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# Evidence for weed quantity as the major information gathered by organic farmers for weed management

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**Abstract** The present major agricultural issues are to feed the world and reduce negative environmental impacts. To this end, organic farming appears as a promising solution. However organic farming has several drawbacks such as difficult weed management. Indeed weeds can reduce crop yields. Therefore there is a need for improved decision support tools for weed management in organic farming. An existing weed competition model actually predicts the effect of early multi-species weed density, both on organic wheat yield loss and on the weed density at flowering stage. However main existing models do not take into account the activity of end-users, e.g. farmers, during model design. Therefore we analysed weed information acquisition by farmers using the dynamic environment theory to design a decision support system that takes into account end-users. We interviewed eight French organic farmers. We analysed interview data using a coding scheme inspired by dynamic environment theory. Our results show

that weed quantity was the information most frequently collected by organic farmers both for short- and long-term crop management. This information was compatible with early weed density, the main input of the previously developed models. Findings also show that procedures for gathering information and processing depended on farmer profiles. We also show that a conceptual model based on dynamic situations and a coding structure were appropriate for taking into account the information elaborated by end-users. Finally we propose further design of a decision support system for tactical organic weed management using a participatory approach.

**Keywords** Weed management · Organic farming · Information · Decision-making · Dynamic situations · Farming systems

## 1 Introduction

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**Fig. a** Organic wheat field in the Diois region

Agriculture is nowadays facing the challenge to feed the world while improving product quality and limiting harmful environmental impacts (Tilman et al. 2002). Organic farming, which bans the use of synthetic fertilizers and pesticides, is an option for achieving these objectives. Reganold et al. (2001) showed indeed that organic farming practices provide better environmental impacts and socio-economic benefits compared with conventional agriculture. In organic farming, weed management is one of the key issues for crop production, as weeds are one of the main limiting factors of yield (Bàrberi 2002). Weed biomass, density, diversity and weed seed number are higher than in conventional agriculture (Bond and Grundy 2001; Menalled et al. 2001). Two types of management have been developed to control weeds in organic systems (Bàrberi 2002): (a) preventative long-term control such as diversification of the crop rotation, use of cover crop or soil tillage management and (b) tactical short-term control such as harrowing, hoeing or flaming. Those techniques can be combined to limit weed population in organic crops.

Over the past decades, decision support systems have been increasingly developed to assist farming system management. Initially, those tools were aimed at making agricultural science more accessible to, and useful for, farmers, transferring information from researchers to practitioners (McCown 2002). In order to assist weed management, model-based decision support systems have been largely developed from the early 1990s until now. The oldest decision support systems were designed in order to estimate the benefit of applying an herbicide, based on economic threshold concepts, and were meant for short-term tactical management (e.g. Cousens et al. 1986). On the other hand, recent tools also include the environmental impact of weed control options and long-term strategic approaches based on crop rotation (e.g. Munier-Jolain et al. 2004). So far, most of the decision support tools were designed for supporting chemical weed control in arable crops. Only a few studies have dealt with mechanical controls and/or organic farming (Kristensen and Rasmussen 2002; Neuhoff et al. 2004). WECOF-DSS, a decision support system based on expertise, was developed to assess *ex ante* the potential ability of crops to compete with weeds in organic farming conditions (Neuhoff et al. 2004). It is based on expected general weed abundance, wheat variety characteristics and crop management over the rotation. It is thus dealing with medium and long term weed management and does not take into account ongoing observed weed pressure during the crop cycle for further tactical weed control.

Recent studies have shown that farmers' resistance to taking up decision support systems was often related to their lack of user friendliness (Parker 2004; Wilkerson et al. 2002). Even if some decision support systems developed for agricultural management have been successful, many of them were never used due to their complexity (Cox 1996; McCown 2002). Other

decision support systems were ignored by managers because they did not fit with how managers make decisions and even when they were used, it was not in the way their designers had anticipated (Jakku and Thorburn 2010). Involving stakeholders in the designing process of a decision support system might help for greater use and success of the tools (Cox 1996; Jakku and Thorburn 2010; McCown 2002). Indeed, designing decision support systems might require not only knowing biophysical processes, but also decision-making processes, and the objectives and constraints of targeted users (Chatelin et al. 2005). In the case of weed management, the designers do not systematically specify in their papers who the targeted users of the decision support systems are. Only a few studies actually involved users in the designing process (Parsons et al. 2009), transferred decision support systems to users (Munier-Jolain et al. 2004) or analysed the use of the decision support system (Rydahl and Boejer 2007).

Recently, we developed two simple within-season models to predict the effect of an early multispecies weed population on organic winter wheat yield loss and on the size of weed populations after mechanical control (Casagrande et al. 2010). Depending on total weed density at wheat tillering stage and mechanical weeding application, the models estimate the probability of reaching a given wheat yield and a given weed density at wheat flowering stage. Thanks to a single input data, namely weed density, it provides information that could be useful to farmers for field diagnosis and triggering technical operations such as mechanical weed control and/or adjusting N fertilization. Nevertheless this model is not part of a decision support system yet. Analysing decision-making processes related to organic weed management is crucial before designing a decision support tool for tactical weed management based on the models developed by Casagrande et al. (2010). Up to now decision-making processes related to weed management have been little studied. Macé et al. (2007) showed that conventional farmers considered three time-scales for weed management: the current year, the rotation and the long term. But they did not study the information used by farmers for weed management. In organic farming, weed management is more complex than in conventional farming because of (a) the higher weed pressure, (b) the lower efficiency of mechanical control compared with chemical control and (c) the interaction of weeds with other factors that limit crop growth and that cannot be easily controlled such as N availability. The decision-making processes and the related information used by farmers that lay behind the complexity of organic weed management have never been addressed. Even if decision-making processes and information management have been previously studied, how information is gathered has been poorly addressed. Indeed, when analysing decision-making processes, information that is collected by the farmer is specified and considered as an

indicator to trigger technical operations according to a set of rules. Nevertheless, the way farmers gather and process information is usually not described. Recently some studies proposed conceptual frameworks that represent information flows and information management on farms (Magne et al. 2010; Solano et al. 2003; Sorensen et al. 2010). The objective of those studies was to describe the way farmers organize and use information for decision-making and to model information flows on farms. They did not provide methodological tools for studying the way farmers gather information for decision-making. In order to check the adequacy of the weed density indicator proposed by Casagrande et al. (2010), it is necessary to focus on what information organic farmers gather for crop management.

Dynamic environment theory provides a basis for analysing the process by which farmers gather information from fields and process the information. This theory is drawn from the domains of cognitive engineering and cognitive ergonomics. Dynamic situations are situations where the human operator only partially controls the environment (Hoc and Amalberti 2005). A cropped field could be regarded as a dynamic situation where biological processes, such as crop biomass growth or seed germination, are considered as an autonomous system, independent of decisions made by the farmer (Sorensen et al. 2010). However, the farmer can partially control some processes. For example, weed infestation might be controlled by mechanical weeding operations. With the ban of synthetic fertilizers and pesticides, control options are more complex in organic systems compared with conventional systems. Dynamic situations are characterized by: (a) complexity, (b) control and supervision, (c) process speeds such as the crop growth rate and (d) uncertainty. Control and supervision activities imply a monitoring of field conditions throughout the crop cycle. For example weed population could be monitored for further planning or immediate decision-making such as operation triggering. This field monitoring activity helps the farmers to update their representation of the environment from short to mid or long-term management. In order to control dynamic situations, a management loop with five elementary activities has been identified: (a) information elaboration, (b) diagnosis and planning, (c) decision-making, (d) execution and (e) execution control. In this loop, internal information, external information or the combination of both might either directly involve decisions and trigger technical operations or be used for updating field diagnosis. Information elaboration activity encompasses here all the processes by which farmers acquire information. In addition to the description of dynamic environment theory, Hoc and Amalberti (2005) provided an analytical framework for studying the activity of information elaboration.

Up to now, no decision support system focused on short term tactical weed management in organic wheat production (*Triticum aestivum* L.) has been made available for farmers.

With reference to McCown's classification (2002), we are aiming at developing a 'small' tool for aiding farmers' tactical decisions. Early weed density was significantly related to yield loss and late weed density (Casagrande et al. 2010), and was therefore in turn an adequate indicator for modelling. Nevertheless this indicator of weed pressure might not be easily accessible to farmers. There is thus a need for further research on farmers' practices before embedding this model in a new decision support tool. According to Cox's statement (1996), we consider that the model we have already developed (Casagrande et al. 2010) could be a preliminary step in developing a new model-based decision support system for use by organic farmers. We aimed at moving from a reductionist modelling approach towards a holistic approach that would take into account farmers' practices. To do so, we analysed the way eight organic farmers gathered and processed information relative to weeds for crop management. The data analysis was carried out using a method inspired by the coding scheme presented by Hoc and Amalberti (2005). First, we assumed that the information relative to weeds used by organic farmers for crop management was different from the indicator identified by researchers, namely weed density. Moreover, the information acquisition and processing might depend on a farmer's profile. We also assumed that dynamic environment theory was adequate to identify and analyse farmers' information. Finally we assumed that taking into account end-users and building on farmers' information could be helpful in designing a suitable decision support system for weed management in organic winter wheat.

## 2 Materials and methods

### 2.1 Case study area

We carried out the study from 2005 to 2008 with 8 organic farms located in the Rhône-Alpes region in south-eastern France (ranging from 44°22' to 45°55'). The farms we chose give a good representation of the pedoclimatic diversity of the region. They are located in one of the three following sub-areas: the Diois region, a hilly sub-area near the mountainous area of Vercors where farming systems are diverse (livestock, arable crops and perennial systems), and two flat sub-areas mostly specialized in arable crops. The latter two sub-areas are the Plain of Lyon and the Plain of Valence which are respectively in the north, with sub-atlantic climatic conditions, and in the south of the region, with Mediterranean climatic conditions.

We aimed at studying farms that differed in the processes used to acquire information. To do so, we selected farms with different characteristics. The eight farms varied according to their location, their size and the proportion of wheat in the total area, the year they converted to organic farming, the averaged early weed density in their wheat fields, their

**Table 1** Main characteristics of the investigated farms

Farm <sup>a</sup>	A3	B2	C2	D3	E2	F1	G2	H2
Location	Plain of Lyon	Diois	Diois	Diois	Plain of Valence	Diois	Plain of Valence	Plain of Valence
Total area (ha)	160	60	43	70	170	31	39	76
% of wheat area	11	33	40	29	29	36	23	33
Conversion year	2000	1992	2001	1998	1999	1984	1998	2000
Early weed density (plants m <sup>-2</sup> ) <sup>b</sup>	73±36	92±88	105±79	20±7	14±12	434±556	74±41	35±48

<sup>a</sup> The number following the letter represents the farm type with regard to farm flexibility (1, 2 or 3)

<sup>b</sup> Early weed density was calculated as an average value of measured total weed densities on at least eight quadrats of 0.25 m<sup>2</sup> for each farmer in 2005 and/or 2006

farm flexibility and their farming system (Table 1). Indeed, the set covers the range of the main regional farming systems. Farmers A, B, D, E, G and H are intensive grain growers that produce cereals using output organic fertilizer and include fodder legumes, grain legumes and spring crops in their rotations. Farm C is a mixed farm with crop rotation including almost 60% of fodder legumes as crops preceding wheat and using their own organic manure. Finally, farm F is an extensive arable farm that produces cereals with limited nitrogen input, and includes fodder legumes, grain legumes and spring crops in its rotation.

Farm types were assigned to the eight farms according to the flexibility classification proposed by David et al. (2010). The numbers in the farm codes stand for the farm type, e.g. A3 belongs to Farm Type 3 (Table 1). Farm Type 1 is characterized by ‘activism and collective willpower’. The strong social integration of the farmer provides flexibility in the labour force. The numerous responsibilities of the farmer have hindered the development and technical supervision of his farm. Type 2 farms are ‘family farms with technical management’. Flexibility in those farms relies on increasing capital, labour availability and off-farm income. This type of farmer is seeking technical improvement while maintaining the family dimension of the farm. In our case study, Type 2 farmers are the intensive grain growers previously described. Type 3 farms are characterized by ‘diversification and opportunism’ and their flexibility is based on constantly finding new sources of income.

We limited the number to eight farms because we attempted to develop an initial in-depth understanding and coding structure for a further larger set of less comprehensive interviews.

## 2.2 Analysing farmers’ information acquisition process through interviews

With reference to the work of Hoc and Amalberti (2005), we aimed at clarifying the way farmers elaborated their information. The objective was to identify the conditions and goals of information acquisition. We carried out two rounds of non-directive individual interviews with the eight selected farmers. Non-directive interviews were done without any set format but the interviewer used some key questions formulated in advance. This type of interviews allowed questions based on the interviewee’s responses and proceeded like a non-threatening conversation. We limited the study to eight farmers because each round of interviews was extremely time-consuming (half a day per farmer).

The first round of interviews was carried out ‘indoors’ (semi-structured interviewing technique) and aimed at gaining a better understanding of the farmer’s wheat crop management with a special focus on weed management. This round of interviews was carried out with open and neutral questions,



**Table 2** Guidelines for the first non-directive interviews

Objective	Interview guidelines
Presentation of the interviewers	'I am an agronomist. My research focus is...'
General description of the farm (area, labour, future projects, date of conversion to organic farming, advising network)	'What is the relative importance of the different crops in your farm? What are your projects for the future?'
Identification of the importance of wheat and the monitoring of this crop	'Who is in charge of wheat management? How do you monitor your fields?'
Description of wheat management	'How do you usually manage wheat along the crop cycle? Let's start with describing the sowing operation...'
Identification of information relative to weeds	'According to what you just explained, you need different types of information...'
Identification of management of unusual situations	'We just described your routine management, what happen if it is a rainy year?'

so that the farmer would describe: (a) general objectives for his farming system and for wheat crop, (b) wheat management and (c) the way he managed uncertainty and unexpected situations. Guidelines for the first round of non-directive interviews are available in Table 2. This first round was meant to identify the conditions and goals of information acquisition as well as decision-making processes.

Based on the results of the first interviews, the second round of interviews was carried out 'outdoors' (in farmers' wheat fields) and aimed at characterizing how farmers collected information in the field, i.e. at detailing the conditions of information elaboration. We thus accompanied them into their wheat fields and asked them to explicitly describe what they were doing while they were collecting information relative to weeds. Each interview (rounds 1 and 2) was fully recorded and transcribed for further analysis.

### 2.3 Description of the coding scheme

In order to analyse the transcripts of the interviews and understand the farmers' information acquisition process we built on the method proposed by Hoc and Amalberti (2005). This method provides a 'coding scheme', a kind of analysis skeleton, which we translated to our domain of application in order to analyse information gathering and processing. In the case of information acquisition, the objective was to distinguish variables that described different dimensions of the activity. Based on the results of the interviews and our knowledge of weed management in organic farming we built a coding scheme relying on eight variables related to the following questions: 'What?', 'Why?' and 'How?' (Fig. 1).

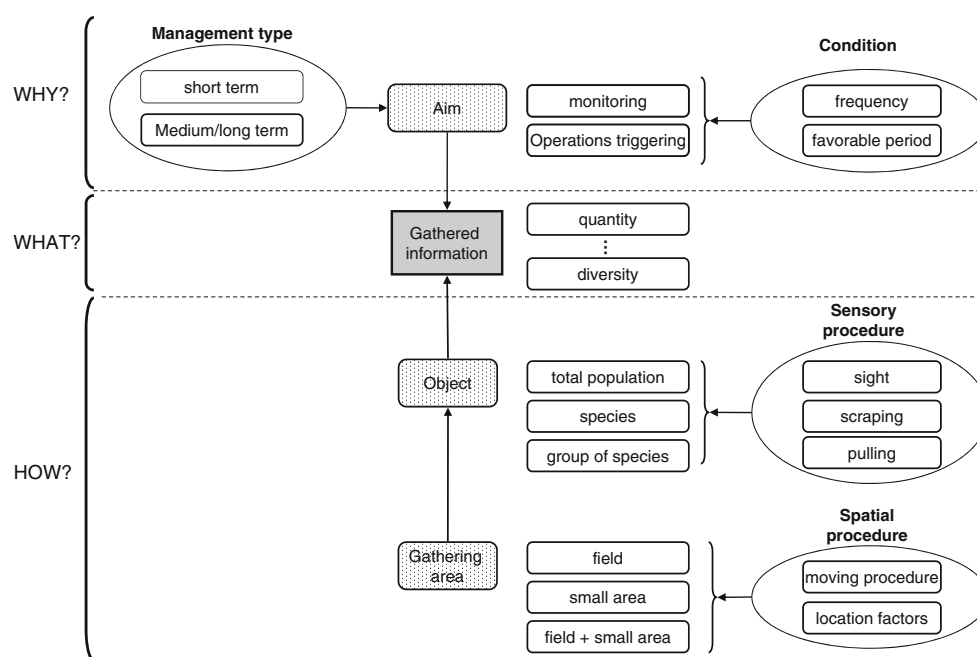
The 'gathered information' variable described the kind of information collected and was the central variable of the coding scheme ('What?' in Fig. 1). We paid attention to the precise way in which information is gathered, whether it be in relation to quantity, quality or competition (Table 3). In the case of quantitative information types, weed quantity refers to the amount of weeds relative to the area, weed height to their

absolute size, weed development to the weeds' level of growth, weed cover to the soil area covered by weeds and weed volume which combines area, height and potential biomass. The farmers assessed those quantitative variables by observation but did not measure them precisely. Weed quantity could thus vary from a low to a high level. In the case of qualitative information types, weed diversity refers to the variety of encountered species, weed root development to the rooting level and weed stage to the growth stage. Finally competitive information types compared weed characteristics with wheat characteristics: weed emergence, weed height and weed density compared with the corresponding wheat variables.

Three variables were used to describe the reason why information was gathered and processed ('Why?' in Fig. 1). The 'aim' refers to why the information is acquired, namely to trigger a technical operation or to monitor the field to update the farmer on the state of the field. The 'management type' refers to the time horizon of management, i.e. short or medium/long term. The 'condition' refers to the necessary conditions for acquiring the information. Conditions for information acquisition could be pre-planned according to a defined frequency of observation or dependent on a favourable climatic period.

Finally, four variables were used to define the acquisition process ('How?' in Fig. 1). 'Gathering areas' refers to locations in the fields where the farmer gathered information: a small area within the field, the whole field or both. 'Spatial procedure' refers either to the way information was collected spatially or to factors relative to the location of the gathering areas (Fig. 1). When referring to the whole field, the farmer's movements in the field were specified and in the case of small areas, location factors were specified. Small areas were specific locations in the field known by the farmer to be usually infested by weeds and thus representative of maximum weed pressure. Location factors described the characteristics of the area that explain its infestation according to the farmers, such as previously infested area, wheel tracks, dry areas, soil compacted areas, inter-rows or wheat-free areas. In addition to specifying the characteristics of the gathering areas, farmers also described

**Fig. 1** Coding scheme based on eight variables for analysing information gathering. The coding scheme describes different dimensions of information elaboration: the information itself ('What?'), the reason for gathering information ('Why?') and the way information is collected ('How?')



the way they moved in the field when gathering information. For example, they might collect on-field information by entering the field on foot or observing it from a vehicle on the adjacent road. The 'object' then refers to what was observed to obtain the information that was duly assessed. For example, total weed population was observed for assessing weed quantity. Acquiring such information could be achieved using different 'sensory procedures' such as looking or touching.

We thus used the following coding scheme for analysing results from the two rounds of interviews: <gathering area>, <spatial acquisition procedure>, <object>, <sensory acquisition procedure>, <gathered information>, <aim>, <management type>, <condition>. The central variable was 'gathered information' while the other variables helped describe the way this information was acquired. For example farmer D3 declared during the first round of interviews 'I go in the field, I walk around, I look to see if there are weed seedlings and if the weed stage is not too advanced, because harrowing is not efficient on overdeveloped weeds'. This was coded as follows: <whole field>, <walking around>, <total population>, <sight>, <weed stage>, <harrowing triggering>, <short term>, <->.

### 3 Results and discussion

#### 3.1 Information acquisition and processing

##### 3.1.1 Information acquisition: type of information, gathering procedure and information purpose

The interview results showed that farmers gathered 11 different types of information for on-field weed assessment that we

classified as quantitative, qualitative or competitive information (Table 3). Results obtained for the eight interviewed farmers showed great variability in terms of (a) objects and sensory procedures, (b) aims, conditions and management types and (c) gathering areas and spatial procedures.

Whatever information was gathered, the most frequent object was total weed population but information could also be related to other objects such as specific weed species or the weed development stage (data not shown). The sensory procedure applied to the observed object could be of three types: sight, scraping or pulling (Fig. 1). All farmers used at least sight for assessing information and weed quantity was always assessed by sight. Five farmers also pulled weed seedlings to check their potential resistance to harrowing and three farmers scraped the soil surface in order to observe radicles of germinating weeds.

Analysis of the results showed that information was collected for different aims that correspond to different management types (Fig. 1 and Table 3). The reason for gathering weed information could be of two types: field monitoring or immediate decision-making (operation triggering). The conditions in which information was gathered for monitoring were poorly addressed during the interviews probably because monitoring was rarely scheduled. In the case of triggering, information was gathered if the period was favourable to the application of the operation. A favourable period is defined here as the combination of 'permitted period' (timing of a crop operation within the overall work organisation on the farm) with 'feasibility conditions' (conditions needed to carry out an operation on a given day in the considered field/weather context; Chatelin et al. 2005). Our results showed that consistently with the findings of

**Table 3** Diversity of gathered information, number of farmers using them to assess weed infestation on their fields, and their associated aims with regard to their time-horizon management

Information type	Number of farmers	Short term			Medium term				Long term	
		Harrowing	N fertilization	Weed topping	False seedbed	Ploughing	Stubble ploughing	Choice of following crop	Monitoring	
<b>Quantitative</b>										
Weed quantity	8	X	X		X	X	X			X
Weed height	5	X								X
Weed development	3	X								X
Weed cover	2	X								
Weed volume	1									
<b>Qualitative</b>										
Weed diversity	8	X								X
Weed root development	5	X								X
Weed stage	5	X								X
<b>Competitive<sup>a</sup></b>										
Relative weed height	2									X
Relative emergence date	1	X								
Relative number of plants	1									X

<sup>a</sup> Competitive information are relative to wheat crop, e.g. relative weed height refers to the weed height compared with wheat height

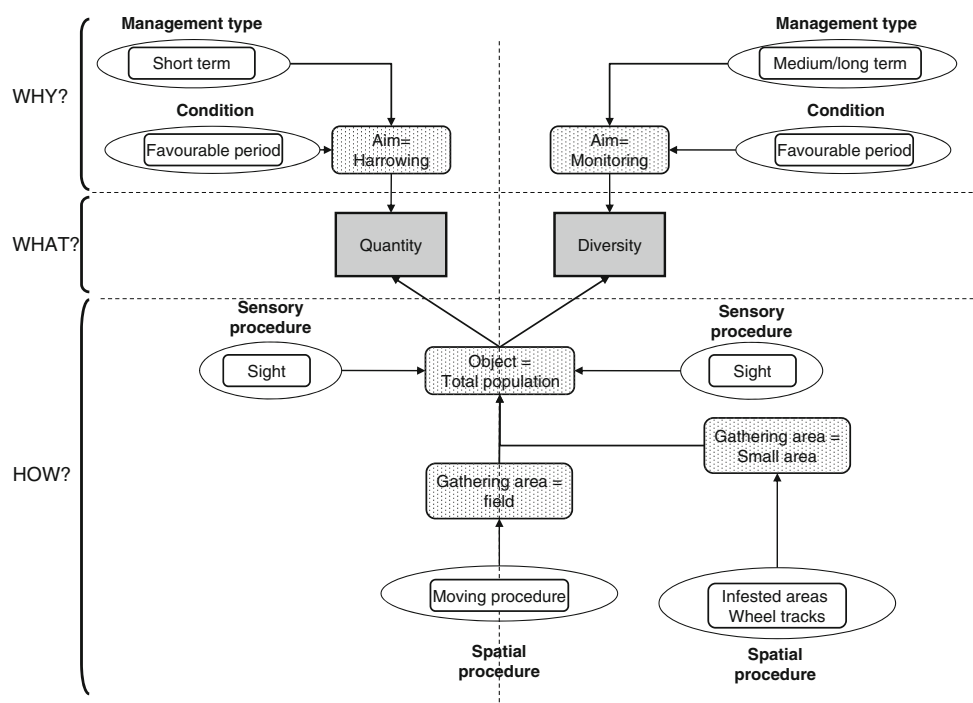
Hoc and Amalberti (2005), in the case of monitoring, collected information was used for updating the farmer’s representation of the state of his field for further long term management (Table 3). In the case of decision-making, the associated management time scale was either short or medium term (Table 3). Short-term management refers to operations having a direct effect during the current crop cycle such as harrowing, while medium-term management relates to operations having a delayed effect or happening later in the rotation such as the choice of the following crop (Table 3). Those management time scales are consistent with the findings of Macé et al. (2007) based on conventional weed management. Indeed, they showed that farmers integrated different management time scales: the current year (short term), crop rotation (medium term) and the long term. The different time scales were associated with different objectives and implied different decision-making processes, as the short-term operations aimed at improving the current crop yield while the medium-term operations aimed at limiting the weed seed bank from growing.

Our study also showed that the choice of the gathering area depended on management type as medium-term operations were mostly related to whole field observations (data not shown). Monitoring activities were mainly based on small area assessment, representative of maximum weed pressure. Some medium-term operations, namely, false seedbeds, ploughing, stubble ploughing and weed topping, only required one information type (Table 3) while other activities such as harrowing, choice of the following crop, monitoring, required the combination of six to eight information types (Table 3). Our results showed that on-field information was not only collected for tactical management but also for medium and long term management (Table 3).

From the set of quantitative on-field information types collected by farmers, weed quantity and weed diversity were the most frequently assessed (Table 3). Characteristics of those information types are shown on Fig. 2. In the case of weed quantity, the total population was assessed by sight at field scale, using different moving procedures depending on farmers (Fig. 2). The main objective for assessing weed quantity was short-term management, namely for triggering harrowing when the period was favourable (Fig. 2). Weed quantity was not only related to total weed population but also to five other objects. Farmers assessed weed quantity not only for the total population but also for specific groups of species such as the family of *Poaceae* or for a particular species considered as prejudicial such as *Cirsium arvense* (L.) *Scopoli*, *Alopecurus myosuroides* and *Avena fatua* L., i.e. creeping thistle, slender meadow foxtail and wild oat. Some farmers also assessed weed quantity only for a given weed stage such as germinating weeds. Results also showed that weed quantity was a generic information type because it could trigger up to 6 different operations (Table 3). Weed quantity could be collected at



**Fig. 2** Characteristics of weed quantity and weed diversity according to the coding scheme. When farmers provided more than one value for a given variable, we showed the most frequent one on the figure



different stages of the crop cycle and combined with other internal information, for instance weed diversity, for decision-making or field monitoring (Table 3). Compared with weed quantity, farmers assessed weed diversity not only on fields but also on small areas such as previously infested areas and wheel tracks (Fig. 2). Weed diversity was generally observed for field monitoring and related to long-term management (Fig. 2).

### 3.1.2 Information processing: combination of gathered information for decision making

The number of information types and their combination for decision-making and monitoring were different from one farmer to another (Table 4 (a) and (b)). We studied in detail the information types that each farmer combined for triggering harrowing operation (Table 4 (a)) and for long-term field monitoring (Table 4 (b)).

In the case of harrowing, we distinguished different farmer profiles (Table 4 (a)). Farmers B2 and C2 collected only one information type, namely rooting or weed stage, to check the potential efficiency of mechanical weeding. On the other hand, A3, F1 and D3 farmers checked the potential efficiency of harrowing by assessing weed root development and also evaluated weed vigour by checking weed height and/or weed development. Finally, farmers E2, G2 and H2 did not assess harrowing efficiency with rooting or weed stage information, informing their decision-making only on the basis of a global weed population assessment such as weed quantity or weed diversity information.

In the case of monitoring activity we also distinguished different profiles of farmers (Table 4 (b)). Farmers D3 and

F1 paid little attention to this activity because they collected zero or one information type (Table 4 (b)). In those farms, diversification of the farming activities (cash crops or vineyards) meant that wheat was not the most important crop from an economic point of view. Moreover, in the case of farmer F1, strong professional commitments might explain why he did not spend time monitoring the wheat crop (Farm type 1, David et al. 2010). In the case of farmer D3, low weed infestation levels (Table 1) might explain the lack of monitoring. Farmers E2 and G2 collected diversity and quantity information to update their field representations. Wheat crop was an important crop for those farmers running arable family farms with technical management (Farm type 2, David et al. 2010). They might have enough expertise to update their field representation with a small amount of information. Those farmers could be compared with the 'seat of the pants' farmers identified by the US North-Central Regional Research team in Farm Information Systems (2000) as farmers relying on their tacit knowledge. Farmers A3, B2, C2 and H2 collected even more information for updating field representation related to weed population and potential competition with the crop. Those farmers could be qualified as 'information hogs' (US North-Central Regional Research team in Farm Information Systems 2000) because they were seeking and using large amounts of information. This group was quite heterogeneous with wheat playing a varying importance in the farm income depending on the importance of other activities on the farm (cash crops, vineyards, livestock or walnut orchard). In the case of farmer H2, recent conversion to organic farming (Table 1) might explain the need for a large amount of

**Table 4** Information gathered by farmers for (a) short-term management: triggering harrowing and (b) long-term management: field monitoring

Information type	A3	B2	C2	D3	E2	F1	G2	H2
(a)								
<b>Quantitative</b>								
Weed quantity	X			X	X	X	X	X
Weed height	X			X		X		X
Weed development				X				
Weed cover								X
Weed volume								
<b>Qualitative</b>								
Weed diversity				X	X		X	X
Weed root development	X	X		X		X		
Weed stage			X	X		X	X	
<b>Competitive</b>								
Relative weed height					X			
Relative emergence date								
Relative number of plants								
(b)								
<b>Quantitative</b>								
Weed quantity		X	X		X		X	X
Weed height		X						X
Weed development	X							X
Weed cover								
Weed volume								
<b>Qualitative</b>								
Weed diversity	X	X	X		X	X	X	X
Weed root development			X					
Weed stage		X					X	
<b>Competitive</b>								
Relative weed height			X					
Relative emergence date								
Relative number of plants	X							

information in order to create his own frame of reference. In the case of farmers A3, B2 and C2, intense monitoring might be explained by high weed infestation levels in their fields (Table 1). Our results showed that farmers collected from zero up to four different information types for monitoring activities. We assumed that those differences between farmers might be explained by farm characteristics such as the economic importance of wheat crop, environmental characteristic such as weed infestation levels or farmer characteristics such as the farmer's skill and professionalism. Nevertheless, these hypotheses need to be confirmed on a larger set of farmers.

### 3.1.3 Comparison of modelling indicator with farmers' gathered information

Previous work (Casagrande et al. 2010) identified weed density as a modelling indicator for informing mechanical weeding

decisions. Because some farmers collected only one information type for harrowing (Table 4(a)), we decided to select only one information type as a promising indicator. By doing so, we aimed at fitting the largest range of decision-making profiles of farmers. Within the set of information types that were identified in this paper, weed quantity was the information type most similar to weed density. Whatever the gathering area (small area or whole field), this information type was the most frequently assessed by interviewed farmers and it was used in the case of short or medium/long term management (Table 3) and especially for weed management operations (Fig. 2 and Table 4 (a)). Those different time scales for weed management are consistent with previous work carried out by Macé et al. (2007) and we showed that a single information type, namely weed quantity, could be used for different time scales. Thus, the modelling indicator, weed density, did not seem far removed from already collected information.

Nevertheless, before proposing a decision support system, two problems need to be resolved: (a) ‘timing’ and (b) ‘translation’. The ‘timing problem’ referred to the possible difference of timing for assessing information. On the one hand, our models (Casagrande et al. 2010) have been developed for a weed density indicator assessed at the end of the wheat tillering stage (around 825 day °C from sowing). On the other hand, this study showed that some farmers regularly assessed weed quantity for monitoring purposes. This ‘timing problem’ raises further research questions: is it acceptable for farmers to assess weed quantity in their fields at the end of the wheat tillering stage, even if they did not plan to do so during this period? Similarly, would the models be usable or adaptable even if weed density is not assessed at the end of tillering stage? The ‘translation problem’ consisted in translating weed quantity into a number of plants per area unit, i.e. weed density (plants m<sup>-2</sup>). Indeed, farmers assessed weed quantity qualitatively as an amount of weeds relative to the area.

### 3.2 Methodological benefits of using dynamic environment theory for studying on-field information acquisition and processing

The coding structure proposed by Hoc and Amalberti (2005) was useful in identifying and analysing farmers’ information acquisition process. The implementation of this approach provided detailed answers to the three questions related to information: ‘What?’, ‘Why?’ and ‘How?’ On the one hand, previous studies related to ‘model for action’ (Aubry et al. 1998) were mainly focusing on identifying the set of rules for decision making. On the other hand, information management studies (Magne et al. 2010; Solano et al. 2003; Sorensen et al. 2010) mainly focused on data organization. In comparison with those previous studies, we really focused on describing and analysing information elaboration. Moreover, we identified different farmer profiles that should be taken into account when designing a decision support tool.

We designed two rounds of open interviews with an on-field round in order to incite the farmers to provide an extensive description of their actions themselves. Nevertheless there was still a lack of precision when describing some information types. For example, ‘weed quantity’ was identified but we

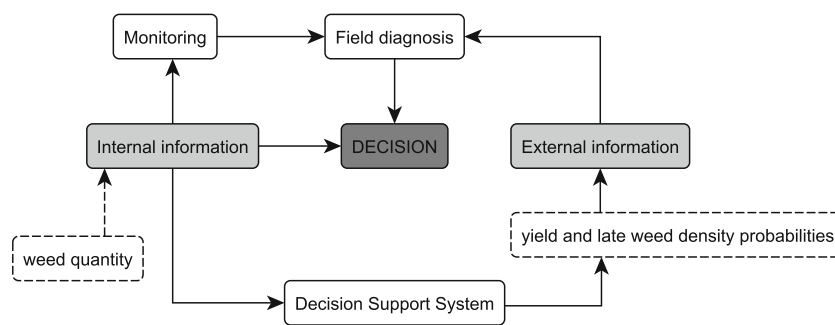
could not systematically characterize exactly how it was estimated by farmers. The study might need an extra round of interviews to complete the results. As we carried out an exploratory study with highly time-consuming interviews the number of interviewed farmers was limited. Nevertheless we aimed at representing as much as possible the diversity of the farming systems in the region (see section 2.1). The farm characteristics influencing the combination and the number of collected information types (section 3.1.2) might also be tested with this larger sample.

Building a coding scheme inspired by industrial studies was adequate for analysing information elaboration in the case of weed management in organic winter wheat fields. Indeed, it provided useful variables for comparing results from interviews. It helped identify common features as well as differences in the results. This scheme could be further used and developed if the sample of farmers was extended. Moreover, this coding scheme was developed for agricultural activities and might be used as a generic coding for a farmer’s decision-making process in the case of different information types and/or management operations.

### 3.3 Towards a decision support system for weed management in organic farming

The first step towards designing a decision support system for weed management in organic winter wheat would be to translate weed quantity, assessed by farmers, into weed density, a modelling indicator. In order to achieve this translation, we thought that we could use pictures representing field quadrats with calibrated weed densities. The farmer could refer to a set of pictures representative of different classes of densities to assess weed quantity in his field, e.g. several pictures of 0–50 plants m<sup>-2</sup> multispecies weed population. Indeed, as Primot et al. (2006) showed that using classes of densities did not decrease the predictive quality of weed biomass models, we do not expect them to notably modify our models’ outcomes. We could also advise farmers to count weeds in their field but a reliable counting method would need to be developed (Colbach et al. 2000) without being too time-consuming.

**Fig. 3** Combining gathered information by farmers with decision support system to help field diagnosis



Magne et al. (2010) described two types of informational resources: internal information, directly collected by the farmer, and external information provided by stakeholders (Solano et al. 2003). For example, identifying weed species on the field produces internal information while references provided by extension services could be regarded as external information. When embedding the simple models developed by Casagrande et al. (2010) within a decision support system, the user would be provided with yield and late weed density probabilities, depending on early weed quantity information and mechanical weeding application. Those outputs could be considered as external information which, combined with other external and/or internal information, could be used for updating field representation and diagnosis and ultimately lead to decisions (Fig. 3). In that case, the objective of a decision support system is not to mimic a farmer's decision-making process but to provide additional information to assist the farmer in making choices while he retains full responsibility for any choices actions he implements.

Further development does not necessarily imply delivering computer-based models because, as stated by Cox (1996), a computer is rarely used as a planning tool. Moreover, in order to avoid costly development, distribution and maintenance of decision support systems, we aim at developing a very simple decision support system that does not require any computer. We would rather provide the users with an easy-to-use tool that simply presents the inputs such as pictures of density classes, and their corresponding outputs such as graphs of the probabilities, in a booklet. Moreover, we chose to provide the farmers with information on the uncertainties (providing probabilities instead of point or mean values) because a decision support system which just predicts a mean, may give the user a false impression of being very precise (Kristensen and Rasmussen 2002).

This paper was the first step of an analytical phase between model designing and decision support system development (Cox 1996). Indeed, further development could involve farmers through a participatory process, creating a connection between stakeholders (farmers, advisors and researchers) for collaboration and co-learning. Running collective workshops with stakeholders might help identify a simple method for assessing weed quantity in fields and provide a way to count weeds compatible with the previous developed models. Using the results of our study as a basis of these workshops is a promising perspective. Involving farmers, advisors and researchers in local workshops should help generate knowledge and innovations by combining local knowledge, i.e. information acquisition and processing, with scientific knowledge, i.e. indicators and models in a complementary or even synergetic way (Neef and Neubert 2010). During the workshops, special attention should be given to the language used by the farmers on the one hand and the researchers on the other hand to describe with different terminologies the same

concept of weed pressure. This type of approach should promote the development of a decision support system that would take into account user specifications and would therefore more likely be used by the stakeholders.

#### 4 Conclusion

This paper presented the results of an analytical phase between model design and its embedment in a decision support system for organic winter wheat management. We mainly focused on describing and analysing the complexity of on-field information acquisition by farmers in order to compare those results with previously identified modelling indicators. This study implemented dynamic environment theory and successfully applied a coding scheme to the data. We showed that using dynamic environment theory was adequate for analysing how farmers elaborate information. Our results showed that the eight farmers in the study had different profiles of information elaboration for immediate crop management and monitoring of their fields. However, weed quantity was an information type always used by farmers in their decision-making processes either for short or medium/long term management. Even if the findings are limited by the small farmer set used, this study gives an example of how information on farmer preferences could inform decision support tools. We identified opportunities for further design of a decision support system conditional on the translation of weed quantity into weed density. Participatory approaches might be useful for finalizing the development of a decision support system for organic winter wheat management.

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