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A Conceptual Model to Design Prototypes of Crop Management: A Way to Improve Organic Winter Oilseed Rape Performance in Farmers' Fields

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1. Introduction

Concerns about the adverse impacts of pesticides on the environment and their inevitable negative side-effects on non-target organisms have been growing since the 1960's. In western Europe, Winter Oilseed Rape (*Brassica napus* L. - WOSR) has to cope with numerous damaging insects (Alford et al., 2003 and Williams et al., 2010), and other diseases and weeds. In conventional farming, as a consequence, an important and increasing use of pesticides is observed in the major french production areas (Ecophyto R&D, 2009, Schott et al, 2010).For the same reasons, WOSR is not widely used in French organic farming as its yield is often low and unpredictable. Nevertheless, this "break" crop is of potential value in terms of market requirements, all the more that stakeholders need regular production to match with the organic oil demand from consumers. The agronomic benefit for the following wheat crop (Kirkegaard *et al*., 1994), and the efficiency of winter oilseed rape as a nitrate trap crop (Vos and Vander Putten, 1997; Dejoux *et al*.,2003) are also well known.

In order to improve the performance of this crop in organic system, the crop management has to combine cultural, biological and mechanical way to reduce pests and diseases. Moreover, many scientists have been arguing, for more than two decades, that the reliance on chemicals could be considerably reduced by making better use of biotic interactions between pests, pathogens, weeds, crop and cultural practices (Chauvel et al., 2001, Meynard et al, 2003, Shennan et al., 2008, Aubertot et al., 2006, El-Khoury and Makkouk , 2010, Lucas , 2011, Mediene et al., 2011). Despite the damaging limiting factors for this crop, biotic interactions have recieved little attention (Valantin-Morison and Meynard, 2008) and most of the studies on this crop underline abiotic factors such as nitrogen and water. Few extensive studies have investigated the effects of the whole crop management on WOSR in organic systems (Valantin-Morison and Meynard, 2008), accounting for the current lack of pesticide-free crop-protection strategies for this crop. Therefore, designing ecologically-

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sound and innovative pest management strategies, mobilizing several techniques, has become a major and urgent issue for organic Winter Oilseed Rape; these strategies should be adapted to diverse climatic and soil conditions.

Among the methods available for designing new crop management systems, model-based methods are often published (Loyce et al, 2002a, b, Chatelin et al., 2005, David et al., 2004, van Ittersum et al., 2003, Le Gal et al., 2010) and reviewed (Ould-sidi and Lescourret, 2011) demonstrating that crop models are useful tools to achieve this goal. Different crop models exist for Winter Oil seed rape (Gabrielle et al., 1998, Jeuffroy et al., 2006) but none of them takes into account the pests damage on the yield and the crop management impacts on pests; none of them has been built as a tool to help in designing free-pesticides crop management. Therefore, agronomic and new technical knowledge has been recently accumulated either by scientists, technical advicers and by farmers themselves. This expert knowledge could be used through the prototyping methodology (Vereijken, 1997), which combines regional diagnosis to identify the constraints and objectives, expert knowledge to build innovative cropping systems and on-farm experimentation to assess and adjust the system. This method can quickly produce innovative cropping systems, and disseminate them among pilot farms (Le Gal et al., 2011); it has successfully produced several innovative crop management systems or cropping systems (Dejoux et al, 2003, Lançon et al., 2007, Rapidel et al., 2009, Valantin-Morison, 2011). In our study case, previous research had produced experimental results on the impact of the date of sowing and nitrogen availability on diseases, slugs and weeds (Aubertot, 2004; Dejoux et al., 1999). Studies of the effect of cultivar on insects (Dosdall *et al*., 1996, 1999; Barari *et al*., 2005; Cook *et al*., 2002, 2006) are also available. Nitrogen fertilisation has received much attention at the end of the 90's and it is now possible to adjust the date and the quantity of nitrogen thanks to several tools (Reau et Wagner 1998 ; Jeuffroy et al., 2006, Valantin-Morison et al., 2003, Rathke et al., 2006). Expert knowledge on mechanical weeding is also available (Lieven et al., 2008). Moreover, a regional diagnosis study in organic WOSR has pointed out the key factors that should be considered (Valantin-Morison and Meynard, 2008): competition for nitrogen due to weeds and nitrogen availability in the system. Despite this, the combination of all cultural practices in a crop management system has obviously received little attention for this crop, except the studies of Dejoux et al., 2003 and Valantin-Morison, 2011 for conventionnal farming.

This paper presents (1) a conceptual model of the effect of cropping techniques on WOSR, based on this knowledge;(2) two prototypes of crop management for organic WOSR designed using this conceptual model (3) the assessment of the agronomic performance of those two crop management systems in a farmers' field network.

2. Materials and methods

2.1 The conceptual model

To elaborate a new crop management system (CMS), scientists had to consider simultaneously cropping techniques, soil-climatic constraints, growers' objectives and their interactions. In this systemic approach of the agro-ecosystem, a conceptual bio-technic model is a useful representation to help in designing new crop management systems. This approach was adapted to organic WOSR, like it has been done for cotton or cacao Rapidel et al. 2006. In our study case, the conceptual model focus on the relationships between crop management, the environment, the crop and the different weeds, pests and diseases.

This conceptual bio-technic model has been designed thanks to the knowledge coming from the regional diagnosis on organic farming (Valantin-Morison and Meynard, 2008) and on conventional farming (Dejoux et al., 2003) and from the factorial experiments enlightening about the effect of different cropping techniques on diseases or weeds (Aubertot, 2004, Dejoux et al., 1999, Ferré et al, 2000). We have also combined the expertise of technical advicer on mechanical weeding (Cetiom, 2008, Lieven et al., 2008) and knowledge of the organic farmers of the network on their own soils, and on weeding techniques. On the contrary of Lancon et al., (2007) and Rapidel et al., 2009, we have not organised an "expert" session, gathering scientists, advisers and farmers, considering that the results of the diagnosis on farmers' fields allowed to design the frame of the conceptual model. Farmers' contribution to the conceptual model was restricted to the incorporation of their know-how on their pedo-climatic conditions and their reaction to the crop management systems proposed. Based on this conceptual model, two prototypes were designed. They were submitted to the farmers, improved according to their advice and tested on their fields; the first one, named "de-synchronization strategy", was based on the avoidance of weeds emergence, disease and slugs thanks to an early sowing, while the second one, named "mechanical control strategy", was based on the destruction of weeds and slugs before sowing and during the autumn thanks to false bed and hoeing. These two CMS aimed at increasing yield performance and reducing pests' impact.

2.2 The experimental design

The network of experiments was spread over 14 farmers' fields, in 12 farms (Figure 1), in 3 regions of France with contrasting climatic and soil conditions (fields M,M,N = Eure-et-Loir in the western Paris Basin; E,B = Puy-de-Dôme in the Center of France ; O,P,Q,R,S = Yonne in the south-eastern Paris Basin). It was studied over a two-year period (2001-2002 and 2003-2004).

As there was not any "reference organic crop management", there was no "control" crop management to compare to the innovative systems. Therefore the two prototypes of crop management systems (CMS) were compared to one another in each site. They were implemented without replicates, on two large plots of farmland (plots sized from 0,5 ha to 2 ha). The two plots were located on a homogeneous area of a same field. The management decisions were based on objectives and decision rules, as recommended by Meynard et al., 1996 and Debaeke et al., 2011. They differed on soil tillage before sowing, date of sowing, plant density, row spacing and mechanical weeding (table 1). Each experiment was named with a letter-figure code, in which the letter is a "field" code and the figure refers to the "harvest year" code (02, 04 for 2002 and 2004 respectively- figure 1). Even if the letter code of the field is the same between the two years (L02 and L04 or B02 and B04), WOSR was not implemented in the same field, because of crop rotation : this only means that fields belong to the same farmer. In 3 cases, farmers tested two soil tillage before CMS: shallow tillage (L02, B02, N02) and deep tillage (L02bis, N02bis, B02bis). Crop management plots, within each experiment, were designated with a little letter-figure code ((a) for the "desynchronisation" prototype and (b) for the "mechanical control" prototype– table 1). Crop management systems were implemented by the farmers while the description of each system were made by the team of researchers. Because of the difficulties to sow turnip rape as a trap crop (availability of the seeds and difficulties of work organisation), only three farmers have tested this landscaping arrangement : L02 and L04 in the west of Paris and B02, B04 in the center of France.

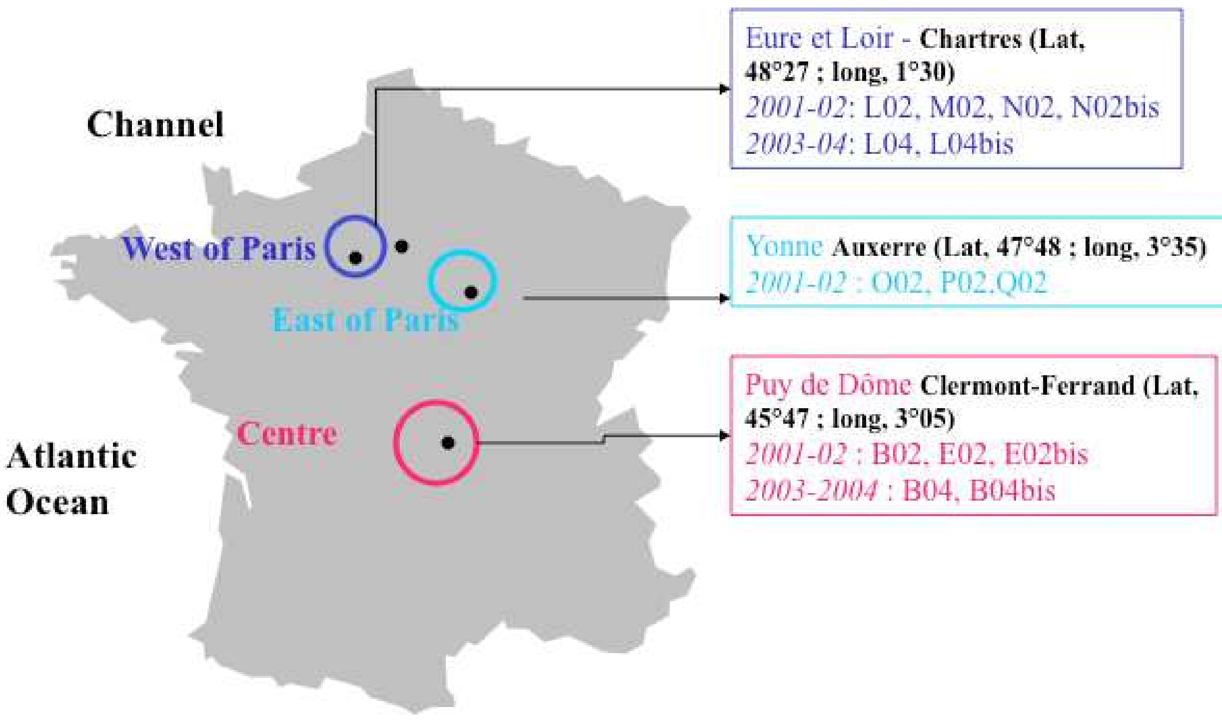


Fig. 1. Map of the fields experienced

2.3 Measurements and observations to assess the agronomic performances of the prototypes

The measured variables were selected to assess the agronomic and economic performances of the prototypes. In order to test whether the objectives assigned to each crop management systems (that are summed up in table 2) were achieved, agronomic measurements and pest damage were made on the crop and on the pests all along the crop cycle : biomass and nitrogen accumulated in the crop and in the weeds, weeds densities, phoma occurrence and severity, and insects' occurrence, yield and its components.

For each plot of CMS, in each farmer's field, whole plants were sampled at four different period of the year: (i) in early winter, before winter drainage and the occurrence of cold temperatures (from early November in the center of France to early December in the western region, which corresponds to a plant growth stage around 19 (Growth stage Lancashire et al., 1991), (ii) in late winter (from the end of January in the center region to mid-February in the western region - growth stage around 21), (iii) at early flowering (Growth stage 65 – beginning of April), and (iv) during pod filling (GS from 71 to 75 – beginning of June). In each field and for each CMS, at each period, samples were taken from six microplots of 0.5 m^2. The plants were counted and the roots separated from the aerial parts after washing. Dry biomass (after 48 hours of drying at 80°C) and the total nitrogen content of green aerial parts and of tap roots (Dumas method) were determined for each microplot sample. The numbers of branches, flowers and fertile pods per plant were counted at the pod-filling stage on 15 randomly chosen plants per microplot. The crop was harvested with a combined harvester, and, for each crop management system, yield was estimated from two samples of 150 m² to 400 m² for each CMS.

Weed infestations were assessed on the six microplots used for plant sampling, at the same dates. We identified the species, counted the individuals of each species and determined the total aerial dry biomass and total nitrogen content of all weeds. Shannon index has been calculated on weeds, which have been identifed until the species. Slugs have been counted on 3 traps per CMS early after crop emergence and later in autumn. Crop damages by pests and diseases were estimated on the sub-samples of 15 plants: we counted the number of plants in which larvae of root maggot, of cabbage stem flea beetle or of rape stem weevil were present. The occurrence of *Leptospheria maculans* (named also phoma or stem canker) in autumn was assessed by counting the number of plants with at least one leaf lesion. At pod filling stage, we counted the number of fertile pods, the number of podless stalks on 60 randomly sampled plants per micro-plot that gives information about the blooming flower abortion linked to the incidence of blossom pollen beetle damage (Nilson et al., 1994) and the number of burst pods in order to assess the pod midges damage.

2.4 Weather conditions for the network

For each field, the nearest meteorological station from either the Meteo France network or the INRA network was chosen. For each period of the crop cycle, the mean temperature and the numbers of days with frost or rainfall are indicated in table 2. The two years were rather similar : as an axample, for the west of Paris Basin, the number of rainy days reached respectiveley in 2002, 192 and in 2004, 176 days. The mean temperatures in the several period were similar between the two years for each regions but he center of France is the colder region in winter : the number of days with temperature below 0° reached 41 days in winter and 2 or 3 days at the beginning of the spring. In none of the regions a water deficiency occurred during winter, but in the Paris Basin, the water deficiencies were rather high during the autumn period specially the second year (table 2). Similarly for the spring period, every region displayed a water deficiency after flowering but with the maximum intensity in the center of France each year. The two years were rather similar in temperature for each region, but during the second year periods, dry weather were longer than in the first year, specially in the west of Paris.

2.5 Statistical analysis

The continuous data such as dry biomass of crop or weeds or nitrogen accumulated were normally distributed (Shapiro-Wilk's test) and the variance heterogeneity was constant (Bartlett test). Therefore we applied standard analysis of variance procedures. Proportions, such as the proportion of plants attacked by insects or diseases,were analysed after an arcsin√ transformation to stabilise variance between groups while the number of leaves counted were transformed with log. A mixed linear regression procedure was used to describe each system variable (crop biomass, nitrogen, weed density) depending on fixed factors (prototypes) and random factors (site and year). All analyses were done with "lme" procedure in R program.

Crop management systems	Prototype (a) = "desynchronisation" prototype	Prototype (b) = "mechanical control" prototype
General principles	-crop vigor (high growth and nitrogen uptake) to enhance crop competitivity against weeds -pest avoidance (slugs, stem canker, autumn insects) - trapping spring insects with turnip rape border strips	-weed avoidance by shifting the period which both cultivated crop and weeds can emerge -crop vigor before winter to reach 8 leaf stage and to reduce the severity of the insects attacks - trapping spring insects with turnip rape border strips
Decision rules on sowing date and organic manure	-Early sowing date : *Before 10th of august* -High amount of organic manure before sowing (objective= 100kg/ha of nitrogen available)	-Normal sowing date : *recommended sowing date for each region* - Destruction of weeds before sowing thanks to false bed - High amount of organic manure before sowing
Decision rules on plant density *	Sow with normal row spacing (17cm) to cover the soil Sow at 80 seeds/m² (high plant density to cover the soil)	Sow with large row spacing (<35cm) to use the mechanical hoe In order to reduce the competition between the plants, sow at 60 seeds/m²
Decision rules on weeding	-When crop reach 3 leaf stage, use the weed harrow	- When crop reach 5 leaf stage, use the weed hoe
Similar decision rules for the two CMS	*Objectives : ensure a good WOSR emergence* Depending on soil type, soil moisture and the equipment available plough (deep work) or disk harrow (shallow tillage) before sowing *Objectives : choice a cultivar in accordance with the whole CMS* Choice of cultivar with the following characteristics: very resistant to Leptosperia maculans, late flowering, reduced susceptibility to stem elongation before winter (in order to reduce the frost risk) and late re-growth ability (Mendel or Pollen). *Objectives : reduction of weed density during crop cycle.* If densities of weeds > WOSR density, use mechanical weeding ; otherwise do no use any tools Depending on soil moisture and tools available on the farm, use decision table for mechanical weeding recommended by technical advisors (Lieven et al., 2008 – www.cetiom.fr) *Objectives : Trap insects* Depending on the sowing tools and the field area, implement a border strips of forage winter turnip rape all the field around.	

Table 1. description of the decision rules for each crop management system.

Year	Region	Period	Mean temperature	Number of days below 0°C	Number of days with rain fall	Water deficiencies
2002	center of France	during autumn	13.7	0	34	23
		during winter	2.7	41	55	53
		regrowth-flowering stages	6.4	2	9	-38
		end of flowering-harvest	11.9	0	46	-143
	west of Paris Bassin	during autumn	16.3	0	50	-41
		during winter	4.1	8	50	80
		regrowth-flowering stages	8.7	0	47	11
		end of flowering-harvest	14.6	0	45	-155
	East of Paris Basin	during autumn	16.1	0	43	-10
		during winter	4.1	27	44	46
		regrowth-flowering stages	9.5	0	5	-60
		end of flowering-harvest	15.7	0	72	-125
2004	Center of France	during autumn	13.7	0	45	47
		during winter	2.7	41	77	232
		regrowth-flowering stages	5.7	3	28	22
		end of flowering-harvest	12.4	0	29	-239
	west of Paris Basin	during autumn	15.6	0	29	-122
		during winter	5.7	7	72	346
		regrowth-flowering stages	6.1	5	42	22
		end of flowering-harvest	13.6	0	33	-117

Autumn was defined as the period from sowing to the first 5 successive days with Temperature below 0°C
Regrowth was defined as the first day of the 5 successive days with temperature above 0°C.
End of flowering was considered as the 30th of april

Table 2. Climatic characteristics of the different regions during the period of experiment.

3. Results and discussion

3.1 The conceptual bio-technic model of a WOSR crop

We considered the crop and the different pests (weeds, diseases, slugs, insects) to be the biological system influenced by environment and by the technical system (crop management) (figure 2). This conceptual model was not designed to be exhaustive but it highligths the main interactions between the crop management, the plant population, the pests (weeds, insects, slugs and diseases) and the environment which helps in understanding the functionning of the "agro-ecosystem". It points out the main limiting factors, that has been identified in the previous study (Valantin-Morison and Meynard, 2008) and by farmers (insects such as cabbage stem flea beetles and pollen beetles). Therefore, the focus of the biological system is clearly on the plant-pest (insects or pathogens or weeds) interactions. It is composed of two compartments: the technical system and the biophysical system. The technical system is a combination of cropping techniques which act individually or in interaction with other ones (for example date of sowing and nitrogen supply interact on growth, competity against weeds ans stem canker development, see below). The biological system is influenced by climate (but not represented) and by technical system. In the biological system three compartments are distinguished : crop, pests and yield components, with each being represented by one or several variables.

Considering the previous study on organic WOSR by Valantin-Morison and Meynard (2008), the main limiting factors are weeds and nitrogen. The other limiting factors were slugs and 3 insect species : cabbage stem flea beetles (*Psylliodes chrysocephala*), rape stem weevil (*Ceutorhynchus napi*) and pollen beetle (*Meligethes aeneus*). But these limiting factors were rather rare in our fields' network (Valantin-Morison et al., 2007) and they were mainly mentionned by farmers and technical advisors. Depending on the type of pests, the damage could be significant on crop vigor (slugs) or on the number of the branches (cabbage stem flea beetles and rape stem weevils) or on the number of flowers (pollen beetles). We will describe the relationships between the technical system and the biological system for each limiting factor (figure 2).

In arable crops, weed demography and weed species are known to depend mainly on cropping history of the field and specially crop sequence and tillage interactions (Mediene et al., 2011 and Chauvel et al., 2001). Although few studies have dealt with the effect of soil management on weed emergence in WOSR, shallow tillage has been shown in corn and wheat crops to result in a larger weed seed bank than ploughing (Barberi and Lo Cascio, 2001; Feldman et al., 1997). Weed emergence flushes in crops can also be avoided or reduced by combining a delay of sowing to let the first germination occur before sowing (Chauvel et al., 2001) and a soil tillage before sowing to destroy the weed flushes. During the crop cycle, two categories of cultural mananagement operations could be used: (i) those reducing the number of weeds by chemical and physical control (see mechanical weeding in figure 2) or by shifting the period which both cultivated crop and weeds can emerge (see timing in crop cycle in figure 2) and (ii) those increasing the crop competitivity for light and nutrients (see crop vigor in figure 2). Numerous mechanical tools exist now to destroy the weeds; they work the inter-row space or inside the crop rows and are often efficient on young weed seedlings in dry soil conditions (Kurstjens ans Kropff, 2001). Mechanical weeding, because of its lower efficiency compared to herbicides, must be associated to other cultural operations. Maximising crop competitive ability can be maximised thanks to a combination of early sowing, dense sowing and high nitrogen availability during autumn. Winter oilseed rape is known to have a weed suppressive potential even in cover crop utilisation and specially when nitrogen is largely available in the soil (Kruidhof et al., 2008), thanks to its ability to catch nitrogen. Moreover, the date of sowing has been reviewed to have a major effect on plant growth at early stages (Dejoux et al., 2003) and the competitiveness of the crop (Whytock, 1993; Ferré et al., 2000). Nevertheless, there is an interaction between sowing date and soil nitrogen availability (Dejoux et al., 1999; Ferré et al., 2000). In cases of low levels of soil nitrogen, crops sown early suffered nitrogen deficiency earlier than crops sown on the normal date. This could have a direct effect on the aerial growth and competitiveness of the crop, opposite to the effect observed in cases of high soil nitrogen availability. Despite high sowing rate is rarely reported to increase the weed supressive ability (Dejoux, 1999, Kruidhof et al., 2008), plant density could have a significant effect on weed biomass and weed density especially when high weed density and large range of weed types are observed (Primot et al., 2005).

The effect of weeds on arable crop yields' is largely documented (Lutman et al., 2000, Vollmann et al., 2010, Vasilakoglou et al., 2010). In the study of Valantin-Morison and Meynard (2008), WOSR yields in organic system appeared to be strongly related to the variations of the number of flowers and the numbers of branches. Weed competition during autumn and nitrogen availability in soil during autumn were the principal factors accounting for the high variability of WOSR biomass at the beginning of winter and the number of branches.m^{-2} at the end of winter.

Similarly to weed, soil-borne diseases occurrence and severity on major crops are often related to crop sequence and soil tillage, this combination playing a crucial role by affecting the sources of primary inoculum (Meynard et al., 2003). Considering cultural control during the crop cycle, crop management could reduce the crop vulnerability, that is in the case of disease the probability to be contaminated by primary inoculum. One of the strategies underlying pest avoidance is the desynchronization between crop susceptibility periods and the biological cycle of pests. In WOSR, the early sowing date permits to shift the periods of highest crop susceptibility to *Leptosphaeria maculans* (Aubertot, 2004). As the primary inoculum of *Leptospheria maculans* generally peaks between September and December (West et al. 2002), early crop sowing leads to a lower risk of infection just after emergence than other sowing dates. Another strategy to reduce crop vulnerability is based on the reduction of Leaf Area Index (LAI) of crop to cut down the number of leaf lesions, which will decrease the disease severity (Aubertot, 2004). Moreover indirect effects of nitrogen can also be foreseen to explain the general relationship (e.g. Agrios et al., 1997) between high N level and diseases: modifications of micro-climate due to high LAI; higher sensitivity to frost that can create wounds easing disease development. Endly, the effect of disease on arable crop yields is also well known and it is often related to a reduction of the grain mass.

Considering insects, the interaction between crop management, plants and pests is rather different since the ability of the pest to choose the host plant plays a crucial role. The cultural control is based on two strategies: (i) pest avoidance thanks to the desynchronization between crop susceptibility periods and the biological cycle of pests and (ii) pest repellent thanks to host plant quality manipulation. A complementary approach aims at enhancing the natural ennemies thanks to crop management and landscape management, but it is not concerned in this description.

Pest avoidance thanks to early sowing is well known: Dosdall and Stevenson (2005) demonstrated that the sowing date of oilseed rape strongly affects flea beetle (*Phyllotreta cruciferae*) damage. Indeed, the damage was greater on spring-sown oilseed rape than on plants sown in the autumn. Flea beetle feeding damage to oilseed rape apical meristems can prevent a compensatory response, but by the time of greatest injury, winter oilseed rape had well-developed, enlarged apical meristems making them less susceptible to damage. But sowing date effects can be antagonistic when considering different pest populations. In this way, Valantin-Morison et al. (2007) have shown that sowing oilseed rape early tended to increase root maggot (*Delia radicum*) damage, whereas it was associated with a lower level of attack by cabbage stem flea beetle. Dejoux et al., 2003 has also noticed that very early sowing crops were not destroyed by slugs on the contrary to normal sowing crops, less developped and so more vulnerable when the weather becomes favourable to slugs. The capacity of insects to identify a host plant suitable for its feeding and reproduction depends on the morphological and/or metabolic characteristics of the plant. The pollen beetle locates its host plant through visual and olfactory signals (Evans and Allen-Williams 1989, 1998). The beetles are principally attracted by the yellow colour of the flowers and by certain chemical signals released by the plant. It has been shown that degradation products of glucosinolates attract insects specialised on cruciferous host plants (Feeny et al. 1970, Finch 1978, Free and Williams 1978). Based on the hypothesis that the production of glucosinolates by cultivars of winter oilseed rape (WOSR) and other Brassicaceae may attract pollen beetles, many studies have focused on the effects of host plants on insect orientation and feeding (Bartlet et al. 2004), oviposition behaviour (Borg and Ekbom 1996), and egg production of the pollen beetle (Hopkins and Ekbom 1999). Turnip rape (*Brassica rapa*) has been found to attract more pollen beetles in both laboratory and field conditions (Hokkanen 1989, Cook et al. 2002, 2006, Valantin-Morison and Quéré, Rusch and Valantin-Morison 2009). The same effect has been reported for other oilseed rape pests such as cabbage stem flea beetle (*Psylliodes chrysocephala*) (Bu̇chi 1995, Barari et al. 2005) and cabbage seedpod weevil (Carcamo et al. 2007). Turnip rape is thus often used in this particular situation as a so-called trap crop. Simulations using a spatially explicit individual-based model show that for herbivores that actively immigrate from a nearby source via the field edge, a surrounding border trap crop is the optimal arrangement (Potting et al. 2005). For more details one can refer to the review on biological control in Oilseed rape (Rusch et al. 2010a). Endly, the impact of insects on yield is not well documented for WOSR except for pollen beetles (Hansen et al., 2004) but we could propose several hypothesis, related to the impact of each pest on the yield components: cabbage stem flea beetles reduce the crop biomass in autumn and the number of branches during re-growth stages, pollen bettles reduce the number of flowers, stem weevils reduce the number of branches, resulting in the decrease of the number of grains.

One can notice that the interactions — between cultural operations, or between cultural operation and crop status — are important and taken into account in this scheme (ie interaction between sowing date and nitrogen supply on weed suppressive ability of the crop). In addition, one technique can be advantageous to limit one category of pest populations (early sowing and cabbage stem flea beetle), but can be detrimental to the control of other (early sowing and root maggot). Instead, many of those interactions and antagonistic effects must be taken into account when designing pest management strategies thanks to this type of conceptual framework of integrated crop management.

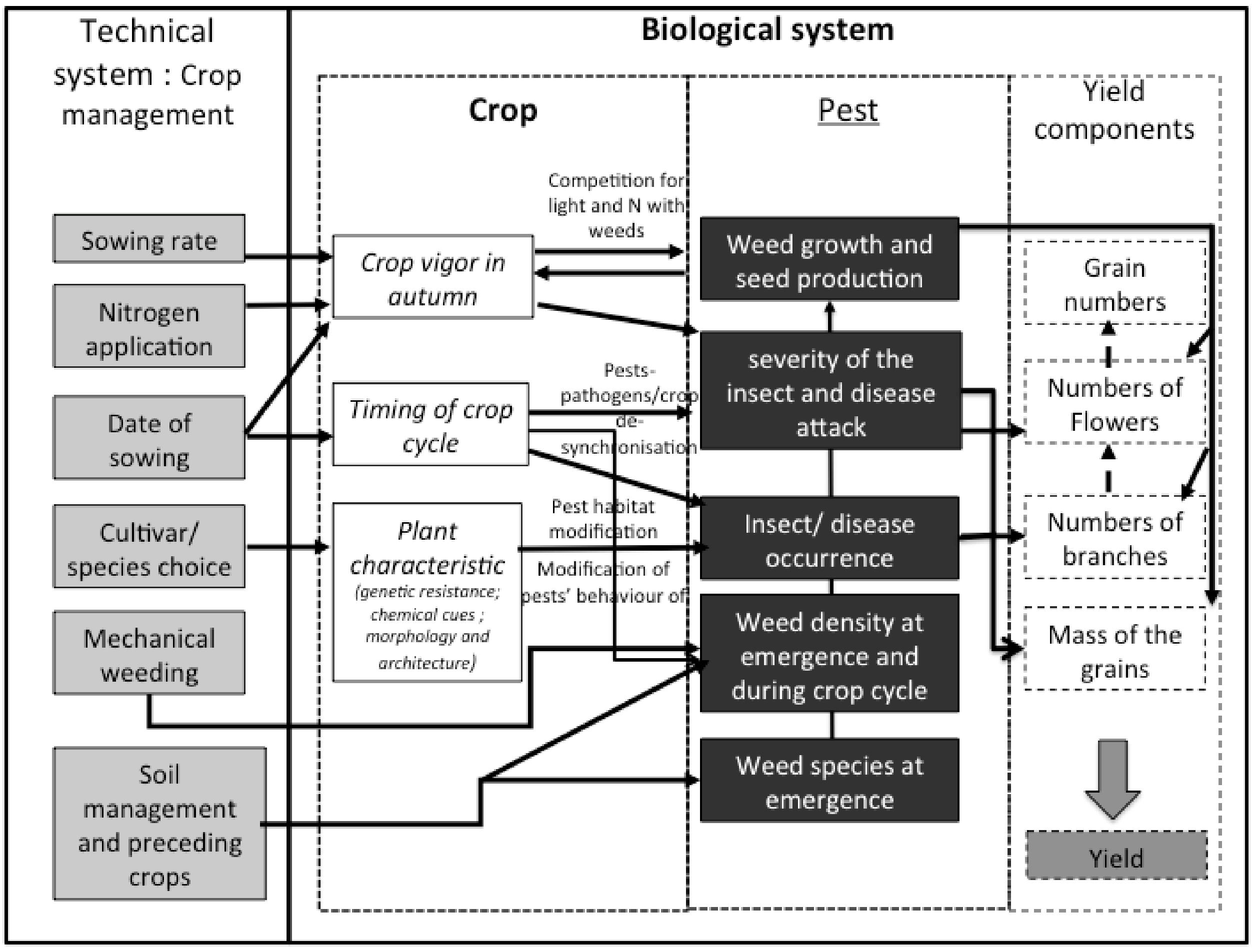


Fig. 2. Schematic representation of the Conceptual bio-technic model of the relationships between crop management, plant and pests. Mecanisms which related the interaction between technical system and crop / pests system are explained on the arrow.

3.2 Description of the crop management systems

In accordance to this conceptual model, two theoretical prototypes have been designed and tested on farmers' fields. They were built in order to limit the impacts of the main limiting factors, i.e nitrogen deficiencies, weeds and insects, mentionned before, in order to maximize yields and gross margins. Following the protoyping method, the cultural operations were combined to design theoritical crop management system (CMS). The prototypes were described either by the principles linked to the combination of cultural operations, by the order of implementaion of the cultural operations and by decision rules for some specific and single cultural operation.

Prototype (a), named "desynchronisation strategy", was built on three principles. (i) The first one was to enhance crop vigor during autumn, (ie crop biomass and LAI) in order to enhance the weed suppressive ability of the crop and to reduce the severity of the insects and slugs attacks; (ii) the second one was to desynchronize pests attacks (slugs, cabbage stem flea beetle and *Leptospheria maculans*) occurrence and susceptible stages of the crop. (iii) Endly, since pest avoidance might be efficient only on autumn insects, we aim at trapping spring insects. Suitable combination of individual cultural practices were deduced from the relationships between the crop variables in the biological system and the technical system. The crop management system was based on a combination of early (before 10th of august) and dense sowing, with organic manure or effluent before sowing. Turnip rape border strips were sown to trap spring insects, and a late flowering cultivar oilseed rape,was chosen to maximise the differences of stages between the border strips and the center of the field). The specific characteristics of the cultivar resulted in a very narrow choice of cultivars: very resistant to Leptosperia maculans, late flowering, reduced susceptibility to stem elongation before winter (in order to reduce the frost risk) and late re-growth ability; we used the two same cultivars in all trials (Mendel or Pollen, depending on the region and on the year). Soil tillage was reduced before sowing, linked to the short period between the cereal harvest and early rape sowing. But we were unable, based on our scientific knowledge and technical know-how, to formulate rules that could be applied nationwide. In each trial, decisions were taken jointly by the farmer and the research team, so as to ensure a high level of crop emergence. Generally, the soil was tilled immediately after harvest of the previous crop to bury stubble and straw and to allow the emergence of cereal volunteers. The type of implement used depended on soil type, soil moisture and the equipment available: plough (deep work) or disk harrow (shallow tillage). Shallow tillage is more often used in the first year than in the second one. Endly, concerning the mechanical weeding (type of tools and date for weeding) we used a decision table formalised by technical advisors (Lieven et al., 2008 ; www.cetiom.fr), which takes into account crop and weed stages, and soil moisture. The CMS (a) is detailled in table 2.

Prototype (b), named "mechanical control strategy", was built on three principles: (ii) The first one was to shift the period which both cultivated crop and weeds can emerge; (ii) the second one was to reach 8 leaf stage before winter and to have enough crop vigor during autumn to reduce the severity of the insects attacks; (iii) the third one was to trap spring insects. The sowing date of CMS (b) was a normal one, i.e. about 20 days later than CMS (a), with organic manure before sowing. The soil was tilled immediately after harvest of the previous crop to bury stubble and straw and to allow the emergence of cereal volunteers (plough or disk harrow). After this initial tillage the soil was turned by numerous shallow tillage operations (disk harrow or cultivator) in order to destroy emerging weeds, The crop was sown at a medium density, with large rows, to permit the weeding harrow. As in prototype (a), a late flowering cultivar was associated with turnip rape border strips. The cultivar choice was based on the same characteristics as CMS (a) and the same Pollen and Mendel cultivar were implemented, depending on the region and the year.

The success of these 2 prototypes underlies on three main hypothesis that we have examined with data collected in farmers' fields:

Hypothesis 1: Prototype (a) allows a better and quicker growth of rapeseed in autumn which permits to cover the soil and smoother weeds, while prototype (b) will reduce the weed population by its destruction before sowing. The efficiency of the two prototypes for weed management are supposed to be similar. The way to assess this hypothesis is to measure the weed biomass and densities in autumn and at the beginning of spring.

Hypothesis 2: Prototype (a) is supposed to reduce better autumn pests, disease incidence and WOSR vulnerability thanks to pest avoidance and crop vigor. The way to assess this hypothesis is to record the number of leaf lesion of *Leptospheria maculans* and the occurrence of insects damage in autumn.

Hypothesis 3: This hypothesis concerns the landscaping of the field around. Turnip rape trap crop around fields allows to reduce blossom pollen beetle damage better than other elements of crop management. The way to assess this hypothesis is to record the number of pollen beetle in trap crop and in WOSR.

3.3 Assessment of the crop management systems

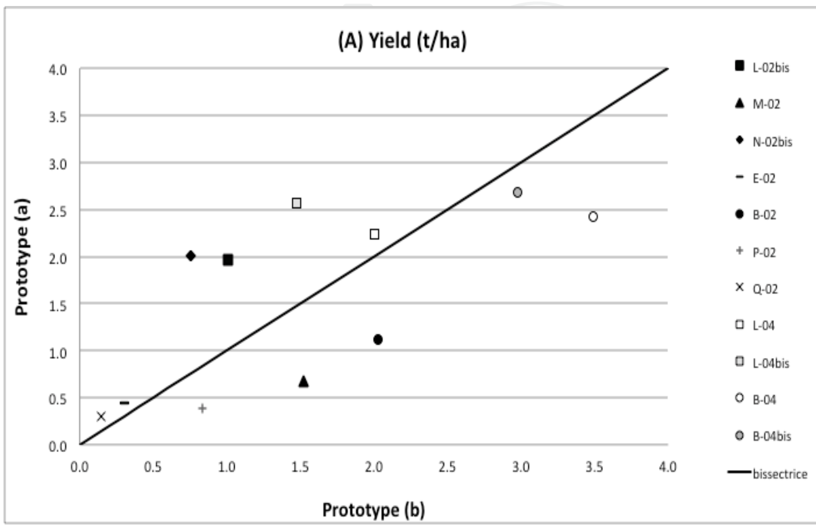
3.3.1 Evaluation of the performance of the systems: Yield and its components

Organic WOSR yields were very variable and sometimes very low compared to conventionnal system (Fig. 3a): It ranges from 0.1 to 3.4 t/ha with a mean of 1.3 t/ha ± 0.95. In conventionnal systems, the mean yield of WOSR in France ranged from 2.9 to 3.5 t/ha during those previous 10 years (Ecophyto R&D, 2009). However, the organic yield of such difficult crop is similar to these results in France (Reference of national agency of organic farming, www.agencebio.fr) and in Suitzerland (Daniel et al., 2011). The differences between the two CMS are rather low and not significant (mean of CMS (a) : 1.4 t/ha ± 0.9 mean of CMS (b) = 1.3t/ha ± 1.1). The highly significant relationship between the number of grains per square meter and the yield (fig. 3b) suggests that the number of grains is the main determinant accounting for yield variations, which could means that limiting factors of the yield resulted in a decrease of the grain numbers rather than an impact of grain weigth. In figure 3a, one can observed that field B (in the center of France) exhibited systematically a yield in CMS (a) lower than in CMS (b) whatever the year, while it is the opposite for the field L (in the west of France). This result will be examined thereafter in the light of weed pressure. It is also noticible that three fields have not been harvested, mainly because of invasion of weeds (L02-CMS(a)), slugs (O02-CMS(b)) and pollen beetle damages (N02).

Considering that the number of grains is determined by several yield components, (the number of branches/m^2, the number of flower/m^2 and the number of pods per square meter), we compared the two CMS in the establishment of those components (Fig. 4). In this figure, the two CMS seem to be similar and the linear mixed model did not pointed out any significant CMS effect, only a year-site effect. However, it is interesting to examine several field results. The very low yield recorded on fields E02 and P02 could be related very early in the cycle to a reduction of the number of branches/m^2 (fig. 4a) and the number of flowers/m^2 (Fig 4b) and thereafter to the number of pods per square meter (Fig 4c). More surprinsingly, the filed Q02 exhibited the lowest yield while the number of branches and the number of flowers displayed respectively high values (from 100 to 400 branches/m^2) and medium values (3000 to 9000 flowers/m^2). Significantly the number of pods per square meter were particularly low for this field, which is a good explanation for the poor yield performance of field Q02. The high proportion of burst pods due to pod midge attack (from 16% to 23% on this field while it reached hardly 10% on the other fields) might be responsible for such reduction of pod/m^2. The highest yield recorded on fields L04 and L04bis are also in accordance with the results on the successive yield components, while the fields B04 and B04bis reached high values of yield and of number of branches/m^2 and relatively medium values of number of flowers/m^2 and pod/m^2.

3.3.2 Crop growth and competitivity against weeds

The weed biomass in early winter is shown in figure 5a. The number of trials for weed biomass is not similar on either side of the bissectrice line, the prototype (a- desynchronisation strategy)



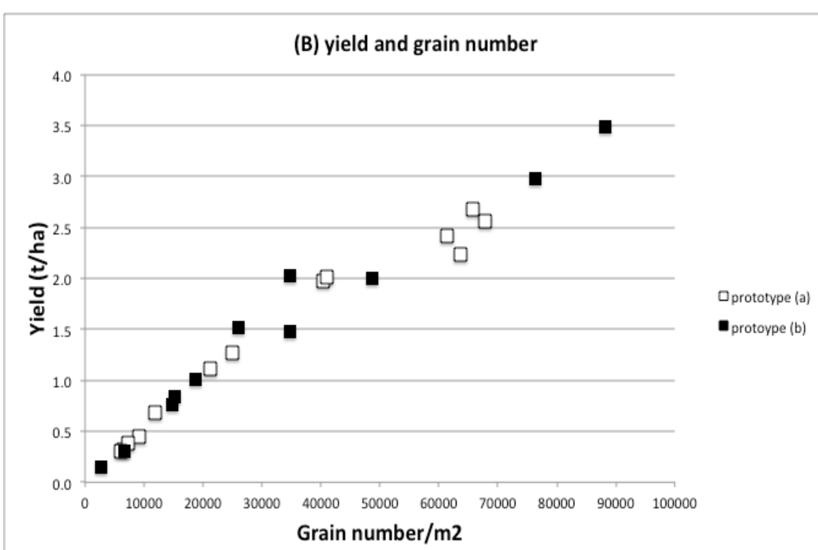


Fig. 3. Yield obtained for the two CMS in each field and relationship between grain number and yield (Two CMS has been destroyed: prototype (b) field O02, prototype (a) field N02 and L02.)

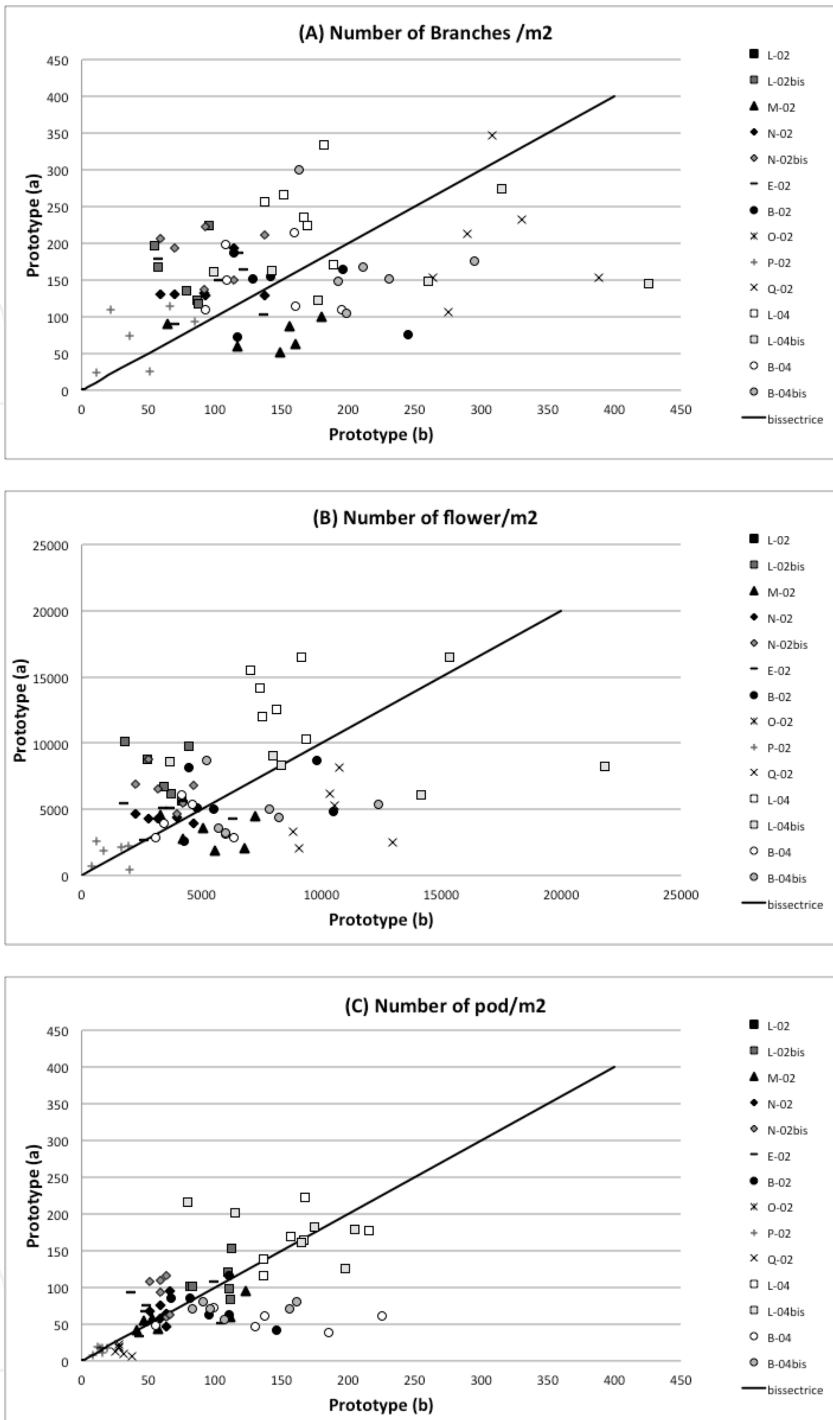


Fig. 4. Yield components of the two prototypes: (A) Comparison of the number of branches/m² in spring (B) Comparison of the number of flower/m²; (C) Comparison of the number of pods/m²

displaying higher weed biomass than the prototype (b- mechanical control strategy) and the first year exhibiting almost systematically higher weed biomass for the prototype (a- desynchronisation). The mean value of weed biomass for the prototype (a) reached 0,57 ± 0,42 t/ha while for the prototype (b) it did not exceed 0,36 ± 0,38 t/ha. Despite weed biomass exhibited a very high variation (figure 5a), the linear mixed analysis demonstrated a significant prototype effect (P<0,001) and a significant year-site effect (P<0,001). In the conceptual model, the weed suppressive effect which could induce a decreasing of weed biomass was assumed to be related to a crop vigor with high crop biomass, and an emergence of the crop earlier than that of the weeds (especially the broad-leaves weeds which emerge in autumn). The crop biomass, the nitrogen accumulation and the number of leaves produced since the emergence are shown respectively in figure 6a, 6e, and 6c. Early sowing exhibited higher plant biomass in numerous cases (means for the two years : (a)=3.07 ± 0.31 t/ha ; (b)= 1.84 ± 0.18 t/ha), which is in accordance with Dejoux et al., 2003), and is consistent with the studies of Ferré *et al.* (2000), Jornsgard *et al.* (1996), Van Delden *et al (*2002). However, this high biomass of the crop and the high nitrogen accumulation in the crop (Fig 6e) for the CMS (a) did not always resulted in a high suppressive weed ability. This suggests that the objective of the first CMS (a), that is enhance crop vigor to smoother weeds, did not succed in every field : sometimes, this strategy was less efficient than that of CMS(b), that is avoid weeds thanks to false bed and mechanical weeding. A covariance analysis (data not shown) demonstrated that soil management, weeding and nitrogen in soil at sowing could explain this variability in weed biomass. Table 3 summarizes these factors that could explain for this differences. According to the data of crop and weed biomass and soil nitrogen and plant density, four situations have been distinguished in table 3:

- For field trials N02, N02bis, L02bis, L04bis, L04, weed biomass was much lower on prototype (a) than on protoype (b). For those trials, crop exhibited very high values of crop biomass in CMS(a); plant density were systematically higher in CMS (a) than in CMS (b), the soil depth was high and and ploughing tillage has been used for the two CMS. Moreover, the high amount of nitrogen in soil was particularly noticeable for those trials(from 135 to 241 kg/ha).
- For fields Q02 and P02, crop biomass in CMS(a) was lower than in CMS(b) but weed biomass remained low for the 2 CMS. The weed densities were rather high (for instance 33 plants/m^2 and 37 plants/m^2 respectively for field P02, CM(a) and CM(b)), but the flora was not very harmful (main weed species recorded in the fields: lady's mantle, veronica, sow-thistle).
- For fields L02 and M02, despite a high value of nitrogen in soil, CM(a) did not resulted in a higher crop biomass than in CM(b), mainly because of shallow tillage, without false bed, before early sowing leading to the emergence of an important population of volunteers at the same period of WOSR emergence. On these fields, a long period without rainfall in august leaded to a very heterogeneous emergence of the crop. As a consequence, CMS(b) was characterised by a higher crop vigor than the CMS(a), and a lower population of cereal volunteers, destroyed before sowing.
- For fields, E02, O02, B02, B04 and B04bis, despite high values of nitrogen in soil, high crop biomass and nitrogen uptake, despite the use of mechanical weeding, both CMS(a) and CMS(b) exhibited a particularly high weed density (for examples from 80 to 140 plants /m2 in field B02) and the weeds species were presumably harmful: sanves, cereals volunteers, foxtail. Therefore we suggest that above a threshold of weed pressure and with very competitive weeds, neither a competitive WOSR crop nor mechanical weeding could permit to suppress weeds.

Despite these observations on the species, considering the diversity of weeds between the two prototypes, shannon index was not significantly different and ranged from 0 to 3,35 with a mean reaching 1,35.

All those results are consistent with the results in conventionnal farming, obtained by Dejoux et al., 2003 but demonstrate that the interactions between techniques need to be understood to propose innovative CMS. It appears that the efficacy of CMS (a) is clearly related to interactions between pedo-climatic environment of the crop and several individual cultural operations such as : date of sowing, nitrogen supplies and soil tillage. The strategy which consists in enhancing crop vigor during autumn, (ie crop biomass and LAI) in order to enhance the weed suppressive ability of the crop is possible thanks to early, dense sowing in specific conditions: when nitrogen supply is above 150kg/ha, in soil with high depth, when crop density is homogeneous and relatively high and if previous soil tillage has permitted to destroy volunteers of cereals or other harmfull weeds (deep soil tillage is recommended). When soil depth is lower than 60 cm and when nitrogen supply in soil at sowing is lower than 100kg/ha, the second strategy, which consists in destroying the weeds (i) before sowing and (ii) by mechanical weeding hoe after the crop emergence, might be more efficient.

description of weed and crop biomass	**description of competition relationships**	**name of the field**	**plant density**	**Nitrogen in soil at emergence**
Weed biomass (a)<(b) crop biomass (a)>(b)	crop vigor=>weed smoothering for prototype (a)	N02 L02bis N02bis L04 L04bis	More plants in CM(a) than in CM(b)	more than 150kg/ha
Weed biomass (a)<(b) crop biomass (a)<(b)	low crop vigor but few weeds in (a) prototype	Q02 P02	More plants in CM(a) than in CM(b)	more than 250 kg/ha
Weed biomass (a)>(b) crop biomass (a)<(b)	crop vigor=>weed smoothering for protoype (b)	L02 M02	less plants in CM(a) than in CM(b)	more than 150kg/ha
Weed biomass (a)>(b) crop biomass (a)>(b)	crop vigor but no weed smoothering for prototype (a)	E02 O02 B02 B04 B04bis	very irregular	from 60 to 300 kg/ha

Table 3. Diagnosis analysis of the differences between the two CMS in the weed management

3.3.3 Pest avoidance and occurence of pest damage

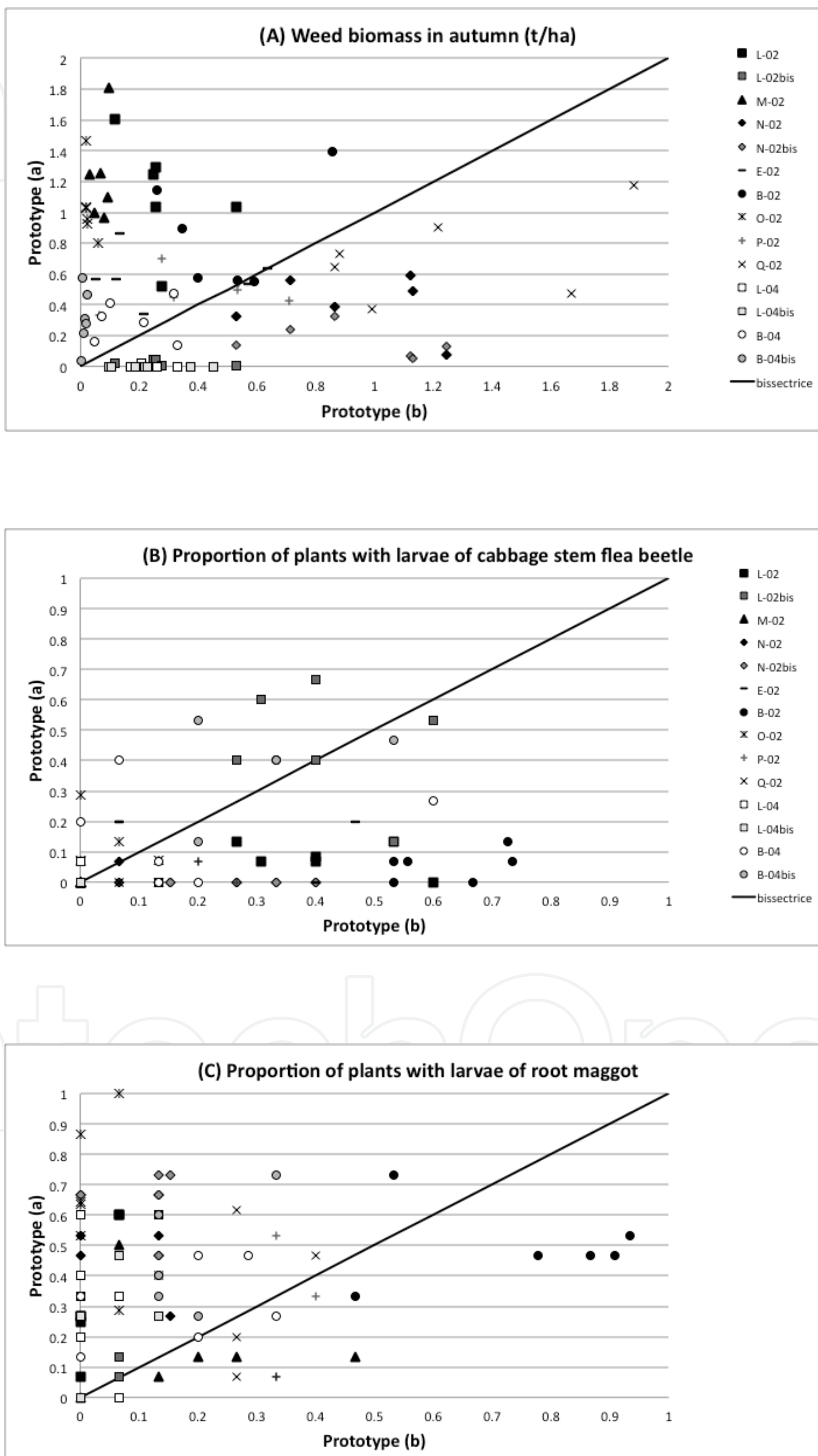
None of the plots sown early were destroyed by slugs while two plots sown normally after 1rst September were destroyed. Slugs counted at the beginning of October never exceeded 5 slugs/m² but there were 0.34 slugs/m² on early sowing plots while there were 1.3 slugs /m² on normal sowing ones. The pest avoidance objective of the CM(a) has been achieved. It confirmed the suggestions, made by Dejoux *et al*. (2003) on very early sowing experiments in conventionnal farming, that were based on the frequencies of molluscicides treatments.

Concerning the cabbage stem flea beetle (*Psylliodes chrysocephala*), figure 5b shows that CM(a) was less attacked by cabbage stem flea beetle (fig 5b- mean for the two years : (a)= 0.13 ± 0.03 Confidence Interval 10%- (b) = 0.20 ± 0.04 Confidence Interval 10%). These results are consistent with findings of Dosdall et al., 1999 and Valantin-Morison et al., 2007 and could largely be explained by insects phenology. Adult beetles invade the crop in mid-September and October and attack newly emerged seedlings by chewing pits in the cotyledons, leaves and stems. Females lay their eggs in the soil from late August onwards and the emerging larvae bore into the petioles and mine the leaves and stems (Alford et al., 2003). For crops sown early in August, the chewing of the leaves was harmless, as the larvae were found in the petioles of leaves destined to fall earlier, before winter. Therefore in this case, the objective of avoidance of the pest thanks to early sowing proposed in the CM(a) has been achieved.

Concerning the root maggot (*Delia radicum*) (Fig 5c), the linear mixed analysis points out significant effects of CMS and of year-site either for the proportion plants attacked by the root maggot: CM(a) was more attacked by than CM(b). Moreover, we observed a very significant effect of CMS in the collar diameter and biomass in tap root: CMS(a) exhibited larger collar diameter (Fig 6b) and more biomass in roots (fig 6d). As a consequence we could argue that root maggot attacks occurred more frequently in CMS (a) than in CMS (b) but were less prejudicial for growth plants, thanks to a high root vigor. Those results are in accordance to those of Dosdall et al (1996) and Valantin –Morison et al., 2007. Dosdall et al. (1996) also showed that root maggot infestations were reduced by sowing Canola in late May rather than mid May and by high sowing density. This result could be explained either by insect phenology (Alford et al., 2003) and host plant preference: this insect lays its eggs in plots sown early and females prefer plants with large collar diameters. Therefore in this case, the objective of avoidance of the pest thanks to early sowing proposed has not succeeded but the plant vigor, observed in the CM(a) permitted to reduce the damage of the attack (figure 6c and 6d).

The number of plants with at least one leaf lesion of *Leptospheria maculans* were higher on normal sowing (Fig. 5d; 0.31 + 0.08 Confidence Interval 10%) than on early sowing (0.12 ± 0.08 Confidence Interval 10%). This result was largely related to the significant difference in the number of leaves produced between the CMS (Fig 6a): plants in CMS(a) produced more leaves than plants in CMS(b) and therefore were less susceptible to receive the first peak of spores during autumn.

As a conclusion, the hypothesis which argued that early sowing could allow pest avoidance was confirmed for cabbage stem beetle and stem canker. The hypothesis argued also that early sowing allowed higher growth of plants, which could be less prejudicial for plants could be confirmed for root maggot since the collar diameter of plants in prototype (b) was higher and that severe damage of root maggot was not observed even if they were more often attacked.



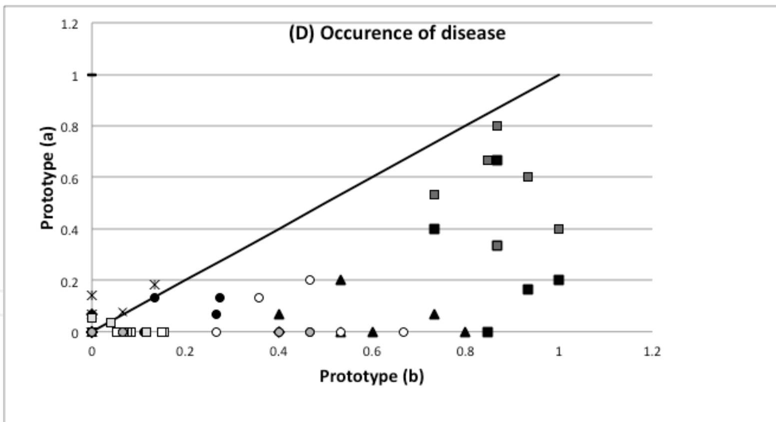
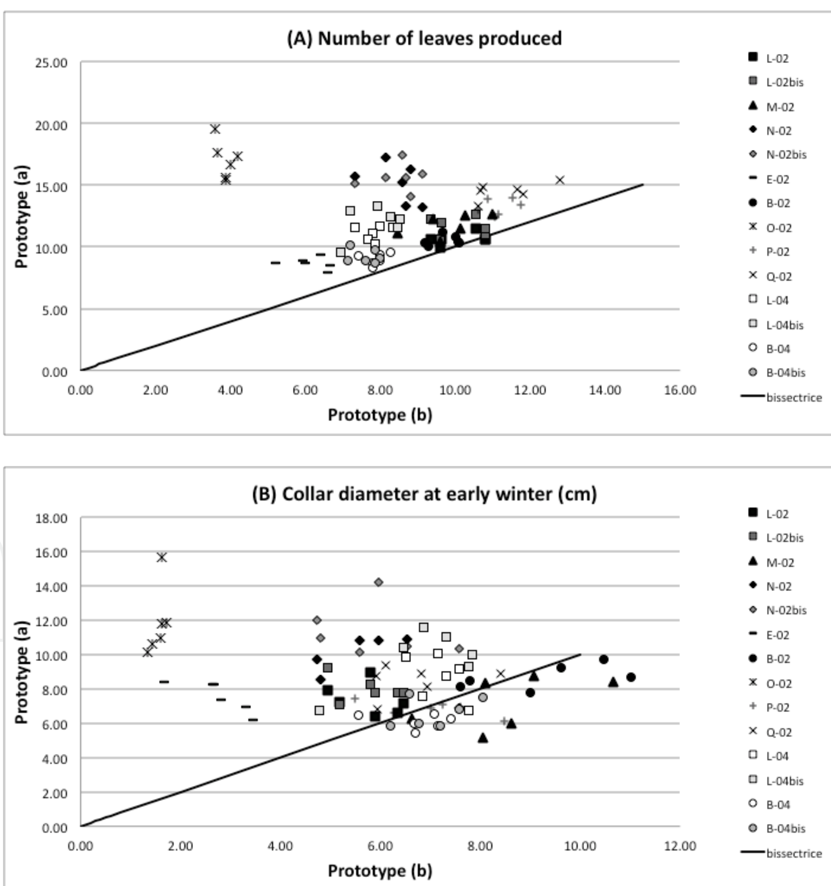


Fig. 5. Weed competition, Disease and pest occurence of the two prototypes : (A) Comparison of weed biomass in autumn (t/ha) (B) Comparison of the proportion of plants with at least one larvae of cabbage stem flea beetle; (C) Comparison of the proportion of plants with one larvae of root maggot (D) Comparison of the proportion of plants with at least one spot of Leptospheria maculans



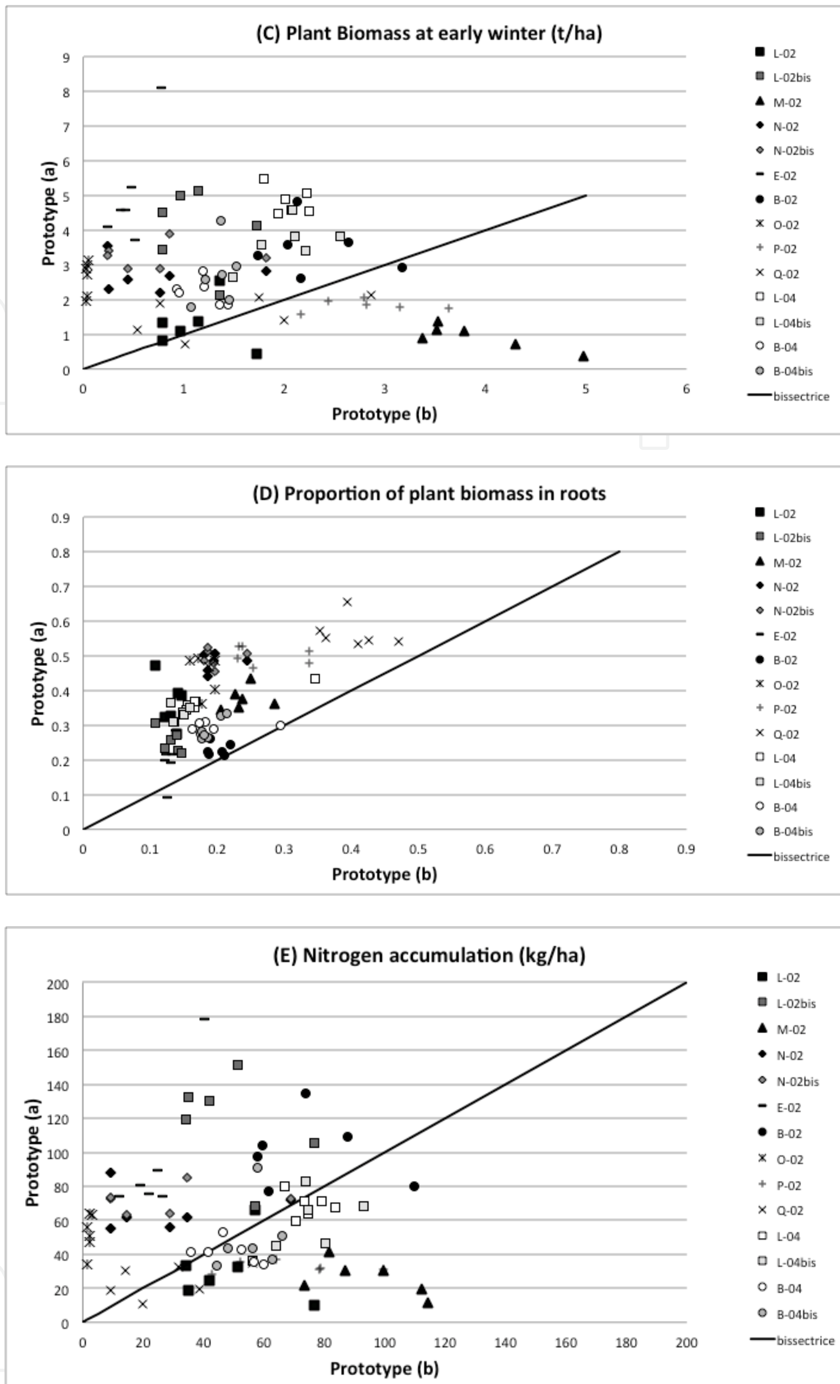


Fig. 6. Plant growth and development of the two prototypes: (A) Comparison of the number of leaves per plant in autumn (t/ha) (B) Comparison of the collar diameter; (C) Comparison of the crop biomass (D) Comparison of the proportion of biomass in tap roots. (E) nitrogen accumulation at early winter

3.3.4 Turnip rape as a trap crop to reduce the damage of insects in WOSR

Turnip rape border strips were sown to trap spring insects, in four fields. The fig 7a shows a significant effect of turnip rape on pollen beetle numbers in 2/4 fields, on cabbage stem flea beetle numbers in 2/3 (Fig 7b) and no significant effect for rape stem weevil damage (fig 7c).

The number of cabbage stem flea beetles and pollen beetles was higher on turnip rape, while rape stem weevils (*Ceutorhynchus napi)* damage seems to be more important on WOSR than on turnip rape, despite the no significant effect.

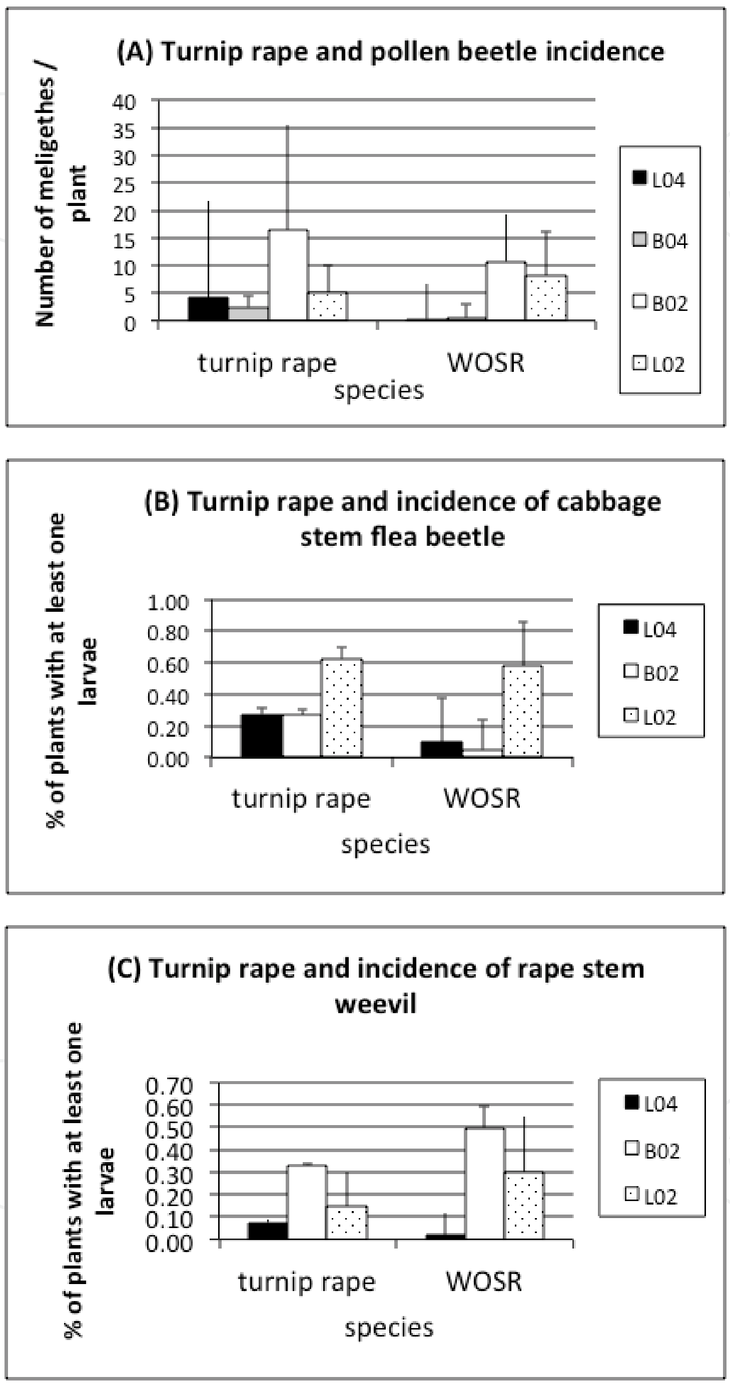


Fig. 7. Turnip rape effect on (A) pollen beetles number (*Meligethes aeneus*), (B) cabbage stem flea beetle (*Psylliodes chrysocephala*) (C) Rape stem weevil (*Ceutorhynchus napi*)

The pollen beetle, the cabbage stem flea beetles and the stem weevils are the most numerous of a suite of pests that attack oilseed rape and has been reported by the farmers and advisors to be the most damaging insects for this crop. For the past decade, control of those pests in France has relied exclusively on the pyrethroid class of insecticides, which is impossible for organic farming systems. Cook et al., (2009) points out that ecological approaches to control of pollen beetles emerging from such research include development of monitoring traps (so that growers can more easily and accurately identify when spray thresholds have been breached), trap cropping tactics, and practices that promote conservation biocontrol.

Trap crops are plant stands that are designed to attract, intercept and retain insects, thereby reducing pest density and damage to the main crop (Cook et al., 2007a). Knowledge of host plant location, acceptance and preferences of pests as well as their natural enemies is exploited in this tactic and has been developped in several studies in the 1990s indicated that turnip rape (*Brassica rapa*) was a preferred host plant of pollen beetles (Hokkanen et al., 1986; Hokkanen, 1991; Büchi, 1995). These field studies using a WOSR model indicated that turnip rape (*Brassica rapa*) shows good potential as a trap crop for pollen beetles as turnip rape plots were more heavily infested (Cook et al., 2006).

The results observed in this field network are in accordance with studies of Cook et al., 2006 and Barari et al., 2005. However, the none effect of turni p rape on rape stem weevils has never been reported. However, this trap cropping tactic suffered from several implementation difficulties: where and how many area of turnip rape could be efficient enough to control those pests ? What about the consequences at larger scales in the lanscape and for the future generation of pests ? Actually, Cook et al., highlighted that recent research developments have now led to a greater understanding of how the strategy works and will enable the development of robust and effective commercial-scale trap cropping tactics for both winter and spring oilseed rape production. An individual-based model developed at Rothamsted predicted that a border trap crop would be the most efficient arrangement of the trap crop, particularly since the pest infests the crop from the edges (Potting et al., 2005). Future studies will test the trap cropping tactic on a whole field scale in commercial systems and examine the effect of field size on the success of the method.

4. Conclusion

It appears that the utilisation of the conceptual model on the interactions pest-crop management and environment helped in building and discussing CMS with organic farmers. The agronomic performances of the CMS tends to be improved despite some low yield performances (P02, Q02, E02). The hypothesis which argue that early sowing could allow pest avoidance was confirmed for several pests: slugs, cabbage stem flea beetle and stem canker. The hypothesis argued also that early sowing allowed higher growth of plants, which could be less prejudicial for plants could be confirmed for root maggot since the collar diameter of plants in prototype (b) was higher and that severe damage of root maggot was not observed even if they were more often attacked. However, the ability of competitiveness agianst weeds for CMS (a) is clearly related to interactions between pedo-climatic environment of the crop and cultural operations such as : date of sowing, nitrogen supplies and soil tillage.

After this study, in the light of these results and considering the farmers' constraints either on soil type, on the availability of organic manure and their nitrogen contents and on labour organisation, on the availability of mechanical weeding tools, we proposed to the farmers to implement only, one type of CMS among the two (table 4).

Soil depth	Availability of organic manure	Availability of mechanical weeding tools	Choice of CMS
Deep (>90cm)	yes	none	Ploughing before CMS(a)
Deep (>90cm)	no	yes	Ploughing before CMS(a) with large row spacing to use weeding hoe
Deep (>90cm)	no	none	Implement WOSR after legume to reach high nitrogen supplies during autumn + CMS(a)
Low (<60cm)	yes	yes	CMS(b)
Low (<60cm)	no	yes	Implement WOSR after legume to reach high nitrogen supplies during autumn + CMS(b)

Table 4. Criteria at farm level and characteristics of soil type to choose the crop management system.

Concerning the insects control, the objective should be to optimise the natural pest control of the CMS and the resilience ability in order to manage such populations. Gurr et al., 2003 proposed to use two complementary ways to enhance natural pest control: "bottom-up" and "top down" approaches. The bottom-up effect of resource quality has been hypothesized as one of the factors determining herbivore abundance and population dynamics (De Bruyn et al., 2002). Because crop management influences resource quality through modification of local conditions, farming practices are assumed to affect pest density in the field (Rusch et al., 2010a,b). Particularly, the plant vigor hypothesis predicts that herbivores will be more abundant on the most vigorous plants (Price, 1991). For instance, pollen beetle have been found to prefer larger buds and plants at later development stages for feeding and ovipositing and to choose their host according to their glucosinolate content (Nilsson, 1994, Hopkins and Ekbom, 1999, Cook et al., 2006), suggesting host-plant selection according to specific quality requirements. In this study it has been proved that crop management variables such as sowing date, nitrogen nutrition and plant density influenced plant development (number of leaves, collar diameter, plant biomass), and thereafter influenced populations and damage at the field scale through host-plant quality. This indirect effect has also been highlighted in a previous study (Valantin-Morison et al., 2007). The « top-down » approach relies on the enhancement of natural pest regulation by natural ennemies. Enhancement of the natural regulation functions of agroecosystems appears to be one of the main ways in which we can decrease the use (Wilby and Thomas, 2002) of chemical pesticides for pest control and increase the sustainability of crop production. However, the factors responsible for the maintenance or enhancement of natural pest control remain unclear. Moreover, the environmental and economic benefits to farmers of increasing the activity of natural enemies of crop pests remains a matter of debate, in the absence of clear scientific evidence. It has been shown that community structure, species richness and abundance, population dynamics and interactions within and between trophic levels are affected by spatial context (e.g., patch size, spatial configuration, landscape composition, habitat connectivity or even the structural complexity of habitats) (Bianchi et al., 2006;

Tscharntke et al., 2007). There is a growing body of evidence that landscapes with high proportions of semi-natural habitats tend to support lower populations of pests than simple landscapes do, due to higher top-down control by natural ennemies (Bianchi et al., 2006) and Thies et al., 2003 has shown this on pollen beetles. In this study we did not focus on the field environment on pest populations, except through the implementation of turnip rape trap crop. But in a previous study it has been found that fields with woodland around exhibited more pollen beetles damage and it has been confirmed and explained in Rusch et al., 2011. This latter study alongside those from the literature suggest that host-plant selection by pollen beetle operates at very fine scales (i.e. selection between potential host plants within the field), whereas host-patch selection is mainly determined by the landscape context. In the ligth of those elements, we suggest that bottom-up effects, related to CMS at field scale, is involved in the ability of the crop to support, to reduce the damage of an abundance of pests determinated by the predominant influence of the landscape context. Thus, in an integrated pest management perspective both crop management and landscape context have to be taken into account together in order to identify and rank the relative importance of local and landscape predictors and their relative scales on pest population dynamics.

Finally, the agronomic performances assessment of such Crop Management system has to be completed by an economic and an environmental assessment like it has been done by Simon et al., 2011, for orchards and annuals crop by Debaeke et al. 2009, Aubry et al. 1998 and Munier-Jolain et al. 2008. The authors have generally used the comparison of organic, IPM and/or conventional systems to assess the performances and the environmental effects of crop management regimes. In such experimental system approaches, the gross margin, the economic efficiency and the pesticides use or impact, the level of inputs and farmers' labour has been quantified within fluctuating regulatory and climatic contexts.

5. Acknowledgment

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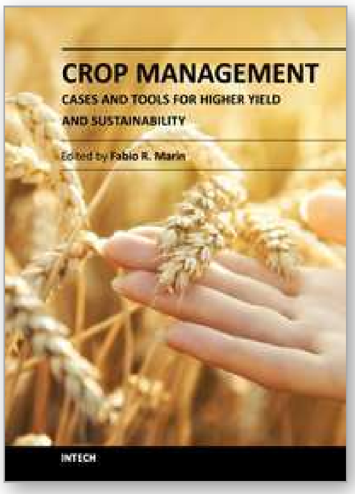

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Agricultural production is related to physical constrains, which may not always be overcomed by technology. However, under the same conditions, it is possible to see well-managed farms consistently making greater profits than similarly structured, neighboring farms. For each abiotical condition, it is well-known there is a difference between the potential and observed yields, which is usually high and often could be reduced through more appropriate management techniques. In this book, we have a selection of agricultural problems encountered in different regions of the world which were addressed using creative solution, offering new approaches for well-known techniques and new tools for old problems.