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Original article

Geo-referenced indicators of maize sowing and cultivar choice for better water management

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Abstract – Agriculture is a major consumer of water, with up to 88% of the total water consumption in summer in irrigated regions, either in France or, for instance, in Australia. Good water management therefore requires an accurate estimation of regional water demand by agriculture, which depends on both soil and weather conditions and on farmers' practices. We studied the farmers' practices that influence maize irrigation: sowing and the choice of cultivar in regard to its earliness. Specifically, we aimed to identify geo-referenced indicators that could be used to estimate the spatial and temporal distribution of the various combinations of sowing date, sowing density, sown area and maize earliness. The study was conducted in a 500-km^2 irrigated area in south-western France. We first conducted a quantitative analysis of postal survey data to identify environmental factors and farm descriptors that could determine sowing practices and the choice of earliness of cultivar. We then interviewed a group of farmers to find out the main constraints relevant to the sowing date and earliness of cultivar. We identified variables that can be used as indicators of the spatial variability of the studied practices. Our results show that the spatial distribution of sowing date and cultivar earliness over a region can be estimated from climatic descriptors of the area and structural farm characteristics. The first factor allows estimation of tactical variables, the sowing starting date and the cultivar earliness groups, while the second allows estimation of sowing and earliness choice strategies. This is one of the first studies identifying on a regional scale geo-referenced indicators of a crop management system, and the first that provides a conjunctive estimation of sowing and earliness choice practices on a regional scale. This study suggests that for estimating any crop management system, it is helpful to treat strategic and tactical variables separately.

agricultural practices / spatial variability / mapping / sowing / earliness / maize / irrigation / water management / regional scale / probabilistic estimation

1. INTRODUCTION

Agriculture is often the main consumer of water. For instance, in France and in Australia, irrigation uses, respectively, 68 and 70% of the water resources (Agences de l'eau, 2007; AWRC, 1987). In summer in some regions, e.g. Midi-Pyrénées in France or the Murray-Darling Basin in Australia, agricultural use accounts for around 85% of all water use (Comité de Bassin Adour Garonne, 2004; AWRC, 1987). Good water management therefore requires an accurate estimation of regional water demand by agriculture. A key point is to be able to estimate both the total irrigation demand and its temporal distribution. For water planning, irrigation demand should, in addition, be estimated for various context scenarios.

Agricultural water demand depends on soil and weather conditions and farmers' practices. The latter include the choice of crops and the management of each crop, among which irrigation practices are of major importance (Maton et al., 2005). However, sowing practices must not be neglected since they determine the timing of the crop cycles, as does the choice of cultivar, which determines the length of the cycle. Recording the spatial and temporal distribution of weather events and of agricultural practices, e.g. sowing and irrigation, and choices such as cultivar earliness for all irrigated crops should enable a prediction of the spatial and temporal distribution of water demand. However, recording current agricultural practice distribution restricts the prediction to very short-term water demand. For water planning considerations, it is necessary to account for changes in agricultural practices in the medium or long term. Since farmers' practices are partly influenced by the socio-economic context, accounting for the links between agricultural practices and the irrigated production context should enable estimation of the effect of potential changes on regional irrigation demand.

Beyond the domain of water management and planning, it is recognised that practices adopted by farmers and other land managers have a critical role in mediating the effects of land use on natural resources. Policy-makers and land management agencies increasingly appreciate the spatial and temporal heterogeneity of landscapes and the processes that control landscape functioning (Lesslie et al., 2006). Land use and land cover studies have been conducted for a long time and related databases are numerous (e.g. Gallego, 1995; Pinter et al., 2003; Lesslie et al., 2006). However, the exhaustive collection of information about land management practices on the

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regional scale is only at its early stage, and is most of the time partial and descriptive, with no comprehension of the links between technical interventions within crop management systems (Mignolet et al., 2006; BRS, 2006). Obtaining detailed and comprehensive information on management practices on a regional scale is difficult because the great number of farms makes surveys long and arduous (Biarnès et al., 2004). To overcome long surveys, various alternatives exist. The first is to use remote-sensing techniques to estimate the spatial variability of specific technical interventions, such as the sowing dates (Launay and Guérif, 2005). But not all interventions can be detected by remote sensing, and such techniques can only provide indications on past practices. The second is to make the best use of existing regional databases. For example, data-mining techniques have been developed to estimate the spatial variability of past crop rotations from such databases (Mari and Le Ber, 2005). Economic models can be used to provide estimations of optimal practices for various context change scenarios (Rounsevell et al., 2003). This approach, however, needs to make some hypotheses or needs some expertise or knowledge regarding the actual constraints (or determining factors) of farmers' practices. The third alternative is to use expert knowledge, as Mignolet et al. (2004) did, to associate a management system with crops or crop rotation. But experts can mainly inform about past and/or recommended practices.

Very few studies have sought to identify the determining factors of agricultural practices on a regional scale. Biarnès et al. (2004) looked for indicators of practices at field, farm, catchment area and district levels to estimate the type of weed control management, but they did not try to explain the temporal distribution of pesticide applications. Dounias (1998) studied agricultural practices in more detail but only on a small number of farms. They found the farm indicators discriminating various practices are generally not collected on a regional basis.

The present article describes a study that aims at identifying determining factors of farmers' practices on a regional scale in order to predict technical intervention in time and in space for water planning studies. It follows two other studies. All three are concerned with maize crop management, since agricultural water demand in south-western France is mainly attributable to maize irrigation. The first assessed irrigation strategy variability (Maton et al., 2005). The second described sowing practices and cultivar earliness choices and identified a great variety of combinations of sowing date, sowing density, sown area and maize earliness (Maton et al., 2007a). The main hypothesis proposed to explain such diversity is the north-south climatic gradient of the study area: in the north, climatic conditions allow early sowing, and very late varieties have been observed over a larger area than in the south, where semi-late and semi-early varieties predominate. No other determining factor emerged clearly, either regarding the soil or farm structural elements such as manpower, daily working time and maize area – factors which are often considered to determine the sowing organisation (Leenhardt and Lemaire, 2002; Debaeke and Aboudrare, 2004; Papy and Servettaz, 1986). The study presented here concerns the spatial and temporal distribution of sowing and cultivar earliness practices. While previous work involved spatial estimation of sowing dates (Leenhardt and Lemaire, 2002), it is the first conjunctive estimation of sowing and earliness choice practices on a regional scale.

2. MATERIALS AND METHODS

2.1. Studied area

The study area is the upper Baïse catchment area. It is a 500-km^2 irrigated area in south-western France within the Midi-Pyrénées Region and includes parts of six small agricultural districts (Fig. 1): Haut-Armagnac, Astarac-Gers, Astarac-Hautes-Pyrénées, Coteaux-de-Gascogne, Coteaux-de-Bigorre and Montagne-de-Bigorre. The sector presents a general north-south gradient of landscape, climate, soil and agricultural activity. The southern part of the so-called Baïse sector is the Lannemezan plateau, while in the northern part we can distinguish a gently undulating landscape on the left-hand side of rivers, and flat areas on the right. The study area presents a north-south climatic gradient (the northern part is hotter and drier than the southern part, which is closer to the Pyrenees) as well as a greater variability, both from year to year and from month to month. During the sowing period (from March to May), the monthly precipitation in Auch varied from 0 to 240 mm over a 39-year period. The main two soils of the sector are called "Boulbène" and "Terrefort". The first is a loamy acid soil, more or less hydromorphic depending on the depth of the clay layer. The second, a clay soil, is encountered mainly in the northern part. The main activity of the sector is agriculture, with some 35 500 ha (70% of its area) used for agricultural purposes by more than 1100 farmers. Livestock farms (cattle production) are mainly found in the upper part of the catchment area, while field crops are mostly grown in the lower part. The main annual crops are winter cereals, winter rape, spring pea, maize, sunflower, soybean and grassland. Half of the farmers irrigate their crops, mainly maize, soybean and pea. In 2000, 80% of the irrigated area was in maize. Most of the farms with irrigated maize have an agricultural area between 20 and 100 ha. In the most southerly part of the area (Montagne-de-Bigorre), maize is not irrigated (Agreste, 2002).

2.2. Surveys

Two surveys were conducted for the study, one in 2003, the second in 2004. Weather data for these two years are presented after the description of the two surveys.

The 2003 postal survey

In 2003, the 701 irrigators of the Baïse sector using the Neste water system were sent a questionnaire by post. It included questions about the general practices and a description of the farm (crop and animal production, areas that are or could

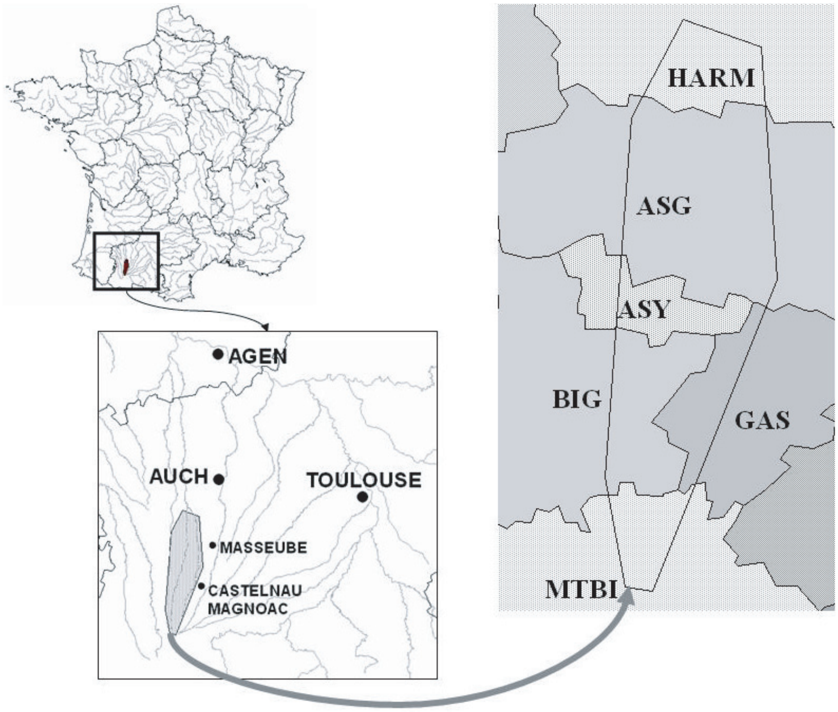

Figure 1. Location of the study area in France and presentation of the administrative zoning corresponding to the small agricultural regions (Haut-Armagnac (HARM), Astarac-Gers (ASG), Astarac-Hautes-Pyrénées (ASY), Coteaux-de-Gascogne (GAS), Coteaux-de-Bigorre (BIG) and Montagne-de-Bigorre (MTBI)).

be irrigated, maize areas, manpower, farm location, supply organisation), and the sowing dates and the varieties sown for the 2003 maize area. For each sowing date and earliness group, the soil type, sowing density, area and the topographical position were also requested.

Some 96 usable questionnaires were returned from all small agricultural districts except Montagne-de-Bigorre. This corresponds to a representative sample of the population of irrigated maize growers of the part of the study area corresponding to the remaining 5 small agricultural districts (Tab. I).

The 2004 farmers' interviews

In 2004, 20 maize growers, evenly distributed over the same area, were interviewed. The sample was chosen to cover the wide diversity of farms (regarding production systems, links with a cooperative or a private firm for supply and individual or collective use of equipment). Half of the farmers are cooperative members, while the others depend on the main private firm for collection and supply. All except three have livestock. Five farmers share equipment, three dry their maize on the farm with a dryer and two dry it both on-farm in cribs and outside through a cooperative.

After a first questionnaire aiming at characterising the farm structure, regarding agricultural area, production, manpower, etc., the interviews consisted of open and semi-open questions (Blanchet and Gotman, 1992) relating to the management of maize sowing and harvest work. The objective was to identify the main constraints pointed out by farmers.

Weather conditions in 2003 and 2004

In general, 2003 was a record year for drought and heat, while 2004 was unexceptional in most respects. During the usual sowing period, from March to May, the study area received more precipitation in 2004 than in 2003: in 2004, total precipitation for these three months was 290 mm, with 13 to 70 mm for each 10-day period and 66 dry days, i.e. with less than 2 mm rainfall, while in 2003 there was only 153 mm of precipitation but 77 dry days and 5 dry 10-day periods, i.e. with less than 10 mm rainfall (Fig. 2). Regarding temperatures, adequate conditions for sowing, that is, when the 7-day moving average of temperature is above 10 °C, occurred much earlier in 2003 (25th February) than in 2004 (30th March).

2.3. Determination of spatial indicators of practices

To predict the spatial distribution of sowing practices and cultivar choices, i.e. sowing date, sowing density, sown area and maize earliness group, we followed a 2-step approach. First we dealt with environmental variables whose spatial distribution is readily available from maps or interpolation techniques (Faivre et al., 2004) and tried to directly estimate the

Table I. Comparison, in terms of distribution per small agricultural district, of the postal survey farmers' sample and the total population of irrigated maize growers in the zone (from 2000 agricultural census data – Agreste, 2002).

Small agricultural district	Area	Total population (500 farmers)			Sample (96 farmers)		
	(%)	Number of farmers (%)	Agricultural area (%)	Irrigated area (%)	Number of farmers (%) (grain & seed)	Agricultural area (%)	Irrigated area (%) (grain & seed)
Haut-Armagnac	27	11	14	11	9	18	6
Astarac-Gers	34	54	56	54	58	57	63
Astarac-Hautes-Pyrénées	18	10	7	10	9	8	11
Coteaux-de-Bigorre	12	18	14	18	19	14	15
Coteaux-de-Gascogne	9	9	9	9	5	3	5

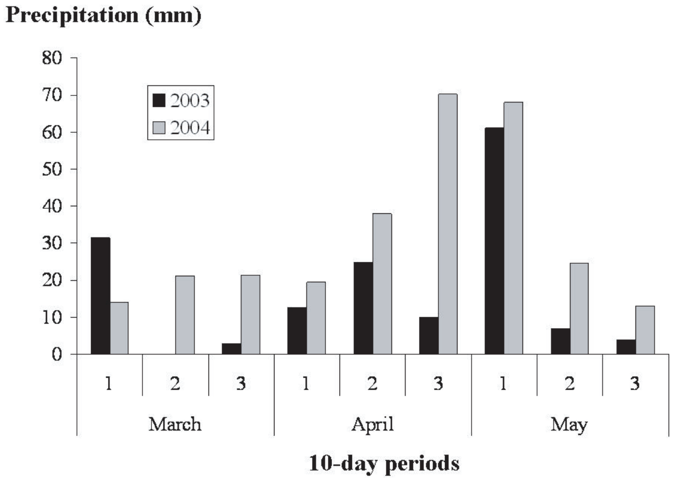

Figure 2. Precipitation for 10-day periods from March to May in 2003 and 2004.

details of the practices. Then, in a second step, we investigated other determining factors of sowing practices and earliness choices among many farm descriptors that can be found in geo-referenced databases. This led us to estimate farmers' sowing-earliness strategies. An additional analysis was finally made to identify the main constraints put forward by the farmers themselves and to see if they could explain or validate the results obtained in the previous two-step approach.

Step 1: Analysing the effect of environmental factors

First we analysed the effect of climate. We checked whether the observed sowing dates, particularly the first ones, were in agreement with the climatic gradient existing in the study area. The underlying assumption is that temperature and rainfall determine the number of days on which sowing is possible (Leenhardt and Lemaire, 2002; Papy and Servettaz, 1986; Maton et al., 2007b).

To analyse the effects of soil and topography, we distinguished two groups of variables. The first group corresponds to variables that are sensitive only on the scale of the farm maize area, that is, the start of sowing work and the number of earliness groups. Farm maize areas are either on one soil type only or on both soil types. The same distinction occurs for topographical positions. The second group of variables gathers those that can be analysed on the field scale, that is, the sowing date and the earliness group. Fields are considered as homogeneous regarding the soil and the topographical position. For the types and the number of earliness groups, we compared the distributions of these variables for each soil type, each topographic position and their combinations. For the start of sowing work and for the sowing dates, we compared the cumulative distribution in time of these variables. This set of comparisons included analyses of the correlation coefficients between these distributions.

Step 2: Investigating determining factors among farm descriptors

The quantitative data collected in the postal survey were statistically analysed. Agricultural practices were classified and indicators of these classes which are readily available on a regional scale were sought. To classify the practices, they must be described by suitable variables. To separate the effect of climate on practices from that of farm structure or organisation, we chose to identify variables that can describe details of sowing and earliness choice independently of the weather effect. As an example, the sowing work was assumed to be continuous (or done in one "session") when interrupted by rain and restarted when the weather improved. Similarly, rather than using the actual dates for the beginning of sowing, the first sowing dates were grouped into three classes (early, average and late) for each farmer in a uniform climatic zone.

Finally, the sowing work is described by 4 qualitative variables: the starting period [START] (3 classes), the number of sowing days [NDAYS] (4 classes), the total duration of sowing [LENGTH] (5 classes) and the number of sessions [NSESS] (3 classes). Choice of cultivar earliness is also described by 4 variables: the number of earliness groups [NGROUPS] (4 classes); the kind of earliness group association [ASSO], which describes which earliness groups are present within the farm maize area (5 classes), the earliness distribution [DISTRIB], which describes whether or not the groups are present in the same proportion within the maize area (5 classes), and

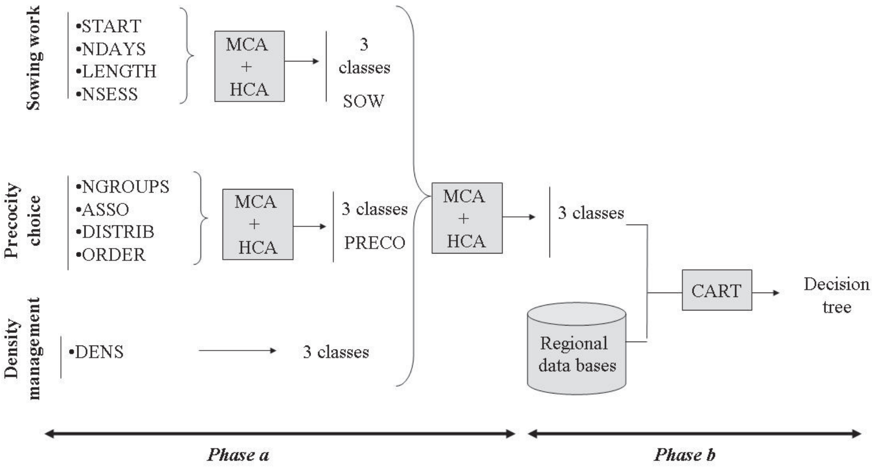

Figure 3. Approach to building sowing-earliness strategies and identifying predictive determination rules linking these strategies to geo-referenced indicators (available in regional databases). The variables describing farmers' practices are: the starting period for sowing [START], the number of sowing days [NDAYS], the total duration of sowing [LENGTH] the number of sowing sessions [NSESS], the number of earliness groups [NGROUPS], the kind of earliness group association [ASSO], the earliness distribution [DISTRIB], the sowing order of the various earliness groups [ORDER], and the sowing density [DENS]. MCA means multi-component analysis and HAC, hierarchical ascendant classification.

the sowing order of the various earliness groups [ORDER] (5 classes). An additional variable [DENS] (3 classes) describes the sowing density management. A detailed description of the classes of these variables can be found in Maton (2006).

The statistical analysis to create a classification and investigate geo-referenced indicators is that used by (Maton et al., 2005). First, classifications defining strategies are built by multi-component analyses followed by a hierarchical ascendant classification. The multi-component analysis describes how the diversity of the sample is structured. The hierarchical ascendant classification classifies the individuals that have similar characteristics. This approach is fully described by Köbrich et al. (2003). Here, because of the large number of variables, we first reduced their number within the first two groups, sowing and earliness variables, before identifying classes of sowing-earliness strategies (Fig. 3 – phase a).

Then (phase b in Fig. 3), the Classification and Regression Tree method (CART) provides decision trees that, when predictive, may be used as a set of prediction rules. This method consists of identifying links between the classes of sowing-earliness strategies and some variables easily accessible on the regional scale. These latter (Tab. II) are variables directly collected on the regional scale by administrative or environmental surveys (general agricultural census, soil maps, regional farm classifications, etc.) or combinations of them (for example, the percentage of maize within the agricultural area). Various values of the variables were tested in order to avoid possible threshold effects.

Identifying the farmer's main constraints

Preliminary interviews with technicians of collection and supply organisations allowed a listing of the possible determining factors of sowing practices and cultivar earliness choices. A group of 20 farmers was then selected in order to cover the range of values of these potential determining variables, and detailed interviews were conducted. Two variables in particular were analysed: the sowing speed (area sown per day) and the number of earliness groups. The analysis was qualitative and consisted of relating these two variables to characteristics of the farm (that could be collected without field observation or monitoring farm work), following Bertin's tables methodology (Bertin, 1977).

3. RESULTS AND DISCUSSION

3.1. Factors linked to environmental aspects

To check the influence of the weather on the date of the start of sowing, we considered the first sowing dates reported by farmers in 2003 for each small agricultural district. We found that, in accordance with the existing climatic gradient, sowing starts earlier in the north (Haut-Armagnac and Astarac-Gers) than in the south (Astarac-Hautes-Pyrénées, Coteaux-de-Bigorre and Coteaux-de-Gascogne), with 2 zones appearing clearly (Tab. III). The delay in the start of sowing between these two zones is around 13 days, but if we consider the dates on which 20% of the area is sown, it is less (around 6 days). This is because it is rare for sowing to start as early as in 2003 and, even if farmers adapt their technical management to weather conditions, they often plan the date from which sowing can start (Aubry et al., 1998). Therefore, despite favourable weather, most farmers might not have taken the risk of sowing so early in 2003.

The distribution of earliness groups per small agricultural district also corresponds to the north-south gradient. The later the maize varieties are, the more heat they need to complete

Table II. Description of variables and their values used to explain the diversity of sowing-earliness strategies.

Variable	Nature
Geographical and environmental context of the farm	
Small agricultural region	Qualitative (5 classes: Haut-Armagnac, Astarac-Gers, Astarac-Hautes-Pyrénées, Coteaux-de-Bigorre, Coteaux-de-Gascogne)
Location	Qualitative (Valley, Hill, both)
Proportion of maize area in hills	Quantitative
Soil type	Qualitative (Boulbène, Terrefort, both)
Proportion of Boulbène soil	Quantitative
Farm structure	
Agricultural area	Quantitative or Qualitative (4 classes: <20 ha, 20–39 ha, 40–59 ha, >60 ha)
Grain maize area	Quantitative or Qualitative (various number of classes tested, e.g: <10 ha, [10; 30 ha[, [30; 60 ha[, ⩾60 ha)
Proportion of maize area in the farm agricultural area	Qualitative (2 classes: ⩾25% which corresponds to an "irrigated maize farm", < 25% which corresponds to a "rainfed crops farm")
Maize fodder silage	Qualitative (2 classes: Yes, No)
Maize seed	Qualitative (2 classes: Yes, No)
Other summer crop sowing	Qualitative (2 classes: Yes, No)
Straw cereals	Qualitative (2 classes: Yes, No)
Livestock	Qualitative (2 classes: Absence, Presence; or 4 classes)
Farm organisation and equipment	
Manpower	Qualitative (3 classes: 1,]1; 2], >2 Man Working Units)
Temporary manpower	Qualitative (2 classes: Yes, No)
Irrigation equipment types	Qualitative (2 classes: 1, >1)
Socio-economic context	
Supply and collection	Qualitative (2 classes: cooperative, private agro-business)

Table III. First sowing dates and dates by which 20% of maize area was sown in 2003. Observed data (from postal survey) presented per small agricultural district of the study area.

Small agricultural district	First sowing date	Date by which 20% of maize area is sown
Haut-Armagnac	15 March	15 April
Astarac-Gers	26 March	17 April
Astarac-Hautes-Pyrénées	10 April	22 April
Coteaux-de-Bigorre	13 April	22 April
Coteaux-de-Gascogne	17 April	21 April

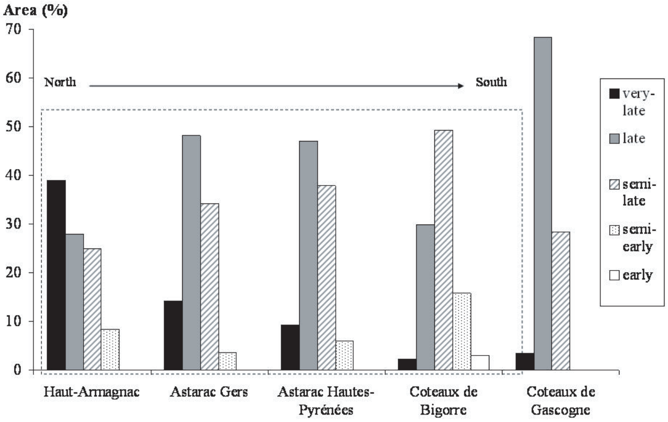

Figure 4. Distribution of earliness groups in each small agricultural district in 2003 according to postal survey answers. The 4 small agricultural districts along a north-south axis are framed. The distribution of earliness groups varies along this axis, with comparatively more late varieties in the north and more early varieties in the south. The small agricultural district Coteaux-de-Gascogne is situated east of this axis.

their growth. Considering the small agricultural districts (except Coteaux-de-Gascogne) from north to south (Fig. 4), we see that areas sown with very late varieties decrease, while those sown with semi-late varieties increase. The situation observed in Coteaux-de-Gascogne is not as consistent. This finding could be due to (i) the warmer Mediterranean influence and (ii) under-representation of this small agricultural district within the sample of farmers.

Regarding soil and topography, the Boulbène soil in valley combination is dominant in our sample, as regards both the number of farmers (27%) and the maize area (56%). It is followed by the Terrefort-valley combination (15% of farmers, 21% of maize area).

Fields on hills are sown before those in valleys, probably because the former warm up more quickly than the latter. But farmers whose whole maize area is on hills actually sow it later than those with all their maize in the valleys. This finding could be due to the fact that (i) farms with all their maize area on hills are not primarily maize farms, therefore other

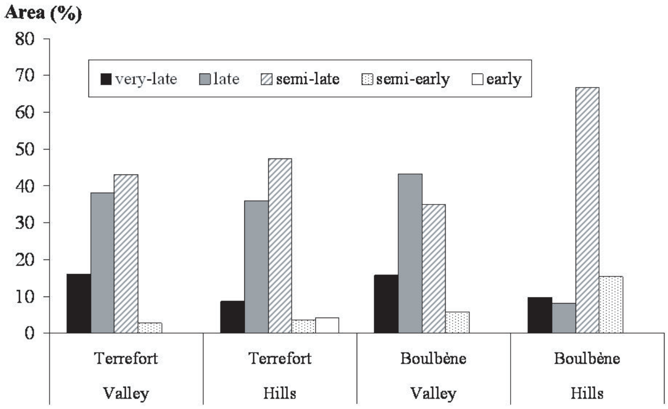

Figure 5. Distribution of earliness groups for each soil-location combination. Similar distributions of earliness groups occur on the first 3 soil-location combinations. On hilly Boulbène soils, semi-late varieties predominate.

work may take priority during the maize-sowing period, and (ii) fields on hills are not always included in farm maize areas situated entirely on hills. In the study area, from our sample data, soil type did not influence sowing order.

Regarding varietal choice, we found that the soil-topography criterion could be an indicator to predict choice of cultivar earliness: on hilly Boulbène soils, semi-late varieties predominate. On other soil-topography combinations earliness distributions are quite similar, with more late varieties and fewer semi-late varieties (Fig. 5). The number of earliness groups chosen by farmers in 2003 was not clearly related to the variability of soil types or of topographic positions within their farm maize area.

Finally, we were not able to identify relationships between the studied practices and soil types. This probably comes from a great within-type variability of soil water properties. To overcome this, we could have either asked farmers about soil water properties (albeit without being sure of a reliable reply) or used a detailed soil map providing estimates of soil water properties (Leenhardt et al., 1994). However, such maps are not generally available on a regional scale. Biarnès et al. (2004), studying weed control practices, also concluded that without a detailed soil map it was impossible to find any link between soil and practices.

3.2. Factors linked to farm constraints and socio-economic context

Factors available in regional databases

We do not present here intermediary results of phase *a* of the procedure described in Figure 3, only the final results: the three classes of sowing-earliness strategies identified. The variables that appeared to discriminate between classes are the number of days and the number of sowing sessions, and the number of earliness groups sown. Despite some internal variability, the classes show specific trends that are presented in Table IV. Farmers using strategy B sow rapidly, in one session, one earliness group, while farmers using strategy C sow in several sessions with three or four earliness groups. Strategy A can be considered as intermediate: farmers sow 2 or 3 cultivars in one session; up to 7 days long. Strategies A, B and C are adopted by 47%, 39% and 15%, respectively, of the surveyed population of farmers.

Note that these 3 sowing-earliness “strategies” are statistical constructions rather than real farmers’ strategies. Like action models (Papy et al., 1988) they can represent what happens but they do not directly reflect the practices as the farmers perceive them.

Phase *b* of the procedure (Fig. 3) showed that, from all variables that are easily accessible on a regional scale and that could explain this diversity of sowing-earliness strategies (Tab. IV), only one classification tree, based on a few farms’ structural data, appeared to have predictive value. This tree is composed of five nodes and six terminal nodes (Fig. 6). The discriminating variables are (i) the agricultural area, (ii) the proportion of maize within this area, i.e. the dominance of irrigated maize vs. rainfed crops, (iii) the proportion of irrigated area, i.e. irrigated vs. dry vs. combined production system, and (iv) the existence of a livestock unit. The terminal nodes are composed of a probability distribution of the three strategies. The classification tree is then probabilistic. For instance, among farms where irrigated maize dominates, where there is not any livestock and where the agricultural area is between 20 and 60 ha, farmers have a probability of 0.75 of using the sowing-earliness strategy A, and a probability of 0.125 of using the strategy B or strategy C.

The variables that discriminate the strategy distributions are all related to farm structure. This result is of particular interest for strategy estimations over large areas: farm structural elements are generally collected by administrative statistical surveys for all farms, and stored in databases where they are geo-referenced by the local government area (LGA) where the farm is based. The LGA can therefore be taken as the location criterion for the sowing-earliness strategies.

The probabilistic nature of the classification tree means that the discriminating structural variables do not explain the whole variability of sowing-earliness strategies. It can be assumed that the farms would need to be described by additional factors to lead to a more deterministic classification tree.

Additional factors raised by farmers

Regarding the sowing work, the number of sowing days and the area sown varied greatly, from 2 to 10 days and 14 to 120 ha, respectively, but with a very low mutual correlation ($R^2 = 0.56$). The sowing speed also varied, from 7 to 20 ha per day. Farmers with the fastest sowing speed are generally those whose agricultural area, maize area, proportion of irrigated area, manpower and seed drill size are the largest. Of all the work organisation and production system factors that could explain the sowing speed, the drill size appeared to be the most discriminating.

Table IV. Characteristics of the maize sowing-earliness strategies obtained from multivariate analyses and classifications for the Baise sector using 2003 postal survey data.

Variables	Strategy A	Strategy B	Strategy C
Number of earliness groups [NGROUPS]	2–3	1	3–4
Associations of earliness groups [ASSO]	Various	–	[very late, late and semi-late] or [late, semi-late and semi-early]
Sowing order [ORDER]	From latest to earliest varieties	–	variable
Earliness distribution in maize area [DISTRIB]	Earliest varieties dominate	–	Late and very late varieties dominate
Number of sessions [NSESS]	1	1	many
Number of sowing days [NDAYS]	7	1–2	Up to 30 days
Density management [DENS]	constant (60%) or modulated with the earliness (30%)	constant	variable

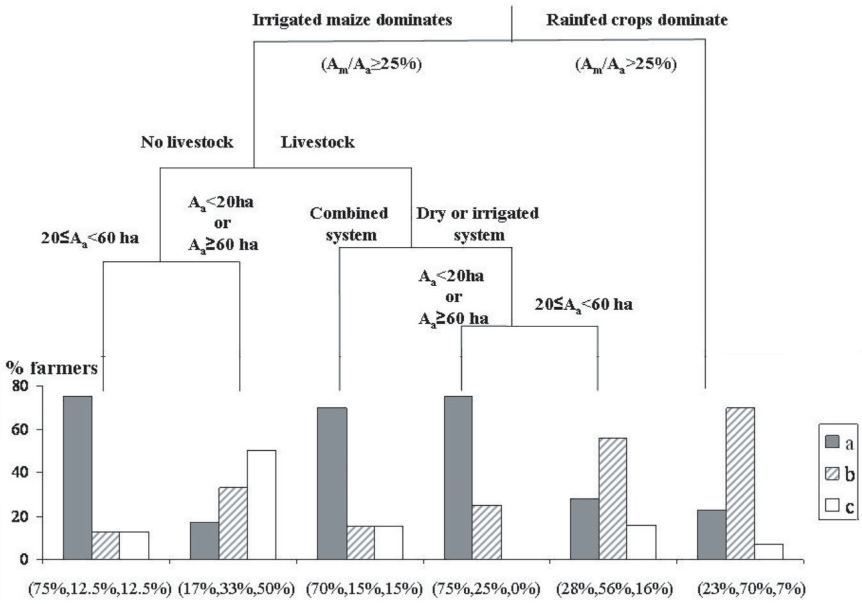

Figure 6. Sowing-earliness strategies classification tree. A_a is the farm agricultural area, A_m is the farm maize area.

In relation to earliness choice, when sowing only one group, this group can correspond to any of the possible groups, from very late to early varieties. When sowing 2 or 3 earliness groups, farmers choose various associations and allocate the late or very late varieties to valley soils (often equipped with centre-pivot irrigators) that are considered to be more fertile, while semi-late and semi-early varieties tend to be grown on hill soils with travelling rain guns. The soil is not considered by farmers as a factor per se, but always considered in association with the topography and the irrigation equipment. Various other trends were observed as to the number of earliness groups sown: the number of groups sown is negatively correlated with the farmer's age; farmers who sow one group are mainly affiliated with private business rather than with cooperatives; and when farmers use shared equipment for sowing and/or harvesting, they do not sow more than two groups.

Farmers who have their own maize dryer make use of the number of earliness groups and the sowing speed to influence their harvest duration: they have to spread out their harvest due to a limiting drying capacity of around 10 ha of maize per day. One option is to sow various earliness groups rapidly (one farmer sowed 3 groups at a speed of 20 ha/day) or alternatively, to sow 1 group slowly (another sowed one group at a speed of 9 ha per day).

The interviews of farmers helped us to attribute the remaining variability in the classification tree to factors related to farm work organisation. However, we are not able to use these factors to improve the spatial estimation of practices because some of them are not easily accessible on a regional scale, e.g. the drill size, the existence of an on-farm maize dryer, or the harvest organisation.

4. CONCLUSION

This study is the first that has considered conjunctively sowing practice and cultivar earliness choice to investigate a method for estimating their spatial distribution over a region. The results show that such estimation is possible from climatic descriptors of the area and structural farm characteristics that can generally be found in administrative databases. Although the results are specific to the studied area, the methodology developed is generic and it can be fairly assumed that, as shown in this study, it is important to investigate separately geo-referenced indicators for variables related to tactical decisions, such as the sowing starting date and the choice of cultivar earliness groups, and those for variables related to more strategic decisions.

This work provides policy-makers with a better understanding of the spatial distribution of agricultural practices and their determining factors. This is important not only for sustainable water management and planning but also for designing and evaluating sustainable agricultural and environmental policies.

The present work also provides a basis for estimating distributions of practices that can provide, for instance, probabilistic predictions of regional irrigation demand. Although this will require a more sophisticated approach to risk management, it is important from a sustainable development perspective that managers and policy-makers are aware of the level of uncertainty related to the spatial distribution of farmers' practices. This uncertainty may be reduced by developing "practice observatories" and thus improving the quality and availability of databases. The analysis of farmers' interviews conducted in the present study provides some insight as to the variables that usefully contribute to regional databases in maize irrigated areas.

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