Union, to manage agricultural subsidies. These databases describe field geometry and land-cover, and provide information on farm characteristics. LPIS data could therefore be used to describe agricultural landscape dynamics, but are seldom put to this purpose by scientists and local stakeholders because it requires the use of GIS software and programming skills. The objective of this paper is thus to present RPG Explorer, a new tool that we developed to analyze agricultural landscape dynamics with LPIS data. RPG Explorer doesn't require any specific skills in GIS and programming allowing non specialist to deal with complex data.

RPG Explorer includes a first module which computes the changes in crop proportions and farm characteristics (numbers of farm, farm area, farm type). A second module computes crop sequences on each farmer block of LPIS data. We also included a crop rotation model in a third module.

We illustrated the use of RPG Explorer for two example neighboring catchments located in western France, the Vivier catchment (16,000 ha) and the Courance catchment (15,000 ha). For example, RPG Explorer easily revealed the evolution of crop proportions, such as the increase of temporary grasslands in the Courance catchment (from 7.2% of the Utilized Agricultural Area (UAA) in 2007 to 11.7% in 2013). The number of farms was also shown to vary a lot: from 230 in 2007 to 207 in 2013 for the Vivier catchment, with a subsequent increase of their mean UAA (from 101 ha to 119 ha). RPG Explorer also showed that more than half of the Vivier catchment UAA (59%) was occupied by only 50 farms in 2013. Concerning crop sequences, the sunflower → winter wheat sequence was the most frequent 2-year sequence in both catchments, but some differences appeared with for example, a higher proportion of winter wheat → winter wheat sequence in the Courance catchment (7.2% against 3.6%). Crop rotation modeling indicated that the rapeseed → winter wheat → sunflower → winter wheat, sunflower → winter wheat and maize monoculture were the three main crop rotations.

Finally, these examples illustrate well the ability for scientist and local stakeholders to easily describe some major agricultural landscape dynamics with RPG Explorer.

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1. Introduction

Apart from food production, new issues are constantly arising in agricultural landscapes, such as the ecological impacts of agriculture (Stoate et al., 2009) and the loss of agricultural land (Thompson and Prokopy, 2009). Local stakeholders thus need to

describe these agricultural landscapes and their dynamics. For example, when a water resource manager develops an agri-environmental scheme, he can be interested in the location of crops and crop rotations which may have the most impact on water quality (nitrate and pesticide leaching, etc.), as well as to quantify their evolution in time. The knowledge of what farmers should be involved to reach the largest area around the water catchment is also important for the implementation of an agri-environmental scheme. Although these kind of issues are common to most agricultural landscapes, the variability and dynamics of these landscapes can be very local, and the study of this local context is often largely ignored in the literature (Benoît et al., 2012).

Describing agricultural landscape dynamics at a regional scale (i.e., thousands of hectares) is thus a challenge for local stakeholders who manage agricultural production or natural resources at landscape scale. Describing agricultural landscapes and cropping systems usually relies on farm or local expert surveys, remote sensing or the use of agricultural censuses (Leenhardt et al., 2010). All these methods suffer from one or more severe limits, such as the amount of work required, the nature of available variables, the accuracy of data, or the public availability of spatialized data.

Recently, a new type of data appeared in Europe. In the framework of the Common Agriculture Policy (CAP), European Commission asked for member states to set up a Geographic Information System (GIS) in order to manage and control subsidies given to farmers (European Commission, 2007). This GIS, called the Land Parcel Identification System (LPIS), has to specify field geometry and land cover, and to be updated yearly (European Commission, 2009). Although LPIS databases were not developed to study agricultural landscapes, their contents could *a priori* make them suitable for that use. LPIS data have thus been used for a wide range of purposes, including rural planning (Verhoeve et al., 2015), spread of weeds (Follak and Essl, 2013) or cattle diseases (Johnston et al., 2011), soil and water conservation (Murgue et al., 2015), biodiversity conservation (Persson and Smith, 2013) and development of new agricultural sectors (Vávrová et al., 2014). Most of the studies identified have only used raw landcover data in LPIS to assess the proportion of one particular crop or its location. Others studies have used several years of LPIS data to determine crop sequences or crop rotations (Leteinturier et al., 2006; Schönhart et al., 2011; Nitsch et al., 2012; Steinmann and Dobers, 2013; Murgue et al., 2015). The spatial delineation of farm cropping areas by means of LPIS data has also been used by some authors, e.g. for studying the effect of land fragmentation on farm performance (Latruffe and Piet, 2014) and on carbon dioxide emissions (Hiironen and Niukkanen, 2014), or for averaging the cost of erosion control measures per farm (Aurbacher and Dabbert, 2009; Martin et al., 2014).

LPIS data have thus been used in a variety of contexts, with different objectives and focuses (landcover, farm cropping area, etc.), to study agricultural landscapes dynamics. However, as their use often requires specific computer programming, it is not an option for most scholars and stakeholders who are not computer scientists. The main objective of this paper is therefore to present the RPG Explorer tool, which we developed to facilitate the use of LPIS data for analyzing agricultural landscape dynamics.

In this paper we first describe the characteristics of LPIS data and of the RPG Explorer tool. We then present the results of LPIS data analysis with RPG Explorer for an agricultural landscape located in western France. Finally, we discuss the potential and limits of LPIS data for describing agricultural landscapes and studying their dynamics. We underline the need for a specific tool such as RPG Explorer to carry out this study.

2. Materials and methods

2.1. Land Parcel Identification System

2.1.1. LPIS data in Europe

In Europe, each member state has to implement an Integrated Administration and Control System (IACS) to ensure that the European Agricultural Guarantee Fund is actually used correctly, and to prevent and deal with irregularities (European Commission, 2007). Since subsidies are area based, a Land Parcel Identification System (LPIS) covering all agricultural areas is part of IACS. LPIS is intented to ensure unique identification of each "reference parcel". Since LPIS is set up by each member state, a diversity of approaches exists concerning its implementation (Kay and Milenov, 2008). For example, reference parcels can be defined as cadastral parcels, agricultural parcels, farmers blocks (one or several agricultural parcels cultivated by a single farmer) or physical blocks (one or several agricultural parcels cultivated by one or several farmers). Land use nomenclature is roughly similar in the different states.

Each year, farmers applying for grants must specify the following for every reference parcel of their farm (parcels that can be granted or not): area, expressed in hectares to two decimal points, location and, where applicable, crop use (European Commission, 2009). This application is established with the use of computerized geographical information system techniques (e.g. aerial orthoimagery), with a minimum accuracy at least equivalent to cartography at a scale of 1:10 000.

Finally, the availability of LPIS to the public also varies in different states, from public access to restricted access.

2.1.2. French LPIS data

In France, LPIS was set up in 2002 and was called Registre Parcellaire Graphique (RPG) (Agence de Services et de Paiements, 2015). The reference unit is the farmer block (see Section 2.1.1). French LPIS contains over 6 million blocks, representing 27 million hectares, cultivated by 400,000 farmers. Every block of farms that had applied for European subsidies are in the LPIS data. According to Cantelaube and Carles (2014), French LPIS covered in 2009 almost all of the croplands (99%) and permanent grasslands (95%) (except moorlands and mountain pastures: 70%), but only 43% of perennial crops and market gardening areas which are not eligible crops for European subsidies. Landcover is described in a nomenclature of 28 groups of crops. A group of crops can correspond to a single crop, e.g., "wheat", or to several crops, e.g., "other oilseed crops" including oil linen, soybean, etc. An anonymous unique identifier for each farmer block and for each farmer is also provided. RPG is updated annually (landcover, farm identifier and block geometry). RPG is provided in yearly databases, with one database for each *département* (NUTS3 scale, the third subdivision of countries according to the European Union nomenclature). A database consists in a set of three files:

- a shapefile containing block geometry and associated unique identifiers,
- a csv file (comma-separated value, i.e., a file storing tabular data in plain text) containing areas of each group of crops per farmer block, and,
- a csv file containing a unique farm identifier and farm characteristics per block identifier (e.g., total utiized area, farm legal status), from 2007 only.

Public access is granted to RPG for every local stakeholder with a public service mission, free of charge or not according to the status of the applicant. In early 2015, only RPG from 2006 to 2013 was available.

2.2. Methods – the RPG Explorer tool

2.2.1. General principles

We developed RPG Explorer to facilitate the analysis of LPIS data. At the moment, the tool only deals with the French LPIS data (RPG), or any other LPIS formatted as the French LPIS (see Section 4.3 in discussion). This tool is based on a PostgreSQL/PostGis database into which LPIS data are integrated. RPG Explorer has been developped to be used by specialists as well as non-specialists in computer sciences, and therefore has a set of user-friendly modules which perform standardized analyses of LPIS. These modules are based on SQL queries and PostGIS (htpp://postgis.net) geographical processing of vector data. The tool is coded in VB.net (Visual Basic. NET).

Each *département*'s annual databse (NUTS3 scale) can be integrated directly into the tool, without any prior modifications of the contents of the files (shapefiles and csv). Once integrated into the PostgreSQL database of the tool, several yearly and/or *département* databases can be analyzed at once.

In addition to LPIS data, RPG Explorer enables users to import the boundaries of certain study areas (as a shapefile), such as catchments, administrative units, etc., included in one or more *département*. RPG Explorer thus allows one to extract and analyze LPIS data for a subset of LPIS *département* databases.

The tool imports GIS layers and can easily export them. However, RPG Explorer has no mapping interface and therefore needs to be used with a GIS software if mapping data or further GIS analyses are required. Likewise, table data in csv format can also be exported to deepen the analysis in a spreadsheet or in a statistics software.

2.2.2. Basic indicators

This module allows basic indicators to be computed from LPIS, describing crop proportions and farm characteristics: yearly crop proportions per subset of a study area (e.g., according to soil unit), crop proportions for each farm of a study area, part of each farm included in a study area, etc. All these indicators are computed from SQL and spatial queries in the database.

In this paper, we first used this module to compute the evolution of some crop proportions in a study area, and to spatialize the differences in crop proportions according to soil units. We also used this module to compute the cropping area of each farm in a study area, and the diversity of crop proportions per farm.

2.2.3. Farm typology

Farm typology based on farm crop proportions is common in agricultural sciences (Duvernoy, 2000; Chopin et al., 2015). Since crop proportions per farm can be computed from LPIS (Section 2.2.2), the possibility to classify farms according to an existing typology based on crop proportions is included in RPG Explorer. The principle is to specify crop area thresholds for categorizing the different types of farm (e.g. the proportions of grasslands for stockbreeders). This method requires one to know in advance the thresholds of the typology to build, for example from existing typologies made by local agricultural experts.

In this paper, we used farm surveys in a study area to define an expert typology based on thresholds of crop proportions per farm. This typology was implemented in RPG Explorer to classify farms in the study area.

2.2.4. Intersection of yearly LPIS data

This module aims to build a link between LPIS farmer blocks of successive years. This link can thus be used to analyze the dynamics of field units during a given time period or to determine crop sequences (see Section 2.2.5).

As the identifiers of farmer blocks change each year in the database, this link cannot be directly defined. As suggested by Leteinturier et al. (2006), we based our approach on the superimposition of successive LPIS. First, the first two consecutive years of LPIS are intersected to extract the common agricultural areas between the two. Secondly, a symmetrical difference extracts the agricultural areas which appear or disappear between the two years. For more than two years, successive intersections and symmetrical differences with the previous years of LPIS are then performed to build a link between all LPIS data. The result of this operation is a new block map, where each polygon corresponds to the minimal common area between the different yearly LPIS data or to the area present in LPIS during only a part of the period. Each polygon is described by a new unique identifier corresponding to the concatenation of LPIS blocks identifiers for each year.

2.2.5. Determining crop sequences

2.2.5.1. Principles.
In the French LPIS, as in many other European states' LPIS (e.g., Finland, Czech Republic or some Länder in Germany) (Kay and Milenov, 2008), landcover is specified per farmer block. More than one agricultural parcel can thus be present in a block, and crop sequences cannot be computed directly from the yearly intersection of LPIS data. For example, considering a given block with rapeseed (*Brassica napus L.*) and wheat (*Triticum aestivum L.*) in year 1, then wheat and barley (*Hordeum vulgare L.*) in year 2, potential crop sequences include not only rapeseed → wheat and wheat → barley, but also rapeseed → barley and wheat → wheat (and any combinations of these two possibilities).

To counteract this limitation and determine crop sequences in farmer blocks, a specific algorithm has been developed in RPG Explorer. This algorithm, based on Leenhardt et al. (2012) is iterative and includes seven rules for crop sequence determination. Each rule is based on a hypothesis about the evolution of crop group areas (see Section 2.1.2) inside farmer blocks over several years. The rules for crop sequence determination are detailed in Appendix A. Each rule allows new crop sequences to be determined but with an increasing uncertainty from rule 1 to rule 7. Once a rule has been applied, the crop group areas corresponding to the estimated sequences are removed from the annual remaining crop group areas in the farmer blocks. If several possibilities of crop sequences exist for a same crop area, none of them is chosen and the sequence remains undefined.

In this paper we used RPG Explorer to determine: (i) two-year sequences, which could help, e.g., to study the risk of nitrogen leaching between two subsequent crops; and (ii) eight-year sequences from which the minimal return time of a given crop was computed.

2.2.6. Modeling crop rotations

Despite the need to determine crop sequences to address agronomic or environmental issues, the set of crop sequences' proportions can be too complex to give a synthetic view of a study area (Murgue et al., 2015). Some biophysical models can also need a limited number of crop rotations as input data, instead of a set of all crop sequences in a study area (Dupas et al., 2015). A rotation model is thus included in RPG Explorer. This model is based on the CropRota model (see Schönhart et al. (2011) for a full description). Briefly, CropRota is a linear programming model. This optimization model allows the computation of the proportions of crop rotations to maximize the agronomic value across the entire study area, while complying with observed crop proportions (Schönhart et al., 2011). To compute agronomic values of crop rotations, CropRota averages the agronomic values of all the 2-year crop sequences included in the rotations. The agronomic values of 2-year crop sequences are input data and have to be determined by expert knowledge. An additional constraint is the maximal pro-

portion of each crop in crop rotations. To comply with observed crop proportions in the landscape, observed proportions of each crop in the study area are used as input data of the model.

In comparison to CropRota, some major modifications have been included in RPG Explorer. First, the proportions of 2-year and 3-year sequences are added as constraints to the optimization model. The modeled crop rotations thus more look like the observed crop sequences. Secondly, the return time is added as a constraint in modeled crop rotations, so that agronomic constraints can be considered more adequately for specific crops. RPG Explorer also allows one to model a set of crop rotations per subset of the study area, e.g., per farm type or per soil unit. The optimization model is coded with LpSolve, which is open-source and free of charge, instead of the GAMS software package originally used in CropRota, which is charged. A free optimization model was chosen in order to facilitate the tool dissemination.

In this paper, we used RPG Explorer to model crop rotations for different types of farm (Section 2.2.3) and different types of soil in a study area.

2.3. Study area

2.3.1. Main characteristics

Our study area is two catchments on the Niort Plain in western France (Fig. 1). The Vivier catchment is about 16,000 ha and corresponds to the area which supplies the water catchment of the city of Niort and its surroundings (about 100,000 inhabitants). The Courance catchment is about 15,000 ha and corresponds to the area which supplies the water catchment of several villages (about 19,000 inhabitants).

The land-cover is mainly agricultural, with a total of approximately 12,000 ha in both catchments (73% and 82% of the total area in the Vivier and Courance catchments, respectively). The remaining areas are mainly urbanized, with Niort in the western part of the Vivier catchment and several villages in both catchments, although there are also a few forests in the Courance catchment. From a geomorphological point of view, we can distinguish three main areas: (i) the alluvial valleys, (ii) the calcareous plateau which covers the western downstream part of the Vivier catchment and most of the Courance catchment, and (iii) the non-calcareous plateau in the eastern upstream part of the Vivier catchment. Accordingly, soil types encompass deep alluvial soils (redoxic fluvisol in the French Soil Reference System), calcareous, shallow to deep calcareous and stony soils (rendosol and calcosol), and deep non-calcareous soils (brunisol). All these types of soil are mainly rich in clay (>30%, clay to silty clay loam soils). The climate is oceanic (Cfb in the Köppen classification), with 867 mm of mean precipitation per year.

Farming systems are diversified: some are specialized in cereals, others in livestock (mainly cattle and goats), and others are mixed crop-livestock farms. The main cultivated crops are winter wheat, maize (*Zea mays L.*), rapeseed, and sunflower (*Helianthus annuus*), while permanent and temporary grasslands still cover a significant part of the catchment (about 20% in the Vivier catchment and 14% in the Courance catchment). Non eligible crops (permanent crops) are almost absent in the study area (0.4% of the UAA at the département scale according to the agricultural census of 2010), LPIS thus covers almost all the agricultural area.

2.3.2. Evaluation dataset for crop sequences

Before using results on crop sequences, users need to know the validity of the crop sequences computed with RPG Explorer. Furthermore, an evaluation of the different rules of crop sequence determination is needed to improve the algorithm of crop sequence determination. This evaluation requires actual crop sequences computed from field surveys.

In the Vivier and Courance catchments and in their surroundings, field surveys were conducted from 2006 to 2009. Land cover was registered annually on all fields in these territories, and computed in a field database (see, e.g., Bretagnolle et al. (2011)). This database was used to compute actual crop sequences at the field scale. It was then used to validate crop sequences determined with RPG Explorer. The database covers an agricultural area of about 35,000 ha, including the whole Courance catchment and a part of the Vivier catchment (6000 ha).

The farmer blocks were intersected with the field database. For each LPIS block, the sequences determined with RPG Explorer could thus be compared to those of the intersected parcels. Only the farmer blocks with a similar land cover to those of surveyed parcels (95% similarity) were used for the evaluation, in order to compare only the sequences and not the equality of land cover between LPIS and field surveys. Therefore, when the crop proportions in a farmer block differed by more than 5% of the crop proportions in the corresponding surveyed parcels, the farmer block and the surveyed parcels were removed from the evaluation dataset.

3. Results – an example of application

3.1. Characterizing UAA and farmer block dynamics

By extracting the farmer blocks in our study area for each year, the changes in the Utilized Agricultural Area (UAA) was studied over the 2006–2013 period. The UAA of the Courance catchment did not vary much during the period, with only a 18 ha decrease (−0.2%). By contrast, a clear decrease was observed in the Vivier catchment (Fig. 2), especially between 2006 and 2007 with the building of a new road and the subsequent loss of agricultural land. The decrease in agricultural area was greater in the Vivier catchment in comparison to that observed at the département scale (NUTS3 scale) (-1.6% versus −0.4%).
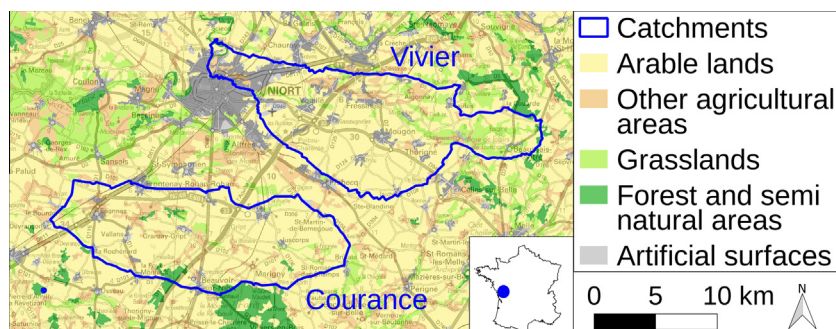

Fig. 1. Study area. The land-cover is mainly agricultural areas and artificial surfaces, with the city of Niort west of the Vivier catchment. source of landcover data: Corine Land Cover 2012, background map: IGN Scan Régional ®
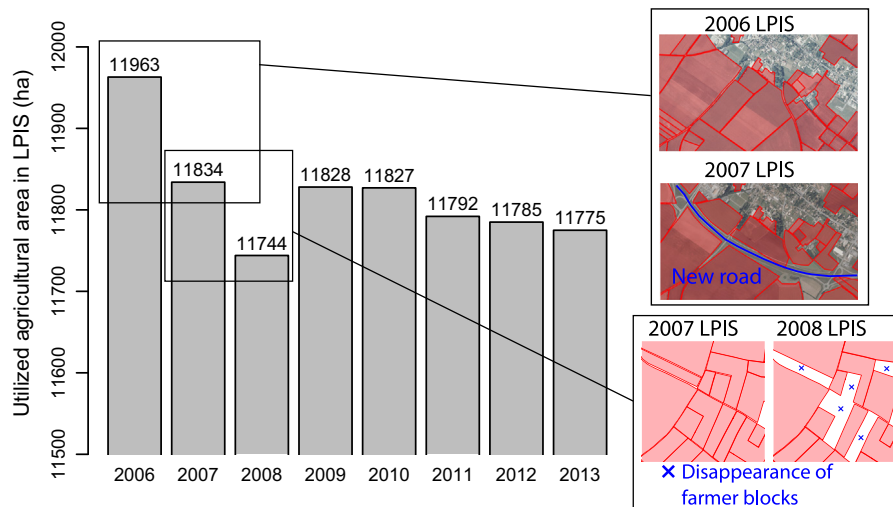
Fig. 2. Changes in the utilized agricultural area of the Vivier catchment in LPIS from 2006 to 2013. Artificialization explained a part of the decrease in UAA, while another part could be explained by a farm disappearing from LPIS data for a year (farmer blocks: RPG_ANONYME_ASP_2006, RPG_ANONYME_ASP_2007, RPG_ANONYME_ASP_2008).

Because only those farms that had applied for European subsidies were in the LPIS data, some biases could appear in the analysis. For instance, the UAA decreased between 2007 and 2008 and then increased between 2008 and 2009 in the Vivier catchment (Fig. 2). The decrease corresponds to the disappearance of a farm from 2008 LPIS data, because it had certainly not claimed for European subsidies in that year (see Section 4.1).

While UAA in the Vivier catchment decreased, the geometry of some remaining farmer blocks changed. The intersection of successive yearly LPIS data in RPG Explorer allowed us to compute the changes in farmer blocks' geometry. In 2006–2007, a significant proportion of farmer blocks (20%) showed a change in their geometry in the Vivier catchment, in relation to the road building (Fig. 2). During the following years, most of the farmer blocks remained stable in both catchments, for example during the period 2008–2009 with more than 96% of stable farmer blocks.

3.2. Identifying the dynamics of crop proportions

The changes in the crop proportions were analyzed by extracting landcover from LPIS with RPG Explorer. For example, rapeseed areas showed an increase from 8.7% and 12.5% in 2006 to 12.2% and 14.0% in 2009 for the Vivier and Courance catchments, respectively, and then a decrease to 5.9% and 9.4% in 2013 (Fig. 3, left).

Temporary grassland areas showed a continuous increase in both catchments, but that was more pronounced in the Courance catchment (from 7.2% in 2007 to 11.7% in 2013 for the Courance catchment, in comparison with 7.4% and 8.8% in the Vivier catchment). In addition to these changes in the major crop areas, LPIS also allowed us to detect the emergence of minor crops (<1% of the UAA), such as lentils (Fig. 3, right).

By adding a soil map in RPG Explorer, the differences in crop proportions according to soil unit could also be easily computed. In calcareous and stony soils of the two catchments, the crop proportions were similar, with 80% of the UAA occupied by five major crops: winter wheat, maize, rapeseed, sunflower and grassland. In comparison to these calcareous soils, valleys showed very different crop proportions, plus a clear distinction between the two catchments: grasslands were predominant in the Vivier valleys (70%) and the proportion of maize remained low (4%) while maize and grasslands each occupied a similar part of the area in the Courance valleys (48% and 31%, respectively).

3.3. Identifying farms' characteristics

3.3.1. The farms of the catchment and the distribution of the UAA

The number of farms decreased over the 2007–2013 period, from 230 and 235 in 2007 to 207 and 222 in 2013 for the Vivier
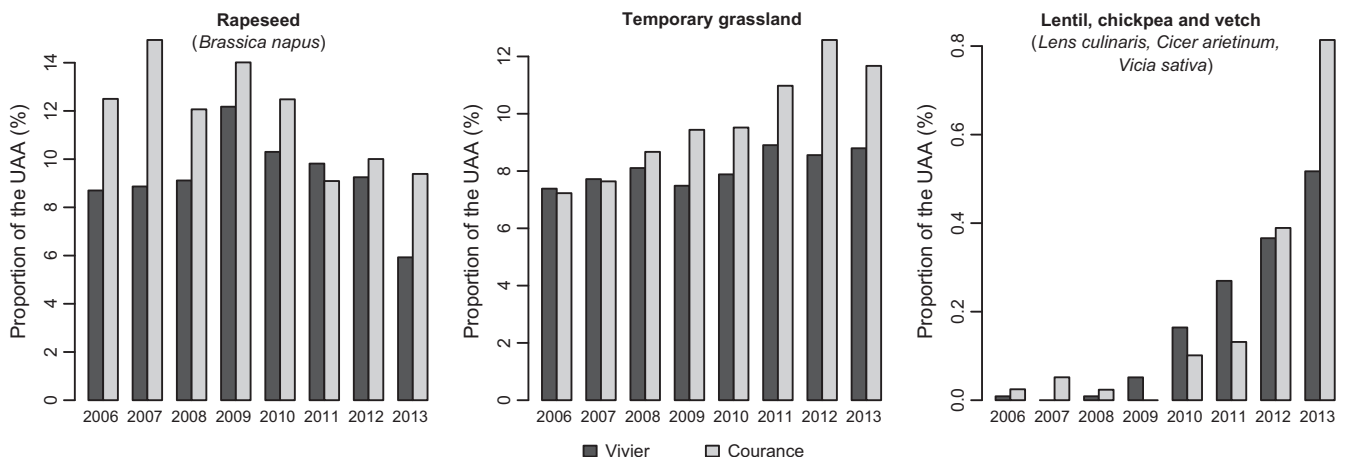

Fig. 3. Changes in the crop proportions from 2006 to 2013 in the two catchments.

and Courance catchments, respectively. In the same period, mean UAA of the farms increased from 101 ha to 119 ha in 2013 in the Vivier catchment, and from 106 ha to 113 ha in the Courance catchment.

3.3.2. Weight and concern of each farm

Although more than two hundred farms were concerned by each of the catchments in 2013, the weight of each farm (Farm UAA in the catchment divided by catchment UAA) and its concern (Farm UAA in the catchment divided by total farm UAA) varied widely (Fig. 4). Finally, more than half of the Vivier catchment UAA (59%) was occupied by only 50 farms in 2013. The same number of farms occupied 57% of the Courance catchment UAA.

3.3.3. Crop proportions per farm

The crop proportions per farm were computed from LPIS 2013 with RPG Explorer (Fig. 5). Apart from the diversity of the crop proportions per farm, the variability of the number of groups of crops per farms was observed. For example, most of the farms in both of the catchments cultivated 4–6 groups of non-perennial crops, but more farms cultivated 7 groups of non-perennial crops in the Cour-
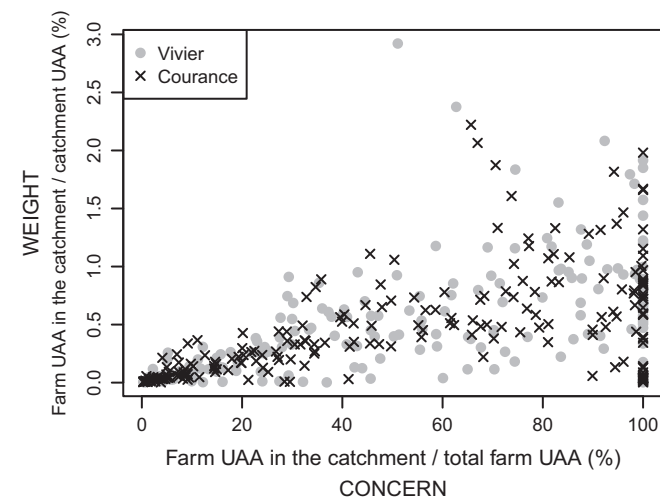

Fig. 4. Weight and concern of each farm in the two catchments according to LPIS 2013. Presentation according to Durpoix and Barataud (2014).
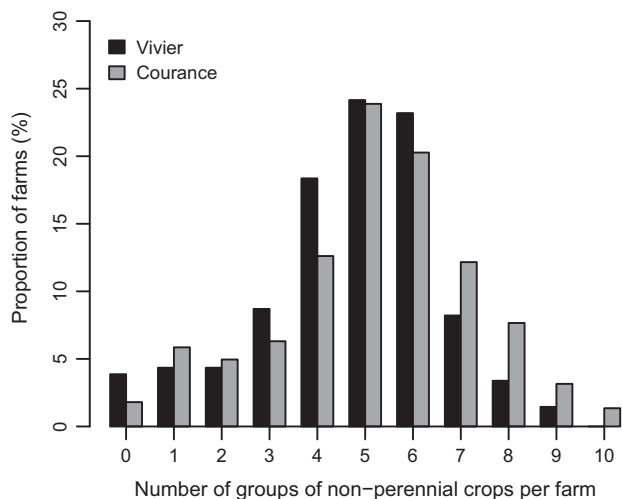

Fig. 5. Number of groups of non-perennial crops per farm in 2013. Farms with 0 groups of non-perennial crops correspond to farm with only perennial crops (permanent grasslands, orchards, etc.)

ance catchment. This number is above the minimum required when applying for the CAP subsidies (3 different crops).

3.3.4. Farm types

According to data about production systems in 100 surveyed farms, we established a farm typology in the Niort plain and applied it in RPG Explorer. This typology distinguished cereal farms (less than 10% of grasslands) from mixed crop-livestock farms (more than 20% of grasslands, or more than 10% and permanent grasslands counting for more than 20% of grasslands). This typology allowed the identification of farms with or without livestock, and thus what farms are more likely to produce organic wastes, which can be interesting for water resources managers. RPG Explorer thus allowed us to classify each farmer block of LPIS according to the type of farm it belonged to (Fig. 6). In 2013, in the Vivier catchment, 128 farms were classified as mixed crop-livestock farms (59% of the UAA catchment) and 64 as cereal farms (31% of the UAA catchment), and the 15 other farms remained unclassified. In the Courance catchment, mixed crop-livestock farms were predominant (118 farms) but represented the same proportion of the catchment UAA as the cereal farms (83 farms) (44% of the UAA for each type). The mapping of farm types showed a spatial heterogeneity of farm types, e.g., a high density of crop-livestock farms in the eastern part of the Vivier catchment (Fig. 6).

3.4. Identifying crop sequences

3.4.1. Crop sequences analysis

RPG Explorer was used to compute the proportion of 2-year crop sequences (Fig. 7). In 2012–2013, the sunflower → winter wheat sequence was the most frequent sequence in the Vivier and Courance catchments, with 11.8% and 10.3%, respectively. Some differences appeared between the two catchments, with for example, a higher proportion of winter wheat → winter wheat sequence in the Courance catchment (7.2% against 3.6%). Finally, the twenty main 2-year crop sequences represented 84% of the Vivier UAA and 82% of the Courance UAA in 2012–2013.

RPG Explorer was used to extract 8-year sequences (LPIS 2006–2013). On this basis, the minimal return time of each crop in the sequences was computed, i.e., the minimal number of years between the same crop during the 8-year sequences. For example, the minimal return time of winter wheat (WW) in the sequences WW-WW-WW-WW-WW-WW-WW-WW and WW-RS-WW-WW-RS-WW-WW is 1 year, while it is 2 years in the sequence WW-RS-WW-RS-WW-RS-WW-RS. At that point, the tool did not compute automatically the minimal return time, we thus used the R software to compute it. The distribution of minimal return time varied widely, according to both crops and catchments (Fig. 8). For example, most of the winter wheat presented a minimal return time of 2 years, but with a significant proportion of winter wheat with one year minimal return time (two successive winter wheat crops), especially in the Courance catchment. A minimal return time of one year was also the most frequent for maize in the Courance catchment, instead of four years or more in the Vivier catchment. The distribution of minimal return times was however very similar for rapeseed in the two catchments.

3.4.2. Crop sequences evaluation

For the 2006–2009 period, we computed 4-year sequences from LPIS database using the seven successive rules (see Section 2.2.5). We then computed the proportion of LPIS sequences that did not match the sequences obtained from field surveys for the same period.

Overall, most of the crop sequences computed with RPG Explorer were validated in our study area, with a proportion of validated sequences of 95%. In detail, the proportion of crop sequences
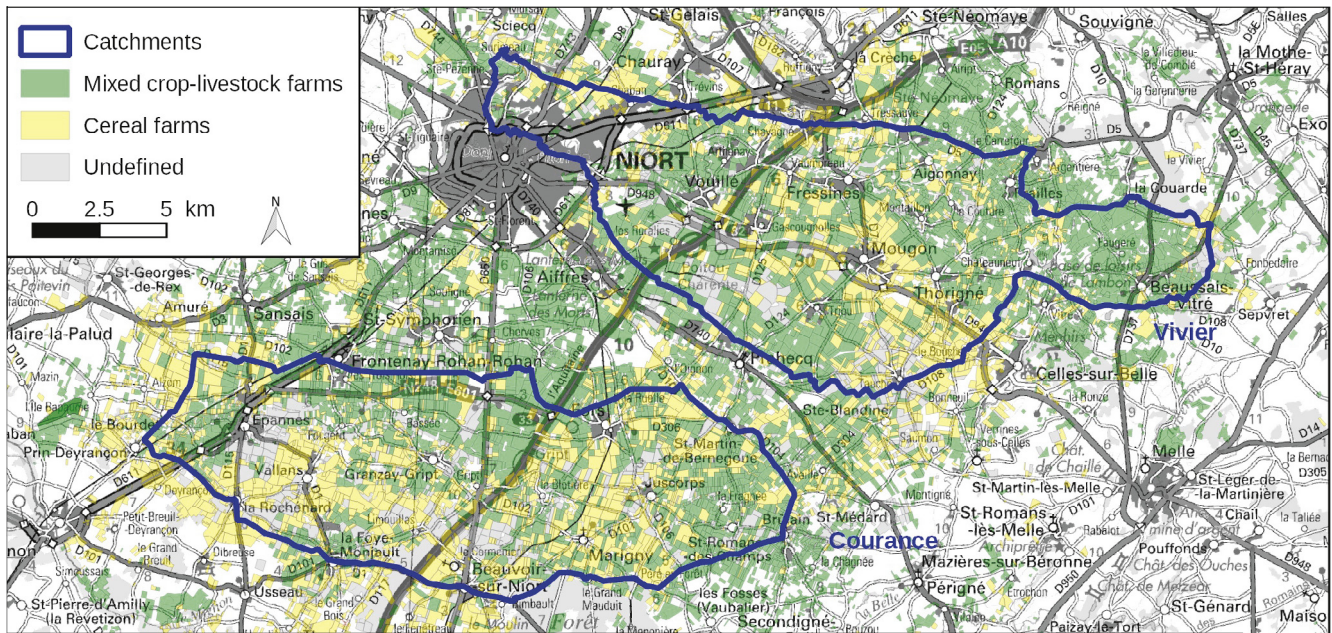
Fig. 6. Type of farm per farmer block. Classification based on grassland proportions and applied on LPIS 2013 in RPG Explorer (background map: IGN Scan Régional®, farmer blocks: RPG_ANONYME_ASP_2013).
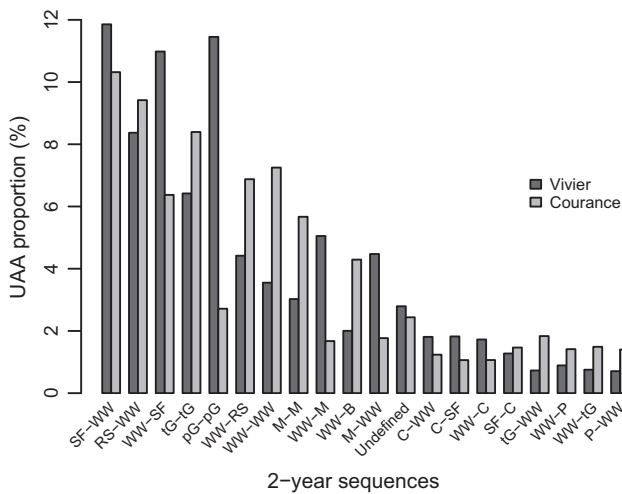

Fig. 7. Proportion of the twenty main 2-year sequences in the Vivier and Courance catchments computed with RPG Explorer from LPIS 2012 and 2013. B: Barley, C: other cereals, pG: permanent grasslands, tG: temporary grasslands, M: Maize, RS: Rapeseed, SF: Sunflower, WW: Winter wheat.

based on rule 1 was high and the proportion of unvalidated sequences was very low (3%) (Appendix B). This very high proportion of crop sequences based on rule 1 was explained by the characteristics of farmer blocks in this area (a lot of small farmer blocks with only one parcel per farmer block). Furthermore, only farmer blocks with a similar landcover to those of field survey parcels were selected for the evaluation, which further decreased the proportion of complex farmer blocks with many parcels inside. Crop sequences based on rules 2–4 represented a smaller but significant proportion of the UAA, with a moderate error (4–9% of unvalidated sequences). By contrast, crop sequences based on rules 5, 6 and 7 represented a very low proportion of the UAA and with a high error (89%, 16% and 36%, respectively), which limited the interests of these rules in our study area. Finally, whatever the mobilized rule, a part of the unvalidated sequences could be explained by a small

difference in landcover between field surveys and LPIS (tolerance on landcover dissimilarity up to 5%, see Section 2.3.2).

3.5. Crop rotations

Monocultures and 2-year to 6-year crop rotations were modeled in RPG Explorer for the two farm types in the two catchments, using as constraint the compliance with the proportions of crops, 2-year and 3-year sequences. About two hundred crop rotations were modeled for cereal farms and about three hundred for mixed crop-livestock farms. However, only five crop rotations represented 39% of the UAA of cereal farms and 36% of the UAA of mixed crop-livestock farms. Rapeseed → winter wheat → sunflower → winter wheat, sunflower → winter wheat and maize monoculture were the three main crop rotations modeled (excluding grasslands) (Table 1). The proportions of areas associated with each modeled crop rotation also differed between farm types. For example, the rapeseed → winter wheat → sunflower → winter wheat rotation, or rotations with other oilseed crops, were much more present on cereal farms.

In addition to this distinction between farm types, a clear spatial organization of crop rotations appeared when rotations were modeled according to soil units. For example, maize monoculture was predominant in the Courance Valley (41%), while permanent grassland accounted for more than 60% of the UAA of the Vivier Valleys for a similar type of soil. In all other soil units (calcareous stony soils of the Courance and Vivier catchments and non-calcareous deep soils of the Vivier catchment), the rapeseed → winter wheat → sunflower → winter wheat rotation predominated, with 13–17% of the UAA.

4. Discussion

4.1. Potential of LPIS data for studying agricultural landscapes

In this paper, we presented several analyses of LPIS data using the RPG Explorer tool. The ability to characterize the evolution of crop proportions, crop sequences and crop rotations using LPIS
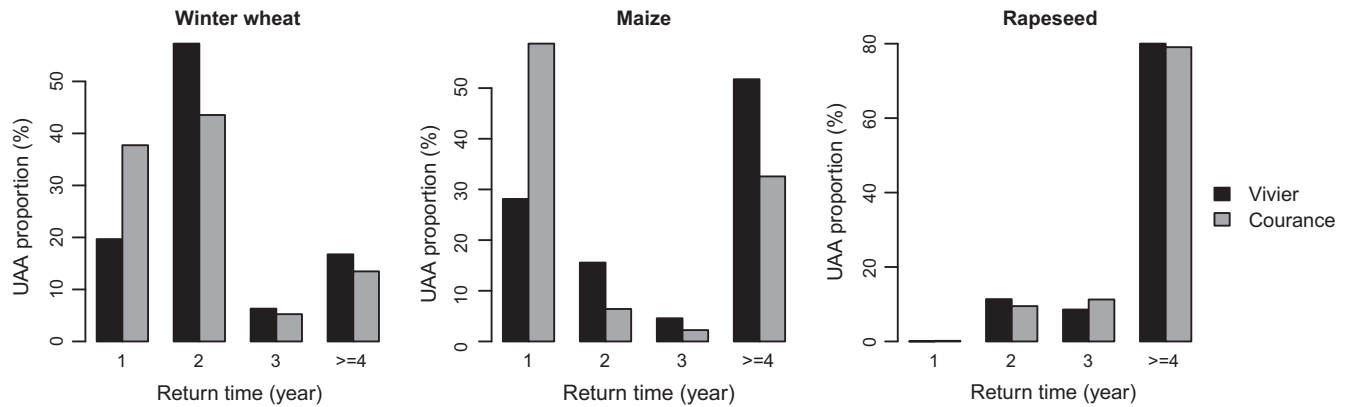
Fig. 8. UAA proportion per crop and minimal return time, computed from 8-year crop sequences extracted with RPG Explorer from LPIS 2006–2012.

Table 1
Proportion of the five main crop rotations per farm type in the two catchments, computed with RPG Explorer from LPIS 2011 to 2013. pG: permanent grasslands, tG: temporary grasslands, M: Maize, OS: other oil seeds, RS: Rapeseed, SF: Sunflower, WW: Winter wheat.

ID	Rotation	Cereals farms		Mixed crop-livestock farms	
		UAA (%)	Rank	UAA (%)	Rank
1	RS → WW → SF → WW	20.2	1	7.6	3
2	SF → WW	7.2	2	3.3	5
3	SF → WW → WW	3.9	3	1.7	8
4	M	3.9	4	3.5	4
5	RS → WW → OS → WW	3.6	5	0.5	34
6	pG	1.1	22	13.9	1
7	tG	1.4	15	7.8	2
–	Five main rotations per farm type	38.7	1–5	36.1	1–5

data was demonstrated, in line with several existing studies (Leteinturier et al., 2006; Schönhart et al., 2011; Nitsch et al., 2012). The yearly update of LPIS is also important to characterize fine temporal variations of agricultural landscapes, which cannot be detected with the common agricultural censuses that are usually carried out every ten years. Another obvious value of LPIS data is its ability to spatialize all this information at the farmer block scale, which until now was not easy to do (Leenhardt et al., 2010). LPIS data were therefore used not only to produce a more detailed land cover database than Corine Land Cover for agricultural land (Kandziora et al., 2013), but also as input data in various models, e.g., catchment-scale nitrogen models (Dunn et al., 2013). In addition to the information on crops, LPIS provides interesting information on farm characteristics and location. Here, we used this information in RPG Explorer to determine the relative weight and concern of each farm in a catchment, as suggested by Durpoix and Barataud (2014). This kind of information can be very useful for local stakeholders when they wish to identify the main farmers of their area. It could also has many other applications, as identified in the literature, e.g., in rural planning (Kerselaers et al., 2015) or in the analysis of the impacts of land fragmentation (Hiironen and Niukkanen, 2014).

These findings indicate that LPIS data could be used more extensively by scientists and local stakeholders for a broad range of applications (see also Steinmann and Dobers (2013)). From the number of citations for "Land Parcel Identification System" in Google Scholar (Fig. 9), we can see that LPIS is increasingly used by scientists, although the number of studies still remains low in comparison to the number of articles related to agriculture, landscapes or other related topics.

Despite the multiple utility of LPIS data, some limits to its frequent use do exist. First, LPIS data are not publicly accessible in all member states (Kay and Milenov, 2008), contrary to France. All uses proposed in the paper can thus be achieved by local stakeholders with a public service mission in line with privacy considerations in France, which may not be the case in other member states. Secondly, the accuracy of information (crop nomenclature, farm characteristics) varies according to member states. Moreover, the crops for which farmers do not necessarily apply for subsidies are poorly represented in LPIS (e.g., vineyards or vegetable gardening). Another drawback of the use of the LPIS database is its variation through time. Some farmer blocks and some farms can appear or disappear through time. This issue was however not frequent in our study area, with only one farm disappearance during one year (see Section 3.1). The reason of this disappearance remains unknown, perhaps some personal troubles of the farmers that year. The accuracy of the database also increase through time with slight modifications of the farmer block limits. RPG Explorer deals with this second issue by considering an area threshold to distinguish actual changes of farmer block geometry from an improvement of the accuracy of the farmer block geometry (see Section 3.1). Finally, if they are to be used by non-computer scientists, some tools to facilitate the use of LPIS are needed, which is the purpose of RPG Explorer.

4.2. Added value of the RPG Explorer tool for LPIS analysis

In our study, the value of LPIS for analyzing agricultural landscapes largely relied on the RPG Explorer tool. Although some anal-
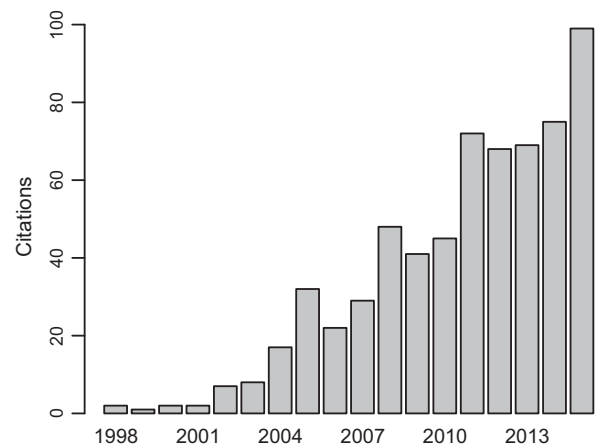

Fig. 9. Number of citations in Google Scholar for "Land Parcel Identification System" from 1998 to 2015 (results of January 2016).

yses could be undertaken rather easily with a spreadsheet software, others needed complex programming, such as crop sequence determination or crop rotation modeling (Schönhart et al., 2011). Our tool also provides an automatic way to compute basic indicators (evolution of crop proportions, farm UAA, etc.), which would be much more fastidious to compute in a spreadsheet or in a GIS software. The tool can be used from the scale of the farm to the scale of a study area of thousands of hectares, except for the crop rotation model which requires at least few hundreds of crop sequences so as to optimize a set of crop rotations.

In the context of landscape agronomy (Benoît et al., 2012), RPG Explorer can help to describe past landscape patterns (land use change and spatial configuration) (Bouty et al., 2014) linked with farming practices (crop allocation in space and time) and natural resources (soil). RPG Explorer has already been used for that purpose with the involvement of local stakeholders. Coupled with biophysical models and ancillary data, the computation of crop sequences or rotations in RPG Explorer allowed the spatialization of the risk of nitrate leaching (Levavasseur and Martin, 2016), the risk of soil erosion (Rosenfelder, 2014) or the potential of carbon storage in soils (Mata et al., 2013). Results per farm (farm UAA, farm type, crop proportions...) helped the water resource manager of the Vivier catchment to better know the farms of their catchment, which could facilitate the animation of their agri-environmental scheme. Many other applications could be suggested. For example, agricultural extension services could use RPG Explorer to adapt their advises, for example with the identification of innovative crop sequences, or on the contrary some crop sequences with a poor agronomic value (Leteinturier et al., 2006). Applications in rural planning to minimize the impact of urbanization on farms could also be suggested (Kerselaers et al., 2015).

Finally, despite the added value of RPG Explorer, the analysis of LPIS with RPG Explorer is not sufficient to capture the complexity of agricultural landscape dynamics. Some methods to couple LPIS data with data on farming practices should be considered (Mignolet et al., 2007; Leenhardt et al., 2010; Murgue et al., 2015), but the tool was not developed for this purpose.

4.3. Use in other member states and beyond

RPG Explorer was developed for analyzing French LPIS. However, there is keen interest in all EU member states in deepening the analysis of LPIS. Two options seems to exist to deal with other LPIS in RPG Explorer: either RPG Explorer should be adapted to recognize the input format of other LPIS (file name and structure, crop nomenclature), or non-French LPIS data should be transformed to look like the French LPIS format. The tool could also deal with data similar to European LPIS but from countries outside EU (e.g., the Cropland Data Layer in the USA (Sahajpal et al., 2014)), with the same adjustments than with the non French LPIS.

The tool interface would also need to be translated if it were to be used in other member states. Because it was intended for local stakeholders, its interface is in French.

4.4. Model evaluation

In this paper, a first attempt to evaluate the crop sequence determination algorithm was presented. This *evaluation* showed that the first four rules used to identify crop sequences were relatively sure (less than 10% of error). Conversely, a substantial proportion of crop sequences identified thanks to the three other rules was false. However, in our study area, the crop sequences based on rules 1–3 represented more than 90% of the UAA, because farmer blocks were rather small and a lot of them contained only one parcel. This algorithm should therefore be tested with more complex farmer blocks which should have more crop sequences

based on rules 5–7, e.g., in northern France where farmer blocks of several dozen hectares are usual and can contain many parcels. To test this algorithm in other study areas, and for various time periods, a larger evaluation dataset is needed. Crop sequences determined from sampling points of the national database Terruti Lucas could be used for example (Xiao et al., 2014).

In RPG Explorer, crop rotations were modeled so that the proportions of observed crop sequences in LPIS were maintained. However, some actual crop sequences could be associated in a non-existent crop rotation. Therefore, the crop rotation model should be validated. Farm surveys could be used to validate the modeled crop rotations and their location according to farm type (Schaller et al., 2012), as a first attempt was made in Levavasseur et al. (2015). Local agricultural experts could also be surveyed to identify the main crop rotations in various areas (Mignolet et al., 2007).

4.5. Tool distribution and further development

At the moment, the tool is free and can be sent to anyone interested in LPIS analysis (https://tice.agroparistech.fr/coursen-ligne/courses/RPGEXPLORER). The user guide can be downloaded to help in getting started with the tool. Two training sessions were also organized in 2015 with about 40 trainees from different organizations: engineering and environmental consulting firms, local government agencies, agricultural extension services, and agricultural research scientists. Moreover, the tool was used in four research programmes in connection with local stakeholders.

The research programmes and the training sessions allowed us to identify further developments which could correspond to local stakeholders' interests. Some recent work on farm territory dynamics (Bouty, 2015) may soon be added to the tool and will serve to identify the evolution of a farm, irrespective of changes of its farm identifier in successive annual LPIS data. Thanks to this new algorithm, it will be possible to produce some individual forms recapitulating the following for each farm of an area: the evolution of its crop proportions, its crop rotations, and its belonging to different catchments, etc. This was identified as an interesting feature by some local agricultural advisers. The analysis of farm territory dynamics will also allow the impact of the changes in farm territories to be considered more fully in relation to the observed changes of crop proportions and crop sequences. Finally, the ability to compute some agro-environmental indicators such as those of Leteinturier et al. (2006) directly into the tool is also under consideration.

5. Conclusions

RPG Explorer was developed to facilitate the analysis of LPIS data at the scale of a study area (from hundreds of hectares to hundreds of thousands of hectares). We used the tool to compute and to spatialize the changes in crop proportions in two catchments in northwestern France. The tool was also used to compute crop sequences that were validated with field surveys. The crop rotation model included in the tool allowed the computation of crop rotations in the study area that were coherent with agronomic expertise. Finally, we used the tool to describe farm characteristics, such as farm type, distribution of the UAA among farms, etc. The tool is expected to be used by non computer scientists and to help local stakeholders and scientists to use LPIS data more frequently. It can help users to better manage crop productions (e.g., which crops per farm and their location in the landscape), to develop agri-environmental schemes (e.g., evaluation of nitrate leaching associated to crop rotations) or to better take into account farm territories in urban planning. The tool is already freely distributed and the development is still in progress in relation to several users.

Appendix A. Rules of crop sequence determination from LPIS farmer blocks with RPG Explorer

The first rule of the algorithm tests whether a farmer block over the investigated years has only one crop group per year. If so, the crop sequence is directly determined by linking crop groups over years (Eq. (A.1)). The second rule is based on the hypothesis of stability of agricultural parcel areas in farmer blocks over time. Accordingly, the corresponding algorithm seeks to determine the crop sequences in which an equality of crop areas can be found over successive years (Eq. (A.2)). The third rule tests whether agricultural parcels inside farmer blocks have been aggregated or disaggregated from one year to another (Eq. (A.3)) (rule 3). Rules 4 and 6 are obtained using a tolerance in the equality of surface from one year to another in the hypotheses of rules 2 and 3, respectively. Rule 5 is the same as rule 3, but to run it again after rule 4 allows new crop sequences to be determined in some cases. Finally, once these six rules of crop sequence determination have been applied, a final rule determines whether the area of only one crop group

remains for each year and, if so, reconstitutes the corresponding sequence. It corresponds to rule 1, but is carried out on the remaining areas not affected to a crop sequence by the previous six rules. Some examples of each rule of sequence determination are presented in Fig. A.10, as well some cases in which sequences can not be defined (several equiprobable possibilities).

n_y is the number of crops in a given farmer block in year y
$C_{i,y}$ is the i-th crop in a given farmer block in year y
$A_{i,y}$ is the area of the i-th crop $A_{i,y}$ in a given farmer block in year y
If $n_y = n_{y+1} = 1$,
$\exists$ a unique sequence $C_{i,y} \rightarrow C_{j,y+1}$ in the block with an area $A_{i,y}$.
$$(A.1)$$

If $A_{i,y} = A_{j,y+1}$ and $A_{i,y} \neq A_{k,y+1}, \forall k \in [1, n_{y+1}]$ and $k \neq j$, $\quad$(A.2)
$\exists$ a sequence $C_{i,y} \rightarrow C_{j,y+1}$ in the block with an area $A_{i,y}$.

If $(A_{i,y} + A_{i',y}) = A_{j,y+1}$ and $(A_{i,y} + Ai',y) \neq A_{k,y+1}, \forall k \in [1, n_{y+1}]$ and $k \neq j$,
$\exists$ a sequence $C_{i,y} \rightarrow C_{j,y+1}$ in the block with an area $A_{i,y}$ and a sequence $C_{i',y} \rightarrow C_{j,y+1}$ in the block with an area $A_{i',y}$
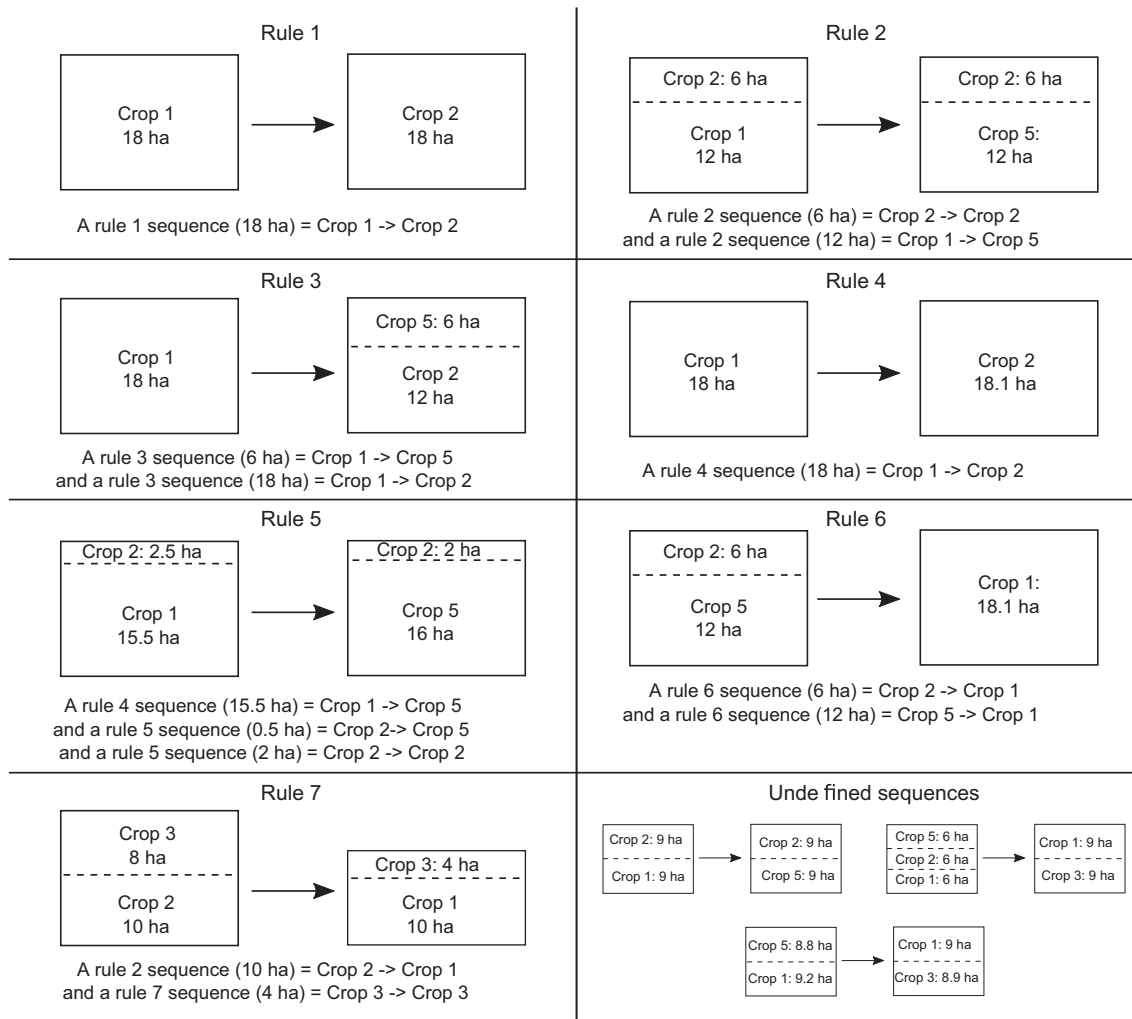$$(A.3)$$

Fig. A.10. Examples of the rules of sequence determination from LPIS farmer blocks with RPG Explorer and of undefined sequences.
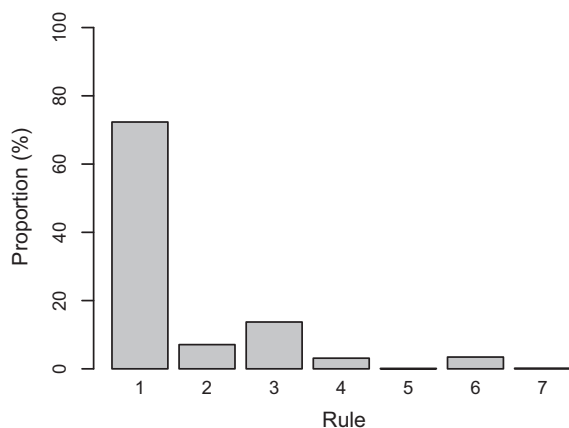
Fig. B.11. Proportion of the total area per rule of crop sequence determination (4-year sequences computed with 2006–2009 LPIS on 35,000 ha including the whole Courance catchment and a part of the Vivier catchment). For example, the sequences based on rule 1 accounted for 72% of the UAA of the evaluation dataset.
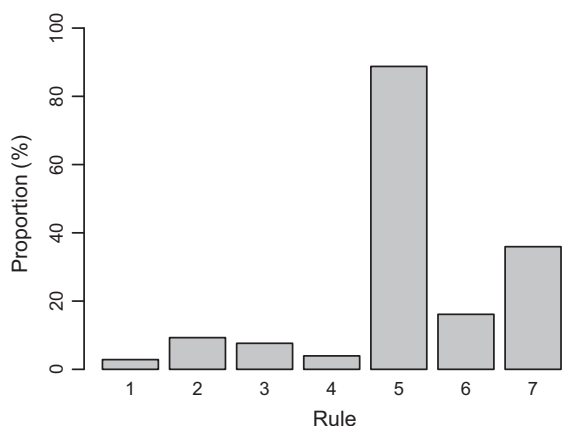

Fig. B.12. Area proportion of unvalidated sequences per rule of crop sequence determination (4-year sequences computed with 2006–2009 LPIS on the one hand, and with field surveys data on the other hand, on 35,000 ha including the whole Courance catchment and a part of the Vivier catchment). For example, the unvalidated sequences based on rule 1 accounted for 3% of the UAA of sequences based on rule 1.

Appendix B. Sequence validation results

See Figs. B.11 and B.12.

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