Spatial dynamics of agricultural practices on a basin territory: a retrospective study to implement models simulating nitrate flow. The case of the Seine basin

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Original article

Spatial dynamics of agricultural practices on a basin territory: a retrospective study to implement models simulating nitrate flow. The case of the Seine basin

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Abstract – Within an interdisciplinary research programme which has aimed at modelling the nitrate flow evolution in the whole Seine basin since the seventies, we propose a methodological process in order to reconstitute and spatialise cropping systems' dynamics, whose characteristics are used to implement the STICS agronomic model. This process makes use of both expert opinions and departmental or national agricultural statistics that are compared, step by step, in order to build the most reliable database in relation to the time and space scales considered. Data mining and statistical cartography methods are, respectively used to model the crop sequences' temporal evolution and to spatialise them over the spatial pattern of the agricultural districts. The results show an important spatial and temporal differentiation of the cropping systems, both in the cropping sequences developed and in the cultivation techniques employed. Crossing several information sources allows the identification of historical trends, but with a decreasing precision as we go back in time.

cropping system / statistical cartography / data mining / inquiry / agricultural statistics

1. INTRODUCTION

For several decades, the water of the Seine basin has deteriorated as regards its quality and its biological communities as a consequence of human domestic, industrial and agricultural activities [18]. The contamination of groundwater and surface water is largely the result of changes in agricultural practices but also of the way they are organised within the watershed. Thus in the last 30 years, the agriculture of the Seine basin has greatly changed, with farms specialising in cash crops showing, on the whole, a clear increase compared with dairy farms and mixed crop/livestock farms. This trend in agricultural production systems has led to changes in land-use patterns, marked by a continuous reduction in the grassland areas (–25% in 30 years), connected with an increasing "cereal-orientation" of the basin (a 50% increase in the wheat area during the same period). This general trend, however, appears geographically differentiated since livestock farms, associated or not with arable farming, are still in the majority on the fringe of the basin (Haute-Normandie, Ardennes, Morvan) [20, 21].

Confronted with an increase in diffuse pollution related to agricultural activity, the Seine-Normandie Water Agency has appealed to the Interdisciplinary Programme in Environmental Research on the Seine basin (PIREN-Seine) so as to have at its disposal a source of information on water quality in the basin in relation to various agricultural scenarios. This tool makes it possible to estimate the nitrate content of water at any point in the basin and to make pinpoint predictions in accordance with hypotheses concerning changes in agricultural practices.

In response to the request of the Water Agency, a multidisciplinary scientific approach was developed during the 3rd stage of PIREN-Seine in order to associate modelling of the nitrate flow in the hydrologic system with an analysis of the basin's agriculture, its dynamics and its geography. The modelling process is based on the combination of hydrological modelling of the water and matter flow in the hydrological system [12] with agronomic modelling of the nitrate flow in the water-soil-plant system. This agronomic modelling is based on the STICS model and most particularly on the module which simulates the nitrate flow at the bottom of the root zone of plants [8]. STICS was chosen principally because of its generic character, which makes it adaptable to various kinds of crops and because of its capacity to deal with the interactions between water and nitrogen.

The simulation of nitrate leaching calls for three types of information about the nature of soils, about the climate and about agricultural practices and, more precisely, the cropping systems. The latter have declined at two levels:

– the crop sequence within a field, rather than the cropping pattern, is a predictor of the risks of nitrate loss between

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Table I. Agricultural professional organisations of the experts.

	Agricultural board	Cooperative	Centre of rural economy	Technical institute	Centre of agricultural technical study	Total
Seine-et-Marne	4	5				9
Marne	3	3		2		8
Haute-Marne	2					2
Meuse	3	1				4
Vosges		1				1
Aisne	3	2			3	5
Ardennes	3	1				4
Oise	9		1			10
Aube	10	1				11
Total	37	14	1	2	3	57

successive crops [16]. The risk attached to a fallow period between crops also depends on its length, on the treatment of crop residues and on the application of cattle manure [10], but also on the proportion of spring crops and the possible existence of catch crops. Crop sequences, however, are rarely studied for themselves: only a few attempts at constructing classifications can be found [3, 13], and these are of limited value because of the extreme space-time variability since technical progress has induced farmers to free themselves more and more from agronomic constraints in favour of more speculative practices;

– the technical sequences represent an organised series of cultivation techniques applied to a crop in order to obtain a certain product. Only the cultivation techniques that are expected to have an effect on the nitrogen cycle are considered in STICS. Of these, the main ones are tillage, sowing and harvesting dates, mineral nitrogen application and organic fertilisation.

Two important consequences follow from the goals of this study. On the one hand, it is necessary to work over the whole basin, that is to say an area of about 95 000 km^2 covering 23 departments in the north of France, but also in a spatially defined manner within the basin. The creation of the tool must therefore include enquiries over a wide geographic area but with precise localisation of processes. On the other hand, owing to the time taken by water to travel to the aquifers, a retrospective attitude must be adopted and the dynamics of agriculture during the last three decades must be taken into account.

The aim of this paper is to describe the methods that were adopted to record and spatialise the development of crop sequences and cultural practices over the whole Seine basin in order to provide an agricultural database which can be used to drive the STICS model. There are three of these methods: identification of the most reliable knowledge by combining different databases that can be applied over a wide space/time range; spatialisation of all information within the basin; temporal modelling of all information since 1970.

2. MATERIALS AND METHODS

2.1. Information sources

Most agricultural statistics provide little information on crop sequences and cultural practices, and even less for the time and space scales that are our concern. For example, we have found only one national survey made by the Central Service of Inquiries and Statistical Studies on agricultural practices: it only concerned the year 1994 and its results were collected on the administrative regional scale, which is too coarse for our study. Other information on crop management can be obtained from some Department Agricultural Boards or from Rural Economy Department Services, but they only deal with the predominant crops of the department and over shorter periods than the 30 years we are concerned with.

2.1.1. Expert opinions

To compensate for incomplete statistical information on the region and time period studied, we chose to document cultivation practices by setting up a directive survey design with agricultural experts. These experts are mainly agricultural advisors with a great deal of field experience and who belong to the institutional system of Agricultural Professional Organisations (Agricultural Boards and Centres of Rural Economy) or to cooperatives (Tab. I). We assume that the agricultural advisor is a favoured observer of agricultural activity in a given area, which enables the researcher to bypass the farmer and go straight to his technical advisors [11]. Although they may deal with only a small number of farmers in a given area, often excluding the most conservative and the most innovative ones, agricultural advisors occupy a significant place in the management planning of agricultural production by distributing information meant to facilitate farm management. We asked them to act as objective observers of the reality of agriculture and to refer not to the "best farmers" or to the "not-so-good" ones, but to an average or a median.

The inquiry questionnaire was designed to collect all the data needed for implementing the STICS model. It consists, for each geographical unit investigated in the Seine basin, of dividing the 30 years surveyed into homogeneous periods of agricultural activity, and then, for each of them, of recreating the predominant crop sequences and of listing the associated cultural practices (sowing and harvesting dates, yield, mineral nitrogen application and organic fertilisation practices, tillage, catch crop practices and so on). In practice, each interview lasts half a day on average, depending on the experts' involvement and their approach to the questions asked.

This type of inquiry suffers from a number of limitations because of its indirect nature. In the first place, the choice of the people to interview, a deciding factor for the reliability of results, is limited because of the timescale adopted. Because of professional mobility in the agricultural development services, it is often necessary to meet several people in the same geographical zone in order to cover the 30 years investigated. The reconstruction of crop and technical sequences can therefore introduce biases linked to differences in the experts' subjectivity, which may be greater for the earliest periods. Consequently, it appears that few people are competent enough to inform on agricultural practices in a given zone and a given period, and that situations for which we can combine information from several experts are rare.

Secondly, agricultural practices as described by experts usually correspond to recommended methods rather than to actual farmers' practices (and we will see later that these recommended methods may also differ according to the Agricultural Professional Organisations the experts belong to). The bias created by the difference between recommended methods and actual practices is increased because of the small proportion of farmers who make use of the Development Services (10% to 25% according to figures) [9]. This bias can be selectively quantified by comparing experts' statements with other sources, such as, for example, departmental agricultural statistics, which will be presented in the following section.

The present survey covers nine departments upstream of Paris, corresponding to the Marne basin and those adjoining it (Fig. 1). In this area, we met with 57 experts, 2/3 of whom worked with Agricultural Boards. Most of them are unspecialised advisors who are used to dealing with general farm management. But we also interviewed advisors who specialised in certain subjects: environmental advisors on catch crops and advisors from the Technical Sugar Beet Institute for management of this crop (which is very localised).

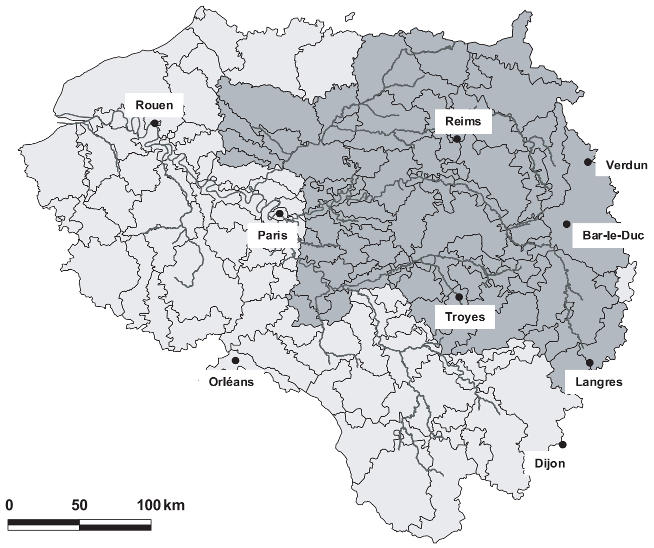


Figure 1. Inquiry zone delimitation.

2.1.2. National and departmental agricultural statistics

Although agricultural statistics appear incomplete as regards farmers' practices, we used some of them, first to improve the precision of expert opinions regarding the definition of crop sequences and then to compare certain cultural practices deduced from expert statements with results obtained from in-the-field inquiries.

Regarding crop sequences, we used two principal sources of information:

– the last four National Agricultural Censuses, taken in 1970, 1979, 1988 and 2000 provide exhaustive information about the structural characteristics of farms. The cropping plans are described and land areas quantified very precisely. The results are collected at all administrative levels (from the "commune" scale to the regional scale) and for units specifically chosen for the diffusion of agricultural statistics, small agricultural districts. The National Agricultural Census enables the land-use patterns in a given area to be described without indicating the actual crop sequences involved. However, we made use of them as blocking points to refine the quantification of crop sequences provided by experts;
– the national inquiry "Ter-Uti" has provided annual data since 1982 on land use for a constant sample (fully changed in 1991) of more than 550 000 points in France (i.e. one sampling point per 100 ha) [1]. Information has been gathered and made available on the department scale for the 1980s, and also on the small agricultural district scale since 1992. The fact that the sampling basis is constant enables one to go beyond the survey of yearly cropping plans and to look for regular patterns in land-use sequences. We have used this inquiry in order to identify and to quantify the crop sequences practised in a given area and to compare them with expert opinions over the last decade.

Regarding cultural practices, only information sources set up at the department level provide information. This is especially true of the Centres of Rural Economy, some of which make detailed inquiries every year among their members about the technical management of the main crops in the department. These inquiries aim particularly at statistically proving the effect of an agricultural practice on crop yield so as to help farmers choose the technical and economic management that will enable them to increase their margins. These inquiries are often available at the small agricultural district level so as to take into account the differences in the potential production within departments. We used the results for mineral nitrogen application and yields in one of these inquiries made by the Office of Accountancy and Rural Economy (OCERA) in the

Aube department since 1970 to compare them with expert statements, to estimate the validity of the latter.

2.2. Method of data spatialisation

2.2.1. Choice of a spatial data aggregation pattern

Relating past agricultural dynamics in the Seine basin to the increase in nitrate contents in the aquifers and rivers calls for spatialisation techniques and, consequently, the choice of a spatial aggregation pattern for the different kinds of data. The choice of this pattern must respond to three main requirements: *(i)* the sources of information in this pattern must be of good quality; *(ii)* its mapping accuracy must be sufficient as regards the area surveyed, but also to provide information for modelling nitrate flows using STICS, and *(iii)* the pattern must be significant in relation to the phenomenon that we aim at exposing (in our case, agricultural dynamics represented by changes in land use and agricultural practices). For these purposes the small agricultural district pattern seems to be the best compromise.

As regards data sources, national agricultural statistical services use this pattern unit when publishing the results of the Agricultural Census and the Ter-Uti inquiry (except that since last year the results of the latest Agricultural Census are provided at the agricultural district level only by request). For data collected from expert statements, the small agricultural district provides a good basis from which to work, since this unit is often used by agricultural professional organisations to define the areas where advisors operate.

The mapping accuracy of the small agricultural districts, numbering 147 in the basin and with an average area of 425 km^2, is fairly satisfactory in relation to the 95 000 km^2 of the Seine basin, to which is added a time-lapse of 30 years. On the one hand, it is unreasonable to expect experts to recall details of agricultural practices over a period of 30 years, so to attempt analysis at the “canton” or “commune” level would needlessly increase the number and length of inquiries since it is quite unlikely that the precision of data would be improved. On the other hand, analysis at the department level – there being 23 departments in the Seine basin – would conceal important heterogeneity.

Finally, because of the method used to determine their boundaries, small agricultural districts are a sound basis for describing agricultural dynamics. They are defined by soil and climatic conditions and by the nature of human activities, especially agricultural ones (land-use patterns, production systems, type of housing, etc.). In view of the age of agricultural districts (established in the early fifties) and the profound changes that characterised French agriculture in the second half of the 20th century, we compared them with the demarcation of homogeneous agricultural areas carried out by the agricultural services in four departments of the Seine basin (Seine-et-Marne, Marne, Meuse and Haute-Marne). In spite of a few differences in certain places, we concluded that small agricultural districts were suitable for describing agricultural dynamics from 1970 to the present day.

Regarding the three requirements that guided our choice, an additional advantage was noted for using small agricultural districts in the study of problems linking agriculture with water quality. We observed, for example, that they agreed well with the great geological areas of the Seine basin aquifers.

2.2.2. Choice of a data spatialisation method

To spatialise data on the small agricultural district pattern, we assumed that crop sequences and cultural practices were distributed at random within each agricultural district, for a period during which agricultural practices were considered by experts to be stable. According to this hypothesis, we built a database intended to bring together all the survey data. Its conceptual model is centred on the cropping sequence, defined and quantified in terms of area by a given expert for a given small agricultural district and a given time period (Fig. 2). For each crop in a crop sequence, cultural practices are detailed according to three principal sets of themes:

- general data on sowing and harvesting times, yield, ploughing in of crop residues, and percentage of area planted with a catch crop before the crop in question;
- data related to mineral nitrogen application and organic fertilisation practices (number of applications, dates and doses);
- data related to the different types of soil tillage, divided into three categories (stubble breaking, surface work and ploughing) and to how they are combined during the cropping cycle.

To simulate nitrogen fluxes below the rooting zone with the STICS model, two other surveys made on other geographical scales were used:

- soil data distributed at random over soil mapping units of the French soil map (1/100 000 scale) [14];
- meteorological data provided by “Météo France” on an 8-km grid.

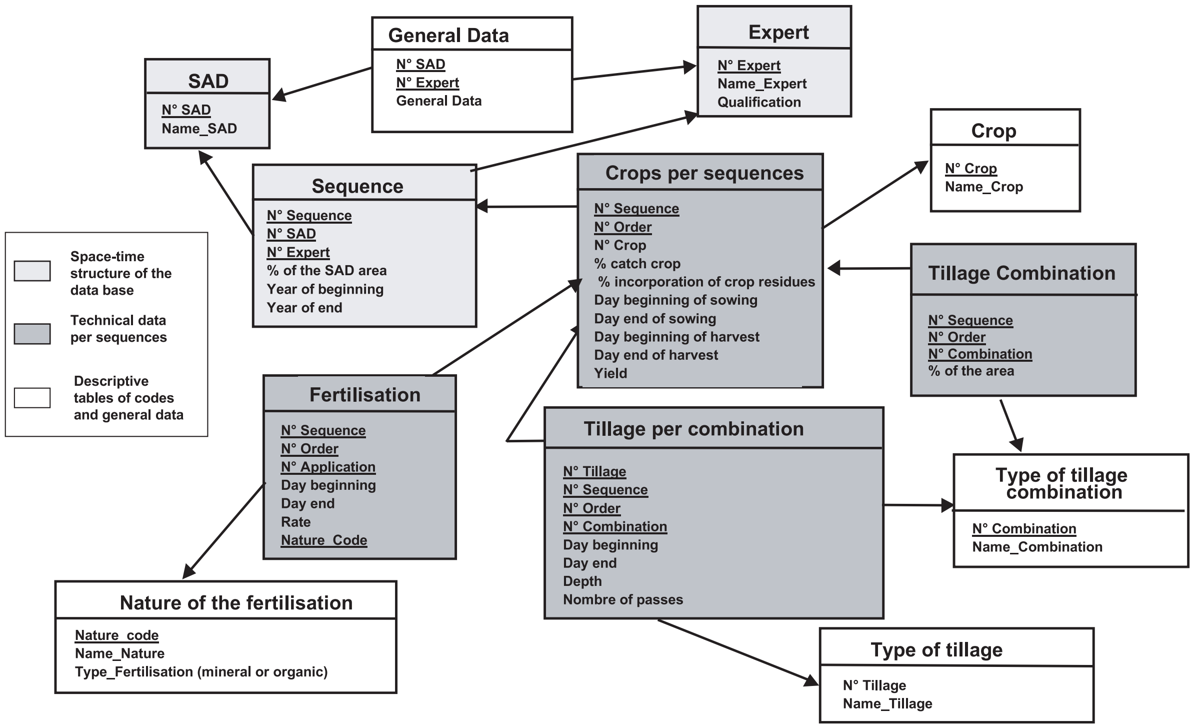
The combination of three spatial patterns resulted in the division of the Seine basin into 11 600 spatial units, which after aggregating those with similar climatic, soil and technical characteristics, yielded 7 900 general simulation units.

2.3. Modelling data over time

In addition to the choice of a method for spatialising agricultural practices, the question arose as to how to represent changes in crop sequences and cultural practices over the last 30 years. Concerning data collected from surveys, consultants were asked, for each small agricultural district, to divide the 30 years into homogeneous periods as regards the crop sequences’ nature and predominance. For each period, we assumed that crop sequences and cultural practices were stable.

To model changes in crop sequences using the Ter-Uti database, we developed, in collaboration with computer scientists, a temporal data mining method using Hidden Markov Models [5, 17]. For this modelling, we hypothesize that:

- the land use in a given region is stationary during a time step: a crop distribution associated with a given time step characterises a state of the region;
- the region’s state at a given time step depends on the states at the one or two previous time steps: a One or Second-Order HMM can be used to describe the evolution of the crop distributions (or states);



SAD = small agricultural district

Figure 2. Simplified physical model of the database "Agricultural practices".

– a field use at a given time step follows the probability density defined by the crop distribution in the considered region at the same time step.

These hypotheses do not take into account the reasons that may explain the land use which can be observed in a given region, but they allow the use of automatic recognition algorithms on databases [17]. In this way, the HMM allows two stochastic processes to be modelled, the first one controlling the second [2]:

– the first process is defined for a range of hidden states for a given observer, each state representing a crop distribution. It is a first or second order Markov chain;

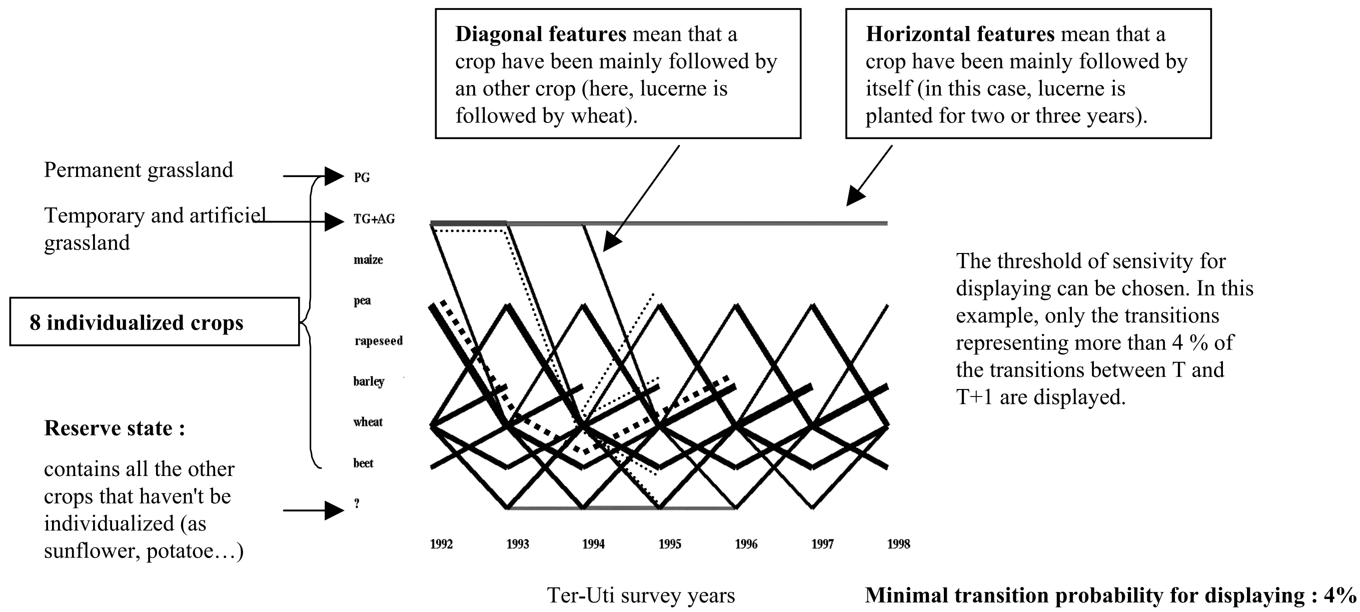
– the second process is termed visible. It provides one observation (i.e. one field use) at each time step (i.e. each year) according to the probability densities defined for each state by the hidden process. Each year, the Markov chain predicts a field use according to the authorised transitions and to the crop probability density of the examined state.

A HMM is actually defined by a group of states with which some distribution rules are associated, and by a transition matrix between states. The choice of the starting parameters (number of states, authorised transitions and distribution rules) allows one to segment differently the data and therefore gives different information. We used the HMM for two temporal classification objectives:

– the first one consists of defining periods during which the crop distribution does not change. The models used are defined by states (usually two or three) in which loop transitions are allowed. They do not allow the transition probability between crops to be measured because each crop only appears within a distribution making up a state;

– to study crop sequences, it is necessary to introduce some states that only correspond to the major crops that we want to study. Then the HMM obtained has two state types: "reserve states" normally corresponding to crop distribution, and "Dirac states" corresponding only to one crop and defined by a density for which this crop probability is equivalent to 1 and the other crop probabilities are equivalent to 0. This last type of HMM has been mainly used to identify major crop sequences of the Seine basin agricultural districts since 1992.

To visualise results from HMM, graphical user interfaces have been developed as diagrams which represent yearly transition probabilities between specified crops and a "reserve state", which contains all the other crops. Figure 3 shows such a diagram and explanatory information.



Interpretation :

In order to discover the regional main crop sequences, it can be useful to interpret a Markov diagram by reading the most thick transitions features connected between themselves. So, in the example above, the dotted line shows a 5-years sequence based on : Pea - Wheat- Beet - Wheat - Barley.

An other example beginning with 2 years of Lucerne and a year of wheat (small-doted line) shows the difficulty to determine which crop follows that wheat.

Figure 3. Interpretation of a Markov diagram.

3. RESULTS AND DISCUSSION

3.1. Changes in agricultural practices in the Seine basin since 1970

3.1.1. Crop sequences

The first part of the inquiry consists of asking the expert to define for a given small agricultural district relatively homogeneous periods, bearing in mind the nature of crop sequences and their predominance in the small agricultural district (expressed as a percentage of the area of the district). Very often, just three periods are found, separated by two of the key dates of the Common Agricultural Policy: 1981 and 1992. Identifying the main crop sequences is not easy for experts more accustomed to reasoning in terms of cropping plans, especially because there are quite a number to consider, as the choice of crops in a sequence has become, since the eighties, more speculative than agronomic. This is especially so in areas where the number of starter crops is large, as in the “Champagne crayeuse” agricultural district.

In the same way, attributing a percentage of area to each of the main crop sequences proves to be difficult. This is very important in the modelling process: the over-representation (or the under-representation) of some crops that leave large nitrogen residues might greatly influence the result of the simulation. To make the nature and the percentage of crop sequences according to expert opinions reliable, we compared them with the statistical sources of the General Agricultural Census and of the Ter-Uti inquiry using a calculation method whose principle is described for a small agricultural district of the Aube department (methodological insert).

Among the 64 small agricultural districts investigated on the river Seine upstream of Paris, large differences appeared, especially along an East-West axis, but also a number of similarities, showing that the different types of crop sequences are not distributed at random. We wanted to group together the small agricultural districts which showed similar trends in land-use patterns and crop sequences in the last 30 years. Therefore, we made three successive selections according to the trend in land-use patterns considered as discriminating, reproduced from the Agricultural Census for the 1970–1979, 1979–1988 and 1988–2000 periods. The occurrence of sugar beet was chosen as the first discriminating variable because sugar beet proves to be the crop most stable in time and the most localised (depending on the contracts with sugar refineries and on the soil properties). Three main categories of small agricultural districts were defined in which sugar beet is either not or hardly present or very important. And then we selected the most discriminating

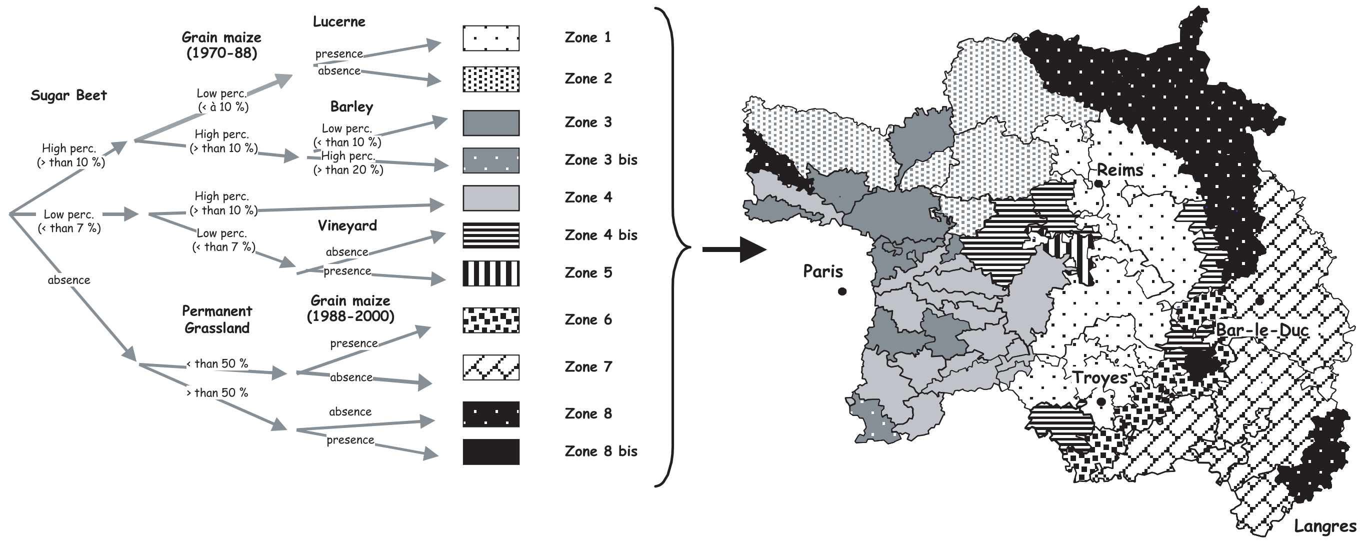


Figure 4. Inquiry zone segmentation according to trends in land-use patterns since 1970.

crop within each category of small agricultural districts to finally obtain a classification into eleven types of land-use patterns for which the trend over time was similar (Fig. 4).

The crop sequences representative of each of these eleven types of small agricultural districts are represented in Table II. This shows the sequences from expert opinions, reworked from agricultural statistics over the last three decades and the Markov diagrams obtained from the Ter-Uti inquiry over the last decade.

The regions with a large proportion of cash crops show, on the whole, a relative stability in their characteristic sequences since these are based on high-value contract crops, such as lucerne (aG) in "Champagne crayeuse" (zone 1), potatoes on the Picardy plateau (zone 2) and sugar beet in these two zones, together with the Valois-Vexin and Gâtinais regions (zones 3 and 3 bis). As sugar beet requires three or four years between crops, it is often grown in a four-year rotation with potatoes or maize, depending on the region. However, it can be observed that the field pea which appeared in the eighties has taken an important place in these crop sequences, especially in "Champagne crayeuse". In the other regions, field pea has either taken the place of maize or contributed to lengthening three-year rotations of the sugar beet – wheat – wheat or sugar beet – wheat – barley types, except in the Gâtinais (zone 3 bis) whose clay-lime soils are not quite suitable. Besides, this zone is characterised by its three-year rotations as it specialises in the production of quality spring barley and of sugar beet. Grain maize greatly declined there and in the whole sector in the eighties. Although it was strongly established in all of the Brie region and in the south of Oise during the seventies, it is now grown (together with oilseed rape) in three-year rotations only on the poorest soils of these regions.

Zone 4 includes most parts of Brie which are unsuitable for growing sugar beet, but which are, however, very favourable to protein/oil crops. These lands, reclaimed in the seventies, have seen almost all their permanent pastures replaced by grain maize, which is grown intensively one year in two or three. As soon as new, more profitable starter crops appeared during the eighties (peas, rape and sunflower), they contributed to the diversification of cropping plans. The result is a wide variety of three-year or four-year crop sequences including all the combinations of the type "starter crop/wheat/starter crop/wheat".

Zone 4 bis, which includes all the intermediate regions of Tardenois, Pays d'Othe and Champagne humide, possesses more or less the same characteristics with a clearer predominance of three-year rapeseed – wheat – barley sequences and a later disappearance of livestock farming, as shown by the presence during the seventies of forage crop sequences based on lucerne, fodder maize and oats (which disappeared later on) and of larger pasture areas.

All the following regions are characterised by an increasing proportion of permanent pastures in their useable farm area and by the presence of forage crops, which are still present. An area that could be called "maizeland" (zone 6) spreads along an arc east of the Champagne crayeuse and corresponds to the Champagne humide, Perthois and Vallage small agricultural districts. These districts were among the first to adopt intensive maize cultivation (as a monoculture) which, unlike in the regions mentioned earlier, has continued or even expanded. The rape – wheat – barley sequences typical of all the eastern Seine basin can also be found, but in smaller proportions.

The introduction of oilseed rape has totally transformed the cropping patterns in the Barrois (zone 7), characterised in the seventies by long cereal crop sequences in which barley (which at that time was commoner than wheat) predominated. Starter crops were essentially fodder crops (lucerne, temporary pastures and oats) and among these, only fodder maize remains. This reflects a significant decline in livestock farming in this zone, and its replacement by arable crops. Oilseed rape, having become the main starter crop, is managed either in the form of three-year rape – wheat – barley sequences (or even two-year

Table II. Crop sequence evolution by zone since 1970.

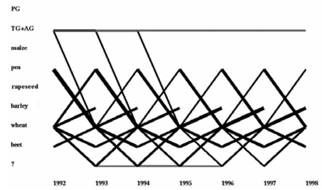
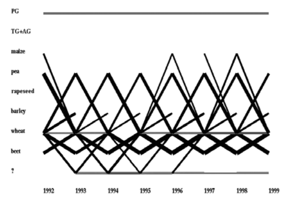
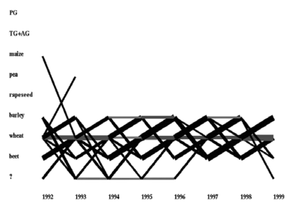
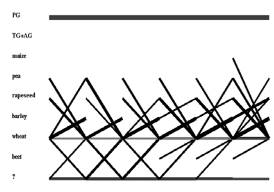
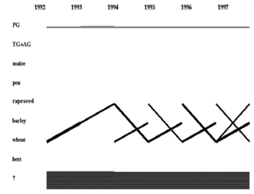
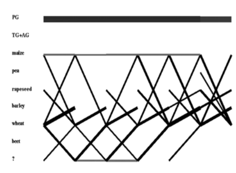
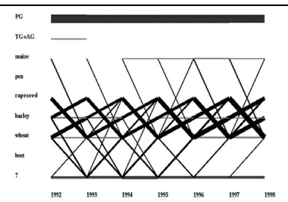
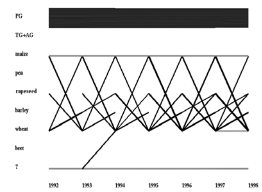
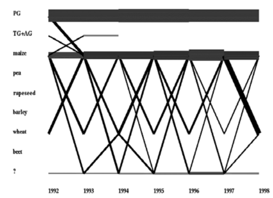
	Crop sequences from expert opinions			Crop sequences from Ter-Uti inquiry
	1970–1980 period	1980–1990 period	1990–2000 period	
Zone 1 Champagne crayeuse	aGaG(aG)-wW-Rs-wW-gM-wW-wB Bt-wW-wB Bt-wW-gM-wW	aGaG(aG)-wW-gM-wW-Rs-wW-wB Bt-wW-P-wW Bt-P-wW-sB	aGaG(aG)-wW-Rs-wW-P-wW-wB Bt-wW-P-wW-sB	
Zone 2 Picardy plateau	Bt-wW-wW (ou sB) Bt-wW-Po-wW	Bt-wW-wW (ou wB) Bt-wW-Po-wW Bt-wW-P-wW	Bt-wW-wW (ou wB) Bt-wW-Po-wW Bt-wW-P-wW	
Zone 3 Valois - Vexin	Bt-wW-gM-wW gM-wW-sB gM-wW	Bt-wW-gM-wW Bt-wW-P-wW gM-wW-wB Rs-wW-wB	Bt-wW-P-wW gM-wW-wB Rs-wW-wW	
Zone 3 bis Gâtinais	Bt-wW-sB gM-wW-sB	Bt-wW-sB gM-wW-sB	Bt-wW-sB Bt-wW-wW	
Zone 4 Brie plateau	gM-wW-sB gM-wW Bt-wW-gM-wW	gM-wW-wB gM-wW Bt-wW-P-wW Rs-wW-wB S-wW-wB	gM-wW-wB Bt-wW-P-wW Rs-wW-wB S-wW-wB Rs-wW-P-wW	
Zone 4 bis Intermediate areas	gM-wW-wB Bt-wW-gM-wW aGaG-wW-O-wW-fM-wW-sB	gM-wW Rs-wW-wB Bt-wW-P-wW P-wW-wB	Rs-wW-wB P-wW-wB Bt-wW-P-wW gM-wW	
Zone 5 Champagne wine region	Vine	Vine	Vine	
Zone 6 Maize regions	gM-wW-wB gM aGaG-wW-O-wW-fM-wW-sB	gM-wW-wB gM fM-wW-wB Rs-wW-wB	gM-wW-wB gM-fM-wW Rs-wW-wB	

Table II. Continued.

	Crop sequences from expert opinions			Crop sequences from Ter-Uti inquiry
	1970–1980 period	**1980–1990 period**	**1990–2000 period**	
Zone 7 Barrois and Langres plateau	O-wW-wB-sB aGaGaG-wW-wB-sB tG-tG-wW-sB-sB-sB fM-wW-wB	Rs-wW-wB-sB fM-wW-wB aGaGaG-wW-wB-sB tG-tG-wW-wB-sB	Rs-wW-wB Rs-wW Rs-wW-wW-wB-sB fM-wW-wB	
Zone 8 Livestock regions	O-wW-wB-sB fM-wW-wB	fM-wW-wB Rs-wW-wB	fM-wW-wB Rs-wW-wB fM-fM-wW	
Zone 8 bis Champagne humide (Haute-Marne)	fM-fM-gM-wW-wB tG-tG-O-wW-wB	gM-fM-fM-wW tG-tG-wW-wB-sB	gM-gM-fM-wW tG-tG-wW-wB	

wW = *winter wheat*, ***wB*** = *six-row barley*, ***sB*** = *spring barley*, ***RS*** = *rape seed*, ***gM*** = *grain maize*, **fM** = fodder maize, ***Bt*** = *sugar beet*, ***S*** = *sunflower*, ***P*** = *field pea*, ***Po*** = *potato*, **O** = oat, **tG** = temporary grassland, ***aG*** = *artificial grassland**, **pG** = permanent grassland.
Crops in italics are considered as cash crops (* only in Champagne crayeuse).

rape – wheat sequences) or in the form of long straw cereal sequences, typical of the Barrois region.

Finally, zones 8 and 8 bis are typical of livestock farming regions: permanent pastures represent more than half the useable farm area and the diversity of crop sequences is limited. They are principally three-year forage maize-based sequences since the disappearance of oats in the cropping pattern. Rape has also appeared as well as the tendency to grow forage maize several years in succession. Zone 8 bis, corresponding to the Champagne humide in Haute-Marne, deserves to be treated separately as it presents sequences both typical and stable in time, corresponding to a monocropping of maize (grain or forage) and to cereal crop sequences starting with temporary pastures.

3.1.2. Cultural practices

To illustrate the evolution of cultivation techniques in the last 30 years, we chose as a first example mineral nitrogen application practices which represent a major factor in nitrate leaching. We will deal here with fertilisation practices for wheat and sugar beet because these two crops are crucial for the farmers in the surveyed zone. Wheat is grown everywhere and provides the farmers' main income, because cultural practices are well controlled, and yields are stable. Sugar beet benefits from a strong involvement of the agrofood industries which are very demanding as regards crop quality. Data that are analysed in this section come from the inquiry with agricultural experts.

As for wheat cultivation, the total nitrogen application has kept increasing in line with yield potentials which have significantly increased with the introduction of fungicides (in the mid-seventies) and growth substances (which have limited the lodging caused by excessive nitrogen in the soil) (Fig. 5). Concurrently, the nitrogen applications have been split progressively so as to adjust the nitrogen supply to the plants' needs, passing from two applications in the seventies to three or even four in most regions in the nineties (the last application enables baking flour with an adequate protein content to be produced). More recently there has been a tendency to delay the first application and to reduce the dose, whilst increasing the second application. Splitting applications and adjusting the date and rate of the first application are practices that limit the risks of nitrate leaching.

Regarding sugar beet fertilisation, the total amounts applied have developed in the opposite direction (Fig. 6). Whereas average yields have kept increasing, thanks to cultivar selection and to the improvement of farmers' technical skill (from 50 t/ha and 16% sugar content in the seventies to 74 t/ha and 17% sugar today according to the Sugar Beet Technical Institute), the quantities of nitrogen fertiliser applied have steadily decreased over the last 30 years from 170 to 130 U N/ha on average. This decrease is the result of strong pressure from sugar refineries which were facing problems with the quality of sugar beet juice owing to its excessive nitrogen content.

These evolution trends of cultivation techniques may be partly explained by changes in the recommendations, which

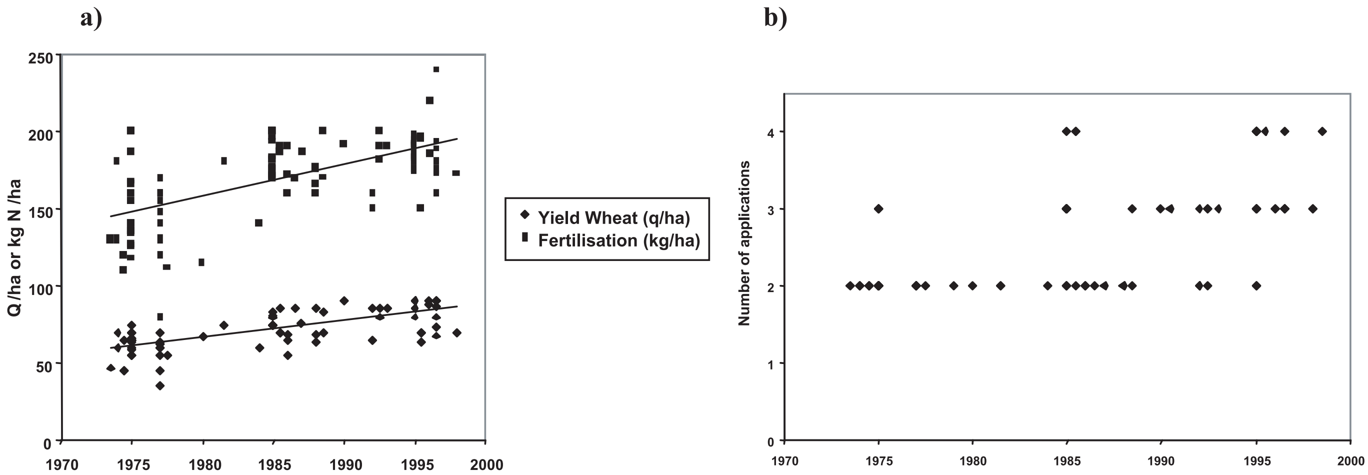


Figure 5. Evolution of mineral nitrogen fertilisation and yield, and evolution of the number of applications on wheat since 1970.

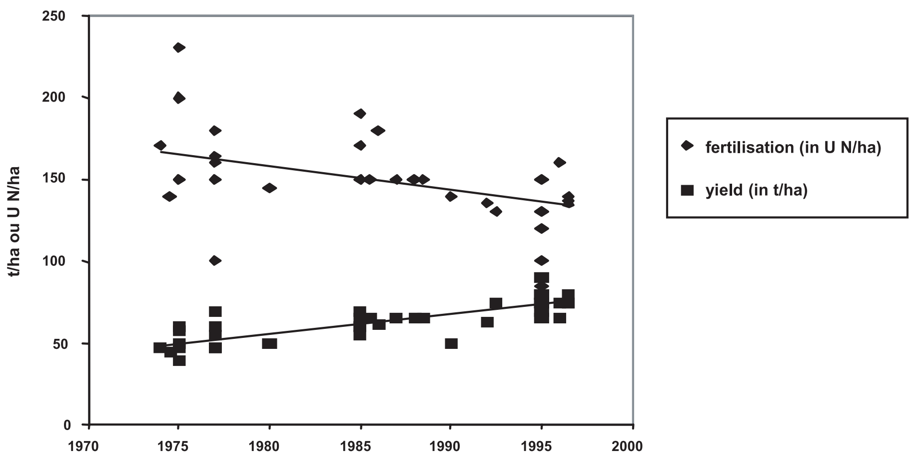


Figure 6. Evolution of mineral nitrogen fertilisation and yield on sugar beet since 1970.

may be themselves linked to research results about mineral nitrogen application methods, especially on wheat. They are not really specific to the studied area. However, maps of these trends show that, just as for the cropping plans and crop sequences, changes in fertilisation techniques are differentiated in space (Figs. 7 and 8). This may be explained by time used to develop those new methods which may have also been adjusted to local characteristics. We can identify the regions with a high wheat yield potential located in the western part of the investigated zone. They are in particular the Plateaux Picards region and the Brie region (zones 2 to 4 according to Fig. 4 typology). The Champagne crayeuse has made up for its initial lag only by increasing the amounts of fertiliser used. Regarding sugar beet, it seems that the efforts to reduce fertilisation have particularly affected the north of the sugar beet production areas (Oise, Aisne and Marne). Among them, Oise seems to be the region that has had the lowest yield increase between the two periods.

Regarding fertiliser application practices, we see that some of these which increased the risk of nitrate leaching have totally disappeared: this is the case for post-harvest nitrogen application on stubble (to accelerate its decay) in cash crop regions from 1970 to 1980 (between 20 and 50 kg N/ha was applied as ammonium nitrate or urea). Instead, new practices have developed, intended to improve management of mineral nitrogen application. From the end of the seventies onwards, the simplified N balance method of nitrogen application management has spread in the Aisne, Seine-et-Marne, and Oise departments. This method was used again in the eighties by a number of agro-industrialists concerned about problems of product quality (sugar beet, vegetables and potatoes) caused by excessive nitrate levels, and they introduced it to farmers. In the nineties, the measurement of residual nitrogen became more widespread, principally in the Oise and Aisne departments where, for example, 30% to 40% of the sugar beet fields in 1997 were subjected to spring mineral nitrogen measurement. As to future

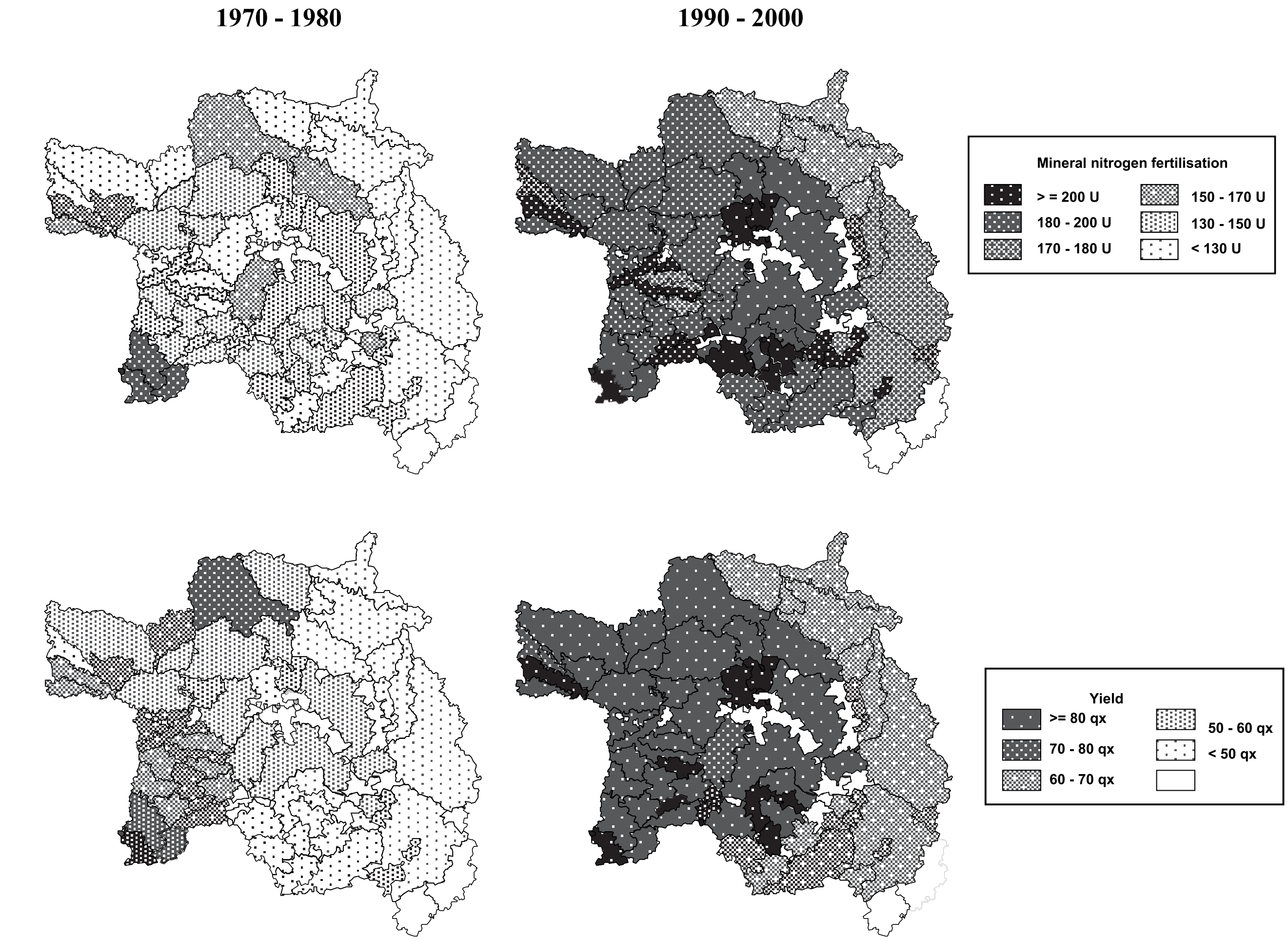


Figure 7. Mapping of total nitrogen application and yield on wheat in the seventies and the nineties.

trends, a promising technique mentioned during the investigation consists of localised variable application of nitrogen at sowing time. This technique would permit the amount applied on sugar beet to be reduced by 20 to 30%.

Growing catch crops is another practice supposed to limit the risk of nitrate leaching by reducing bare-soil periods. It turns out that in general, this practice is confined to the Champagne crayeuse and the Picardy plateaux, generally before sugar beet and, to a lesser extent, before pea or potato. Mustard is always preferred because it is easy to establish. This practice already existed in the seventies but with different aims: these crops were not considered as "nitrogen traps" but as "green manure crops" and only received a moderate application of fertiliser (about 50–60 nitrogen for mustard). It can be seen (Fig. 9) that this practice appears to be on the increase and, as such, more than for other practices, technical advisers play an important role in its promotion. The diagram should be regarded as an indication of a trend rather than a source of absolute values, because the data reflect what technical advisers observe among their own clients, and may not apply to all farmers.

3.2. Comparison of experts' statements

To assess the validity of experts' statements, we have compared results from investigations for one small agricultural district with advisors from different agricultural professional organisations. We take the example of the "Barrois" of the Meuse department, where we were able to meet two farm consultants who gave us information over the whole period from 1970 to 2000 (which was rarely possible): one of them is an agricultural advisor of the Meuse Agricultural Board, and the other is a technical advisor of the "Champagne Céréales" agricultural cooperative, which operates in several departments of northeastern France. The aim of the comparison is to assess the influence of the consultants' professional background on the information collected.

3.2.1. Crop sequences

Major crop sequences described by the two experts for each decade revealed some differences, although the cropping pattern

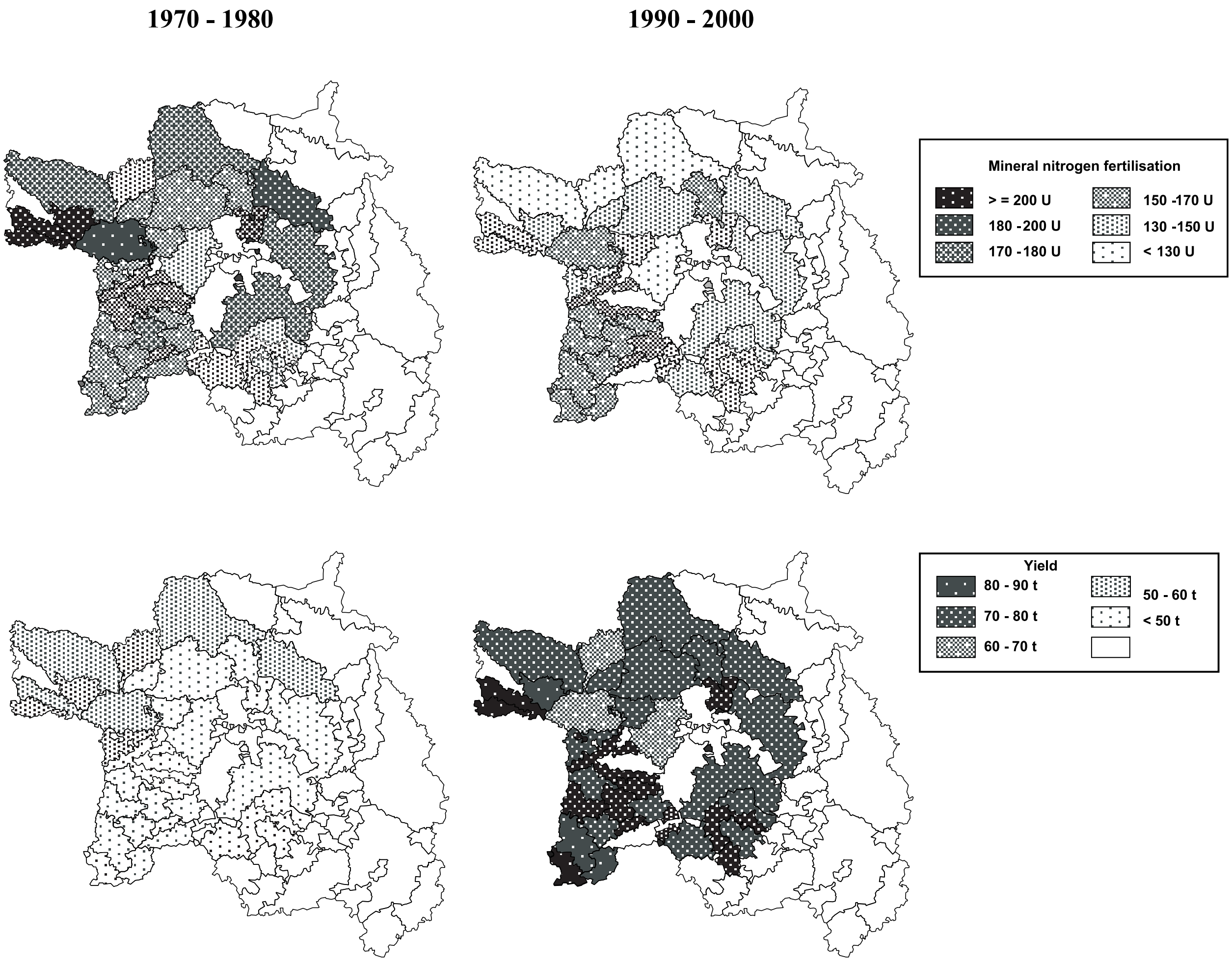


Figure 8. Mapping of total nitrogen application and yield on sugar beet in the seventies and the nineties.

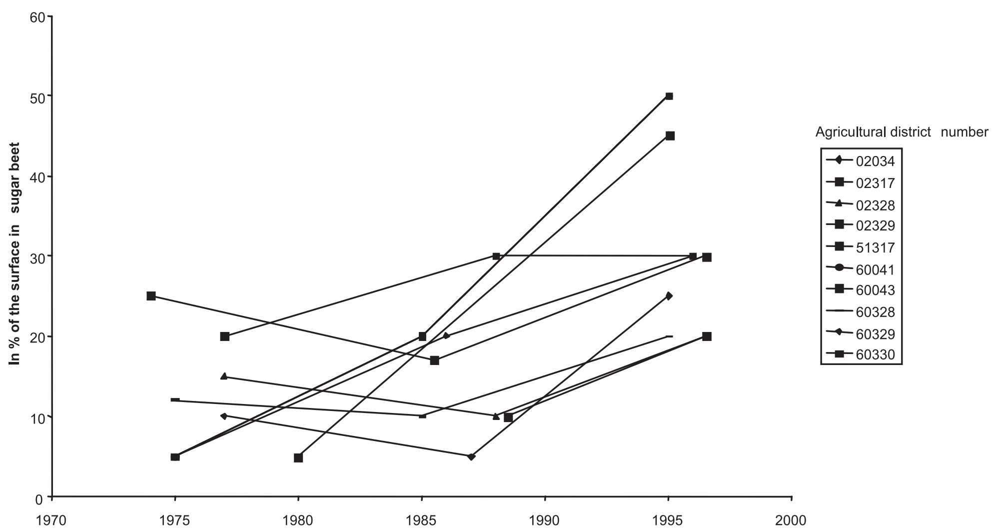


Figure 9. Evolution of catch crop growing before sugar beet from 1970 to 2000.

Table III. Comparison of crop sequences defined from expert opinions and assessed from the agricultural census for the Meuse Barrois (agricultural district 55314).

	Expert 1 (agricultural board)		Expert 2 (agricultural cooperative)		Calculation from agricultural census	
	Main crop sequences	% in the district	Main crop sequences	% in the district	Main crop sequences	% in the district
1970–1980	pG	40	pG	45	pG	38
	Oat-wW-sB	6	Rs-wW-sB-wB	20	Oat-wW-sB-wB	25
	fM-wW-sB (ou wB)	30	fM-wW-sB }		aGaGaG-wW-sB-wB	12
	spring rape seed -wW-wB	10	fM-wW-wB }	25	fM-wW-sB-wB	10
					Rs-wW-sB-wB	8
1980–1990	pG	35	pG	35	pG	34
	Rs-wW-wB	45	Rs-wW-wB	45	Rs-wW-sB-wB	28
1990–2000	pG	25	pG	30	pG	28
	Rs-wW-wB	50	Rs-wW-wB	50	Rs-wW-wB	42
	fM-wW-wB (ou sB)	25	fM-wW-wB	20	fM-wW-wB	14
					gM-wW-sB	8

was quite simple. We compared them with crop sequences estimated from the French National Agricultural Census by the method developed in the methodological insert (Tab. III).

Differences between the experts' assessments and the French Censuses' estimated crop sequences are largest for the 1970–1980 decade. The consultants seem to overestimate rape- and fodder maize-based crop sequences (which began to increase during those years) and conversely, they seem to underestimate the commoner fodder crop sequences with oats and lucerne. Although each of these two crops represented about 6% of the Barrois cropped area during this decade, only the Agricultural Board advisor mentioned the existence of the oat starter crop-based sequence. In the same way, the position of barley in crop sequences was underestimated, although more of it was grown than wheat in the whole Barrois and it was usually grown at least two years running, as shown by one of the crop sequences described by the cooperative advisor.

For the eighties and the nineties, the two farm consultants suggested similar crop sequences with relative percentages that were closer to those estimated from the National Census (if grain and fodder maize are merged).

Similarly, we found increasing agreement, both qualitative (i.e. the type of crop sequence) and quantitative (the % of the land area) between the consultants' assessments and National Census estimates of crop sequences for the most recent periods. It may be that the differences are due to the consultants' "selective" memory which might lead them to emphasise expanding crops rather than declining ones, or to a bias linked to the sample of farmers these consultants were working with during the seventies. If they were innovative farmers, the advisors may have acquired a distorted view of this period of agricultural practices. This example illustrates the need to supplement consultants' statements with other data sources, such as agricultural statistics.

3.2.2. Mineral nitrogen fertilisation techniques

As in the case of crop sequences, information given by the two experts about mineral nitrogen fertilisation practices shows better agreement for the most recent decade, both as regards the total amounts used and the number and timing of applications (Tab. IV). For the earlier periods, the total amounts of fertiliser used were somewhat larger according to the cooperative advisor than according to the one from the Agricultural Board, in particular for cereals (from 10 to 30 U more on wheat, barley and 6-row barley). But the general trends in fertilisation (for example, the increase from 1970 to 1980 and subsequent decrease in the early nineties on wheat and rape) were described by both experts.

The biggest differences were for the application dates described by the Agricultural Board advisor, which were often earlier than those given by the cooperative one, sometimes by a whole month (such as for the first application on wheat, for example). Organic manuring rates recorded by the Agricultural Board advisor were higher. He mentioned a 90 t FYM application on maize in the seventies (against 50–60 t for the cooperative advisor) and also some applications to oilseed rape since the nineties and on barley during the seventies, not mentioned by the other.

Lastly, the Agricultural Board advisor tended to mention more traditional practices such as nitrogen application to rape in autumn until 1990, higher doses for the first application on wheat and a single nitrogen application on barley in the seventies (against two applications for the cooperative advisor).

3.2.3. Consequences of the choice of the experts in the survey design

The differences found between the information given by the two experts suggest, in this case, that the Agricultural Board advisor tends to describe a more traditional agriculture, characterised by the mixed crop-livestock farms which still predominate (for example, he mentioned the manure as part of the nitrogen fertilisation), as opposed to the cooperative advisor who gives a more "modernist" view of agricultural practices in this agricultural district.

Table IV. Comparison of mineral nitrogen fertilisation techniques defined by experts on the Meuse Barrois.

		1970–1980		1980–1990		1990–2000	
		Expert agricultural board	Expert cooperative	Expert agricultural board	Expert cooperative	Expert agricultural board	Expert cooperative
Winter wheat	Total nitrogen application (in nitrogen unit)	120	150	190	200	160	190
	Number and timing of applications	2 15/03 – 30/03 20/04 – 30/04	2 10/03 – 15/03 25/03 – 5/04	2 10/02 – 20/02 1/03 – 15/03	2 1/03 – 10/03 25/03 – 5/04	3 20/02 – 1/03 10/03 – 20/03 1/04 – 10/04	3 20/02 – 1/03 10/03 – 25/03 1/05 – 10/05
Rape seed	Total nitrogen application (in nitrogen unit)	-	150	220	200	180	180
	Number and timing of applications	-	2 20/03 – 30/03 20/04 – 30/04	3 10/09 – 20/10 1/03 – 15/03 20/03 – 30/03	2 20/03 – 30/03 20/04 – 30/04	2 20/02 – 25/02 15/03 – 20/03	2 20/02 – 5/03 15/03 – 1/04
6-row barley	Total nitrogen application (in nitrogen unit)	120	140	160	170	160	160
	Number and timing of applications	2 1/03 – 15/03 1/04 – 15/04	2 5/03 – 10/03 10/04 – 15/04	2 20/02 – 1/03 20/03 – 30/03	2 5/03 – 10/03 10/04 – 15/04	2 20/02 – 28/02 10/03 – 20/03	2 25/02 – 5/03 25/03 – 5/04
Spring barley	Total nitrogen application (in nitrogen unit)	90 + 40 t (organic)	120	120 + 40 t (organic)	-	140	140
	Number and timing of applications	1 10/03 – 30/04	2 15/04 – 25/04 1/05 – 10/05	1 10/03 – 30/04	-	2 1/03 – 10/03 1/04 – 10/04	2 1/03 – 10/03 1/04 – 10/04
Fodder maize	Total nitrogen application (in nitrogen unit)	120 + 90 t (organic)	140 + 55 t (organic)	150 + 60 t (organic)	140 +50 t (organic)	150 + 50 t (organic)	140 + 50 t (organic)
	Number and timing of applications	1 20/04 – 15/05	1 20/04 – 15/05	1 15/04 – 10/05	1 20/04 – 15/05	1 10/04 – 25/04	1 20/04 – 15/05

Three main reasons can explain these differences:

– advisors may work with a different agricultural public. The "Champagne Céréales" cooperative members tend to represent the "big" cereal growers of the region, whereas the Agricultural Board is more concerned with mixed crop-livestock farmers, whose specialisation towards cash crops has not begun or is just beginning;

– they may have received different training: "Champagne Céréales" advisors may have been taught about the early experiments in the Champagne crayeuse of the Marne department. For example, in the late seventies, INRA did research on technical sequences on winter wheat in the "Champagne crayeuse" small agricultural district [7, 19]. These studies may have been more rapidly known by the "Champagne Céréales" advisors, as the cooperative used to working in the Marne and Meuse departments, than by the advisors from the Meuse Agricultural Board;

– they may vary in their subjectivity: possibly the Agricultural Board advisor described practices he was used to noticing on the farms he visited, while the cooperative one was more inclined to describe his recommendations (which are certainly driven by raising the quantity of sold products).

This example is probably not sufficient to draw conclusions about the influence of an expert's professional background on the quality of the information collected. However, we can say that for the last two decades, there has been much convergence in the advice given to – and certainly applied by farmers – from the different Agricultural Professional Organisations. So the expert's professional background induces less variability for the last decade. This may be partly explained by environmental concern emergence which has led to voluntary operations (such as the operations called "Fertimieux" in which voluntary farmers commit themselves to using better fertilisation practices), to incitement measures (such as agri-environmental ones based

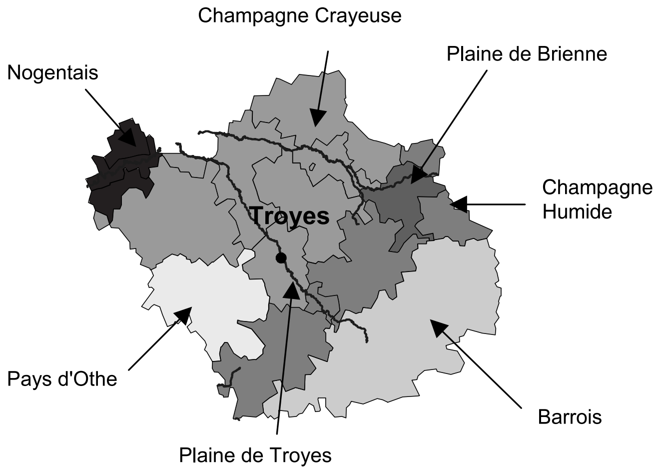


Figure 10. The eight agricultural districts of the Aube department.

on fertiliser reducing) and to regulation (such as the European Nitrate Directive). These operations induced quite a homogenisation of the fertilisation practice recommendations, which have been more and more based on decision support tools [4, 15, 22].

On the other hand, for earlier periods, and especially for the seventies, it seems that Agricultural Board advisors, because of their concern with development, may be more able to take an overall view of an area's agriculture, while cooperative advisors may be more limited in their task by the commercial nature of their employer (this is shown in particular by their tendency to recommend higher rates of nitrogen).

In order to keep some homogeneity among inquiries, it might be better to survey advisors from the same Professional Organisation and to make them clearly specify whether they are describing advised or observed practices. These two conditions would not remove all bias but these ones would be the same for all inquiries.

3.3. Comparison between the expert's statements and data from direct investigations on farms

We have shown that identifying crop sequences and percentage in each agricultural district is reliable only if expert opinions and agricultural statistics are compared. Concerning cultivation techniques, we developed a similar process in order to assess, from different information sources, the reliability of sequences as described by experts. We are taking here the example of the Aube department, by comparing expert opinions and results from farm investigations made by the Office of Accountancy and Rural Economy (called OCERA) on eight small agricultural districts (Fig. 10).

The OCERA investigation was concerned with the major cash crops of the department: wheat, barley, 6-row barley, maize, pea, rape and sunflower. They concern about 10% of Aube farmers, whose representativeness is difficult to assess. We are presenting here some comparisons on mineral nitrogen fertilisation and yield, for which complete series are available yearly for each small agricultural district in 1969 and since 1980 for all crops, and yearly since 1969 for wheat. Sugar beet yield data, for their part, result from departmental sugar industry records. To compare them with expert statements which cover the eighties and the nineties, we calculated the decade average of the annual values. For the seventies, and except for wheat and sugar beet, we calculated the arithmetical average between results of the 1969 investigation and results from that of 1980. So the OCERA sample representativeness and the way it is used may induce some bias, again difficult to assess.

Table V. Student tests on mineral nitrogen fertilisation and yields from expert opinions and from OCERA in the Aube department.

	ddl	μ	σ	t	τ_α	Prob > |t|
Mineral fertilisation	64	3.18	16.92	1.516	2	0.05
Yield	61	–2.51	7.87	–2.531	2	0.05

In order to estimate differences for each pair of values "measured" by OCERA and "estimated" by experts, corresponding to each crop during a given decade and in a given small agricultural district, we used the Student's test (Tab. V). On the one hand, concerning mineral nitrogen fertilisation below the 5% threshold, expert opinions are not significantly different from the OCERA investigation results. On the other hand, they are significantly different as regards yield.

To improve these statistical conclusions in a more qualitative way, and in particular to search for differences linked to periods or to crops, we graphed the paired observations (Fig. 11). Expert statements generally tend to rather underestimate fertilisation values and to rather overestimate yields, especially for the seventies. However, for these two variables, fertilisation and yield, the studied period seems to have a strong influence on the result: the points which present most dispersion with regard to the bisecting line are the seventies observations. They tend to gather along the bisecting line for the following decades. This illustrates the limitations of the human memory for recalling this type of information before the eighties.

In comparison with the period influence, the crop influence is much more critical to analyse. For a given crop, fertilisation and yield may be more or less well estimated according to the period and the investigated small agricultural district, that is to say, finally according to the expert.

4. CONCLUSION

The application of the STICS model to a large area of the Seine basin and to a long period in the past raises the question of the availability of data on changes in agricultural practices and their localisation. The method we have developed to reconstitute these data makes use of both expert opinions and departmental or national agricultural statistics that we compared, step by step, in order to build the most reliable database in relation to the time and space scales considered. However, the comparison of expert opinions with one another or of expert opinions with agricultural statistics has shown that differences exist which increase as we go back in time. So it seems to us that the approach chosen is adequate for identifying historical trends,

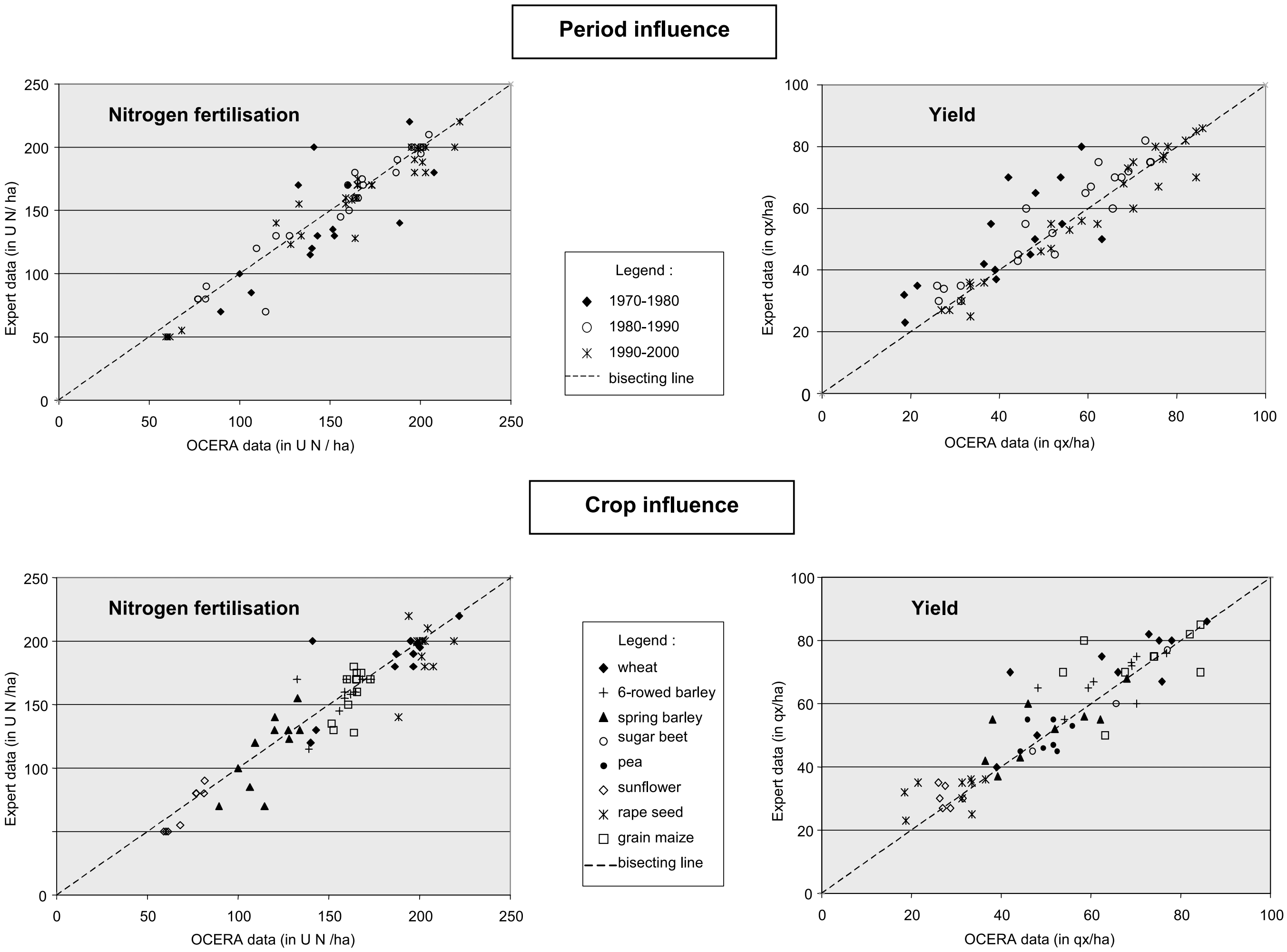


Figure 11. Comparison of OCERA and experts' values concerning yields and amounts of nitrogen application according to periods and crops.

both from one decade to another and from one small agricultural district to another, but that it is certainly not suitable for describing precisely the agricultural practices in a given year and in a given place. This is relevant to the STICS simulation results which we believe should be used to identify zones more at risk than others, but with more difficulties as regards threshold values such as drinking water standards.

The use of STICS for mapping predictions also raises the question of the possible ways of combining the different land mapping units used for climatic, soil and agricultural data. As for now, in the absence of rules for associating crop sequences with soil types, we assume that cropping systems are distributed at random within each small agricultural district, which is an oversimplified representation of reality. We need better knowledge of the relation between cropping systems and their environment so as to increase the accuracy of simulations.

More generally, the two difficulties that we have just mentioned concerning the identification of cropping systems spatialised on a regional scale lead to questions about the cropping model spatialisation. A model's output is normally spatialised by spatialising the input data. Another way would be to construct cropping system models with spatial constraints, which would include different specifications depending on the places where they would be used: for example, the oil rape – winter wheat – winter barley crop sequence is located on large fields, often far from forests and near large roads and ways. On the contrary, heifer pastures on permanent grasslands are located on small pastures, often near forests and far from buildings. Such a method of research is proposed by Thinon and Deffontaines [23] through the definition of the "Unités Agro-Physionomiques" which can be translated by "homogeneous units of agricultural landscape". In those units, cropping systems are recognised with land structure patterns. Using such units in Lorraine allowed us to recognise relationships between cropping systems and spatial characteristics of the landscape pattern [6].

Finally, we have raised the problem of the serious shortage of data on agricultural practices for areas of varying size. Thus, a knowledge of agricultural practices (with more precision than is possible from annual land-use data), of their changes and localisation within large areas, becomes a recurring question for research on the environmental impact of agriculture. Diffuse pollution of water resources, soil erosion, transgenic flows and the greenhouse effect are among the problems raised on continuous areas for which the reliability of environmental diagnosis and the efficiency of changes in agricultural practices recommended to remedy them are closely dependent on the study of past and present practices, and of the way they are organised within regions. Depending on the environmental problem considered, it is not necessarily the same practices that are the cause. It seems, however, that a good number of environmental issues require an understanding of the diversity, the evolution and the spatial organisation of crop sequences. Towards this aim, the temporal data research methods based on the HMM which are currently used in genome recognition and that we apply here in the search for patterns in land-use sequences seem to be an important step forward. They must still be improved, particularly to identify more easily long sequences that spread over three or four years. Some recent developments in computer science also enable the HMM to be used to locate spatial regularities, that is to say, areas where crop sequences and their evolution are homogeneous.

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Methodological insert : method for crop sequences calculation from experts' statements, General Agricultural Census and Ter-Uti inquiry data

Example of the agricultural district of "Pays d'Othe" (10319), 1990 - 2000 period

1 - Assessment of expert defined crop sequences reliability

The expert described the following crop sequences :

Expert's crop sequences	% in the agricultural district	% of each crop of the sequence
Rape – wheat – barley	75%	25%
Pea – wheat – barley	10%	3.5%
Sunflower – wheat – barley	5%	1.5%
Maize (monoculture)	10%	10%

We can infer the percentage of each crop in the usable farm area of the agricultural district according to the expert (example for wheat : 25 + 3,5 + 1,5 = 30%), and compare it to the average of the values of the two Census which enclose the period (1988 and 2000) and to the crop average probability calculated by HMM on Ter-Uti data from 1992 to 1998.

In %	Agricultural Census (average 1988-2000)	Ter-Uti (1992-1998) By HMM	Expert's opinion	Difference (Agricultural Census – expert's opinion)
Wheat	36%	31.4%	30%	-6%
Barley	20%	18.8%	30%	10%
Grain maize	4.5%	5.2%	10%	5.5%
Rape	13.5%	13%	25%	11.5%
Sunflower	4.5%	5.5%	1.5%	-3%
Pea	5.5%	4%	3.5%	-2%
Permanent pastures	5%	7%	0%	-5%
Set-aside	3.4%	6.3%	0%	-3.4%
Total	92%	91.2%		

2 - Correcting methods of expert's opinion

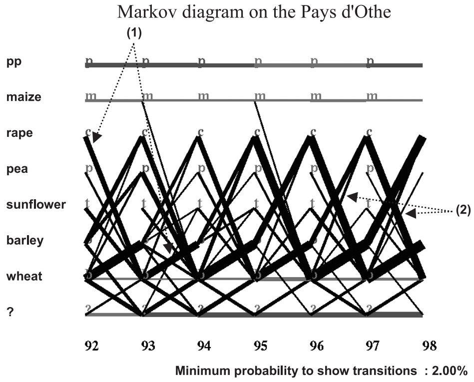
In order to correct the expert's opinion, two solutions can be considered :

- improving the percentage affected to each crop sequence by attributing to each crop of the sequence the percentage value of the starter crop according to the Agricultural Census : for example, as rape is estimated at 13,5% of the district usable area by the average between the 1988 and the 2000 Census, the rape-wheat-barley sequence would represent (13,5 x 3) = 40,5% of the agricultural district. Thus is made an adjustment which is conditional upon the percentage of starter crops, but which may distort the percentage of cereals. In the previous example, barley will have the same percentage as wheat, although Agricultural Census show a great preponderance of the latter. This lets us suppose that some other crop sequences are not mentioned by the expert.

- improving the nature of the crop sequences, even searching for new ones, when the expert's crop sequences can obviously not adjust with a satisfying way to Agricultural Census values. In the previous example, we suppose that the expert gives a too high percentage to three-year crop sequences such as starter crop-wheat-barley, although two-year or four-year sequences combining one or two starter crops and wheat may certainly exist. To find them, we are conducted to study Markov diagrams built from Ter-Uti data.

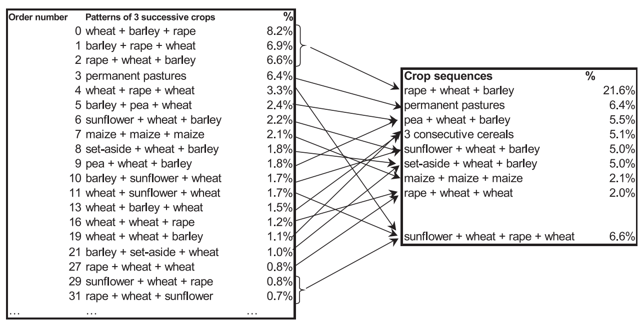
3 - Searching for crop sequences by HMM on the Ter-Uti inquiry

Markov diagram on the Pays d'Othe



The diagram clearly shows the predominance of the rape-wheat-barley sequence, but it also indicates that rape can be preceded by wheat within crop sequences of the ?-wheat-rape-wheat type. In order to find the first starter crop, which may be another rape, sunflower or pea, we use HMM to calculate transition probabilities among patterns of three successive crops.

Probabilities of patterns of three successive crops from 1992 to 1998 and building of crop sequences



The three-year crop sequences are obtained by merging patterns that combine same crops and then by calculating the total percentage. To reconstruct the four-year crop sequences, we regroup patterns combining two starter crops : as the sunflower-wheat-rape and rape-wheat-sunflower patterns are the most likely ones, we build the sunflower-wheat-rape-wheat sequence.

4 - Final adjustment of Ter-Uti crop sequences with General Agricultural Census

The three-year crop sequences and the maize monoculture described by the expert are well rediscovered. To these ones are added three-year crop sequences including set-aside or rape followed by two wheats, four-year crop sequences of sunflower-wheat-rape-wheat type, and cereal monocultures over at least three years running (as wheat-wheat-wheat, wheat-wheat-barley or wheat-barley-barley).

The percentages affected to each crop sequence can finally be refined by adjustment with the Agricultural Census with the method explained in the first step.

Final crop sequences of the Pays d'Othe from 1990 to 2000

Crop sequences	% in the agricultural district
Rape + wheat + barley	22.5%
Sunflower + wheat + barley	6.8%
Pea + wheat + barley	16.5%
Set-aside + wheat + barley	10.5%
Rape + wheat + wheat	11.3%
Sunflower + wheat + rape + wheat	9.0%
Maize in monoculture	4.5%
Wheat + wheat + barley	7.5%
Permanent pastures	5.0%
Total	94%