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Analyzing the impact of the farming context and environmental factors on cropping systems: A regional case study in Burgundy

N. Aouadi[a], J.N. Aubertot[b], J. Caneill[c], N. Munier-Jolain[a,*]

[a] *INRA, UMR 1347 Agroécologie, Dijon, France*
[b] *INRA, UMR AGIR (Agroécologies, Innovations et Ruralités), Toulouse, France*
[c] *AgroSup Dijon, UMR1347 Agroécologie, Dijon, France*

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ABSTRACT

Developing cropping systems able to improve overall sustainability requires socio-economic drivers, farm features, environmental conditions and local constraints to be taken into account. The aim of this study was to analyze the relationship between the farming context and the cropping system (CS) and to identify the components of a production situation (PS) that drive the CS characteristics. Surveys on cropping practices in 2006 in the Burgundy region were analyzed using multivariate analysis including hierarchical clustering. Thirteen groups of CS were identified and their crop sequence and level of pesticide and fertilizer use were described. A multivariate analysis was used to study the diversity in PS according to their climate, soil, and farm features. Classification and the regression tree method (CART) identified the PS variables which were most influential on CS, and defined six groups of PS that minimized intra-group CS variability. However, this variability remained high, suggesting that differences in farmer's objectives and knowledge also contributed to differentiate cropping systems in the region studied.

1. Introduction

The main objectives of agriculture in the 21st century are to produce agricultural products in sufficient quantity and suitable quality, and to provide income for the farmers while reducing harm to the environment. New issues like climate change, water scarcity, biodiversity, erosion, energy transition, market price variability, associated with new regulations, mean that farming systems must be adapted. In Europe and other parts of the world, farmers are notably firmly encouraged to reduce pesticide use by adopting the principles of integrated pest management (European Directive 2009/128/EC on sustainable use of pesticides). Agricultural stakeholders (farmers, advisers, researchers, policy makers) need to learn about cropping systems that can reconcile the different aspects of sustainability (Foley et al., 2011). We particularly need to evaluate the potential for adopting such cropping systems, taking into account the variability of agricultural situations, and to evaluate the possible consequences of such changes in agricultural practices on crop production, farmers' incomes, environmental impacts and other significant issues.

The concept of cropping system (CS) was defined by Sebillotte (1990) as "a set of management procedures applied to a given, uniformly treated area, which may be a field, part of a field or group of fields". Boiffin et al. (2001) later extended the concept to a sequence and/or a spatial combination of crops and the corresponding technical operations, not only during the crop growth periods, but also between main- crop periods, with either bare soil or a plant cover. The word 'system' is used because the technical choices are interdependent, hence providing an overall consistency to the set of management components constituting cultural practices (Meynard et al., 2003).

The FAO proposes another definition of CS which highlights the link between CS and drivers of the farming context. The CS was defined as a cropping pattern used on a farm and its interaction with farm resources, other farm enterprises, and available technologies which determine technical cropping options. The CS is a subsystem of a farming system as a given farm might implement several CS and include other activities such as livestock husbandry (FAO, 1996).

Several drivers affect farmers' choices when designing cropping systems. In a specific context of banana production in the West Indies, Blazy et al. (2009) showed that the farming context includes economic factors (e.g., labor costs, investment capacity), biophysical factors (e.g., type of the soil, topography) and social factors (e.g., age of the farmer, objectives) that might influence the technical nature and performance of the cropping system. In a different con-

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* Corresponding author. Tel.: +33 380693035; fax: +33 380693262.
E-mail address: munierj@dijon.inra.fr (N. Munier-Jolain).

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text of cereal crops in Europe, Bürger et al. (2012) found that the weather (temperature and precipitation), and the farm characteristics (farm activity, farm area, and sales) influenced the level of pesticide use, which was therefore, driven by factors other than the level of biotic stress. Olesen and Bindi (2002) highlighted the importance of environmental and socio-economic drivers shaping European agricultural practices. These drivers include farm structures and characteristics, target markets, climate and soil conditions (Rounsevell et al., 2003). For example, soil-related features such as high clay content and stoniness might be unsuitable for some cultivation techniques such as ploughing (Godwin and Spoor, 1977). Soils that used to be considered too wet, too shallow or insufficiently fertile for grain crops were in the past commonly used for pastures, but the development of drainage, irrigation and fertilizers tended to increase the range of possible agricultural options over a wider range of soil types (Bakker et al., 2013). The local market opportunities, input costs and output prices, price volatility, along with regulation and policies, are important factors taken into account by farmers when defining crop sequences and management options (Bowman and Zilberman, 2013).

Farmers make decisions according to both (i) their knowledge and personal objectives; it is usually assumed that farmers typically tend to look for optimized systems to provide the best possible income in the local context (e.g., Savary and Willocquet, 2000 Willocquet et al., 2008), and (ii) their perception of the production situation (Aubertot and Robin, 2013). The concept of production situation (PS) was defined as “the physical, chemical and biological components of a given field and its environment that are not directly managed by the farmer, as well as socio-economic drivers that affect his decisions” (Aubertot and Robin, 2013 adapted from Breman and de Wit, 1983). The ‘environment’ of the field is here considered as the local weather and the surrounding landscape that can directly or indirectly influence cultural practices and crop growth and yield in the considered field. In the area of crop protection, the interactions between PS and CS affect, for example, the dynamics of pest populations, the combinations of injuries on crops and hence crop damage (Aubertot and Robin, 2013).

To summarize the framework of this study focusing on arable crops (Fig. 1), any CS (i.e., a crop sequence and a set of management techniques for each crop) is defined by the farmer’s decision according to his own objectives, his knowledge and his perception of the PS, with both bio- physical and socio-economic components. The performances of the system for the different aspects of sustainability depend upon the proper matching between the technical options and the farming context.

However, the relative weight of the two main drivers shaping CS (constraints and opportunities of the production situation vs. farmer’s specificities and preferences) remains poorly documented. Assisting farmers and supporting the change toward more sustainable cropping systems requires that the range of constraints affecting their decisions is better understood in order to assess the potential for the development of new systems (Cardona et al., 2012). The objective of the present study was to investigate the relationship between PS and CS at the regional scale, so as to document the relative weights of the two types of drivers shaping CS in the particular studied region (Burgundy, France), and thus to identify pathways to drive farming systems toward more sustainable ones.

2. Materials and methods

2.1. The Burgundy region

The Burgundy region is one of the 27 French administrative regions, located in the center-east of the country. The agricultural area is 1.7 million hectares, managed by a decreasing number of ca. 20.000 farmers (statistics of the French Ministry of agriculture). The agriculture in the region is rather diversified, with about 35% of the area dedicated to grain crops, mainly soft wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), oilseed rape (*Brassica napus*) and maize (*Zea mays*), 30% used for beef livestock, and 20% for mixed crop-livestock farming. The remaining 15% are used for a range of agricultural crops, including vineyards that are mostly concentrated on a thin North–South strip separating uplands and lowlands in the south of the region. The climate is semi-continental, with rather cold winters (average temperature in January ranging from 0 to 3 °C), and rather warm summers (average temperature in July ranging from 17 to 20.5 °C). Temperatures are colder in the uplands of the center and the south-western parts of region, and warmer in the lowlands of the south-eastern areas. The average rainfall ranges from 650 to 1000 mm, are also correlated with the altitude, which mostly ranges from 160 to 600 m for agricultural areas. Farms producing arable crops only are mainly located in the northern and eastern parts of the region, either in uplands with shallow clay–limestone soils and low water storage capacity (WSC, often below 50 mm) or in lowlands of the northern and eastern part of the region, where soils are deeper, with mainly clay–loam or loamy textures, and WSC higher than 100 mm. Beef cattle is located in uplands of the south-western part of the region, associated with permanent grasslands, while mixed farming can be found in most districts but only with a low proportion of farms. Association of arable crops with chicken farming is typical of the small ‘Bresse’ district in the south of the region, where soils are either clayey or sandy.

2.2. Data on cropping systems: crop sequences and associated crop management

Surveys of cropping practices in the Burgundy region were carried out in 2006 by the Department of Statistics and Forecasting of the French Ministry of Agriculture. The surveys were focused on arable crops, and therefore, did not consider fields either with permanent pastures or vineyards. The data describe crop sequences over a 6-year period (2001–2006) and crop management from the harvesting of the previous crop to the harvesting of the main crop in year 2006 for 795 field plots from 709 different farms. Crops harvested in 2006 were winter wheat, winter and spring barley, maize and oilseed rape. The variables chosen to describe both cropping systems and production situations were selected according to (i) their relevance, (ii) their availability, (iii) the number of missing data, and (iv) the data variability throughout the dataset. Nine variables were used to describe crop management plans (Table 1), namely the sowing date, the tillage type (mouldboard ploughing vs. shallow cultivations only), use of mechanical weeding, amount of nitrogen (N) fertilization, and amount of pesticides used (herbicide, fungicide, insecticide and others) expressed by the treatment frequency index (TFI) which gives the number of treatments equivalent to full rates and full field application (see for example Gravesen, 2003). The nature of the previous crop was considered as a factor potentially explaining differences in crop management sequences.

2.3. Data on production situations: soil, farm structure, climate, pests

The IGCS database (*Inventaire, Gestion et Conservation des Sols*; Inventory, Management and Soil Conservation) was used to provide information on soil characteristics, i.e., soil depth, soil texture, limestone content, abundance of coarse fragments, and average water storage capacity (WSC). Each field was associated to soil properties of the most represented soil type in the most repre-

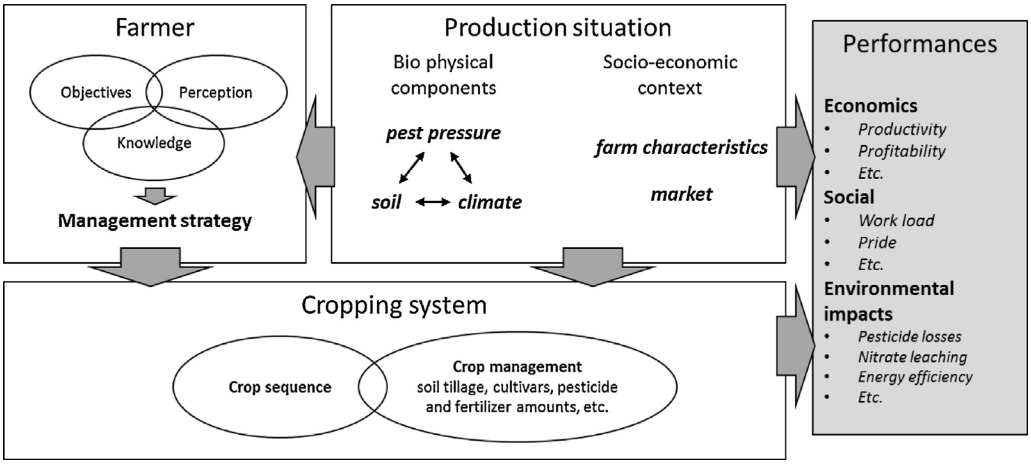

Fig. 1. Connections between the farmer, the components of the production situation and the cropping system. The farmer uses his own knowledge to design the cropping system according to his perception of the production situation, the performance of the technical options, and the farming context.

sented soil map unit in the corresponding village district. Records from weather stations in Burgundy over 23 years (1987–2010) were used to describe the climate: rainfall data (annual, spring, summer, autumn, winter) were obtained from a network of 186 stations; average, minimum and maximum temperatures (annual, spring, summer, autumn, winter) were obtained from a network of 85 stations (Moisselin et al., 2002). At each site, the data from the closest available weather station were used.

The Department of Statistics and Forecasting of the French Ministry of Agriculture also provided information about field size, farm size, and the nature of livestock production on the farm (beef or dairy cattle, poultry, pigs etc.), when relevant.

We attempted to compute a pest pressure level for each surveyed field from monthly agricultural warning bulletins (French Ministry of Agriculture) that provided information on local variation in pest pressure for 2006 (i.e., the year of crop management data). The main warnings issued during the growing season in the different agricultural areas were identified for each crop and synthesized on a four-level scale: absence of warning; low, medium and high level of risk. The main pests considered in this risk assessment were those with potential large scale dissemination, namely *Septoria tritici* blotch for wheat, corn borer (*Ostrinia nubilalis*) for maize, and pollen beetle (*Meligethes aeneus*), brassica pod midge (*Dasineura brassicae*), and winter stem weevil (*Ceutorhynchus pictarsis*) for oilseed rape. Unfortunately, the spatial distribution of pest pressure for a given crop was highly correlated with the spatial distribution of this crop, indicating very little variation in pest pressure for a given crop throughout the region during this particular year, and no information available in areas where the crop is not grown. In the end, this 'pest pressure' indicator conveyed too little information, and was removed from the analysis.

30 variables, either quantitative or qualitative, were available to describe PS. Correlations between all those variables were studied ('Cor' function of the R software) and redundant variables were removed. For example, average temperatures during spring, summer, autumn and winter were highly correlated (R^2 coefficient ranging 0.68–0.94), so that the average yearly temperature only was used as the descriptor of the average temperatures. The rainfalls across seasons were also highly correlated (R^2 coefficient ranging 0.73–0.80), and (not surprisingly) soil depth and soil WSC were partly redundant (R^2 coefficient = 0.58). Finally, after removing redundant variables, each PS was characterized by nine variables (Table 1) describing the weather (minimum winter temperature, annual rain), the soil (texture, WSC, limestone content) and the farm characteristics (farm size, field size, type of livestock, if any).

2.4. Data analysis

2.4.1. Typology of cropping systems

Maton et al. (2005) identified two main families of methods to create typologies: (i) the "positivist methods" are based on

Table 1
Variables describing crop management and production situations.

Crop management		Production situation	
Describing variables	Range	Describing variables	Range
Winter wheat sowing date	15 Sept.–30 Nov.	Annual rainfall	646–1084 mm
Winter barley sowing date	15 Sept.–15 Dec.	Mean annual temperature	9.6–12.3 °C
Spring barley sowing date	15 Feb.–30 Apr.	Min winter temperature	−0.6–3.3 °C
Oilseed rape sowing date	01 Aug.–30 Sept.	Soil texture	Sand/sandy loam/clay loam/clay
Maize sowing date	01 Apr.–30 Jun		
Tillage	Ploughing vs. shallow cultivation	Limestone content (effervescence level)	Qualitative note [0–4]
Mechanical weeding	Yes vs. No	Water storage capacity (WSC)	12–194 mm
Treatment frequency index			
TFI-herbicide	0–4.6	Field size	0.2–63 ha
TFI-fungicide	0–3.2	Farm size	2.1–67 ha
TFI-insecticide	0–8.2	Farm type	Arable crops only/beef cattle/dairy cattle/mixed farming
TFI-others	0–0.6		
Amount of N fertilization (mineral and organic N)	0–465 kg ha^{-1}		
Previous crop			

statistical analyzes of data sets without any prior knowledge (Mignolet et al., 2007; Köbrich et al., 2003) whereas in (ii) the "constructivist methods", types are defined from assumptions based on expert knowledge and then validated by surveys (Perrot and Landais, 1993; Landais, 1998; Girard et al., 2001). Multivariate analyzes, including principal component analysis (PCA) and multiple component analysis (MCA), usually associated with hierarchical cluster analysis (HC), are the most frequently used 'positivist' methods (Bürger et al., 2012; Mignolet et al., 2007). In this study, a typology of CS was created to organize the complex information available about the diverse crop sequences and crop management. We defined groups of crop management systems for winter wheat, winter and spring barley, oilseed rape and maize using multiple correspondence analysis (MCA) and ascendant hierarchical classification (AHC, Ward's method; Ward, 1963). For each crop, the classification defined three groups of management systems, roughly corresponding to three input levels (see Section 3). The number of clusters was chosen based on the analysis of the inertia gains. The ward method suggested a cutting level defining three clusters corresponding to the highest inertia gain (Ward, 1963).

Six-year crop sequence patterns were explored using the datamining software 'Teruti-Miner' (Le Ber et al., 2006). This software is based on simple counting of each two-year or three-year sequence pattern in each six-year sequence. It was useful to identify and sort the most frequent crop sequence patterns in the data set (mainly oilseed rape/winter wheat/winter barley and maize monoculture). The other more diversified crop sequences (all of them including winter cereals) were classified according to the presence of diversifying crops, namely (i) temporary pasture, (ii) maize, (iii) peas, and (iv) sunflower. The remaining sequences (less than 5%, usually including sugar beet and/or legume crops other than peas) were classified as 'complex crop sequences'.

A CS type was defined as a combination of a crop sequence type with a crop management type (i.e., input level). As only one year (2006) was actually described for crop management, the combination of crop sequence types with crop management types was based on the hypothesis that the input levels for a given cropping system would be the same for successive years throughout the crop sequence. We chose not to distinguish different input levels for crop sequences that were less frequent (e.g., maize monoculture and pasture-based systems).

2.4.2. Describing the diversity of production situations

A 'Hill and Smith' analysis (Hill and Smith, 1976) was carried out using the nine variables describing PS. This method is usually used for multivariate analysis when the studied population is described with mixed quantitative variables and qualitative factors. It made it possible to describe the structure of the PS variables across the 795 field plots.

2.4.3. Relationship between production situations and cropping systems

A classification and regression tree (CART) method was used to identify the components of the production situations which determine CS. The CART method aims at building a tree-based regression or classification model, by recursively partitioning the data into groups so as to minimize variability within a group, while maximizing variability between groups (Breiman et al., 1984). The CART method produced a partitioning of PS that best discriminated the cropping systems.

All multivariate analyzes were performed with the R 'FactoMineR' and "Ade4" packages. The R 'rpart' package (method = 'class') was used for classification trees.

2.5. Expert knowledge

Results were compared to the local expert knowledge of four farm advisers and one farmer representing five different districts covering the diversity of agriculture in Burgundy. All of them are involved in the extension of integrated pest management-based cropping systems, and are therefore, familiar with the concept of cropping system and with the diversity in agricultural practices in the area. They were asked to react and provide their expert validation of (i) the typology of PS that we obtained from the statistical analysis, (ii) the geographical distribution of each PS type (data not shown), and (iii) of the diversity of cropping systems most frequently observed within each PS type.

3. Results

3.1. Typology of cropping systems (crop sequences and management plans)

Winter cereals were the most cultivated crops over the 2001–2006 period in the surveyed fields (47%, see Table 2). The analysis of triplets of successive crops (see the crop codes in Table 2 and Table 3) among the 795 crop sequences showed that the triplets OR–WW–WB; WB–OR–WW and WW–WB–OR were the most frequent (16%). Crop sequences with the exact OR/WW/WB pattern (OR–WW–WB–OR–WW–WB) and crop sequences with approximate OR/WW/WB pattern (e.g., OR–WW–WB–OR–WW–WW or sequences where either WW or WB was replaced by another winter cereal, e.g., oats, triticale) formed the first dominant group in Burgundy (Group 1, 51.4%, see Table 3).

Crop sequences involving maize included maize grown in sequences with winter cereals and maize monoculture. 20.4% of surveyed fields were associated with crop sequences based on both maize and winter cereals, but this group included patterns dominated by winter cereals (e.g., WW–WW–M–WW–WB–M), patterns dominated by maize (e.g., M–M–WW–M–M–M) and other crop sequences where maize and cereals had similar frequencies (e.g., WW–M–WW–M–O–M). Maize monoculture was less frequent (2.6%; Group 5, Table 3).

Crop sequences including pastures represented 11.5% of the dataset (Table 2). Temporary pasture was associated with maize and/or winter cereals and/or oilseed rape (Group 4, Table 3).

The other main diversifying crops were sunflower and pea, which together represented 3.2% of the crops grown in the surveyed fields during the considered period. These crops were mostly associated with oilseed rape and winter cereals, and the corresponding crop sequences represented 15.7% of the dataset (Group 3, Table 3).

The other types of crop sequences were less frequent. These included sequences with sugar beet (Group 6, Table 3) and diversified crop sequences (Group 7, Table 3) involving legume crops other than pea (e.g., faba bean, lens) or patterns involving at least three starter crops not classified in the other groups (e.g., crop sequences with oilseed rape, maize and sunflower).

Table 2
Frequency of cultivated species in the surveyed fields over the period of 2001–2006.

Species	%
Winter wheat (WW)	28.3
Winter barley (WB)	18.4
Oilseed rape (OR)	17.4
Temporary pasture (TP)	11.4
Maize (M)	10.1
Sunflower (S)	2.4
Other pasture (OP)	0.9
Pea (P)	0.8
Others	10.2

Table 3
Distribution of crop sequences types in Burgundy.

Group	Crop sequence types	Examples	Frequency
1	Oilseed rape/winter wheat/winter barley; winter cereals	OR–WW–WB–OR–WW–WB; WB–OR–WW–WW–WB–OR; O–WW–WB–O–WW–WB	51.4%
2	Crop sequences based on maize and winter cereals	WW–WW–M–WW–WB–M; M–M–WW–M–M–M; WW–M–WW–M–O–M	20.4%
3	Oilseed rape/winter cereals/sunflower or peas	WW–OR–WW–S–WW–OR; OR–WW–WB–P–WW–WB	15.7%
4	Pasture associated with maize, winter cereals and oilseed rape	TP–TP–TP–M–M–WW; TP–TP–TP–TP–M–M; TP–TP–TP–WB–WB–OR	5.4%
5	Maize monoculture	M–M–M–M–M–M	2.6%
6	Crop sequences with sugar beet	WW–Sb–WW–Sb–WW–Sb	2.5%
7	Diversified crop sequences	WW–WB–WB–F–WW–WB; S–WW–OR–WW–M–WB	1.9%

WW (winter wheat); WB (winter barley); S (sunflower); TP (temporary pasture); OR (oilseed rape); M (maize); Sb (sugar beet); O (oat), F (faba bean); P (peas).

Multivariate analysis (MCA and HCA) carried out for wheat, barley, oilseed rape and maize separately revealed three types of crop management. E.g., for winter wheat (225 fields), the two first dimensions of the MCA performed on the six variables describing winter wheat management plans, summarized 25.5% of the total inertia (Fig. 2A). On one side, the low amount of nitrogen input was associated with late sowings, limited use of herbicides (low TFI-H), and ploughing before wheat seeding. On the other side, a large amount of nitrogen fertilization was associated with normal sowing dates, high levels of fungicides (high TFI-F) and other pesticides such as molluscicides (high TFI-others), and to a lesser extent with high herbicide inputs (high TFI-H). This distribution of management variables, therefore, supported the hypothesis of crop management consistency, stating that the different components of the crop management plan are defined so as to get an overall coherence of the system. The clustering analysis (Fig 2B) performed on the MCA allowed the differentiation of three groups of crop management systems according to 3 levels of pesticide (Fig. 3) and fertilizer use: (i) high level of pesticide and fertilizer use without ploughing; (ii) low inputs with ploughing and (iii) a medium level of inputs. Similar results were obtained for winter and spring barley, maize and oilseed rape (data not shown). In maize, the cluster corresponding to low input management included the few fields managed with mechanical weeding.

Combining crop sequence types with crop management clusters resulted in 21 CS groups. For the most represented crop sequences, each crop sequence corresponded to three types of CS, with low, medium and high input levels, respectively.

3.2. Diversity of Production Situations

The first two axes of the Hill & Smith analysis explained 27% of the variance (Fig 4). Variables describing the soil (WSC, limestone content, texture) as well as the average annual temperature and the type of livestock (none/beef cattle/dairy farming/mixed farming) significantly contributed to the first two axes. The absence of limestone in the soil was associated with sandy and loamy textures, and high clay content, often correlated with shallow soils in the area, was clearly associated with low WSC and low average temperature. Farms producing arable crops only and mixed farms (arable crops and livestock) were associated predominantly with large farm size, large field size, and clayey soils.

3.3. Analysing the relationship between cropping systems and production situations: classification and regression trees

The classification and regression trees aimed to explain the frequency of the various CS types by the variables describing the PS, and therefore, to identify the components of PS that drive the main features of CS (Fig. 5).

The first node of the tree segregated CS that were not associated with livestock from CS in farms with either beef cattle or dairy production. The first group was then split according to the average annual temperature. CS based on maize monoculture and diversified CS including legume crops were more frequent in areas with high temperature (Annual temperature ≥12 °C) (PS-group #4). The third PS variable that determined CS features was the soil water storage capacity (WSC). High WSC (WSC ≥144 mm) was frequently

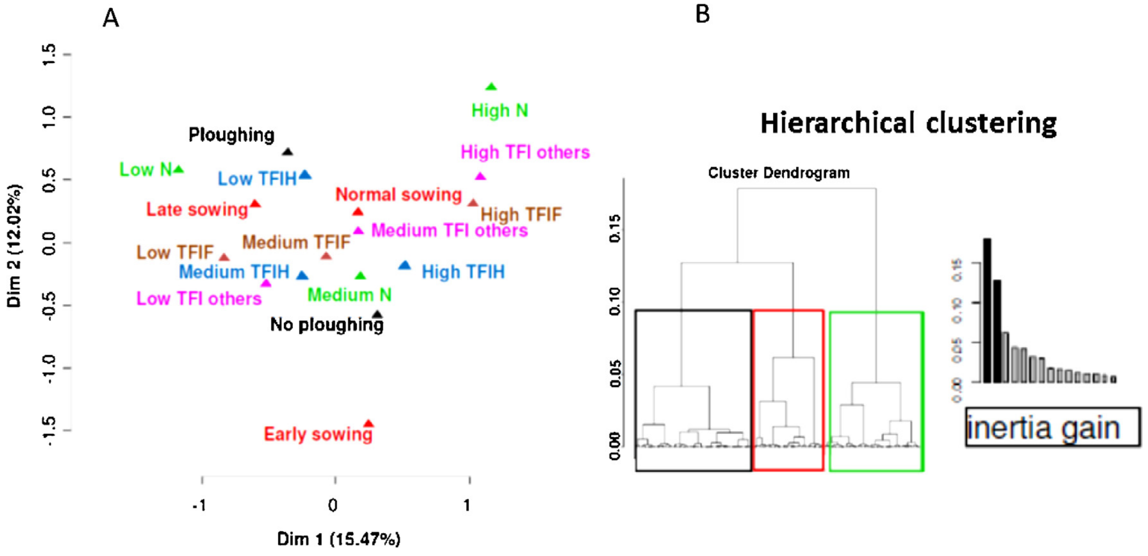

Fig. 2. Multivariate analysis on 225 fields (from 205 farms) for variables describing winter wheat management: A) multiple component analysis; B) hierarchical analysis on MCA. TFI: treatment frequency index. TFIH: TFI for herbicides. TFIF: TFI for fungicides. TFI others: TFI for other types of pesticides.

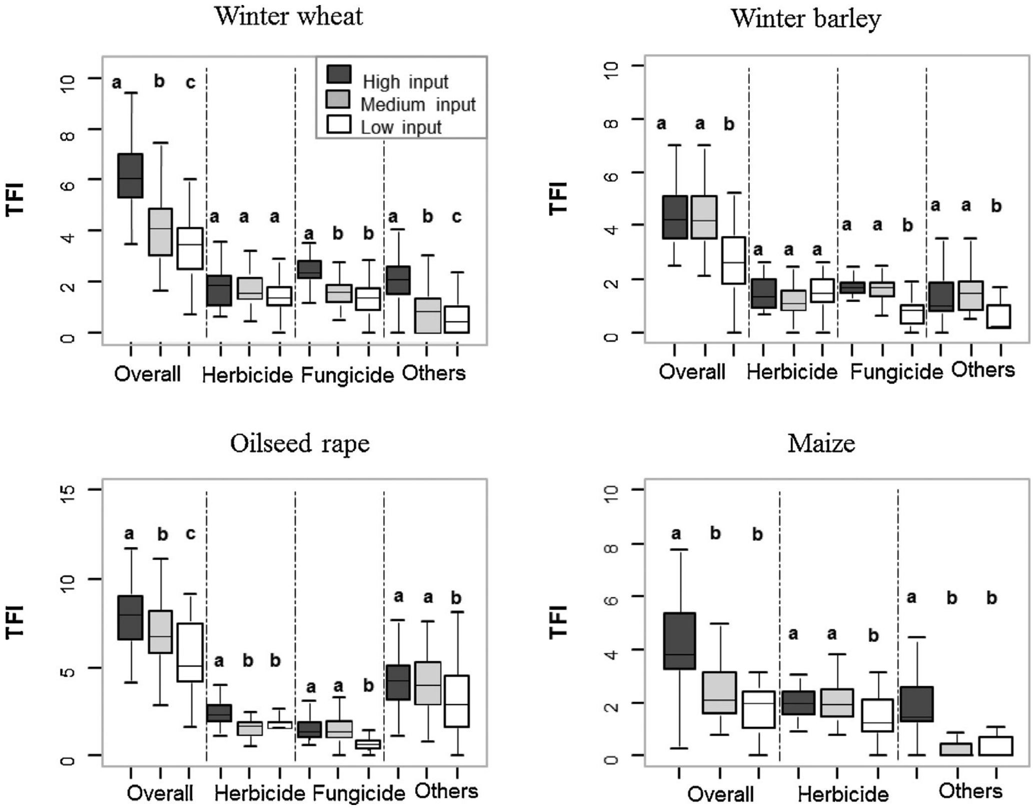

Fig. 3. Variability of pesticide and nitrogen use in the three clusters for winter wheat, winter barley, maize and oilseed rape. For a given pesticide type, TFI distributions are significantly different if associated with a different letter (Wilcoxon test, p = 0.05). Outliers were deleted to match with the French legislation on statistical confidentiality, but were included in the analysis.

associated with diversified cropping systems based on peas or sunflower (PS-group #3). Cropping systems based on the OR/WW/WB crop rotation were present in nearly all PS types but were mainly dominant in situations with low WSC (PS-group #1 and #2). The field size appeared to be related to the level of intensification, as small fields (PS-group #2, below 9.6 ha) were more frequently associated with low inputs in CS based on a OR/WW/WB crop rotation than larger fields (PS-group #1). The group of PS with beef

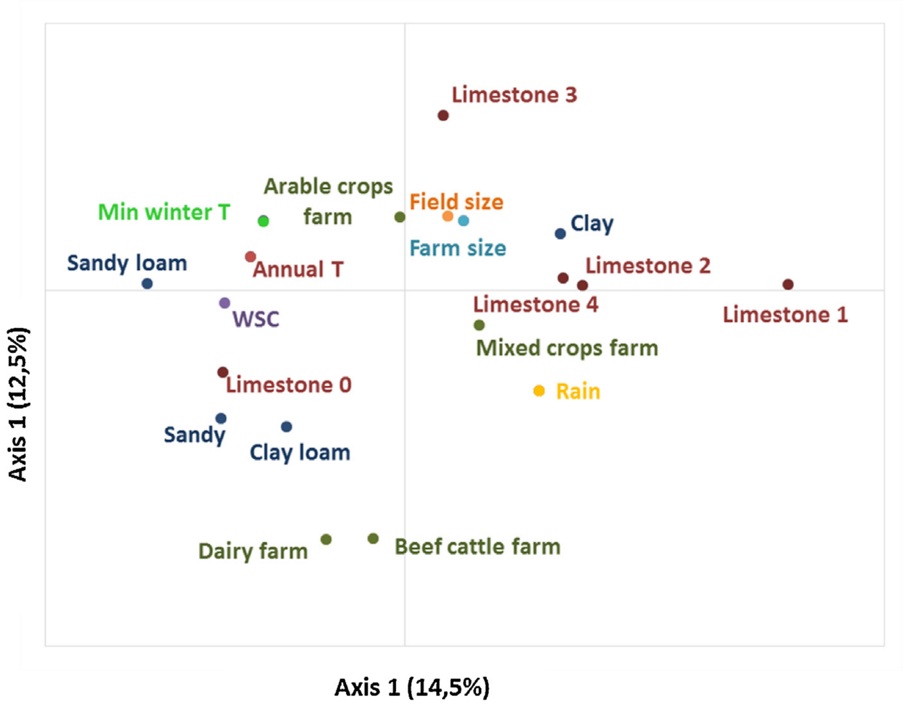

Fig. 4. Hill & Smith analysis on PS variables for the 761 fields. Limestone 0–4 are for increasing classes of limestone content.

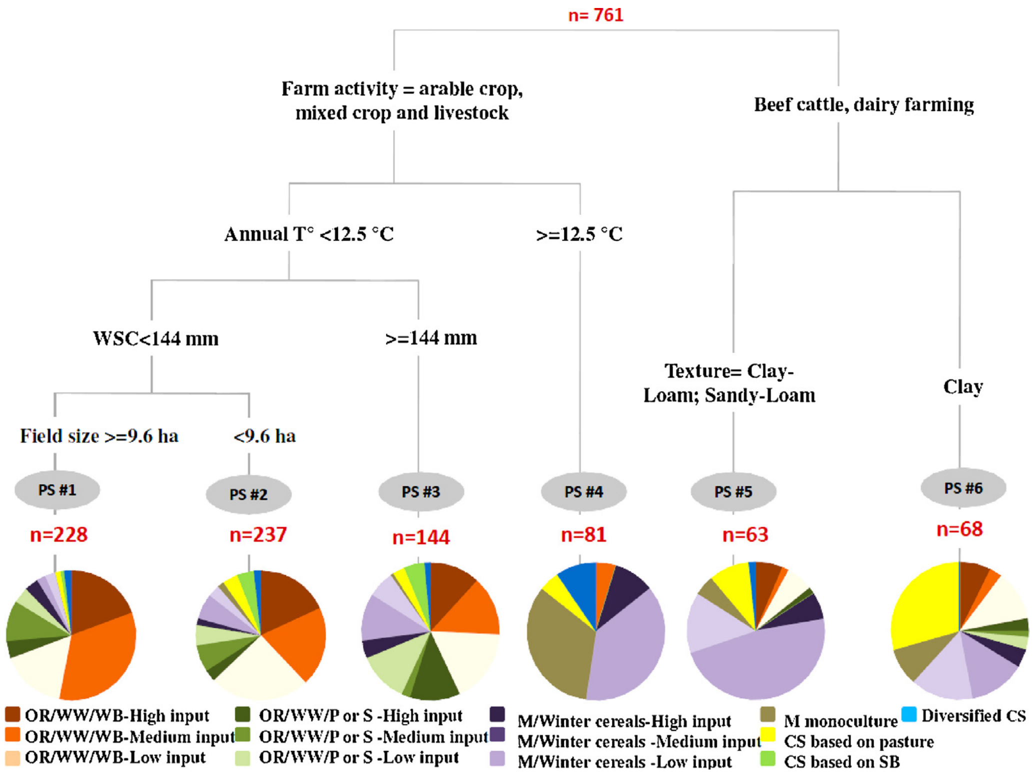

Fig. 5. Regression tree model describing the CS frequency as a function of the variables describing production situations.

cattle and dairy farms was split according to soil texture: clay soils were more frequently associated with cropping systems including pastures (PS-group #6), whereas clay–silt soils and sandy loams were more frequently associated with systems including maize in crop rotations (PS-group #5). The proportion of low input cropping systems was higher in ‘beef cattle’ and dairy farms than in ‘arable crops’ farm, both for cropping systems based on the OSR/WW/WB rotation and for maize-based crop rotations.

The method of classification trees, therefore, led to six groups of PS with different proportions of the different types of cropping systems (Fig. 5). However, the diversity of CS type within each PS group remained high. The proportion of a given CS type never exceeded 48% within a given PS group (crop sequence based on maize and winter cereals in the group PS #5 of farms based on beef or dairy farming on clay–loam or sandy loam soils). In the group PS #3 (farms based on arable crops, sometimes mixed with livestock, in uplands with low temperatures but soils with high WSC), no CS type exceeded 20% and six CS type exceeded 10%.

4. Discussion

4.1. Choice of explanatory variables

A set of variables that were available and likely to explain part of the diversity in cropping systems was used to describe PS diversity, and we were careful to avoid redundancy (i.e., highly correlated variables). Some variables described the farm context, and particularly an indication of the nature of any associated livestock, as mixed crop-livestock farming is known to affect cultural practices and provide opportunities for crop diversification and reduction in the crop’s reliance on external inputs (Schiere et al., 2001). The other variables mainly described the soil and the climate. Weather data sets can produce a huge number of descriptive variables with a high risk of redundancy, so we had to select some of them based on a correlation analysis (data not shown).

The regional soil database included information about the limestone content, a soil feature which is commonly used for differentiating soil types in the area. In our result, the limestone content indeed contributed significantly to the first axes of the Hill & Smith analysis. Nevertheless, the limestone content was not selected as a segmenting variable by the regression tree method, suggesting that either this variable indeed had limited impact on the cropping system design, or that it was correlated with other segmenting variables. Conversely, the mean annual temperature had a rather limited weight in the structure of the descriptive variables of PS, but it was the first one that was selected to discriminate cropping systems of farms based on cash crops (possibly mixed with livestock), segregating PS-group #4 from PS-groups #1, #2, and #3. Indeed PS-group #4 corresponded predominantly to maize-based cropping systems, either in crop rotations or in monoculture, and maize is known to be favored by warm temperature, both because warm spring temperatures result in rapid canopy closure, hence maximizing early solar radiation interception, and because warm temperatures throughout the growing period mean an early harvest, usually in good conditions.

4.2. Cropping system drivers

To our knowledge it is the first time that the relationship between properties of the PS and the main features of CS has been clearly established for arable cropping in temperate climates. The results of the regression tree model (Fig. 5) agreed with local expertise about the structure of agriculture in Burgundy. Each expert found the results consistent with his/her own knowledge of the diversity of farms within the agricultural areas he/she was familiar with, even though experts also noted that the systems had slightly changed since 2006, with a trend for further simplification of crop rotations. According to their expertise this trend did not however, jeopardize the CS classification produced by our analysis. They provided some hypothesis tending to explain the agronomic reasons for the observed relationships. As expected, the combination of animal husbandry with arable cropping was identified as the main factor influencing CS. Livestock feeding requires the growing of forage crops, mainly maize, temporary pastures or cereal crops in the area. The diversity of forage crops tends to widen the diversity in crop sequences, especially when forage crops and cash crops are mixed within a given CS. Clay soils might be difficult to till, particularly in the fall and in winter, which is why they could be more suited than loamy soils for pasture-based CS, including multi-annual crops, and therefore, a low frequency of soil tillage, or possibly for forage maize monoculture, as seeding maize in late spring may not require tillage during winter. Conversely, seeding winter cereals late in the fall after the maize harvest might be difficult in such clayey soils, and this might explain the rather low frequency of CS combining maize and winter cereals on clay soils in farms with animal husbandry. In farms without livestock, or mainly based on cash crops, the soil WSC was identified as a significant determining factor of CS. Soils with low WSC (that geographically correspond to the so-called 'plateau' area of the center of the region) were mainly cultivated with cropping systems based on winter cereals and oilseed rape only, i.e., winter crops with growing periods roughly matching the rainy seasons of late autumn, winter and early spring. On the other hand, land that is less prone to water shortage in the spring and summer due to a higher WSC allowed more diversified CS, introducing diversifying spring crops such as sunflower, spring barley or peas. Interestingly, in cool areas with scarce livestock and restricted WSC, the field size seemed to be related to the intensification level. Indeed, the proportion of low-input CS (either based on oilseed rape or just cereals, or including diversifying crops such as sunflower or peas) tended to be higher in relatively small fields than in larger ones, suggesting that areas where consolidation has been rapid in recent years, leading to large fields, are also areas where farmers adopted high-input intensive CS. Finally, the annual mean temperature was shown to significantly affect CS in farms that are not mainly based on livestock. Indeed, CS in the warm lowlands of the south of Burgundy are known to differ from systems in northern cooler areas, as crop sequences there are much more dominated by maize, which is often grown in monoculture in this area, unlike in other areas of Burgundy.

The diversity of CS within each identified group of PS remained high, indicating that all the determinants of cultural practices were not included in the analysis. The context of each CS might have been insufficiently described with the set of variables that were available. However, the results also suggested that the diversity of CS in a given type of PS might be related to the diversity of farmers, who have different objectives, different knowledge about the farm management, and different degrees of risk aversion etc. These considerations suggest that different pathways are possible for policies intended to drive European agriculture toward more sustainable practices. Policies could indeed aim to change the context of each farm, through regulations or incentives adapted precisely to the territorial diversity of each country, or promote the development of agroecological knowledge among farmers. Both pathways should probably be explored at the same time.

4.3. *Methodological reflexion on CS and PS*

To our knowledge, relatively few articles report studies focusing on the diversity of PS and the impacts on CS, whether with a methodological approach or with other objectives. The few available studies analyzing the relationship between CS and PS rarely deal with the context of arable crops in temperate areas. In the particular context of pastures in montane farming in the Alps, Camacho et al. (2008) identified strong links between the spatial structure of the environmental conditions and the spatial distribution of agricultural land use. In the tropical context of the West Indies, Chopin and Blazy (2013) analyzed the spatial variability in banana yield, and established the causal relationships between the physical and economic situations of the farms, the banana cropping systems and their performance. They identified the technical components of cropping systems that were related to high yields (e.g., chemical treatment against nematodes, ploughing) and studied the range of possible constraints that might limit the adoption of some crop management practices (e.g., steep slopes, small farm size, low cash flow). Very recently, a typology of maize-based cropping systems was established from surveys in the northern mountains of Vietnam, an area with a high diversity of farming situations (Hauswirth, 2013). The author characterized the drivers of the CS diversity by relating CS features with the farm context (district, mean farm size in the area and main crops, altitude etc.), farm types and field biophysical conditions. Those descriptive variables explained about 50% of the variability in cropping systems, hence suggesting that other drivers, including the specific history of the farmers and their personal objectives, could partly determine cropping practices.

One possible reason why the question of the relationship between CS and PS has rarely been addressed might be that it requires large datasets about cropping systems that are typically missing at the regional or national scale. Many studies dealing with cropping systems at the regional scale tend to simplify the concept of cropping system to its primary characteristic, i.e., the species grown (Leenhardt et al., 2010) or the crop rotation (Castellazzi et al., 2007). When the spatial distribution of cultural practices is required to analyze environmental issues at the regional scale, the information is usually restricted to land use at the field scale, distinguishing crop species or even crop groups such as winter cereals, temporary pastures etc. (e.g., Verburg and Veldkamp, 2001; Rounsevell et al., 2003). The dataset we used in this study included information about crop sequences over 6 years, but provided the details of crop management only for the last year. For each of the four crop species we analyzed, a typology of crop management roughly corresponding to low/medium/high input levels was identified. We assumed that a cropping system with a certain input level in one crop of the sequence would have the same input level for the other crops. Based on this assumption we could use a typology of cropping systems that was defined by the type of crop sequence and its input level. The assumption seemed reasonable according to the expert knowledge of local farm advisers we interviewed, but it should be tested with a proper dataset describing a wide range of different CS at the regional or national scale, including details of crop management for the whole crop sequence. To our knowledge, such a data set does not currently exist in France, although the DEPHY-farm network, that was launched two years ago by the French Ministry of Agriculture with the aim of demonstrating CS with low pesticide use, should soon provide such valuable data at the CS level.

5. Conclusion

This study deals with (i) the diversity of cropping systems in a given region, (ii) the diversity of production situations, and focuses on (iii) the relationship between cropping systems and production situations at the regional scale. The use of data provided by the Department of Agricultural Statistics mixed with data from soil and weather databases made it possible to characterize the context of agriculture and the diversity of cropping systems. The use of the regression tree model succeeded in identifying key features of the agricultural context that appeared as drivers determining the diversity of agricultural practices within the studied region. Some identified drivers were not surprising, such as the mixed farming with cattle breeding that impacts the nature of crop grown. It was however, worth highlighting other drivers, such as the soil properties that tend to impact the diversity of cropping systems and the input level. The diversity of cropping systems varied across production situation types in Burgundy, but remained high within each type, emphasizing the potential scope for farmers in this region to adapt their practices as a function of their own preferences

From a practical point of view, recognizing the significance of major factors of the farming context influencing cropping systems does not imply that there would be no room for agricultural changes to improve sustainability. However, it is important for policy makers to consider the diversity of production situations when anticipating the consequences of policies aiming at fostering more sustainable cropping systems. The next step to evaluate the potential for changing cultural practices in the Burgundy region could be to explore different scenarios of innovative cropping systems for each production situation that we identified in this study, evaluating the potential consequences of each alternative cropping systems for the different components of sustainability, including farmers' profit, but also social and environmental performances.

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