Conception and evaluation of organic arable cropping system in Bretagne
Production of knowledge for cropping system design and ex-ante evaluation with ®MASC

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The field of Agro ecology sciences tends to enlarge the vision of agriculture toward a systemic approach in order to enhance "ecological concepts and principles to design and manage agro ecosystems in a sustainable way" (Gliessman, 1998).

Content

1. Is organic sustainable?

The recent growth of organic production was observed worldwide. This development had positive impact on environment, for instance, the avoidance of chemical inputs enhanced nature conservation. Fast organic growth also opened market to new consumer and led to favourable conditions for conversion (Best, 2006). Nonetheless, worldwide, undesirable consequences of this late model were observed. In 1997, Buck et al., submitted the "conventionalization hypothesis". In their vision, organic was becoming a model of conventional. According to these authors, elements of industrial agriculture are implemented into organic pushed by imperatives of commodities production (Buck et al., 1997). The transformation of the organic sector was characterized by a growth of farm size, specialisation, input substitution and high mechanisation (Best, 2006). This model was either perceived as modernization of organic agriculture (Darnhofer, 2006) or as a relaxation of organic standard (Buck et al., 1997). Goldberger, 2011 went further in here analysis of the relation between sustainability, organic and conventionalization. Organic farming and sustainable agriculture are two different concepts (Ikerd, 1993). Goldberger (2011) emphasize that the principle of sustainable agriculture "may lie at the heart of the organic agriculture movement". Organic movement promoted "organic integrity" enhancing nature conservation, energy use efficiency, social conditions, worker health, food safety, local development and fair price (Sligh, 2002). Thus it is questionable if conventionalized organic farming respects the principle of sustainable agriculture. In 2008, Goldberger pointed out that organic producers perceived organic as eco- friendly but were mostly motivated by profitability. In 2011, she analysed sustainability in organic agriculture from two major views: conventionalisation and civic engagement and came to the conclusion that there is a disconnection between motivations and perceptions of sustainable agriculture. She tested the hypothesis (established from reviewing) that conventionalization may have negative effect while civic engagement may benefit to sustainable development. On one hand, large scale organic farm are perceived positively for farmers' incomes, working conditions and local employment while she hypothesis that those farm contribute less to sustainable development. On the other hand, civically engaged farmers contribute more to sustainable development but did not perceived it as profitable activity. There were no significant relationship between civic engagement and perception of economic viability (Goldberger, 2011). This conclusion raises the risk that farmers rather intensify organic production than develop organic system integrated in the principle of organic movement. Actually, the recent increase of organic farmer coincides with specialisation of farming system (Best, 2006). The hypothesis of conventionalisation was tested in many countries. Best (2006) reported his results from Germany. Indeed he observed that mixed farm decreased over year, it dropped from 19% for the period 1998-2000 to 15% in 2001. Two direction are drawn; cropland farm not raising livestock (and therefore without grassland) increase and grassland farm tend to be specialized with single livestock (Best, 2006). The number of farmers that concentrate on crop production and arable systems increased (Schmidt et al., 1999). And in average, it concerned more new organic, which are slightly bigger and more specialized. The mixed farm system is the most sustainable one as nutrient are recycled on farm. Crop and livestock complementary can lead to higher level of autonomy. Nonetheless, stockless organic farm tend to increase. Organic cereal production is limited because leys crops are not perceived profitable enough for organic cereals producer. Actually, they did not consider the positive effect of grass land but the negative impact on their economic development.

In France, 845 440 ha or 3.1% of land are cultivated according to the organic standard (Agencebio, 2011). 61% is still devoted to grass or forage and 20% to cereals production (Agencebio, 2011). A National project "Rot AB" was developed in 2011 in order to evaluate the sustainability of cropping system in arable organic farm all over France. The objective was to investigate under conditions of specialized farm if it would be possible to manage technical challenge with rotation adapted to farmers' context and opportunities. The project development was based on the hypothesis that in organic stockless farm, rotations are the main agronomic tool to manage soil fertility and weeds. The conclusion of the project went back on the fact that the most sustainable cropping system should include fertility building elements (leguminous leys). Lucerne for instance turned out to be the best solution to handle technical challenges. Even if it seems to be a major advantage for high sustainability, Rot AB promoted that sustainability can be reach by alternative means (rotation, mechanical weeding, cover crops...). Indeed, the viability of rotations including leys is depending on market opportunities (as fodder or derived products like dehydrate Lucerne) (Rot AB, 2011). Regarding this context, I could address the following problematic: Under conditions of "conventionalisation" of organic farming, would it be possible to design organic cropping system that meets the common criteria of sustainable development? Under this problematic sub question are related to the method of conception and evaluation of innovative cropping system. I needed to characterize what kind of cropping system is sustainable for organic cereals production in Bretagne. The challenge is to provide a cropping system that meets the standard for organic production, the criteria of sustainability and farmers' request in term of productivity. The broad goals of organic and sustainable agriculture include economic profitability, preservation of the environment and acceptable working conditions (Goldberger, 2011). Ideally, it should take into account:

Environmental dimension: achievement of organic requirement for the cropping practices. It means no use of pesticides, herbicides and fungicides. Weeds, fertilisation and other issues have to be controlled according to the European legislation for organic. Nitrogen leaching and losses must also be controlled.

Economical dimension: demand for organic cereals is increasing. The objective is to increase farmer benefit from cereal production. It will pass by decreasing production cost and/or increasing quality and/or quantity of cereals in the crop succession.

Social dimension: It must not damage working time and be accepted by farmer.

Sustainability is a multi-dimensional and complex concept (Sadok et al., 2009) it is not measurable and encompasses numerous objectives. Nonetheless, it is becoming a criterion of quality to characterize farming system. Evaluation of sustainability can enhance the implementation of "new forms" of organic farming systems (Gasfi et al., 2006).

The green box of the figure 1 summarized the principal elements of the mission. I wonder who I should include into the conception, how to design sustainable cropping system for arable farm in Bretagne and how to evaluate them. The main question was to establish a prototyping method adapted to the context of on-station experiment and participation of farmers. I focused on the validation of local knowledge. My objectives were to assess if organic arable system can be productive in long term and to validate the relevancy of participative approach in the context of on-station experiment.

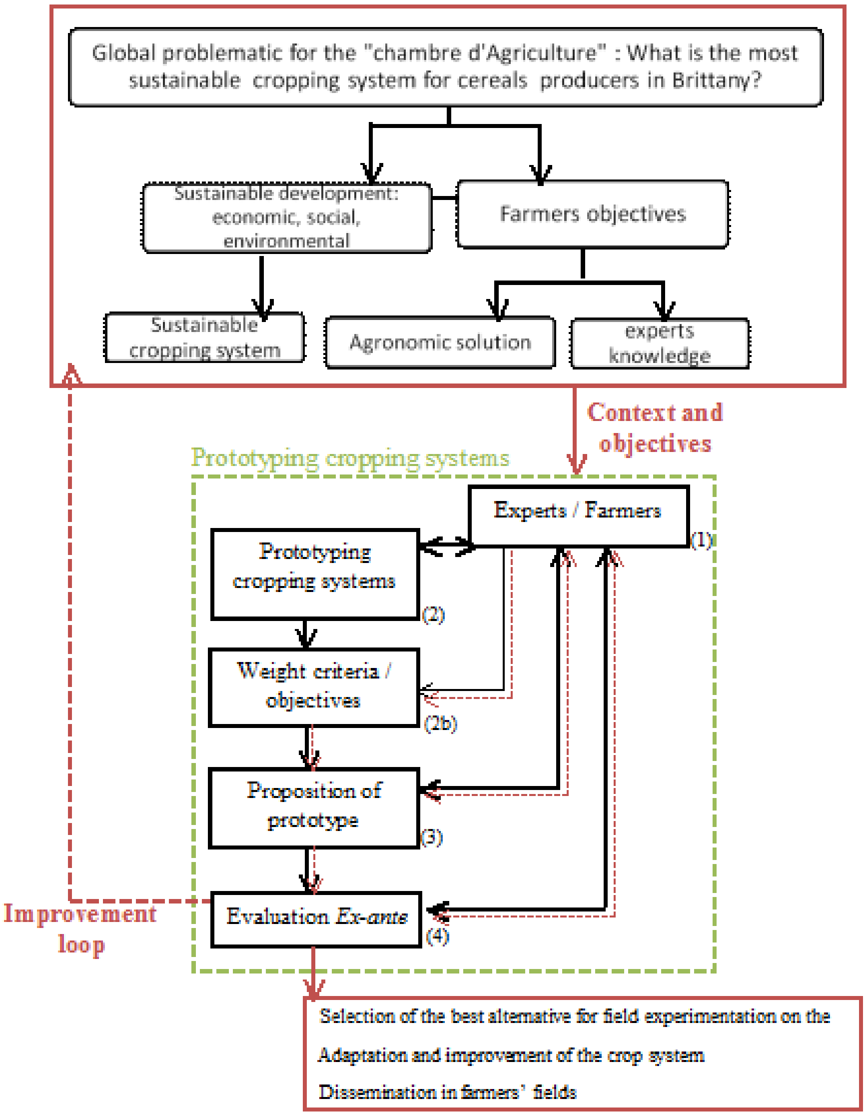


Figure 1: Master thesis context and objectives. Red= C.A. decision part. The red box is the general problematic to be assessed by the C.A. Green= my mission. The red arrows are part of the improvement loop.

2. Organic agriculture in the region of Bretagne

Today, organic cereal production without livestock is not the most representative farming style. In the region of Bretagne, the most popular farming systems are beef and dairy cows. 3.2% of the land area is converted to organic. It is the equivalents of 4% certified farm within 75% are mixed system (Rot AB, 2011). The number of arable organic farm is estimated towards eighty (FRAB, 2006), nonetheless there is a great opportunity for farmers to develop their cash crop production. 87% of the cereals production is devoted to animal feeding. The deficit of production for animal feeding is estimated around 29.000

tons/years. Conversion towards organic are not enough enforced to cover human and animal feeding's needs. And yet, at regional scale, organic production is embedded in a dynamic context. Market's conditions are gathered to enhance conversion: There is a high demand for organic cereals from breeder. Consequently, prices are higher than the national average (IBB, 2011). Logistic cost for collecting and storing decreased thanks to a well develop network of cooperative and industry. Institute and agricultural organisation are supporting organic production with technical advices and research to optimize crops' productivity. In addition, professionals association emphasized that poultry farm (both for meat and eggs) tend to increase (IBB, 2011). It suggests that conversion land will expand and needs for organic cereals increase. The demands for sustainable and productive cereals cropping system increase. Sustainable development needs to be supported and it is necessary to anticipate future farmers' wishes to improve cropping system sustainability. An increase of organic cropland area will stimulate demand to improve current productivity (yield per hectares) and conversion to organic. Agronomical and technical innovations are needed to manage production issue for organic farmers. Mechanical and hand weeding are the two main management solutions, but they are not optimized, not always efficient or too expensive. Fertilisation may not be a problem on mixed farm. But, organic manure is a scare resource (Borgen., 2012), and farmer who does not breed animal may fail its fertilisation. A specific dispensation allows organic farmer to spread conventional manure on their field (CE, 2011). Apart from ethical question, the issue is that farmers using it rely on a non-sustainable solution. But one should consider that sometimes it is the best fertilisation solution. Farmers are looking for innovative and sustainable cropping system. The role of the Chambre d'Agriculture (C.A.) is to support farmers' demands for solutions adapted to the specific context of the region Bretagne (see box1). The initiative of the C.A. is relevant towards a wider challenge that requires providing innovative and sustainable cropping system for organic agriculture. The C.A. will carry out field experimentation to support and advice organic producer (box1). The project "conception and ex-ante evaluation of sustainability of cropping system" was designed to support a future increase of organic cropland in Bretagne. The C.A. problematic was expressed as: **What would be the more sustainable cropping system to be implemented in Bretagne? (fig 1)**

The C.A. is developing the research on organic production to provide solution for expected future changes and must serve future development of organic agriculture. The C.A. shows one's willingness to do intensive organic production to be in ad equation with Breton's farmers. This project was managed under conditions of specialized and slightly intensive production system (relatively to organic movement). This is mainly due to a general trend of agricultural production system. Indeed, Bretagne could be characterised as one "pantry food" of France. With 6.1% of the agricultural area, Bretagne account for 20, 6% of the breeding activity of France. It is about 56% of the French pig production that come from Bretagne (RA, 2010). Consequently to this high concentration of livestock, the crop production is oriented towards animal feed. The classical crop rotation in Bretagne is "maize – winter wheat". In addition to poor diversification of crop production, the intensive farming activity is causing water pollution. Phosphorus and Nitrogen leaching are the main challenges that face the Breton's agriculture. It is often assumed that it is due to intensive agricultural system and concentration of animal manure on the territory (Leon et al., 2005). The national government and environmental association exert pressure to improve the current situation. In this context, the global agriculture of Bretagne is moving towards more sustainable farming style. There is a need to investigate means to improve cropping system and look for new forms of agriculture. It is conceivable that conversion towards organic system may be a solution to solve environmental issue. If farms are less intensive in organic, higher price compensate the decreasing activity. But Bretagne is embedded in a context of high production and even organic system must be highly productive.

Box 1. The organisation of the Chambre d'agriculture:

C.A. are consular organism that support and advice farmers. Their challenge is to optimize farming systems, support local development and gather innovative knowledge to serve farmers' interests. This institution is financed by taxation, subsidies and lucrative services. Elected members represent farmers' interests in front of French authorities for political decision in order to enhance agricultural development under the territory. They have a role of farmers' representative and act for sustainable development of farming system. Their actions are oriented towards farmers' issues and future development opportunities. The C.A. led similar project on organic dairy production and attempt to enlarge system experimentation in the scope of agro biology. The project is carried out by regional department Chambre Régionale d'Agriculture de Bretagne (CRAB). These experimentations are run by the Research & Development (R&D) department and co-managed with regional technicians. It is also connected to the national institute of agricultural research (Institut National de la Recherche Agronomique; INRA) and the technical institute for research on organic farm (Institut Technique pour l'Agriculture Biologique, ITAB) which supports systemic experimentation in organic research.

Before to assess sustainability, it is essential to understand that its perception depends on the origin and context. The design of sustainable systems is not a common knowledge that would be shared worldwide. Its broad definition will need to be interpreted within the specific working conditions. I made a state of the current methods to design and evaluate sustainable cropping system. The detailed review is presented in appendix1. It roughly describes the approach towards systemic research, the different conception methods and evaluation tools. It supported the research question: "How to design cropping system and evaluate them with model?" I built the methodology of the mission process. The material and methods used to achieve the conception and assessment of sustainability are presented for the specific context of the organic agriculture in Bretagne. I took back the different criteria used for sustainability assessment. The results obtained along the mission are presented. Then in the discussion part I argued on the selection of the most promising systems supported technical knowledge. I also discussed the method and tool before to conclude.

3. Materials and methods

The challenge is to propose a cropping system that will insure a long term, stable and high yield production (box 2). It should respect local conditions, farmers' interests on short term and C.A. objectives. The crop succession will be experimented in a station - an organic plot within an arable farm. It permits to estimate its potential in the local context and adapt it before implementation into farmers' fields. The targets were producers of organic cereals. The C.A. identified objectives to be achieved with the systems experimentation; they had been classified according to their importance:

1. The cropping system must be **economically efficient** compare to national and regional organic references
   - ⇨ Profitable production (increase yields / decrease production cost)
2. Cereals and protein crop yields' must be close to Experts' wishes and at least equal to references
   - ⇨ **Control parameters responsible for decreasing and unstable yield** (weeds and fertility)
3. The cropping system must **sustain production** in time
   - ⇨ The practices must at least maintain organic matter content, and N, P, K highly available.
   - ⇨ Fertilization should not pollute water and more generally the close environment.
   - ⇨ Resources such as water, soil, organic fertiliser, flora and fauna diversity must be respected, used carefully and not wasted or damaged.

Box 2. Studied scale: The cropping system

The cropping system seems to be a relevant concept for agronomist to design new cultural method (Papy, 2008). Most of the environmental impacts and of some socio-economic factors on a farm are occurring at cropping system (Sadok et al., 2009). This unit is defined as "a set of management procedures applied to a given, uniformly treated area, which may be a field, part of a field or a group of fields" (Sebillote, 1990). Cropping system is defined in time and space in interaction with the farming system. It is as a coherent set of cultural and management practices, including farmer's decision and adaptation, at farm or field level (Papy, 2008). This scale of study is challenging combination of agronomist knowledge and farmer "savoir-faire". The system is defined by observers (outside and inside) as the relevant area for action. It is the specific place of decision to achieve system's purposes (Ison, 2008).

The mission to achieve included two steps: (1) designing cropping system and (2) assessing their sustainability. Prototyping and modelling are two approaches towards cropping system conception that are hypothetically complementary. Prototyping is a designing[1] method while modelling is a mean to integrate contextual knowledge with scientific knowledge (Sterk et al., 2006). I followed the prototyping method proposed by Lançon et al., (2008) and adapted it to the specific context of the experimentation. This method proposed to design innovative cropping system through participative approach and evaluate them with modeling tools.

[1] Designing was defined by Le Gal et al.,(2011) as a process of changes that involves: existing knowledge; use of possible modelling tools based on the generic properties of the system to be design; new knowledge produce during the process and a range of innovative proposals that are not defined *a priori*.

I provided a three step approach to achieve the selection of the most promising cropping system to be tested. The process is built on a bottleneck framework (Fig.2). This figure is described step by step in the first section of the report. This was the most logical process within a short time. In the first part of the methodology, I focused on the cropping system conception with interest on the means to collect and interpret data from participants. The second part presents ®MASC and the criteria aggregate to assess the sustainability.

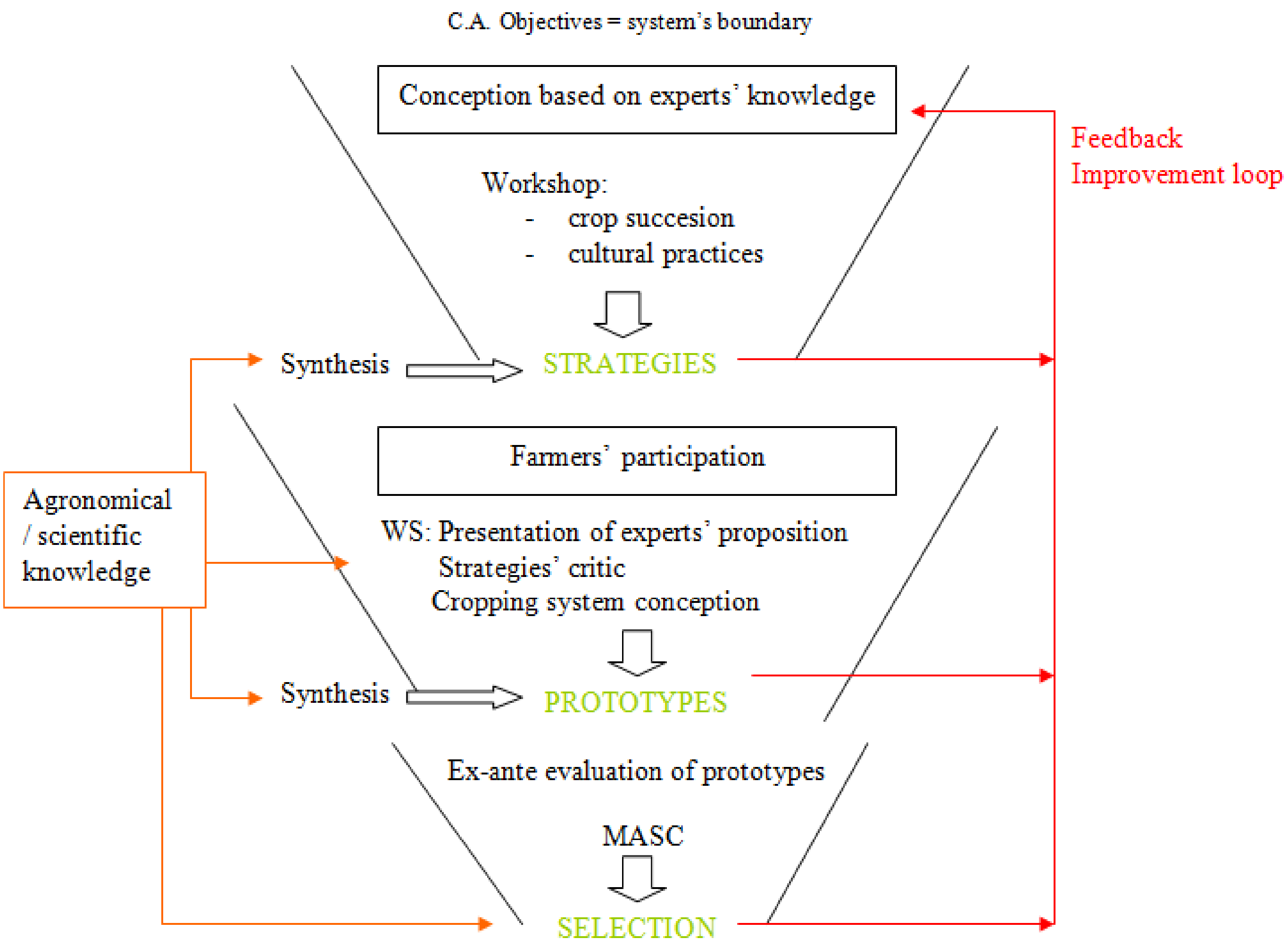


Figure 2. Bottleneck approach I developed to answer the question: How to design innovative cropping system? and the one addressed by the C.A. : What is the most sustainable cropping system?

3.1. Prototyping method: design innovative cropping systems

Prototyping's purpose is to create systems that will be evaluated, tested and adapted along experimentation. It is a tool to improve or implement new cropping system.This method can be embedded in participatory program (Vereijken, 1997; Rossing et al., 1997; Meynard, 1998). The participation of farmers, scientists and professional organisations appears to be essential at different steps of the conception. Lançon et al., proposed a participative methodology - adapted from Vereijken - to design innovative cropping system based on expert knowledge (2008). Experts are the representative of regional organic farmers. This multi-disciplinarily approach emphasizes on optimization of local knowledge. Experts' knowledge were collected in respect of farmers' primer objectives.

3.1.1. Conception based on experts' knowledge (fig.2)

The project started with the experts' workshop. They set out strategies. Then participation was enlarged to farmers. Experts' feedback coupled with critics of the strategies led to decision rules for cropping system conception. Prototypes were submitted to experts for improvement and validation before evaluation. They support prototypes conception with technical and practical elements. For the last feedback loop, they were in charge of the selection of the most promising cropping system.

The group of experts

The regional responsible for organic R&D are deeply involved in the process of cropping system innovation. The reflexion group included (1) Four experts on organic production; specialized in cropping system and organic management practices; (2) The responsible for the experimental station. As responsible of the plot, he will apply the cropping system, thus his opinion needed to be considered at the beginning of the project. We introduced him as a "control" person, as he knows constraints and capacities of the experimental farm he can judge the feasibility of propositions. In addition to those technical experts, the project included a responsible for coordination and training. She supported and advised me for the organisation of the workshop with farmers.

The workshop with experts

According to Lançon et al., 2008 prototyping success depends on the scope statement. Expert and designer must refer to it for adaptation and improvement of the prototype. We proposed a meeting with regional organic experts in order to present the local context and define generals objectives This meeting was implemented to collect information to start cropping system conception. First, we introduced general information about systemic approach and innovation. These generic terms needed to be defined in the reflection group and appropriated by the experts. It was a mean to highlight the context and the approach to achieve the mission. The major part of the meeting was devoted to individual reflection and group discussion. Experts' participation led to cropping system strategies. Before to propose them to farmers, experts were individually asked to improve and change them. The objective was to validate information added and relevance of proposition. After validation (Fig.1, feedback loop), the strategies were presented to farmers in order to design cropping system.

3.1.2. Participatory research: collaboration of researchers and local people

Farmers participation (fig.2)

Participatory Research (PR) is defined as a "bottom-up" approach (Cornwall et al., 1995) in opposition with linear conventional research. Incorporating local stakeholder's knowledge and innovative capacities is a new approach that has the potential to enhance sustainable agriculture management (Neef & Neubert, 2010). According to Biggs classification, collaboration is a research driven method of participation. It includes participants that are self-selected on the basis of interest (Cornwall et al., 1995). The C.A. has an organic farmers' network. It was the database to contact participants. Farmers were selected according to:

- The area (close to the experimental station, close pedo-climatic context)
- Their activity: arable or mixed (pig and poultry) farm.
- The degree of initiative in favor a re-conception of their cropping system. Concretely, focused was made on farmers willing to experiment new cultural practices or innovative crops.

I organized the workshop in order to (1) collect specific data; (2) critic strategies and (3) design cropping systems. Only two farmers attended the workshop. They were both in process of changing their system. The first one acquired thirty hectares more, thus she was thinking of the crop rotation for her new land. The second one was forced to stop his pigs' production, consequently he wanted to rethink it crop production. The workshop outline was:

1. Presentation of the research program: Objective of the experimentation and of their participation.
2. **Critic of the strategies**: Presentation of the four cropping system strategies. I used example of rotation to illustrate the strategies[2]. Question such as "how to do" were asked on the strategies to orient the discussion. It was mainly focused on strength and weaknesses for each.
3. Definition of sustainable. I used a mind mapping in order to reach a common vision of sustainable development and to highlight farmers' objectives.
4. **Cropping system design**: This step was an individual or group reflection around crop succession to propose cultural practices. As it is shown into the bottleneck approach (Fig 2), the area of reflection was enlarged. Farmers worked on crop rotation elaborated from the synthesis and had the opportunity to make their own proposition for crop succession. We kept close from experts' strategies without excluding farmer's innovation. Farmer's role was to give feedback and adjustments along the designing process, according to their own experience.
5. Group presentation: Each farmer presented and argued in favor of its system. Proposition were discussed according to farmers' objective. The fact remains that each farmer had its own vision of sustainability and innovation, thus discussion was not very productive. It was like if people were

[2] See appendix 6 for example of rotation proposed to farmers to critic strategies.

talking about the same subject but not together. It was expected to have a common analysis on each cropping sytem but finally it was more individual opinion on one cropping system.

I provided document to guide farmers into the conception phase and information about the experimentations, the plot and station. The document[3] is presented in appendix 3.

Individual interviews with farmers

As this workshop was not as productive as expected, individual meetings were planned before to synthesize farmers' knowledge. Two farmers were visited. The first one was a dairy producer, nonetheless he had innovative practices. He is one of the few farmers that hoe his cereals. The second stopped dairy cows and was thinking of the best way to valorize his grassland. The interviews were built on the same framework as the workshop. The strategies were proposed to them and they were asked to analyze them. In order to gather additional technical information, farmers were asked to present and critic their own crop rotation.

Cooperative technicians

Finally, participation was enlarged to cooperative technicians. Technicians have a close relation with farmers, local and technical knowledge. Four organic crop technicians were interviewed in order to achieve the design of cropping system and propose innovation.

3.1.3. Interpretation of the collected data

All the data collected during meetings, were analyzed through SWOT[4] analysis. The SWOT is a method extracted from the *soft system methodology (SSM)* which has a predominant role in interpretation of informal data (Ison, 2008). I used the SSM to validate information without personal interpretation. SSM provide a method to analyses information collected within the studied system. Different steps are guiding the learner in his investigation of a situation. From the scope statement to the reflective practices, SSM proposes models to characterize improve and broadcast information and innovation (Checkland et Poulter, 2006). According to the bottleneck approach (fig3), the first results reach with the participative approach was the strategies proposed by experts. These strategies were then proposed to experts for validation and to farmers and cooperative technicians to improvement and details of the cropping system. I realized a SWOT with the data collected during interviews and workshops. SWOT objectives were:

(1) To highlight farmers' objectives and insure the C.A. objectives' matches experts' vision and farmers' needs;

(2) To orient cropping system design according to participants' recommendation;

(3) To validated strategies' relevance and feasibility.

[3] The appendix consists of the document used to communicate with farmers (in French only)

[4] Strengths, weaknesses, opportunities, threats

3.2. Ex-ante assessment of cropping system sustainability

Participative prototyping can be coupled with modelling tools for evaluation of cropping systems. Lançon et al. (2008) emphasized that modeling might help researchers to match their recommendations for management issues addressed by farmers. It is an integrative approach towards research program (Coquil et al., 2009). Models to assess sustainability need holistic method dealing with mixed data (quantitative and qualitative) and including the common criteria of sustainable development. I used ®MASC (Multi-attribute assessment of cropping system sustainability) to evaluate the prototype.

3.2.1. Multi-attribute assessment of cropping system sustainability

®MASC is built on 39 criteria to assess the three dimension of sustainability. Actually, some are depending on other criteria, increasing the total number of criteria to evaluate or calculate to 59 criteria (appendix 4). They are evaluated separately without compensation. Quantitative inputs are calculated with mathematical model. Qualitative data are opinion based. They were presented either on the form of satisfaction evaluation scale or modalities and informed about preferment and specific context. The assessment of cropping system sustainability requires homogenizing quantitative input into qualitative data (Colomb et al., 2009). All these criteria are characterized with "Low, Medium, High" denomination on a 1 to 5 scale. Then criteria are progressively aggregated following ®MASC arborescence. The process is based on "If...then" decision rules. ®MASC will provide *in fine* an overall sustainability of the tested systems. There are three categories: (1) **fixed**[5] criteria: these criteria are fixed from one system to another; (2) **estimated** criteria: these are criteria that require expert's knowledge to be estimated and (3) **calculated** criteria: these are criteria that need to be calculated to be evaluated. Some environmental criteria were calculated with specific tools. Nitrogen losses were estimated with ®Territ'eau[6]. Energy was calculated with ®EGES[7]. For the estimation of the organic matter content I used ®INDIGO[8]. ®MASC is furnished with a calculation manual. It is published in French but, there is an article available in English for further information (Sadok et al., 2009).

3.2.1.1. Economical dimension

Economic product of the cropping system

[5] See appendix 5 for all the fixed criteria. I refer to this appendix in the following part with the appellation "a5".
[6] Territ'eau is an evaluation tool proposed by INRA specific to Bretagne. It assesses N losses at the cropping system scale with consideration of environmental conditions such as water annual rainfall, plant growth precocity, and organic fertilization.
[7] EGES is a tool for evaluation of energy and greenhouse gasses produced by farming activity. It is proposed by Arvalis, the French institute of beet and CETIOM, (French institute for oil and protein crop production).
[8] INDIGO is a program that permits to calculate some indicator or sustainability (Bockstaller., 2008)

In this module, the most important for farmer was the operating profit. It included three specific variables: Profitability, autonomy (independency and efficiency) and equipment specific needs. Profitability is calculated for each crop in the succession with the net gross margin (box 3). Autonomy is an indicator estimated by the aggregation of two indicators: Independency and Efficiency (box 3).

Box 3. Calculation economic criteria

Formula were given into ®MASC's manual

GM = [$^{(1)}$ gross benefit + $^{(2)}$ annual aid – $^{(3)}$ operational charge – $^{(4)}$ mechanisation charge]

(1) Gross benefits are evaluated crop by crop as price in euro multiplied by yield. Prices and yields are not fixed and varied along years. As it is ex-ante evaluation, these data are "references". Prices were collected from the national project ITAB, 2011. The yield were proposed by experts and compared with regional data extracted from the organic farmers' network. Those parameter correspond to the objective of the cropping system (see § 1.1 Objectives' hierarchy)
(2) Annual aid: coupled aid: 100 €/ha for cash crop and 80€/ha for forage crop (CERFrance, 2012).
(3) Operational charge are calculated as proposed in MASC instruction, nonetheless, it is not including fertilisation cost. To make it appears; we included it into occasional working force. Actually, the fertilisation is delegated to outside workers. It represents a cost for working time and we added the price of animal manure into it if needed.
The fuel consumption is calculated for each cultural intervention. The price for fuel consumption had been estimated for each tool (appendix XX).
(4) Mechanization charge is estimated according to the experimental station data with fixed charges for the tool and the associated tractor plus maintenance charge.

Independency: IND= [1 – (annual aid/gross margin)*100]
Efficiency: EFF= [Gross benefit / (Operational charge + Mechanisation charges)*100]

Long term productivity

This indicator referred to C.A. objectives as the capacity to control components that could affect yields. Indeed, it was important to be economically sustainable; nonetheless, it also relied on the capacity to sustain the production. To estimate this notion ®MASC considered chemical and physical soil fertility and pests and weeds' management along the crop succession. A first module encompasses soil structure, acid-basic status and P, K fertility.

(1) Soil structure is evaluated through two modules. On the one hand, the degradation of the soil is estimated by equipment and harvest conditions; estimated by experts. On the other hand, the regeneration of soil structure depended on intrinsic soil status (soil analysis) and soil tillage practice.
(2) Acid and basic status is peculiar to the plot. It also includes impact of fertilization practices such as acidifying practices (refers to use of urea or ammonia) or basic amendment. This indicators estimate nitrogen equilibrium for each crop considering proportion of leguminous and crop residues' exportation.
(3) P and K fertility calculation depended on the soil furniture capacity and P, K outcomes and recycling. Those modules are estimated according to regional data for P, K content in harvested products and residues.

A second module estimated pest and weeds management efficiency. Yield fluctuation is directly influence by pests and weeds' control along the rotation. This indicator aims to estimate the effect of cultural practices on pests' control. It includes all technical criteria such as tillage modalities, ploughing, sowing date, crop diversity, catch crop, plot surrounding, plant genetic resistance, biological agents of control….

Products' quality

Quality is estimated according to varietal resistance of crop, to products' quality (technological quality) and with the contribution to emergence of new market. This criterion reflects farmers' capacity to adapt their cropping system to market development and opportunities.

3.2.1.2. Social dimension

The contribution to social dimension is evaluated through two modules:

(1) Farmers' social conditions. These indicators are made on the basis of experts' estimation of additional working time, health risk (a5), works difficulty, complexity of cultural intervention and number of crop grown.

(2) The second module is devoted to society's satisfaction. There were two indicators related to society; contribution to local employment and raw material supply.

3.2.1.3. Environmental dimension

This module included different criteria that required different calculation tools. ®MASC is coupled with ®INDIGO. Nonetheless, I needed it for few indicator, thus I used other tools developed to estimate some criteria. The environmental impact of the cropping system is estimated following three modules. Nitrogen module was calculated with ®Territ'eau. Energy module was calculated with ®EGES.

Contribution to the quality of the environment

This module is shared in three entities:

(1)Water: Pollution of water includes pesticides losses in ground and surface water, nitrate leaching and phosphorus losses (Box 4)

(2)Air: It includes pesticides (a 5) and nitrogen (ammonia and nitrite) emissions.

(3)Soil quality includes organic matter content and quality (accumulation of toxic elements) evolution along rotation, plot sensitiveness towards erosion, influence of covering soil during erosion periods and soil tillage applied.

Pressure on resources

This module estimates the pressure that the exploitation of the cropping system may exert on resources such as: water resource depending on irrigation practice, energy pressure and phosphorus (a5) (box 4).

Biodiversity conservation

(1)Living on soil and flying fauna diversity. It is correlated to cultural practices such as pesticides use (a5), effect of tillage, crop diversity and organic matter content.

(2)Flora diversity is characterized by abundance of plant and diversity (estimated by aggregation of crop diversity, surrounding hedge and use of herbicides)

(3)Soil microorganism estimated according to practice that could harm it.

Box 4. Phosphorus problematic in Bretagne:

Phosphorus is essential for plant nutrition and generally the initial soil fertility is not enough to cover plant needs (Prasuhn et Flisch, 2005). That is why, farmers add mineral fertilizer. In organic standard, there is no use of P from non-renewable resource; it relies on organic manure P content. Poultry manure contain high amount of P (it can be up to 36kg/m^3 in dry slurry*). In pig slurry* it is less, 5.5 kg of P/ m^3 but quantity applied are more important. P is also a key element for algae growth in wetland (Prasuhn et Flisch, 2005). The littoral zones of Bretagne face pollution issue caused by algae development. The main reason is the intensive pig production. In this context, P loses is a very important factor to consider. ®MASC include 4 criteria to estimate P loses:

- Erosion risk
- Initial soil P content
- Quantity brought (mineral and organic form)
- Incorporation practice (The risk of P loses decrease when incorporation occurs directly after amendment)

*Standard references published by the C.A. Also used as data references in ®MASC.

3.2.2. Interpretation of the results

Multi-criteria analyses have a predominant role in assessing cropping system sustainability (Bockstaller et al. 1997). Compensation between indicators was not possible and interpretation of isolated indicators would not be relevant. Sustainability was evaluated for the unit “cropping system”, thus interaction between indicators was important to be considered. The aggregation method evaluated the overall impact of practices. It is based on the aggregation tool Dexi (Bohannec, 2008). The arborescence (fig 3) is proper to ®MASC decisions rules.

The last dimension (A5, Figure 3) was the result of a set of rules within ®MASC. Nonetheless, the explanations of the results were found at lower level of aggregation. In order to provide a relevant reading of the result, prototypes were analysed within their context (objectives addressed by stakeholders).

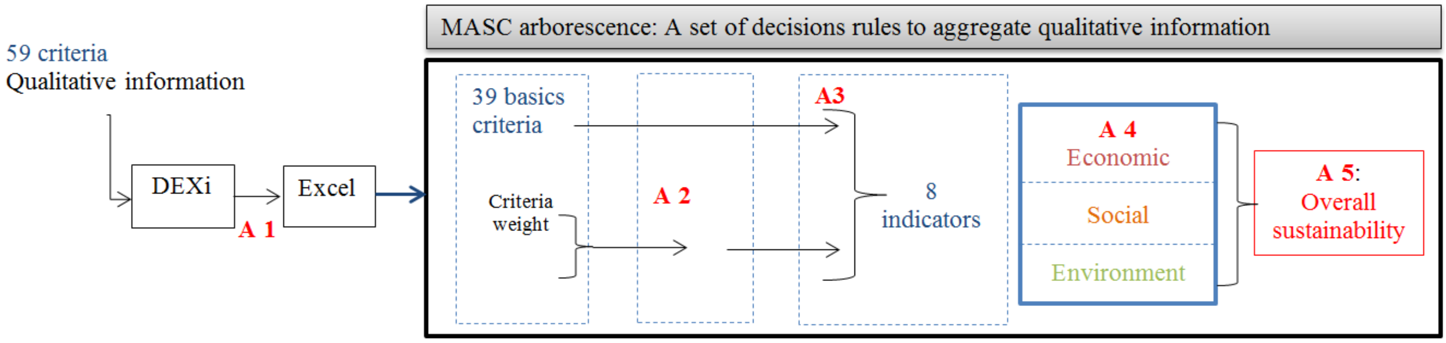


Figure 3. Schematic representation of ®MASC aggregation model. From the 59 criteria calculated or estimated to the aggregation 5: The overall sustainability of the cropping system. (A=aggregation)

In order to keep the integrity and the logic of the tool ®MASC, I did not change the weight of the criteria within the tool but I proposed to do it outside. Otherwise, it would be necessary to justify all change made in the tool. I selected the most important criteria within the 36 criteria calculated for ®MASC and/or criteria proposed at upper level of aggregation (Fig 3). In ®MASC, each dimension of sustainable development has its criteria: (1) the **economic dimension** (2) The **social dimension** (3) the contribution to **environmental dimension** (Craheix et al., 2011)

I compared the prototypes on criteria with the following characteristics:

- Extracted from the same dimension of sustainable development
- Basic criteria (criteria calculated or estimated for local conditions)
- Aggregated criteria (criteria resulting from the aggregation of at least two criteria according to ®MASC set of decisions rules)

Prototypes were ranked according to their responses to criteria of interest (Bergez et al., 2010). I weighted each criterion according to their importance for the stakeholders. It permitted to remove cropping system(s) that was (were) not satisfying the general objective to reach (Meynard et al., 1996). This first selection permitted to keep only the most promising and adapted systems. In order to progressively discriminate prototypes, I looked at criteria to optimize. At this step of the evaluation, optimisation referred to agronomical and agro-ecological practices (Bergez et al., 2010; Meynard et al., 1996). I suggested their degree of improvement's feasibility, on the basis of what was possible in the experimental context. As proposed by Bergez et al., 2010, the evaluation must be flexible and optimisation of the cropping system must be done within and improvement loop. Each evaluation step regarding objectives and feasibility permitted to extract system and reduce the number of prototypes along the selection. By this way, I attempted to select a cropping system that reached the objectives of sustainability in the specific context of Bretagne.

4. Results

This part is devoted to the presentation of the results of the mission.
In the first part, I present the results of prototypes' conception. It includes conception and design's results. The method applied to design cropping system mixes theoretical knowledge and adaptation to the specific context.The participatory approach furnished "informal" knowledge. The conception phase led the design of six prototypes. I gave a short description and hypothesis for each one. The cropping system (crop and corresponding practice) are presented in appendix 8.
The second part is the evaluation of sustainability. The six prototypes were tested and evaluated with ®MASC. I selected the criteria corresponding to our priorities to propose a ranking of the prototypes.

4.1. The prototypes' conception

The conception of cropping system was embedded into action research methodology. The willingness to combine theoretical and practical knowledge was achieved by including experts' knowledge, farmers' participation and scientific models (appendix 2[9]). Before designing, it was necessary to validate produced knowledge. The C.A's objectives were agreed by all participants. It was in a sense a way to reach a common vision of sustainability. "Informal" knowledge obtained by gathering experts and farmers' knowledge was validated. The analysis of participants' knowledge validated decisions rules for the rotation principle, weeding method and fertilization. The analysis of the critics of strategies led to technical and practical advices to apply to the cropping system in order to achieve the objectives.

4.1.1. Production of knowledge

The perception of what should be a sustainable cropping system depends on the context and the participants' opinion. To have a contextual opinion on what is sustainable, it was essential to address the general context in which a conception of sustainable cropping system occurred. We set out objectives, advices and decisions rules on cultural practices to design sustainable system adapted to the Breton's context.

Objectives of the cropping system experimentation
Sustainable may not be perceived similarly depending on the origin of participants. In order to set out general objective to design a sustainable system, I gathered and interpreted collected data. I compared farmers, experts, technicians and C.A. point of view. The results are presented in the following table:

[9] See in appendix 2 the theoretical process suggested by Lançon et al., 2008 for the conception of innovative and sustainable cropping system with experts' knowledge.

Table 1 Summary of the objectives by group of participant.

	Experts	Farmers	Technicians	C.A.
1	Economic (yield)	Incomes	Productivity: yield and quality	Profitability
2	Weed	Weed	Weed	Weed
3	Fertilisation	Fertilisation	N fertilisation	Fertilisation
4		Working time	Production of biomass (OM content)	Long term (eg objts)

We can see that C.A. and experts' priorities were closed to farmers' objectives. The classification proposed by participants was interpreted as following: (1) Profitability; (2) Weeds management; (3) Soil fertility (N fertilization and organic matter); (4) Long term productivity; (5) Farmers' working conditions and (6) N leaching.

Principle of a sustainable rotation

The referential crop rotation for organic arable farm in Brittany is: Faba bean - Maize – Winter wheat

According to the recommendation made by participants (table 2), this rotation should:

- Be extended. All agreed that 3 years rotation is too short and it should be at least stretched over 4 years in organic farming system.
- Rotate summer and winter crop. This permits to enlarge sowing date and thus affects weed growing season.
- Include leguminous crop. It is a condition in favor of nitrogen fertilization. In addition, it diversifies the rotation.
- Sustain the production. This rules means that the crop succession should sustain organic matter content and other essential nutrient.

Table 2 Principle of the rotation to design relevant prototypes. (b) Innovative crops that could be implemented into the experimentation

Experts	Farmers	Technicians
Extend crop succession	At least 4 years	Extend rotation
Include forage	Rotate spring crops and fall crops	Balance C/N and keep organic matter
Rotate summer and winter crops	Condition: climate, farmers' objectives, need for animals	Use mixed cereals and leguminous crops
Balance between cereals and leguminous crop	Maximizing N recycling	Rotate spring and fall crop
Sustainable cropping system include perennial crop	Keep organic matter content	

Innovative crops were also proposed (table 2b). According to participants, they are interested if they:

- Are high added value crop
- Extend and diversify the rotation
- Permit to produce high quality protein for animal feed.

Their main disadvantage was their difficulty to be implemented in Bretagne climate. There are not references; this is a reason why experts, technicians and farmers would like to experiment them on fields.

Table 2(b): Innovative crops:

		+	-
Concentrated protein	Blue lupine	Cultural practices	Less yield than white lupine
	Soya	High price	Few in the region (not adapted to the climate) No experience
	Rapeseed	Coupled with vesce High price	Weed and regrowth Uneven yields Pests and diseases
	Vegetables	Short growth cycle Control over aphids High demand	No experience Pests

Weeds' management

One of the main challenges for organic farmers is to manage weeds. The analysis of information led to advice to control weeds within a rotation (table 3). It referred to agro-ecological practices such as:

- Avoiding crops that are not enough covering (sole crops) or those presenting regrowth problems (potatoes, rapeseed).
- Include allelopathic crops (buckwheat)
- Include inter-cropping crops.
- Include grassland or other long cycle crops.
- Use cover crop in between crop to limit weeds implementation.
- Rotate tillage and cover crop. Rather tillage for summer crops (wider period of interventions) and cover crop for winter crops.

Table 3 Rules for weeds' management

Experts	Farmers	Technicians
Faba bean difficult to manage: rather it mixes with other crop Rapeseed is very difficult in organic system: dirty soil and regrowth Superficial tillage for spring crop and cover crop for fall crop	Rapeseed is very difficult in organic system: dirty soil and regrowth Superficial tillage for spring crop and cover crop for fall crop Faba bean difficult to manage: rather it mixes with other crop Buckwheat: clean dirty plot After grassland: 2 years without weeding intervention	Sow cover (clover) under cereal Up to 3 month between two crops, rather cover than false seed bed

Fertilization

On organic farming system, fertilization is an important point and need to be considered at the farm scale. In arable farm, it is an issue and farmers may fail N, P, K fertilization. The dispensation for organic farmer (EC, 2011) permits to spread conventional manure (subjected to treatments such as composting, airing…). From a technical point of view, it is good for crops' nutrition. From an ethical point of view, organic should stay organic and conventional manure may contain antibiotic or other harmful substance. Participants agreed that arable organic system should be as autonomous as possible. It could be reached with:

- Permanent cover crop (sown under cover crop).
- Intercropping (nitrogen fixing crops).

Table 4 Rules for fertilisation

Experts	Farmers	Technicians
Avoid conventional manure If nitrogen lacking would rather permanent cover crop system	Increase crop autonomy If nitrogen lacking then rather permanent cover crop system Agronomy to recycle nutrients	Avoid N leaching by covering soil Leguminous + cereals = nitrogen autonomy

These decision rules were the basis of the design of cropping system prototypes. I kept in mind those rules to improve the strategies. The results obtained from the interpretation of the critic are presented in the next section.

4.1.2. Production of knowledge to design prototypes

Experts' participation led to four different strategies. They were illustrated with crop succession and complemented with theoretical knowledge (appendix 6) before to be proposed to farmers. Strategies refer to innovative means to produce crops in a sustainable way. The strategies aimed at the management of the main issues encounter by organic farmers. All strategies:, "Crop fixing atmospheric nitrogen" , "permanent cover crop block", "Mechanical weeding" and "stifling crop succession" were focused on means to manage weeds. The last two above mentioned strategies were also including innovative techniques such as reduce tillage or N-fixing crop to enhance cropping system's autonomy.

These strategies were proposed to farmers and cooperative technicians. Their roles were to detail cultural practices, dates, tool, depth of tillage; etc. Unfortunately, farmers were stuck into their own system and it was difficult to combine their knowledge with the proposition made by experts. Cooperatives' technicians added technical knowledge. However, the critic of strategies, permitted to design cultural practices and crop sequences adapted to the region.

The comparison of participants' critics included:

(1) Experts' knowledge. Feedback loop from synthesis strategies to expert (Fig.2).
(2) Farmers' knowledge. Critics and improvement collected during the workshop (Fig.2) and individual meeting.
(3) Technicians' knowledge. Complementary information for improvement of the strategies.

The SWOT analysis was made for each strategy, the details are presented in appendix 7[10]. Results are presented in the following section.

4.1.2.1. Perennial crop at the beginning the rotation

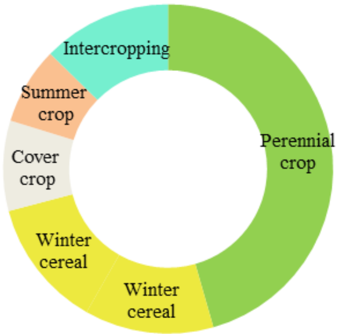


Figure 4. Perennial strategy

The strategy of perennial crop at the beginning of the rotation is presented as on the figure 4. It consists mainly of a leys crops followed by winter cereals. This strategy includes cover crop before implementation of summer crop. According to the results obtained this strategy is the only one agreed by everyone. Strengths, weaknesses, opportunities and threats are approximately the same for the three groups. They judge the strategy efficient for weeds management. Perennial crop are usual on mixed farm. Cattle valorize it by grazing. In arable farm, the main challenge is to have grass as a productive (cash) crop. The three parts agreed that grass valorization was possible. If they would be able to sale their production they would do it, because it is a sustainable practice. This proposition may not be innovative. Indeed, agronomist know that long cycle crop at the beginning of a rotation enforce soil fertility and insure at least two years without weeding intervention. Nonetheless, farmers, experts and technicians wanted to have an evaluation of cropping system based on leys crop. The rotation built on this strategy will be tested with ®MASC in order to evaluate its degree of economical sustainability.

4.1.2.2. Stifling cropping system

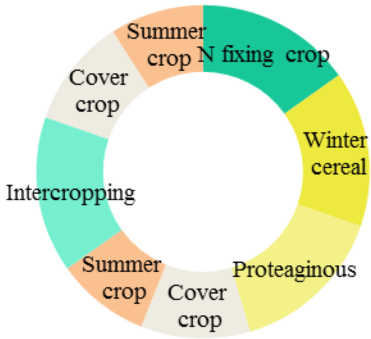


Figure5. Stifling strategy

This strategy is based on crops' competitiveness. Experts selected crops with high covering capacity such as intercropping and protein crops (fig 5). They proposed to focus on species and varieties that may naturally enhance the effect of the stifling strategy. It may limit the type of crop grown nonetheless, it also enhance crop diversification. In this rotation, every popular type of crops (intercropping, summer and winter crop, N fixing, protein crop and cover crops) are used to achieve the objective of maximum soil cover. Fertilization must permit to enhance crop covering capacity. According to the participants, intercropping is well adapted to this strategy because it is an autonomous, rustic and covering crop. In addition, it permits to produce protein. Sole protein crop are not experimented because they tend to be less covering. For participants, intercropping is a satisfying solution. Protein crop and N fixing crop may be associated with secondary crop such as clover (to insure a part of the nitrogen fertilization) or oat (limit weeds overgrowth in the crop). But there is no rose without a thorn and it is difficult to control the secondary crop. This issue was mentioned by all participants testifying of the technical challenge it represents.

[10] Appendix 7 presents the table of the information collected from the three group of participant to establish the SWOT analysis.

4.1.2.3. Cover crop cropping system

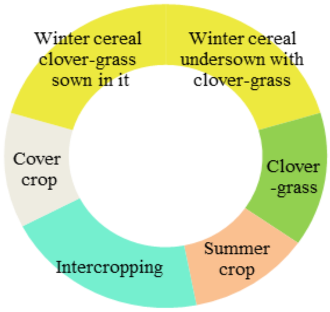


Figure 6. Cover crop strategy

This strategy is maybe the most innovative one. It would permit to furnish the nitrogen needed for the crop without external manure, nonetheless, many challenges remained: it induces reduced tillage practices and no mechanical weeding. Few farmers are doing no tillage and/or permanent cover crop. The system could lead to better soil functioning, but there are too many constraints and farmers do not want to take this risk. Investment in specific equipment was received as a weakness by all. Crop are sown into living cover; representing a high risk to be overloaded by the secondary crop. The strategy was oriented towards autonomous crop rather than direct sowing or association of crop (figure 6). Intercropping was also mentioned as relevant for fertility. Nonetheless, the strategy made out after critic is slightly different from the one proposed to farmers. It appears that permanent covering sequences were not relevant for Bretons' farmers. Farmers and experts proposed mulch as an alternative to protect soil and experiment direct sowing.

4.1.2.4. Mechanized cropping system (hoe on cereals)

Figure7. Mechanized strategy

This rotation is based on mechanical tools to manage weed, thus the succession of crop is more depending on the context than on the strategy (Figure 7). Actually every crop can be hoeing, if the sowing distance is large enough to pass with the machine. The mechanization appears to be a relevant solution to control weeds. According to participant, hoe:

- Could be more efficient on certain weed species
- Is a means to rotate weeding practices and avoid weed resistance along the rotation
- May have good impact on the soil and thus induce a positive effect on the rotation
- Permits to sow cover crop at the last hoe passing. Hoe strategies can be implemented in "intensive" rotation without cover crop and could also fit with more extensive system willing to implant cover early.

The mains threats described by participants is that

- It requires investment
- There is no insight on this cultural practice. There are currently few organic farmers doing it, mainly in conversion.

Nonetheless, it is also a reason why it would be interesting to test it. This could help farmers' conversion to organic.

The conception phase was the results of a combination of knowledge. The cross interaction permitted to validate uninformed knowledge. The proposition of strategies design on experts' knowledge permitted to orient farmers' participation and to design practices acceptable for validation. A compilation of basic decision plus objective critic of strategies plus farmers participation to design cultural practices led to the conception of prototypes. The rotations designed during the project are presented in the following part.

4.1.3. Concretization of collected data into prototypes

Participants were asked to concretize the agro ecological practices they proposed with their critics to design sustainable cropping system. Experts, technicians and farmers' participations were gathered to complete each other. I finally got to six cropping systems design through participative and multidisciplinary approach. The prototypes are described with the hypothesis they rely on. The details of the cultural practices are presented on appendix 8.

P1: Long perennial (fig 4)

8 years – 8 crops: Lucerne (3 years) / Backing winter wheat / Radish (cc) / Maize / Triticale-pea / Oat (cc) / Buckwheat / Triticale pea.

This system is based on a long cycle crop at the beginning of the rotation, it belong to the first strategy (figure 4). It may not be accepted by farmers who do not breed cattle. Nonetheless, Lucerne is known to be efficient to manage weed and nitrogen fertilization. Farmers use this solution to break down weed cycle. It is interesting to propose a detail evaluation of the sustainability of this rotation.

However, hypothesis have to be confirmed:

- H1: After three years of Lucerne, wheat can reach high protein content and low weeds pressure. The following wheat is expected to be of backing quality.
- H2: Lucerne can be sold as a cash crop. There are market opportunities for this production.

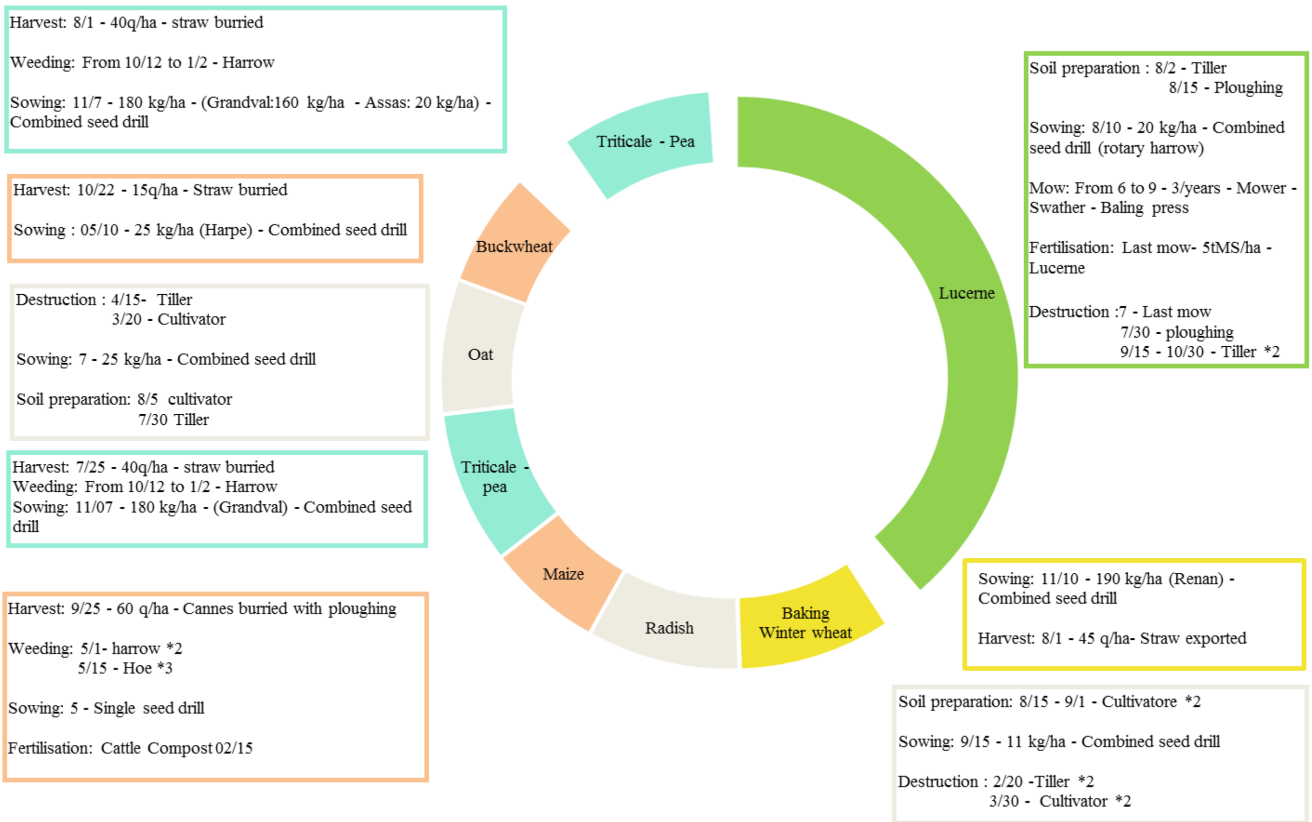


Figure 8 Prototype 1; detailed crop succession and cultural practices

P2: Short perennial (appendix 8**).**

7 years. White clover / Maize / Triticale-pea / Winter Faba bean / Winter wheat / Phacelia (cc) / Buckwheat / Triticale-pea. (Figure 9)

This prototype resulted from the strategy perennial at the beginning of the rotation (figure 4). It was proposed to test clover at the beginning of the rotation to introduce long cycle crop without damaging economic dimension. Clover is known to be a fertility building elements as it fixes atmospheric nitrogen. It may also be efficient to manage weeds after cereals succession. Nonetheless, it is difficult to estimate how long its effect will persist. This rotation may be more interesting than the one with Lucerne because, it include the same number of crops after the perennial and it is shorter. In addition, crops are more diversified, actually more than for the first prototype (long perennial), participant were more concerned with N autonomy along the rotation. Two hypotheses were to be tested:

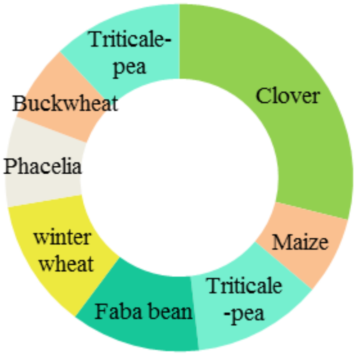


Figure 9 The crop succession designed for prototype: “short perennial”.

- H1: Clover breaks down weed cycle.
- H2: For a positive effect on the rotation, growing clover is less impacting gross margin.

P 3: Autonomous (appendix 8).

6 years. Triticale-pea / Oat (cc) / Blue lupine / Triticale / Winter Faba bean / Maize / Triticale-pea. (Figure10).

This rotation results from discussion about permanent cover crop (strategy 3, figure 6). It is composed of annual cash crop and based on simplified soil tillage. The direct sowing practice happens to be the greatest method of conservation tillage. The strategy purpose was to propose a permanent soil covering first and then “block” of permanent cover (appendix 6). Debates about feasibility, led to the conclusion that it is too risky and clover destruction is not mastered within Bretagne organic system. Propositions were finally oriented on autonomous system with possibility to include direct sowing practice. Experts proposed to focus on maize sown under rolled Faba bean. There is demand for method and advice to implement it into fields. Hypotheses referred to farmers’ need and C.A. action:

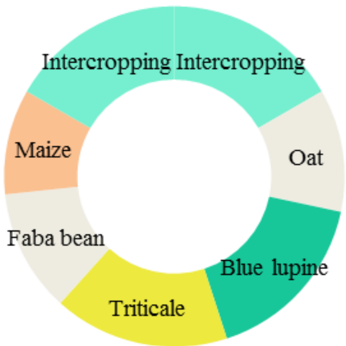


Figure 10 The crop succession designed for the prototype: “autonomous”

- H1: Under sown Maize is easier to manage with Faba bean than with clover.
- H2: Maize sown under Faba bean is a method to manage weed and this crop association would not need weeding intervention.
- H3: Direct sowing is efficient for stockless systems to manage weeds, N fertilisation and superficial soil tillage.

P 4: Hoe (appendix 8)

6 years – 7 crops: Winter Faba bean / Winter wheat / White lupine / Triticale-pea / Oat (cc) / Maize / Buckwheat. (Figure 11)

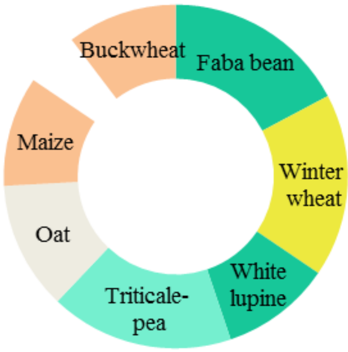


Figure 11 The crop succession designed for the prototype: "hoe".

As I presented it in the strategy (figure 7), hoe can be apply to every crop as weeding machine assuming that sowing distance is increased compare to classic management. Hoeing cereals is becoming more and more important in organic farming. It mainly concerns late converted farmers. This method is not well known, there are less than ten organic farmers doing it in Bretagne. It is based on several hypotheses that can be tested with calculation of criteria and field experimentation.

- H1: there is no effect on the gross margin due to the investment for a specific hoe.
- H2: there is no additional cost of fuel because of the hoe.
- H3: hoe is efficient in long term dimension and satisfies weed management.
- H4: hoe also has impact on soil structure and quality. Thus there is a positive effect because of hoeing during the rotation.

P5: Late sowing (appendix 8).

5years – 5 crops: Triticale-pea / Backing winter wheat / Triticale-pea / Maize / buckwheat. (Figure 12)

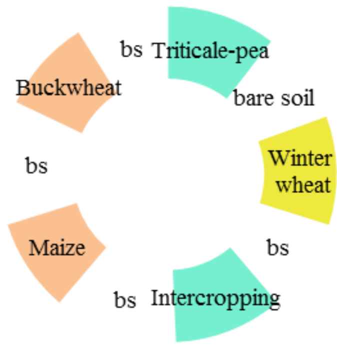


Figure 12 The crop succession designed for the prototype: "late sowing".

This prototype was entirely designed by farmers. They proposed a cropping system based on the mechanized strategy (appendix 6, figure 7). This rotation is entirely based on late sowing to control weed growth. It is an interesting practice but maybe too much depending on climate conditions. In addition, it refers to one farmer practices. It is not enough representative of the C.A. objective for the experimentation, nonetheless, there are hypothesis that would be interesting to be tested.

- H1: the fact to delay sowing date decrease weed density
- H2: The natural cover crops protect the soil during winter time. Regrowth is enough to cover soil.
- H3: The fact to not cover soil during winter time does not too much damage soil quality.

P6: Stifling (appendix 8)

6 years – 8 crops: Winter Faba bean / Winter wheat / Rapeseed – clover / Barley / Triticale-pea / Phacelia / Buckwheat. (figure 13)

This system was proposed by experts. Farmers were less interested into the rotation as they believed it cannot be efficient. Nonetheless, we kept it as it is representative of what farmers do in their field. In addition, it was interesting to introduce rapeseed into the crop rotation. This crop, characterized as innovative, is missing on the organic market. There is high opportunity to increase margin with this production. It is not integrated into farmer practices because it is risky and difficult to manage. The challenge is to manage weed and rapeseed regrowth. We proposed three hypotheses to test:

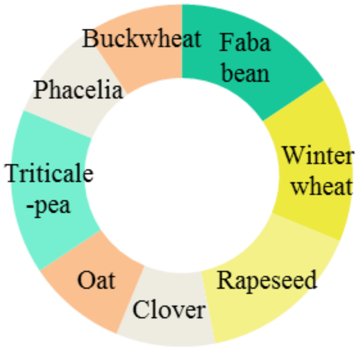


Figure 13 The crop succession designed for the prototype: “stifling”.

- H1: Stifling strategy coupled with fertilisation on demanding crop is a method to manage weeds.
- H2: Sowing clover under rapeseed is an efficient way to fertilize this crop.
- H3: Rapeseed’s regrowth are difficult to control over the rotation. Regular ploughing increase rapeseed colonisation, less ploughing along rotation decrease rapeseed‘s seed germination.

Table 5 Prototypes denomination according to the strategy they come from and the type of cropping system

Strategy		Prototype	Denomination	N°
S1	Perennial crop at the beginning of the rotation	Long perennial at the beginning of the rotation	Long perennial	P1
		Short perennial at the beginning of the rotation	Short perennial	P2
S2	Cover crop	Autonomous cropping system	Autonomous	P3
S3	Mechanical cropping system	Hoe cereals	Hoe	P4
		Late sowing	Late sowing	P5
S4	Stifling	Stifling	Stifling	P6

This table summarize the name of the different prototypes made out of the strategies. The prototypes will be named with the denomination presented in the table and along the description of the results of the evaluation; I will rather name them P1 to P6

4.2. Evaluation of cropping system sustainability

The evaluation with ®MASC permitted to compare the prototypes to the national average. This induced a comparison with both organic and non-organic systems. It appeared that all prototypes presented a high level of sustainability (overall appreciation were up to 5/7). Their overall contribution to sustainable development was almost similar (appendix 9).

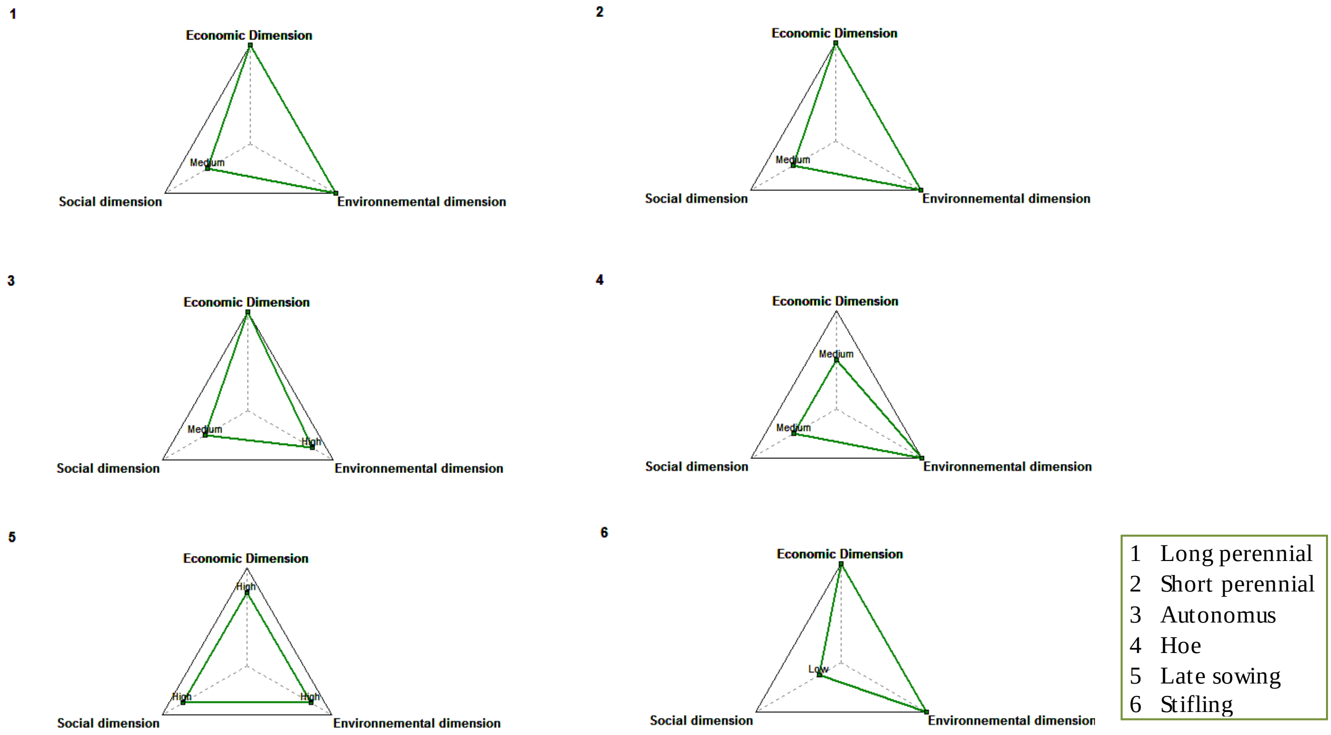


Figure 14 Representation of the contribution to the three dimensions of sustainability (MASC –DEXi)

®MASC allowed maintaining that our organic systems were above the French average. But this result did not permit to differentiate the cropping systems. The comparison of the different prototypes must be done at deeper level of analysis. ®MASC arborescence presented different levels of aggregation for each cropping system (fig 3§3.3). Prototypes must be detailed to deeper layers of criteria aggregation. ®MASC was used to reach an "ideal" cropping system according to the objective set at the beginning. In order to provide a relevant analysis of the prototype, we decided to compare cropping systems according to the objectives proposed by the participant during the conception phase (§4.1.1).

4.2.1. Cropping system response to objectives

Prototypes cannot be differentiated on the basis of their contribution to sustainable development. Prototypes were classified according to their performance on:

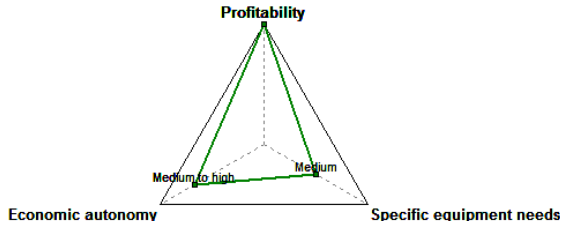
(1) Economic results (profitability); (2) Economic dimension; (3) Weed management ; (4) Soil fertility; (5) Long term productivity; (6) Farmers working conditions ; (7) Environmental impact (N leaching)

(1) Economic results

The main objective to be achieved by the cropping system within economic dimension was profitability. This criterion is included into the module “economic results”. According to the figure 15, we can say:

- P2, P5 and P6 had medium profitability / P1, P3 and P4 had high profitability
- P1 and P3 will required more specific equipment than other to be implemented
- P3 is the more autonomous
- P5 is the less competitive system.

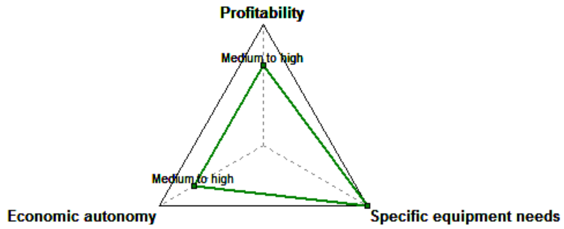
1



P1 Long perennial

4	/4 Profitability (656.4)			4/4	Economic results
4	/4 subsidies independency	3/4	Economic Autonomy		
2	/4 Economic efficiency				
2	/3 Specific equipment needs				

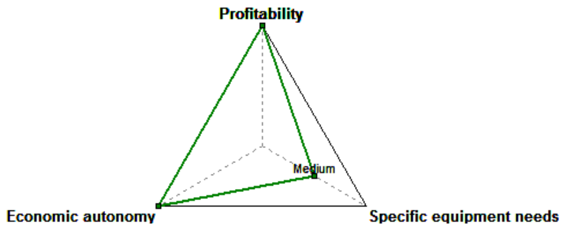
2



P2 Short perennial

3	/4 Profitability (562.6)			4/4	Economic results
4	/4 Subsidies independency	3/4	Economic autonomy		
2	/4 Economic efficiency				
3	/3 Specific equipment needs				

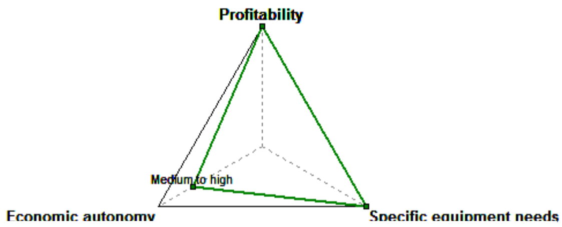
3



P3 Autonomous

4	/4 Profitability (723.7)			4/4	Economic results
4	/4 subsidies independency	4/4	Economic autonomy		
3	/4 Economic efficiency				
2	/3 Specific equipment needs				

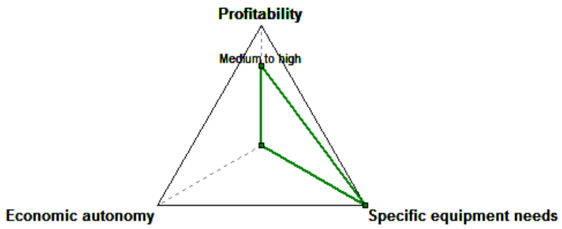
4



P4 Hoe

4	/4 Profitability (603.1)			4/4	Economic result
4	/4 Subsidies Independency	3/4	Economic Autonomy		
2	/4 Economic Efficiency				
3	/3 Specific Equipment Needs				

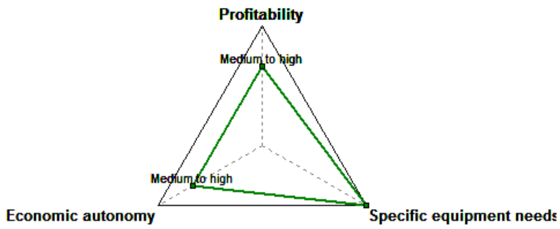
5



P5 Late sowing

4	/4 Profitability (598.6)			3/4	Economic results
1	/4 Subsidies independency	2/4	Economic autonomy		
3	/4 Economic efficiency				
3	/3 Specific equipment needs				

6



P6 Stifling

3	/4 Profitability (478)			4/4	Economic results
4	/4 Subsidies independency	3/4	Economic autonomy		
2	/4 Economic efficiency				
3	/3 Specific equipment needs				

Figure 15 Representation of the contribution to economic results. It refered to the aggregation of: profitability (50%) – (gross margin €/ha/year), economic autonomy (38%) and specific equipment needs (11%).

(2) Economic dimension

According to the objectives, it was relevant to differentiate the prototypes on the basis of the economic analysis. The chart 16 represented the contribution to economic dimension. It resulted from the aggregation of: economic results (33%), long term productive capacity (33%) and contribution to local development (33%) It permitted to quickly have the classification of the 6 prototypes.

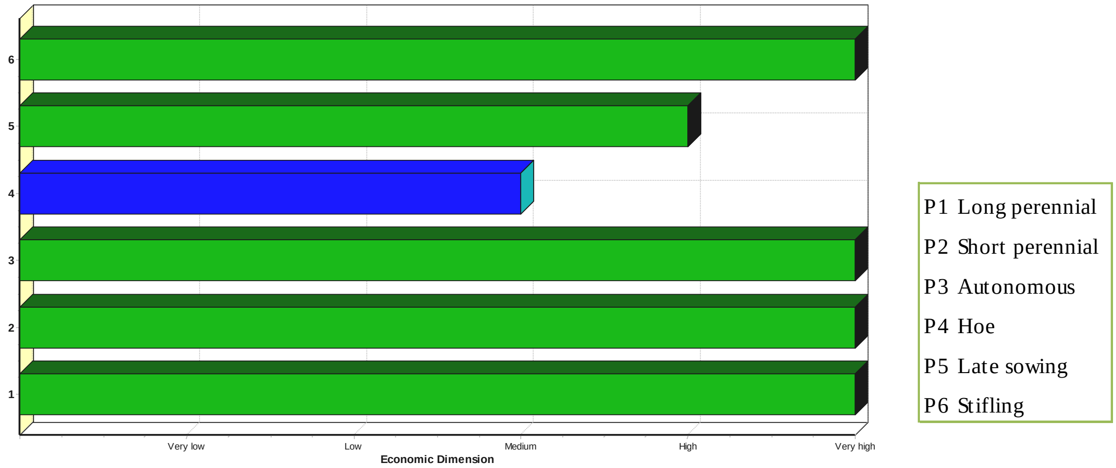


Figure 16 MASC output: Contribution to the Economic dimension. On the x-line, the qualitative classes, from left to right "very low, low, medium, high, very high". On the y-line, the prototypes from 1 to 6.

Apparently, cropping system 4 and 5 are less competitive. In order to rule out prototypes, I detailed the economic dimension. The figure 17 is a representation of the contribution to the three indicators aggregated. We can see that:

- P5 had lower level of economic results. It explained the low contribution to Economic dimension.
- P4 did not participate to the local economic development. Discriminatory for Economic dimension.
- P1, P2, P3 and P6 had good overall evaluation with high results and medium economic development.
- P6 was very high for the long term productive capacity

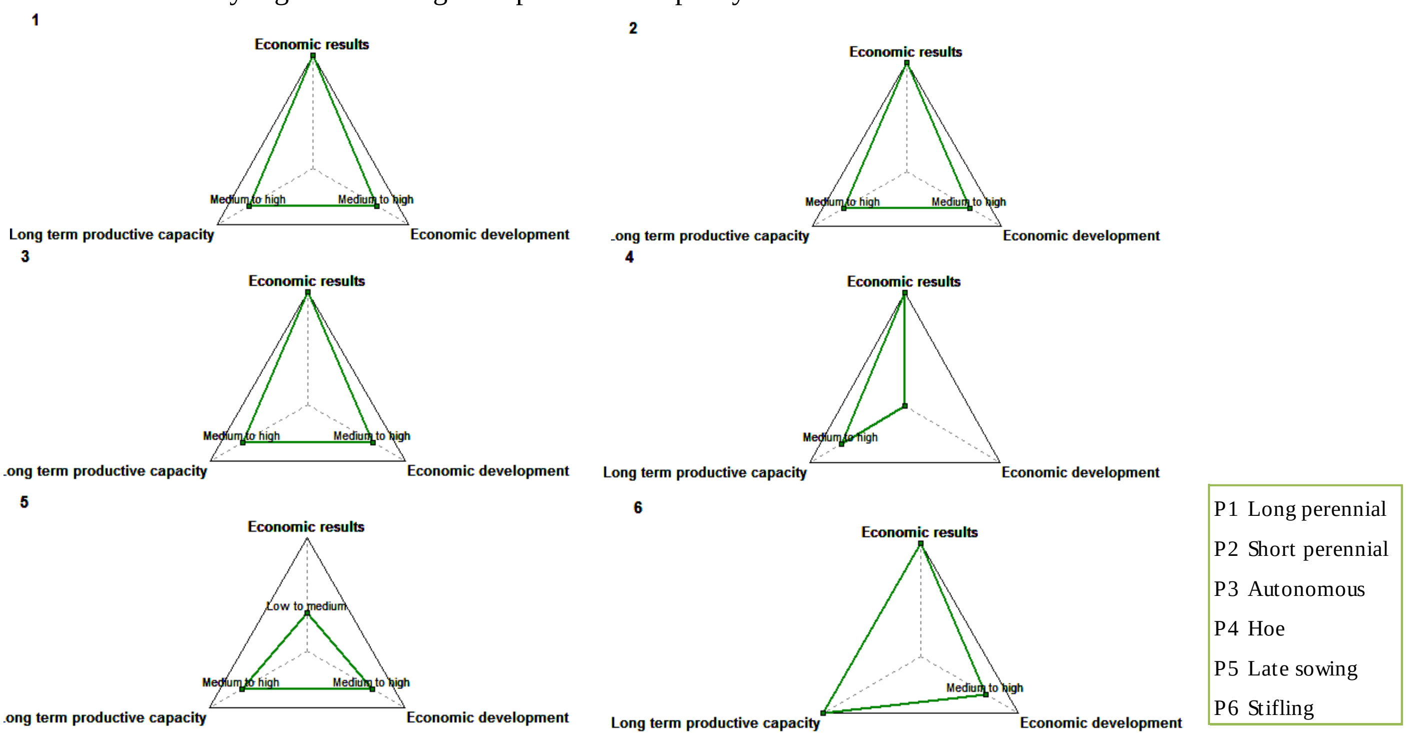


Figure 17 DEXi charts. Aggregation of the three indicators that represent the contribution to economic dimension

(3) Weed management

The estimation weeds control is made out the aggregation between the effect of diversity of sowing date, soil tillage and effect of weeding intervention and practices (table 6). On the figure 18 we see:

- P3 and P6 had more diversified sowing date.
- P5 sowing date were not enough diversified to have a positive effect on weeds' control.
- Weeding method applied to the rotation are efficient for P2, P3, P5 and P6, they are not performing in P1 and P4.
- Ploughing effect is not discriminatory has all rotation would be plough

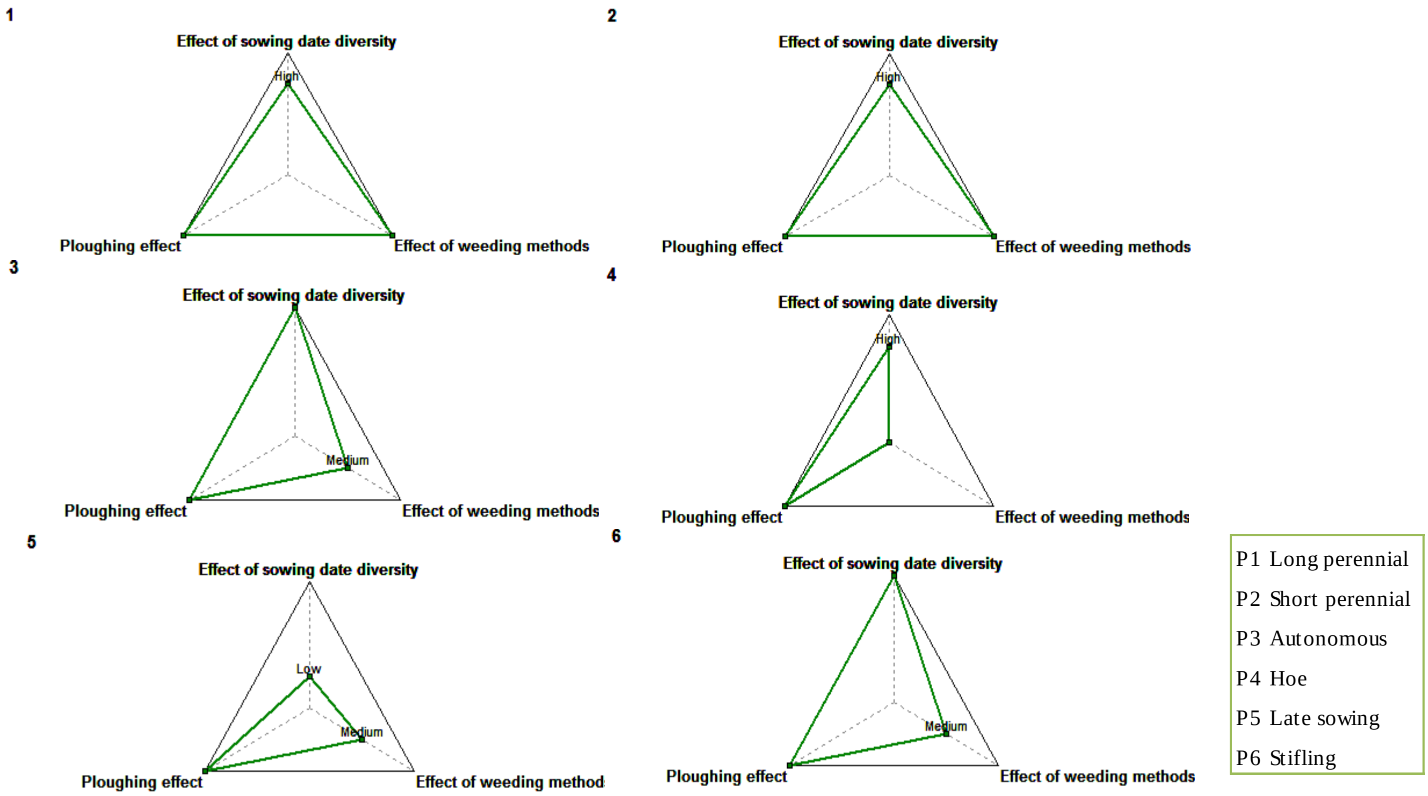


Figure 18 Satisfaction of the three criteria implied in weeding method evaluation.

The estimation of the weeding methods is subjective and fixed by ®MASC (table 6). I present the evaluation of the practices proposed by ®MASC to clarify this indicator.

Table 6 ®MASC indication to estimate the effect of weeding methods. For each crop and cultural practices between cash crop marks were affected following ®MASC advices. The effect of weeding methods was estimated per crop and was brought back to the rotation scale.

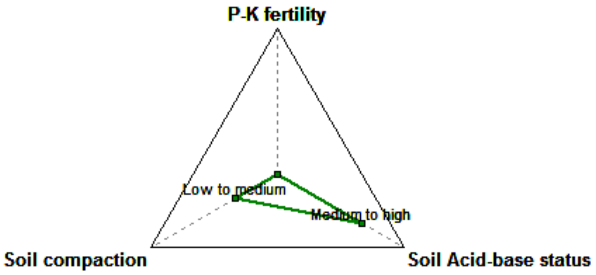
Physical control (Lpi)			Control with cover crop (Cci)		
Seed bed preparation or cover crop	Average: 2 superficial tillage(plough in straw + seed bed preparation)	0	SB or CC	No cover crop	0
				Cover crop with medium covering capacity	1
	3 interventions ST	1		High covering capacity or mulch	2
	> 3	2	Crop	Low covering capacity	1
Crop	No mechanical weeding	0		Crop with medium covering capacity	2
	1 to 2 passing	1		High cover(intercropping, direct sowing)	3
	At least 3 passing	2		High covering capacity (Hemp, grassland, mulch)	4

(3) Soil fertility

There are no specific indicators to inform about fertility. The closer indicator is the evaluation of long term productive capacity. Soil fertility is estimated as a compilation between P and K fertility, soil compaction and soil acid-base status. According to ®MASC figure19 for those indicators:

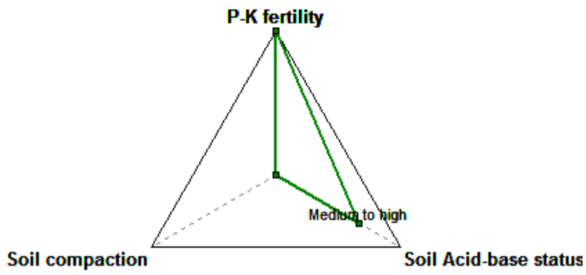
- The soil acid base status is good enough to ensure nutrient availability.
- P2, P4, P5 and P6 had good P, K fertility while P1 and P3 did not permit to maintain tolerable level.
- P1, P2, P3 and P4 had lower soil fertility than P5 and P6. System less fertilize.
- The risk of soil compaction is lower for P6, then P3, P1 and P5. The higher risk is for P2 and P4.

1



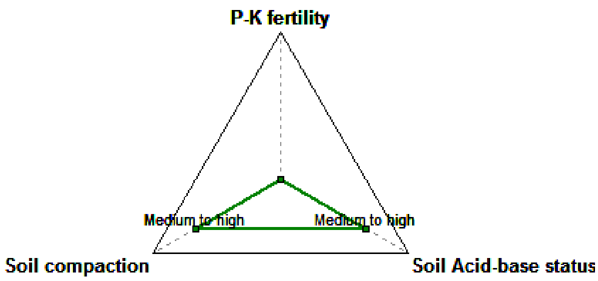
3	/4	Soil Acid-base status	2/4	Physical and Chemical fertility
2	/4	Soil compaction		
1	/4	P-K fertility		

2



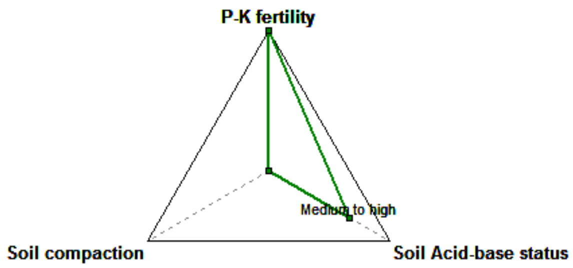
3	/4	Soil acid-base status	2/4	Physical and chemical fertility
1	/4	Soil compaction		
4	/4	P-K fertility		

3



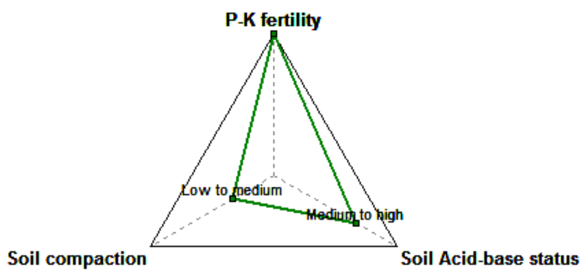
3	/4	Soil Acid-base status	2/4	Physical and chemical fertility
3	/4	Soil compaction		
1	/4	P-K fertility		

4



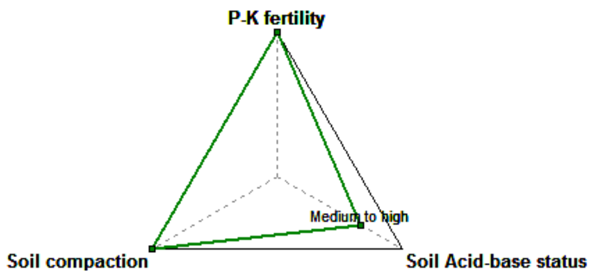
3	/4	Soil Acid-base Status	2/4	Physical and Chemical fertility
1	/4	Soil compaction		
4	/4	P-K Fertility		

5



3	/4	Soil acid-base status	3/4	Physical and chemical fertility
2	/4	Soil compaction		
4	/4	P-K fertility		

6



3	/4	Soil acid-base status	4/4	Physical and chemical fertility
4	/4	Soil compaction		
4	/4	P-K fertility		

Figure 19 Aggregation of three criteria to estimate the physical and chemical evolution of soil fertility along the rotation. Diagrams extracted from MASC are complemented with DEXi aggregation table

(5) Long term productive capacity

The long term productive capacity is estimated with the aggregation of pests' control (50%) and P and K fertility (50%).The figure 20 are extracted from ®MASC represented the contribution of each prototypes to the long term productivity and the evaluation of P and K fertility (table 8) and pests' control (weed (table 6) and pests(table 7) control) indicators. We can say that:

- P6 had the better long term productive capacity with the two indicators very high.
- P5 had the best fertility control.
- P1, P2 and P4 presented the same aggregation with medium P, K fertility and high pest control. That means that fertility was the most influencing factors for long term productive capacity.
- P3 was the less efficient
- P3 and P5 had lower level of pest control.

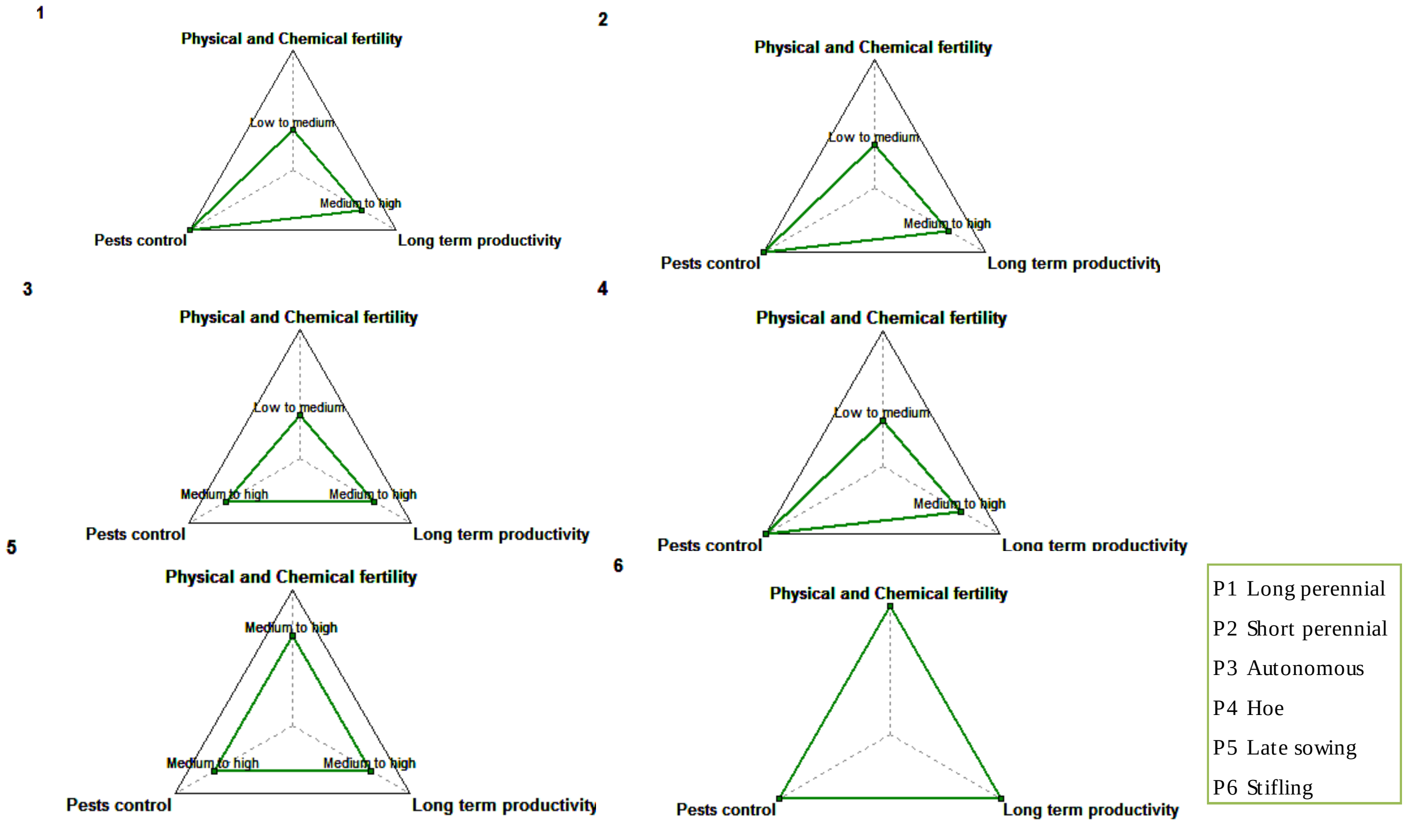


Figure 20 DEXi chart, represents the aggregation of physical and chemical fertility (50%) with pests control (50%) to estimate the long term productive capacity.

Table 7 As for the effect of weeding practice, ®MASC gave indication to estimate the effect of pests control

Genetic control (CGi)		Biological pest control (LB)		Chemical pest control (LCi)	
Low resistance to telluric parasitic	0	None	0	Use frequency (without herbicides)	0
Medium resistance	1	Biological pest control agents	1		
Resistant variety	2				

Table 8 Calculation models and information needed to evaluate P and K fertility at the rotation level. An example of calculation is presented in appendix 10.

$$\text{Recycling residues}_K = (\text{Quantity of residues} * \text{content}_K)/\text{year}$$

$$\text{Annual Outcomes}_K = (\text{K bringing in} - (\text{Yield} * \text{Content}_K))/\text{year}$$

(6) Farmer working conditions

Farmers' satisfaction was evaluated in the social dimension in ®MASC. Cropping systems 4 and 5 had better level of satisfaction. In order to identify the strength and weakness of each proposition, I detailed this indicator. The module "farmers' satisfaction" aggregated "implementation" (50%) and "working conditions" (50%).

(6a) Implementation: The figure 21 represents the implementation level for each system. They were two groups of systems: "low to medium" and "very high". Implementation resulted from the compilation of crop complexity (72%) and number of crop (28%) According to its relative importance, complexity is more influencing "implementation" than number of crops. To explain the classification obtained by the indicators "implementation", we focused on complexity (figure 22). We can conclude that P1, P4 and P5 were simpler to implement. P3 was the most complex. P2 and P6 were in between.

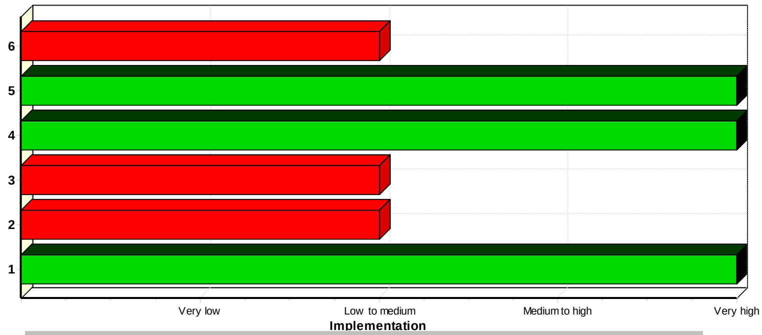


Figure 21 MASC chart for the indicator "Implementation".

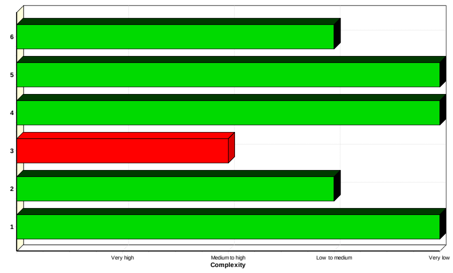


Figure 22 MASC chart for the criterion "Complexity".

(6b) Working conditions:The chart 23 represents the level of satisfaction for working conditions. Systems P2 and P3 had high satisfaction of working conditions, 1 clearly presented a risk to not be acceptable for farmers. P4, P5 and P6 were not differentiable. Working conditions referred to workload distribution (18%), health risk (41%) and physical difficulty (41%). Figure 24 allowed to conclude that system P1 is time consuming, P4, P5 and P6 could be acceptable for farmers and P2 and P3 were less demanding than other cropping system. In order to differentiate the prototypes it was needed to establish priorities.

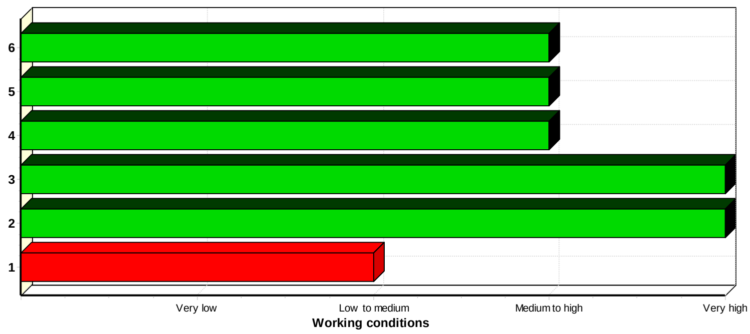


Figure 21 MASC chart for the indicator "Working conditions"

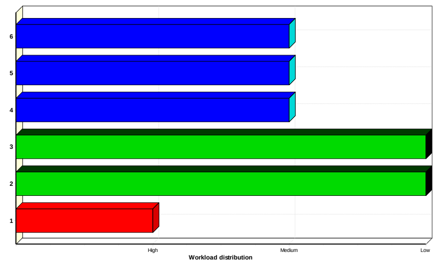


Figure 22 MASC chart for the indicator 'Workload distribution".

We fixed the hypothesis that: the criteria "quality of working conditions" is more important than "complexity" for farmers. The notion of working time was expressed by farmers during the workshop (§4.1.1). Thus the prototype P1 was the worse, P6 was low to medium, P4 and P5 had a medium level of satisfaction, P2 and P3 were good with the advantage for P2.

(7) Environmental impact (N leaching)

A high contribution of cropping system to environmental dimension was a rule of thumb. Nonetheless, in Bretagne there are water pollution issues. Even if systems are organic, phosphorus and nitrogen leaching must be controlled. This issue was introduced by the technicians from cooperative (objectives §4.1.1.).

Nitrogen losses were estimated for each prototype, the figure permitted to differentiate the prototypes:

- There was no risk for N2O emissions.
- There were no risk of leaching or volatilisation for P1, P2 and P3
- There was a medium risk of volatilisation for P4 and P6 and high risk for P5.
- P6 could cause N leaching

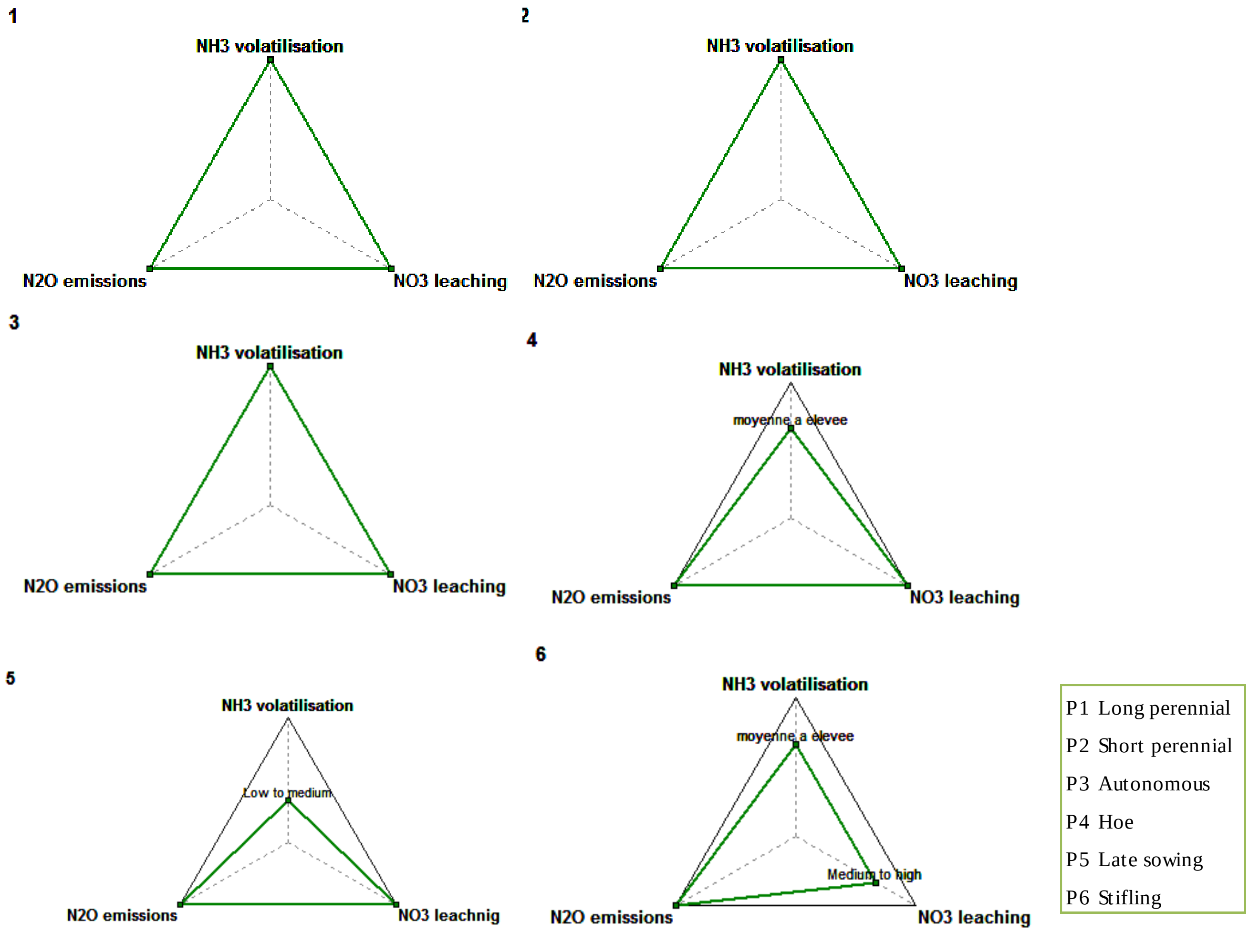


Figure 23 MASC representation of the module Nitrogen

4.2.2. Classification according to objectives

Indicators were hierarchized according to stakeholders' priorities. The table 9 summarizes the results presented above.

Table 9 Classification of the cropping system according to their response to the main objectives proposed by stakeholders

Objectives		Organization into a hierarchy					
		+++	++	+	-	--	---
Profitability Economic autonomy Specific equipment needs	(1) Economic results	Autonomous	Hoe	Long perennial	Short perennial / Stifling		Late sowing
Economic results Long term productivity Economic development	(2) Economic dimension	Stifling	Long / Short perennial / Autonomous			Late sowing	Hoe
Sowing date diversity Soil tillage Effect of weeding methods	(3) Weed management	Long perennial	Short perennial	Autonomous / Stifling		Hoe	Late sowing
Soil structure P-K fertility	(4) Soil fertility	Stifling	Late sowing	Short perennial / Hoe		Autonomous	Long perennial
Physical Soil organic matter content Pests control	(5) Long term productive capacity	Stifling	Late sowing	Long / Short perennial / Hoe			Autonomous
Implementation Working conditions	(6) Farmers' satisfaction	Short perennial	Autonomous	Hoe / Late sowing		Stifling	Long perennial
NH^3 volatilisation N_2O emissions NO^3 leaching	(7) N leaching	Long / Short perennial / Autonomous			Hoe	Late sowing	Stifling

The first column takes back the indicators and criteria aggregated by ®MASC. The second column designates the criteria of ®MASC selected to represent the objectives proposed during the conception. The third column is the classification of the prototypes for each objective. This table must be read in line. For instance line one is the economic results: For this criterion: Autonomous is better than Hoe > Long perennial > Short perennial, Stifling > Late sowing. That means that cropping system "Autonomous" had the best response the criteria economic results. And at it opposite, prototype "Late sowing" had the worth response to economic results. When more than one cropping system is in a box, it means that the different prototypes presented exactly the same response to the criterion. For instance, for N leaching we see that, long and short perennial and autonomous cropping system are all "+++", if we look back to MASC representation of the criteria (figure 25), we see that they have the same degree of satisfaction of NH3, NO3 and N2O.

Prototype classification

This classification did not highlight on cropping system. In addition, all criteria have the same importance while it is not true in the reality. Indeed, the objective classification permitted to clearly identify priorities such as the economic dimension. Prototype classification was made in consideration of the relative importance of each objective[11] (appendix 11). Each rank (established from the previous table 9) and criteria (established from objectives hierarchy table 1) got a "value" (see appendix for more details). By weighting rank and objective, I reached an evaluation of the prototypes on the basis of ®MASC evaluation. The following table 10 presents the classification obtained by this mean:

Table 10 Classification into point according to objectives' weight.

	P1 Long perennial	P2 Short perennial	P3 Autonomous	P4 Hoe	P5 Late sowing	P6 Stifling
+ Profitability	14	14	28	21	0	14
Economic results	18	18	18	0	6	24
Weed management	20	15	10	5	0	10
Soil fertility	0	12	4	8	12	16
Long term productivity	3	3	0	3	9	12
Farmers' satisfaction	0	8	6	4	4	2
- N leaching	4	4	4	2	0	0
Total point	59	74	70	43	31	78

In this table, the first column corresponded to the criteria or indicators selected for the evaluation. Then columns 1 to 6 are the prototypes. Each criterion got a weight in descending order from 7 to 1 (see appendix 11). It is supposed to highlight contribution to the most important criterion. For instance, for "profitability", each prototype will get seven times the note it obtained from the ranking. The total point was made by column; it represents the amount of point obtained by each prototype for the evaluation of the criteria of interest. In the present context, the most sustainable systems are the **stifling (P6), short perennial (P2), autonomous (P3) and long perennial (P1)**. Their score are too close to definitely exclude one of these. For prototypes **hoe (P4) and late sowing (P5)**, the difference is significant and I conclude that they are less adapted to the situation. Even if they are excluded from the finalist list, I can still refer to some of the practices that appear to be sustainable during the evaluation.

Synthesis of the results obtained

Each prototype was described in order to point out weaknesses and strengths. It combined the general appreciation of the prototype and the axes of improvement proposed through the analysis of the criteria. If more details are needed, prototype description according to ®MASC analysis is presented in appendix 12[12]. The arborescence proposed by ®MASC supported the classification; I checked if the ranking was respecting ®MASC evaluation. It also helped for the analysis of strengths and weaknesses.

The table 11 is the synthesis of the results obtained during the conception and the evaluation of the cropping systems' sustainability. This table will serve the following discussion part to "make a decision" and propose the most appropriated system for the field experimentation.

[11] Appendix 11 presented the details of the ranking methodology. It may help the reader to understand how I get to this classification.

[12] Appendix 12 presented MASC arborescence. It is the raw result obtained from MASC evaluation of the 6 prototypes.

Table 11 Synthesis of the results obtained for the cropping systems. It took back ®MASC evaluation, recommendation and description of each prototype.

	Hypothesis	Strengths	Weaknesses	Criteria to optimize
P6 Stifling	Fertilisation permits to express crops' covering properties Clover under rapeseed is fertilizing Irregular ploughing permits to limit rapeseed to regrowth	Experiment the association clover-rapeseed Rotate winter and summer crop Production of protein Rotate tillage and cover crops Rapeseed	Rapeseed (control regrowth) Risk of N losses Lot of cultural intervention 4 crops under 6 are winter crops: workload distribution	Profitability Working conditions Organic matter content Biodiversity
P2 Short perennial	Clover breaks down weeds cycle With a positive effect on the rotation, clover is less costing than Lucerne	Long cycle crop Optimisation of autonomous crop Rotate weeding tools Production of protein Use cover crops	Effect of clover cannot be compare to the Lucerne Crop succession long after clover (5 years) Recycling clover mows	Profitability Soil structure Working conditions Organic matter content Biodiversity
P3 Autonomous	Direct sowing master with Faba bean while it is not with clover Faba bean cover allow to not weed	Autonomy for N fertilisation Use inter-cropping Optimisation of the soil cover Rotate winter and summer crop Rotate weeding tools	Risk of N deficiency Direct sowing is risky Decrease of grain yield when direct sowing Lupine: factors anti-nutritional Faba bean not harvested	P, K fertility Complexity of cultural practices Organic matter content Weeding methods
P1 Long perennial	After 3 years of Lucerne, wheat has baking quality Lucerne can be valorised as a cash crop	Insure to breaks down weeds cycle Enhance soil N content with Lucerne Optimisation of the cereals production for 5 years Use cover crops Rotate winter and summer crop	Lucerne must be sale for a minimum price Working conditions (lot of interventions) Need to compensate Lucerne exportation 5 years of crop after 3 years of Lucerne may be too long	Economic efficiency P, K fertility Working conditions Organic matter content Biodiversity
P4 Hoe	The investment does not damage economy Hoe is efficient on long term Fuel consumption does not increase compare to harrow Positive effect of hoe at the rotation scale	Easy to implement To be apply in case of ecologically intensive production Reassuring tools Weeds control on the row	Sole crop Lupine Hoe investment No cover crops To be combined with other weeding methods	Sanitary quality Workload distribution Soil fertility (OM) Nitrates Profitability
P5 Late sowing	Late sowing decrease weeds implementation into the crop Let natural cover during winter decrease the soil seed bank No damage of soil quality	Innovative methods for weed preventive control Cultural practices easy to implement Match markets' opportunities Adapted to the climate	Lack of soil covering Workload distribution Soil quality No cover crops Not looking for any models of autonomy	Economic efficiency Weeds control P losses N volatilisation Organic matter content

5. Discussion

5.1. Make a decision

®MASC permitted to realize a multi-criteria evaluation of the different cropping systems. The ranking (table 10) highlights system with high participation to the most important criteria. The classification gave an indication on what seems to be the most sustainable system but none were performing well all criteria. According to the evaluation, cropping systems P6, P2, P3 and P1 (respectively: stifling, short perennial, autonomous and long perennial) are interesting. Cropping systems P4 and P5 would not be acceptable for the stakeholders. Even with a high participation to the overall sustainability of the cropping system (appendix 12), they are less favourable regarding to the objectives' hierarchy. As mentioned by Bergez et al., (2010) simulation models for cropping system evaluation permits to identify the best system not only on one criterion but also on notion of risk or efficiency. The interpretation of the results must be done by a clear description of all relevant aspects of choices (Bergez et al., 2010). Inherent impact of practices must be considered into the final decision. In order to make a relevant choice for the C.A., the perspectives of the experimentation must be further detailed. The experimentation objectives were no clear since the beginning of my mission. On one hand, the C.A. wanted to enlarge systemic experimentation on arable cropping system. They focused on innovative practices for specialized systems (producing grain without recourse to leys). On the other hand, the C.A. wanted to have a field experiment to demonstrate. This implied to take less risk on innovation and insure that the cropping system will perform. Elected members (see box1) were asked to take position on the finality of the experimentation. They expressed preferment on innovation and were willing to experiment something new that serve organic farmers interest. They enforced that economical approach was a priority for the farmers. They believed that cropping systems with leys are not satisfying farmers' needs and took position for specialized cropping system. It reminds the conclusion set out through Rot AB (2011), where it was emphasized that leys are more sustainable but other practices can permit to manage technical challenge without damaging farmers' viabilities. Cropping system P1 and P2 were highly sustainable nonetheless they do not interest the C.A. thus I eliminated these cropping systems.

The analysis of these prototypes pointed out interesting practices that may be relocated into other prototypes to enhance their contribution to sustainable development. Cropping systems P1, P2, P4 and P5 includes many agro ecological practices and crop sequences that must be considered. In the appendix 13, I come back to the description of those prototypes in order to highlight their advantages and weakness. ®MASC permitted to rule out four prototypes, but I could not conclude on the selection of the most promising. In the next section, I discuss prototypes autonomous and stifling. It should permit to conclude on the strategy to orient the experimental design and to improve the current system with practices highlighted during the discussion of the removed prototypes.

5.1.2. Focus on the most promising cropping system

Regarding, to the hypothesis of cropping systems P3 and P6 it is difficult to ensure that they can succeed (table11). Hypotheses are based on non-predictable events, thus, only field experiment could tell us whether it is an innovative technique or not. Nonetheless, it is possible to improve those two systems in consideration of their main weakness (table11) and by including techniques from other prototypes or strategies.

About stifling prototype (P6):

The main weakness of "stifling" prototype is its low profitability. One should be aware that any additional intervention to improve the global sustainability of the system may impact profitability and decrease the economic results. In other words, any change in the crop succession or practices could potentially affect gross margin. Apart from this economical point, this system could be further improved. For instance, if it is possible to balance winter and summer crop, it could improve the workload distribution and the enhance weeds management. In order to limit N leaching, it may be interesting to decrease the fertilization and remove the liquid manure. If this rotation includes more autonomous crops and limit nutrient lacking by using building nutrient crops, it may be possible to eliminate N losses.

About autonomous prototype (P3):

The cropping system "autonomous" was the most innovative one because of its fertilisation autonomy. However the main threats are concerning soil fertility and risk of N lacking, so it seems to be necessary to apply at some point an organic fertilization with organic manure. One should also be aware that the evaluation did not reflect the effect of weeding and autonomous fertilisation of intercropping. Farmers proposed that intercropping does not need weeding intervention because they are enough covering, Nonetheless, if we look at the evaluation of the weeding methods proposed by ®MASC (table 6), we can see that evaluation of such advantages is not highlighted. Indeed, a sole crop, with low covering capacity that would have at least 3 mechanical interventions obtained the same ranking than intercropping. If we compared to a more covering crop, such as triticale with 3 mechanical weeding and intercropping, then the effect of the weeding method is more valuable for the sole crop. This indicator on the effect of weeding methods is interesting but in some case could create contradiction. This rotation also introduces the technique of direct sowing. I made the hypothesis that direct sowing is master in organic agriculture and would not damage too much maize yield. There is a risk of competition between maize and Faba bean. To be really damaging on the global rotation economy, the maize yield should be more than 50% lower than the expected yield (table 12).

Table 12 Effect of maize yield decreasing on the cropping system gross margin

Maize yield q/ha	Gross margin €/ha	®MASC class
60	723.7	very high
35	603.7	very high
30	579.7	medium to high
0	435.7	medium to high

It would be interesting to complete the experimentation with some analytical trials to test this practice apart from the system experiment. When it will be proved that it works (or not) it would be possible to include it (or not). To be implemented, it should success maize fertilization and Faba bean mulch should be highly covering.

To conclude on the selection of the most promising system, it appeared that none of the cropping system should be implemented as they were initially designed. A loop of improvement was needed to reach the optimal system based on the principle of “stifling” and “autonomous” strategies. They appeared efficient to manage weeds and fertilisation under conditions of specialized cropping system.

As it was not so easy to conclude which cropping system is the best, I rather focused on means to ensure long term productive capacity. In the next section, I focused on agro ecological practices and the possibility to introduce them in our context.

5.1.3. Do they meet the common practices of organic farming?

The main challenge expressed by participant was economic viability; it is assumed that economic relies on market price but also on the production’s performances. Issues focused on weed competition and crop fertilisation; two essential points to assess sustainability. Economy relies on factors that can have negatives impact on the yield on. An agro ecosystem should enhance practices enhancing favourable conditions for crops.

Weed management

Weed is a key issue in organic agriculture and technical innovation are needed for organic production. During the last decade, increasing attention was paid to it. Weed control relies on different strategies, depending on the agro-ecosystem and the control strategy. Riemens et al., (2007) proposed an interesting reflection on weed seed bank depletion. They highlighted an important question stretched by organic farmers and technicians: should we intensify weeding, control residual weeds or prevent weed seed return to soil. Beyond these questions, issue is also: it is possible to empty (or even decrease) soil seed bank? Three strategies to control weeds based on the weed population dynamic were examined by Riemens et al., (2007). Strategies relying on annual control of weeds to prevent yield loss were less relevant compare to strategy focused on seed bank depletion (Riemens et al., 2007). Intensifying curative weeding did not have significant effect on weed seed storage; hand weeding is better to prevent seed return (Riemens et al., 2007). It may be proposed as a complementary method but weeding strategy should not be only focused on seed bank depletion. An efficient weed control pass by limiting seed return but also affecting weed life-cycle (Riemens et al., 2007).According to Bàrberi weed management should be integrated to other cultural practices in order to reach an optimal system. For instance, cover crops provide a protection of the soil against weed growth but also have an effect on nutrient availability and pests’ management. Bàrberi emphasize that analytical experimentation and reflection around weeds only are not efficient. The objective should not be weeds, but how to reach a steady state by combining preventive and curative weeding methods appropriated to the specific situation (soil, flora, tools...). All the strategies proposed by Bàrberi to manage weeds on organic farming are presented in the table 13 bellow.

Table 13 Preventive methods to manage weeds in organic farming. (**Adapted from** Bàrberi., 2001)

Preventive methods	
Diversification of the cropping system	Alternation between: winter and summer crop; grain and root crops; nutrient-depleting and nutrient building crop Inclusion of a ley phase (long cycle crop)
Diversification of primary tillage	Alternation between : ploughing and non-inverse tillage; type and time of seedbed preparation (false seed bed - ridging)
Diversification of the system	No repetition of the rotation Crop sequences: changing the system other time Allopathic crops
Cultivars	Faster seedling emergence Canopy establishment Organic seed quality (selection and production)

Cultural methods
Efficient since they maximize the differential of development between crop and weed
Modification of crop sowing date, density and pattern
Sow in pairs row to hoe the row
Using of intercropping
Flexibility for readjustment over time

Fertilisation

According to the result obtained with ®MASC and the current knowledge on crop autonomy, it would not be possible to manage fertility without organic manure. Borgen et al., (2012) investigated the potential of rotation and ploughing to improve N fertility. They referred to the management of N losses (mostly by leaching) and use of green manure to fertilized stockless crop rotations. Even if their results were obtained into the specific conditions of the North European climate, their results show that green manure can be efficient but may damage soil organic content. The evaluation of the prototypes showed that for all prototypes organic matter content may be problematic. We can wonder the relevancy of these indicators and especially the" organic matter" that is evaluated with INDIGO (Bockstaller, 2008) which is not totally transparent and not adapted to organic. In order to collect data rather than a classification as proposed by ®MASC, an analysis of the carbon balance should be planned during the experimentation in field. That result coupled with the conclusion made out by Borgen et al., (2012) highlights the importance of organic manure. This raises again the question of reintegrating livestock (Borgen et al.,2012). In addition to this theoretical conclusion, practical issue limited the use of green manure in Bretagne. N fixing plants can be implemented with cover crop, intercropping or pure leguminous crops. Nonetheless, in stockless farm, the best solution would be cereals under sown with clover. At the beginning of my investigation, I had four strategies (table 5 p25), from those strategies, I designed six prototypes. If you look into details, the strategy "permanent soil covering block" did not led to a specific prototype. I classified the prototypes "autonomous" under this strategy, nonetheless, we rapidly ruled out sequences with crop under sown with clover. In Bretagne, those techniques are not feasible. Actually, those strategies rely on arid and frozen winter to damage the secondary crop. In Bretagne, winters are wet and mild. In consequence, organic farmers encounter technical challenges to stop clover growth and ensure cereals competitiveness.

Weeds can be managed by including some of the practices presented in table 14. Those recommendations are commonly accepted and the different prototypes often referred to them. For the fertilization, it is more complex as "under sown crop" is not yet mastereed by organic farmers. The C.A. objective is to be innovative; nonetheless it should not be too risky. It seems that fertilization will have to rely both on crops autonomy and organic manure. At this step of the discussion, it appears that some practices can be easily introduced to enhance weeding methods and long term productivity. In order to reach an optimal system, it is essential to consider carefully the crop succession; indeed cropping system is defined with practices and crop rotation to finally implement a logical succession of crops and techniques (Papy., 2008).

5.1.4. How to choose the crop succession?

During this project, we often referred to "famous" crop in cereals production. In every prototype, crops such as wheat, maize, triticale, buckwheat were proposed. Nonetheless, some other crops were discussed. If they are often less known, farmers and experts are interested to test some of them. First, I discussed innovative crops and their feasibility into Bretagne; then I detailed the intercropping sequences.

Innovative crops:

One part of the discussion during the conception process was oriented toward "innovative" crops in organic farming (Table 2b). They referred to crop that are potentially profitable, -high sale price - but not mastered yet. The discussion focused on hemp, vegetables and protein production with soya (tab.14), rapeseed and lupine (tab15). Within the proposition of innovative crops, only two were proposed into the rotation, lupine and rapeseed. A detailed description of the reason to rule out these crops is presented in appendix 14.

Table 14. Innovative crops ruled out for the conception

Innovative crops	Reason to not implement it
Soya	Climate - Grain maturity
Vegetables	farmers' category
Hemp	Harvest complexity

Table 15. Innovative crops ruled out after evaluation

Innovative crop	+	-
Lupine	easy to implement	Anti-nutritional factors: - Animal feeding (Chilomer et al., 2011). - Allergen for human (Jappe et al., 2010)
Rapeseed	economic	Sensitive to pest (Valantin-Morison et al., 2006). Harvest conditions (wind) Small seed (return to soil)

I proposed some interesting crop sequences on the basis of the recommendations done till now. A summary of the general recommendations is provided in appendix 15. In respect of it, I proposed the following sequences:

- Intercropping / Cover crop / intercropping. The cover crop could be for instance a brown mustard; it has a short growing season and would be developed quickly to cover soil. Analytical research focused on the anti-fungi action (Michel, 2008) of the mustard. Compared to similar crops, it gives also the advantage to be a mean to protect the plant.
- Winter wheat / false seed bed - rapeseed/ winter cereals. Rapeseed is well known to be good preceding crop to cereals. Actually, this crop has many advantages for an organic system: it improves soil structure with its roots; it presents a good covering capacity favorable for weeding management (ITAB, 2007). In addition, it has high N exigencies, thus it can be used as N catcher after winter cereals (even more if cereals are fertilized, it can limit post-harvest N leaching). Rapeseed breaks down specific cereals weeds. It is advised to realize one or two false seed bed preparation before it implementation. Actually, cereals straw can be problematic (ITAB., 2007). Then ploughing should be placed before rapeseed and if possible limit to plough right after (FRAB., 2009).
- Maize/buckwheat/winter cereal. Those are two summer crops. A proposition consisted in a rotation of two summer crops and two winter crops. Buckwheat is a covering and allelopathic crop, thus it is often used at the end of a rotation to decrease weed density. Maize is most often introduced into farmers' rotation; it is a staple feed for monogastric animals. In between, it could be planned to introduce a cover crop. Ideally, it should be implanted into the maize. Actually, maize is harvested late and sowing a cover after October is not relevant. Another solution would be to do mulch out of crop residues. This is disputable as for the moment it is still illegal. The role of the cover crop is to limit nitrogen leaching. Be careful, buckwheat allelopathic effect is not proved yet, it is just an "intuition". In addition, it was observed that buckwheat can cause negative effect especially on summer crop, thus it is better to avoid maize or potatoes right after it and rather winter cereal or intercropping.
- In between winter and summer crop: Phacelia can be used as green manure. This crop also has powerful covering capacity. It should be sown early (before September) so it should implanted before or right after harvest. Radish can also be introduced to join two crops. It is a nitrogen catch crop and permits to relieve soil compaction. It is a root crop, thus respects alternation of root and grain crop. Nonetheless it may not be enough covering. It is possible to associate it with other cover crop and thus combine type of roots and canopy establishment.

To conclude, the combination of local and theoretical knowledge led to the exploration of different crop sequences that are efficient in the Breton's context. Economic efficiency can be achieved with stable yield and consequently solution to manage overgrowth and fertilization. On the basis of all recommendations I gathered and the results of the evaluation, I would proposed the following crop succession.

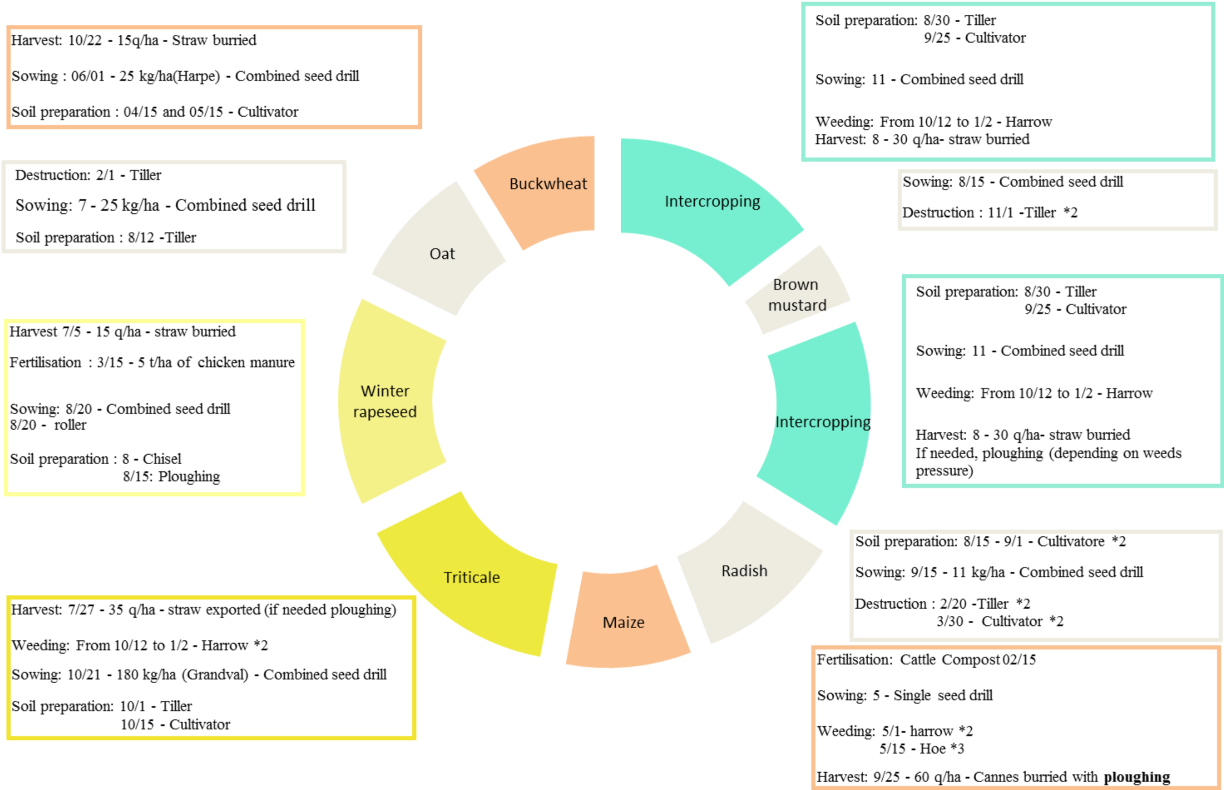


Figure 24 Prototype made with information gather from local people, MASC analysis of sustainability and theoretical knowledge.

Along the experimentation, cover crop can change, it is possible to rotate with phacelia (interesting because green manure). Summer crops can also be changed, for instance buckwheat with rye, maize with summer rapeseed, barley, summer faba bean. If the experimentation of direct sowing of maize into faba bean mulch succed, then it can be introduced instead of the radish, a faba bean can be implanted and maize directly sown. Ploughing can be introduced when needed, nonetheless it would be prefearable to avoid it after rapeseed. Rapeseed must rotate once every four or five years. Consequently, this rotation can be extended if problems appears with rapeseed pests and deseases. I would also propose to introduce a ley crop for at least two years when weeds issues can not be handle in a different way. It would permit to evaluate the effect of a two years of clover compare to three years of lucerne.

5.2. Methods

5.2.1. Conception

Conception of cropping system was the first step of the mission. I believed that designing with experts and farmers was appropriated within the time available. I followed methods proposed into literature and oriented the conception towards a collaborative model (e.g. Bigg's classification). It refers to a combination of knowledge into project design, initiated and managed by researchers (Cornwall et al., 1995). According to Mischler et al.2008, innovative cropping systems can be done only by a co-conception - share of knowledge between farmers and experts- with farmers. The integrative approach is efficient on-station experimentation adapted to local conditions (Vereijken 1997; Meynard et al., 1996; Doré et al., 2011). For Mischler et al., researchers should include farmers' opinions, wishes and observations. The authors proved that co-design and participative approach was successful in different conditions. They evaluated the positive effect of farmer participation in three projects of cropping system design, two in France and one in Brazil. One of the French projects was close to the specific context of this master thesis as it was initiated by the C.A. of Picardie (North West of France). After a diagnosis and description of the local context, project leader empowered interaction between farmers and agronomist. In my case, it was not possible to gather participants to create a group of discussion. Then farmers were consulted for validation and experimentation in their fields. In our case, farmers were consulted after diagnosis and in order to provide local knowledge. In addition, it was an on-station experiment and consequently, farmers' interest for collaboration was limited.

Farmers were selected on their interest for innovation, their participation led to greater innovation into cropping systems. Nonetheless, knowledge elaborated from farmers' "savoir-faire" was not always relevant within a systemic approach. For instance, they proposed practices such as cereals under sown with clover. It could be relevant to experiment it, but in conditions of a specific experimentation, it is too risky to include practices and methods that are not yet proved to be efficient in Bretagne. It comes back to Cornwall et al., 1995 reflection that experts' knowledge method may be completed with other experimentation such as: factorial experimentation, model-based conception or analysis of practices.

5.2.2. ®MASC

The ex-ante assessment of sustainability is a relevant approach before long term experimentation. ®MASC does not aim to evaluate one specific practice but the degree of satisfaction obtained for a long sequence of crop. It is a complete tool that permits to have a global vision of the system. It also proposes to the designer to change the different weight of each indicator, according to Prost et Cerf., 2010, it gives a representation of the utility and the user. I decided -with my master thesis supervisor- to not change the weight within the tool and I proposed to do it outside. I reached a classification of my prototypes without damaging the tool's integrity. If I had moved weight according to my preferment within ®MASC arborescence, I would have had to prove and testify why I did so.

I was able to compare the proposition with the national average. This confirmed that all the prototypes seemed to be sustainable. However, I was not able to clearly differentiate all the prototypes. I used it more as a decision aid tool. It pointed out systems' strengths and weaknesses.
It was essential to look at a deeper layer of aggregation. For some results, the conclusion was clear, such as for the nitrogen losses (fig 25). For other indicators such as working conditions, it involved other indicators at different level of aggregation. In this condition, I may have done some personal interpretation.

I think it is a relevant tool to experiment within the scope of conception and design of cropping system. It can be useful to support observation and collection of data along field experiment. As the final objective is to make a global evaluation of sustainability, it may be interesting to keep the same indicators and the same fixed data. I would propose to the responsible for this experimentation to keep ®MASC as the evaluation tool each year. It should permit to highlight evolution and the effect improvement made along the experimentation. The evaluation tool was discussed along the detailed analysis of the results. We can say that some indicators are more or less relevant depending on the situation (weeding methods, organic matter content). For important indicators such as organic matter, it would need further measurement to establish a diagnostic.

6. CONCLUSION

I addressed the question of sustainability under conditions of "conventionalisation" of organic agriculture. I believed it is possible to be productive in organic production but the introduction of conventional elements did not seem to be the most promising path to develop organic. The two prototypes based on mechanized method, disconnecting ecosystems' services and crop production were less sustainable than strategies based on rotation and cultural practices to manage organic issues. I expected the system I finally proposed to match the specific demand of the C.A. I tried to introduce into it, as agro ecological practices as possible in order to ensure a good functioning of agro ecosystem with productive and profitable crops. The proposition extends the common crop rotation observed in organic farm in Bretagne, however I believe a longer rotation where crop and practices are diversified can be more beneficial for sustainable development.

The approach for the conception of the prototypes adapted to Breton's organic agriculture was initiated in order to link farmers' knowledge and on-station experimentation. Conception and evaluation of prototypes of cropping system benefited from farmers participation. As proposed by Mischler et al., 2008, farmers should take part in the experiment. It was also the purpose of Vereijken (1997) prototyping method, focused on farmers' need. However, it is questionable what farmers will get for exchange. I believed that within the given time, it was difficult to form an association of farmers around this project. It is assumed that farmers are a source of knowledge that deserves the revitalization of current agronomical knowledge. Research is oriented towards the production of generic methods that could permit to produce and evaluate innovative techniques for conception of sustainable cropping system (Doré et al., 2011). Multi criteria evaluation tools permit to assess sustainability of a compilation of practices and their impact on the functioning of the agro ecosystem. It also allows including and validating endogenous knowledge into the evaluation. It is a mean to validate local knowledge. It permits to evaluate a cropping system on the basis of many criteria while research usually focuses on one criterion. In the scope of agro ecology it is interesting to be able to experiment a global cropping system and not only crops or practices.

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List of Abbreviations, figures and tables

AR	Action Research
C.A.	*Chambre d'Agriculture:* It is a French institution operating at the departmental level to support, encourage and advice farmers.
CC	Cover crop (every crop in between two cash crop)
CRAB	*Chambre Régionale d'Agriculture de Bretagne:* It is the centralization to regional level of departmental C.A. It enables action at regional scale
FRAB	*Fédération régionale des Agrobiologistes de Bretagne.* Regional federation of agrobiologist. It is mostly an organic farmers' union
INRA	*Institut National de la Recherche Agronomique:* National institut for agronomical research
ITAB	*Institut Technique de l'Agriculture Biologique* : Technical institute for organic agriculture
®MASC	Multi-attribute Assessment of the Sustainability of Cropping systems
N	Nitrogen
ONIGC	*Office National interprofessionnel des grandes cultures.* National comity of professional of the cereals production in France.
PR	Participatory Research
R&D	Research and Development
SWOT	SWOT analysis (strenghts, weaknesses, opportunities, threats)

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Conception and evaluation of organic arable cropping system in Bretagne

APPENDICES

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APPENDICES

Appendix 1: Literature review

Sustainable development is a multi-dimensional and complex concept (Sadok et al., 2009). Sustainability is not measurable; its definition encompasses numerous objectives. Nonetheless, it is becoming a criterion of quality to characterize farming system. Evaluation of sustainability is central for implementation of "new forms" of farming systems (Gasfi et al., 2006). The principle of the mission is to design and evaluate "new" system to be implemented in Bretagne.

The first part of the review is devoted to the question of the modalities of a research that aimed to assess sustainability. It described the relevancy of the systemic research in the context of sustainability assessment. C.A. research used to be focused on analytical experimentation; nonetheless, as suggested by Alrøe and Kristensen (2001), experts, local farmers and scientists' knowledge have to be gathered by researcher for conception of innovative systems. Systemic research can be done through different means.

The second part of the review presents different types of PR approach. This part detailed the proceeding for participation and the nuances of this method. We focused on Participatory Approach (PA) to design the cropping system. Action Research is extended to prototyping models. Principles are explained through the presentation of the original method. Finally, I proposed to adapt Vereijken (1999) and Lançon et al., (2008) prototyping methodologies to design a scientific framework for the conception step.

The third part of the review is focused on the evaluation step. It presented the relevant study scale and the principle of the model applied to ex-ante evaluation of cropping system.

1. How to assess system sustainability?

Sustainable development is a priority for agricultural research. Sustainability is a holistic and complex concept which requires multi-dimensional approach to be assessed (Sadok et al., 2009). The objective is to assess the potentiality of each studied system from theoretical knowledge (Erghott, 2005). Moreover, investigation on systems' optimisation must provide the best alternative in a reduce range of time (Erghott, 2005). System research needs holistic method dealing with mixed data (quantitative and qualitative) and including the three dimensions of sustainability. Economic criteria are not sufficient to assess the global sustainability of cropping system (Bockstaller et al., 1997; Meynard, 1998; Munier-Jolain et al., 2008; Sadok et al., 2008). Social and environmental dimension must be taken into account (Reau et al., 1996; Meynard, 1998; Munier-Jolain, et al., 2008; Sadok et al., 2008). The field of Agro ecology sciences tends to enlarge the vision of agriculture toward a systemic approach in order to enhance "ecological concepts and principles to design and manage agro ecosystems in a sustainable way" (Gliessman, 1998).

1.1. Wholeness-oriented research

Before the development of multi-attribute model to optimize cropping system, agronomical experimentation was based on simple comparative and analytical tool. Reau et al., 1996 identified and described three main types of factorial experimentation applied to cropping system.

The “simplest” method to measure or evaluate the effect of practices on crop production is mono factorial experimentation. The principle is to change one parameter from one experimental plot to another. Results are interpreted and analysed through statistical methods. For instance, a mono factorial experimentation could be to estimate the effect of sowing density on the yield. However, this method is characterized as restrictive. Indeed, it focuses on one criteria and the system’s response is analysed for one specific action. Consequently, the effect on the whole system is not measure and can only be hypothetical. Mono factorial experimentation can be efficient for optimisation but interactions may not be considered. A result of mono factorial experimentation could be an increase of yield, with an increasing sowing density.. Bi factorial method enables to estimate the effect of interconnected factors. The principle is to look at the effect of one factor on the variation of the first production factor (Reau et al., 1996). An example could be to measure the yield fluctuation according to the sowing density and date of sowing. The objective is to estimate whether sowing density or date of sowing have a greater impact on yield. This model was a first step in multi factorial evaluation and optimisation of cropping system but it appears to be innovativeness (Reau et al., 1996). Indeed, you test couple of factors, and it does not includes time and space scale.

Test interactions within the system

	Systemic trial	Analytic trial
Objectif	Contribution to sustainability	Impact of one technic / effect of 1 or 2 factors togeher
Interactions	Several criteria	1 or 2 criteria
Evaluation scale	Holistic	Narrow
Results	Optimization of the cropping system	Optimization of one interaction or one parameter

Optimization of interactions

Figure 1. Comparison and complementarity of experimentation model. Adapted from Reau, R., et al., 1996

This method does not consider the cumulative effect of practices. For system optimisation, scientific turned towards holistic and multi criteria approach (Bockstaller, 2003; Reau et al., 1996). All factors are included to give an overview of the entire system. System thinking researchers understand components as part of a whole system [1](Ison, 2008).

1.2.Systemic research

Conventional science deal with complex system as the sum of independent component studied separately. Factorial experimentation breaks down systems into small units to explain cause-effect relationships (Reau et al., 1996; Drinkwater, 2002). In this conception of science, researchers operate without being actors; they are detached and objective observer. At its opposite, researchers can be involved actors but

[1] System research is defined by Checkland as a practice of thinking that encompasses both systemic and systematic thinking and action. Systematic refers to linear connection within a whole (Ison R., 2008).

they may fail to be scientist (Alrøe & Kristensen, 2001). In systemic research, researchers are objective and self-reflective. The reflexive objectivity permits to limits individual perspectives and includes contextual value of the studied system (Alrøe & Kristensen, 2001). System experiment is an innovative approach towards agricultural research (Drinkwater, 2002). Agricultural system research implies a cross disciplinary approach encompassing agronomical and social sciences. Agronomy is view as the set of tools available to improve the current system sustainability. Social science is related to the understanding of the demand, the interpretation of the results and the method used to provide solutions adapted to the societal context. It implies to cover interactions within the agro system and with humans' practices. A cognitive system encompasses three level of context: (1) Societal context: It is the social system that the relevance of the research refers to; (2) Intentional context: It consists of the goals and values that guide the research; and (3) Observational context: It refers to tools needed to perform the research. Researchers have to adapt the production of knowledge in the specific system by combining scientific, specific, experts and farmers' knowledge. Actually, system research methodology implies participation of inside observer (Alrøe & Kristensen, 2001).

"Wholeness-oriented" researches, combines conventional and systems approach. Avoiding reductionism implies a reflexive awareness of context and use of validated and new knowledge. The application of both model of science leads to an optimal solution adapted to the specific context. According to Meynard et al. (2006), systems researches include: (1) **Holistic evaluation**; to understand the global capacities of the studied system to achieve the objectives. (2) **Agronomical evaluation**; to estimate the relevance of the decision rules applied to the system. (3) **Analytical experimentation** to bring missing knowledge (see fig1). As suggested by Alrøe (2001) researchers (outside observer) have to refer to inside actors to provide a representation of the entire context. The authors emphasize that the inside point of view is an "indispensable" part of the systemic research. This connection between inside and outside may be done by different means such as stakeholders interviews or participatory research.

2. Action Research (AR)

AR is a way of learning from experience to improve a current situation. In Action researching, researchers attempt to learn how to achieve their objective and produce public knowledge. It includes field experimentation, methodical collection and treatment of farmers' contribution. It combines theory and practice to achieve system research's objectives (Bawden, 1991). AR can take several forms. We focused on Participatory Research (PR) to achieve our systemic research.

2.1. General principle of PR

PR is often used instead of AR in agricultural research (Sterk et al., 2006). The principle of PR had its origin in the development of AR approaches within R&D domain. PR was developed because of the need to focus on local knowledge (Martin & Sherington, 1997). PR embedded in AR facilitates complementary and cross-disciplinary approaches for researchers. PR was proved to benefit to researcher as they gain a better understanding of a complex situation (Martin & Sherington, 1997; Lançon et al., 2008). PR emphasize on farmers interest to improve and innovate in their farming style. It is risky, time consuming and costly for farmers to individually test innovation by their own. Biggs distinguishes four modes of participation related to the empowerment and responsibility of farmers within decision (Martin & Sherington, 1997). Participation can be contractual[2], consultative[3], collaborative[4] or collegiate[5] (Cornwall et al., 1995) depending on the institutional context whether PR is "research driven" or "development driven" (Fig 3). There are different means to approach a PR program. Le Gal et al.,(2011) presented the two extremes approaches in agronomy research. The linear approach (a, Fig 2), is a vertical integration of knowledge. Farmers are the last step of innovation process for implementation. At its opposite, there is the interactive and participative process (b, Fig 2). This approach relies on the participation of farmer in the design process. Farmers are consulted along the process to insure the relevance of the innovation.

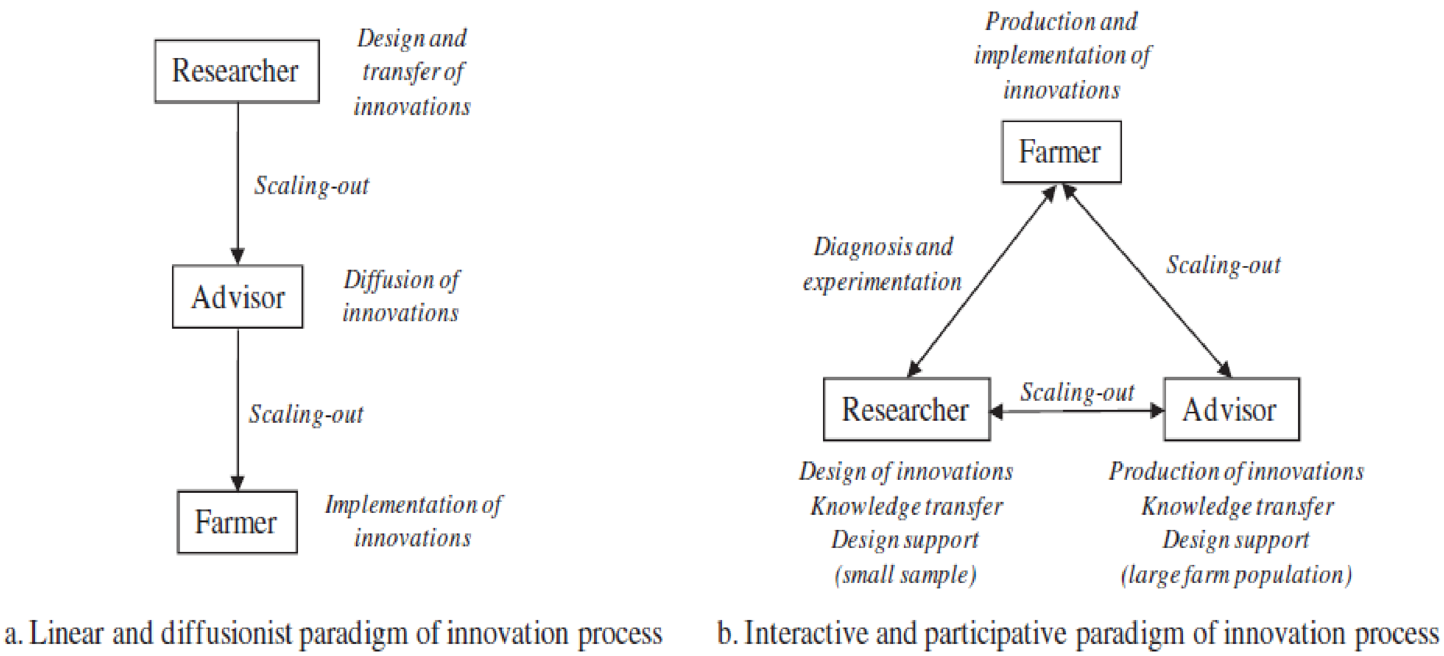

Figure 2: Schematic representation of two innovation process paradigms including farmers, advisors and researchers. The concept of 'innovation" includes both new technologies and new ways of organizing and managing production systems. (From Le Gal P-Y., Dugué P., Faure G., and Novak S., 2011)

[2] Contractual: people are contracted into the projects of researchers to take part in their enquiries or experiments
[3] Consultative: people are asked for their opinions and consulted by researchers before interventions are made
[4] Collaborative: researchers and local people work together on project designed, initiated and managed by researchers
[5] Collegiate: researchers and local people work together as colleagues with different skills to offer, in a process of mutual learning where local people have control over the process.

Participation can take several forms depending on the objectives, experts' availability and farmers' involvement. Le Gal et al., proposed two categories of participatory program: (1) "design": prototyping and design modelling for design oriented studies and (2) "design support": participation, support modelling and advisor for design support oriented studies. "Design" refers to project led by experts, institute, and professional organization while "design support" refers more to project asked by farmers themselves. The second category refers to project where scientist may have a consultative role. Expert and technicians participate in the process of conception "later". Farmers present their objectives; they set out the project and determine the main issues. Then scientist can propose tools and methods to evaluate the proposition of farmers.

2.2. Participative prototyping

Prototyping method is an example of AR project. These methods aim to identify farmers' constraints and problems as the basis for planning research. It is an iterative and integrative approach. Vereijken, 1997, proposed a prototyping method based on the following 5 steps:

1) To make a hierarchy of objectives in consideration of local constraints.
2) To set up from these objectives a set of multi objectives parameters, which are corresponding to a set of multi objective farming method to achieve them.
3) To Design the theoretical prototype.
4) To set out on farm – experimentation on field for test and improvement.
5) To disseminate of the new system through regional network.

Objectives, context, goals and values of the studied system are included into the conception process. System approach allows adaptation to specific situation. The purpose is to justify the methodology we choose for the conception because it includes farmers to answer to the C.A. problematic. As a simulation model was selected to achieve the evaluation of the cropping system, it was request to adapt the prototyping method (box 4).

2.3. Participation coupled with models

Participative prototyping can be coupled with modelling tools for evaluation of cropping systems. Models are means to "formalize, expand and refine expert knowledge" and to integrate this with scientific knowledge (Sterk et al., 2006). Lançon et al. (2008) emphasized that modeling might help researchers to match their recommendations for management issues addressed by farmers. It is an integrative approach towards research program (Coquil et al., 2009). Data are evaluated with computer models, based on mathematical model. Simulation models are based on decision rules: "if conditions then action". Rules must reflect scientific knowledge and experts' representation and preferences (Colomb et al., 2009). Those methods are implemented in order to evaluate cropping system at different step (1) before to experiment the prototype. The ex-ante evaluation increases opportunities to reach the best alternative. As all the suggested systems cannot be experimented, evaluations before experimentation enable a relevant selection (Sadok et al., 2008) (2) during field experimentation. This implies that observers collect data for the evaluation of the cropping system (3) after the field experimentation. The principle is to make a post crop succession assessment. It is a mean to compare what happens to what was expected.

The model-based approach was proved to be an efficient tool, Rossing et al., (1997) illustrated its potential with two study cases. In both, a holistic approach had led to sustainable improvement of cropping system (Rossing et al., 1997). The hypothesis is that prototyping and theoretical modelling could benefit from crossing interaction. Incorporation of model in prototyping process could reveal options for extrapolation on the result (Sterk et al., 2006). Prototyping as proposed by Vereijken does not include ex-ante evaluation (box 4). After the co-designing step, the cropping system is evaluated into fields. Cropping system prototypes are evaluated according to stakeholders' objectives into their situation. However, field experimentation is costly and time consuming. To obtain results, the experimentation must stretch at least as long as the crop succession. Fast ex-ante evaluations are required to evaluate the feasibility of a proposed innovation before field experimentation (Reau et al., 1996; Meynard, 1998).

Box 1. The prototyping method selected to achieve the mission:

Prototyping's purpose is to create systems that will be evaluated, tested and adapted along experimentation. It is a tool to improve or implement new cropping system. In addition, it provides a framework for the conception process. This method can be embedded in participatory program (Vereijken, 1997; Rossing et al., 1997; Meynard, 1998). The participation of farmers, scientists and professional organisation1 appears to be essential at different steps of the conception. Lançon et al., had proposed a PR's methodology - adapted from Vereijken - to design innovative cropping system based on expert knowledge (2008). Experts are the representative of regional organic farmers. This multi-disciplinarily approach emphasizes on optimization of local knowledge. Experts' knowledge are collected in respect of farmers' primer objectives. The method follows four steps (appendix 2):

1) A diagnosis of the situation to understand the local constraints and advantages. This step is essential to select indicators that fit with the local context; choose the tool that will be used and define a referential system.
2) To design prototypes by interpretation of local knowledge and capacity.
3) To propose the prototypes. At this step, experts must agree on a system adapted to local constraints and farmers objectives. The authors propose this step to be mixed between self-reflection and team work.
4) To evaluate the prototypes. The most promising system are selected to be tested ex ante and compared together.

3. Principle of sustainability evaluation

Sustainability is evaluated for the unit “cropping system” (box 2). Interpretation of isolated indicators is not relevant and aggregation methods should be provided to evaluate the overall impact of practices. In addition, compensation between two indicators should not be possible. Indeed, a single environmental risk is enough to put in question the sustainability of the system. The evaluation must take into account the effect of the different components on the system and their interactions. Thus, multi criteria methods are seen as an alternative to the aggregation approach (Bockstaller et al. 1997). Multi-criteria analyses have a predominant role in assessing cropping system sustainability. Bockstaller proposed some agro-ecological indicators to create estimation of the impact of cultivation practices. They are either direct measurement or calculated from available data. Indicators are an alternative where measurements are not possible, they “are estimators of the impact of cultivation practices on the agro system and it environment” (Bockstaller, 1997). They refer to a common perception of sustainability and should weight depending on priorities and objectives. Using indicators involves a degree of subjectivity whereas there are no scientific rules to decide which impact is more important (Bockstaller et al., 1997). They are embedded in a holistic approach as they deal with a set of cropping practices within a farming system.

Box 2. Studied scale: The cropping system

The cropping system seems to be a relevant concept for agronomist to design new cultural method (Papy, 2008). Most of the environmental impacts and of some socio-economic factors on a farm are occurring at cropping system (Sadok et al., 2009). This unit is defined as “a set of management procedures applied to a given, uniformly treated area, which may be a field, part of a field or a group of fields” (Sebillote, 1990). Cropping system is defined in time and space in interaction with the farming system. It is as a coherent set of cultural and management practices, including farmer’s decision and adaptation, at farm or field level (Papy, 2008). This scale of study is challenging combination of agronomist knowledge and farmer “savoir-faire”. The system is defined by observers (outside and inside) as the relevant area for action. It is the specific place of decision to achieve system’s purposes (Ison, 2008).

3.1. Interpretation of the results: simulation models

Simulation models are based on indicators. They are calculated separately and thus, models are required to interpret the result (degree of sustainability). Many tools and models were developed to assess system sustainability. They are based on common or appropriate criteria and indicators. Making an inventory of current models and tool available for assessment of sustainability would be a non-exhaustive task. Existing models are not always focused on the cropping system scale; nonetheless, they are evaluation tool at different scale and/or specific to a domain. This part is only devoted to tools for assessment of cropping sustainability and a specific focus on MASC.

Specific tool for sustainability assessment

In France, three main tools to assess sustainability were developed. MASC is one of them.

- IDEA is a communication tool, adapted for farmer participation toward sustainable development. This model is devoted to the definition of sustainability by farmers in order to improve a farming system. This tool is based on simple criteria; it covers the three dimension of the sustainability. However, it is not adapted for ex ante simulation. It is only a descriptive tool.
- ARBRE is a tool adapted for farmers. User-friendly, it is a communication tool for improvement of sustainability at farm level. Based on simple indicators, it provides strength and weaknesses of the current situation. It does not allow for a deep analyse of farmers' practices.
- MASC (DEXi, Bohanec, 2008) is the only tool available today in France for ex-ante evaluation of cropping systems sustainability. This method is gathering indicators from IDEA and INDIGO methods to cover the three dimensions of sustainability.

Optimization of crop production

CROPSYST is a "multi-year, multi crop and daily time step simulation model" (Stöckle et al., 2003). It was developed by Claudio O. Stöckle and it last version is described in the article "CropSyst, a cropping system simulator" (Stöckle et al., 2003). Cropsyst is an analytic tool to optimize the crop growth according to the soil, climate and environmental context. The principle is based on growth simulation. As the crop grows, resources are depleted. This model simulates depletion and deterioration of the environment along crop growth. It objective is to evaluate the impact of soil and climate on management and productivity of the cropping system. It mainly compares yield according to local conditions and inputs quantity. It also simulates environmental pollution due to pesticides, herbicides and fertilizers' use. Therefore, economic and social dimension can be added to the simulation. This tool can be adapted according to different objectives. For instance, it was developed in Catalonia as a decision aid tool for evaluating innovative cropping system in specific context. It can also be adapted to evaluate a specific component of the system. For instance, an extension of the model is devoted to watershed statement along the period of crop growth.

Contribution of agro-environmental policy to farming system sustainability

SEAMLESS is oriented towards the assessment of agro environmental policy sustainability at different scales surrounding and within a farming system. It aims at evaluating the integration of agricultural and environmental policy in agriculture. The model, is " providing analytical capacity to assess sustainability of agricultural systems in the European Union and contributions of the EU's agricultural systems to sustainable development at large, including some effects on the entire production chain" (Van Ittersum et al., 2007). Thus, it requires flexibility to include a broad variety of policy questions and multi-scales capabilities. It covers all the hierarchical levels needed for holistic implementation of policy. According to the creator of the model, it was essential to be able to link micro (field) and macro (market) levels. Interdisciplinary is highly recommended to address policy questions. The model is based on criteria and indicators which could be used in MASC. And it also requires a personal statement on production objective and perception of sustainable development.

The French tool box

French researchers developed a wide range of tool in order to assess sustainability of farming systems. Bockstaller et al., gave us a rundown on evaluation tools (Bockstaller et al., 2008). This analysis is based on tool for sustainability assessment. There are different ways to classify those methods; the authors chose two categories: specific tools focused on the environmental dimension and holistic tool for multi-dimensional sustainability.

Tool oriented towards the environmental dimension

The purpose is to have a quick view on the type of method to evaluate the environmental dimension of sustainability. This part will highlight the diversity of tools.

- DAEG is an indicator of the effect of practices on the environment at the plot scale. It is an interesting tool for diagnosis and improvement of practices. It can also be adapted as a communication tools towards valorisation of landscape at farm scale.
- SALCA is a comparative tool to propose improvement. It has a large scope, from plot scale to the entire food chain based on scientific approach. It can treat only quantitative data. It is used mainly for analysing strength and weakness of a system.
- PLANETE is a model focused on energy use at farming system scale.
- AQUAPLAINE is an evaluation tool especially for water pollution issues. It helps farmers to change practices for decreasing pollution risk at the field, farm and landscape scale.
- INDIGO is diagnosis tool for improvement of cultural practices, specific for cropping system. It is used in ex-ante evaluation tool for it agro-environmental indicators. Its indicators provide a well detailed analysis of practices. This indicator is implemented in MASC.

Specific tool for sustainability assessment

In France, three main tools to assess sustainability were developed. MASC is one of them.

- IDEA is a communication tool, adapted for farmer participation toward sustainable development. This model is devoted to the definition of sustainability by farmers in order to improve a farming system. This tool is based on simple criteria; it covers the three dimension of the sustainability. However, it is not adapted for ex ante simulation. It is only a descriptive tool.
- ARBRE is a tool adapted for farmers. User-friendly, it is a communication tool for improvement of sustainability at farm level. Based on simple indicators, it provides strength and weaknesses of the current situation. It does not allow for a deep analyse of farmers' practices.
- MASC (DEXi) is the only tool available today in France for ex-ante evaluation of cropping systems sustainability. This method is gathering indicators from IDEA and INDIGO methods to cover the three dimensions of sustainability.

Among other, MASC was selected by the C.A. to assess the overall sustainability of innovative and sustainable organic cropping system (see box 3). Within the French tool box it was the only one counted for cropping system scale. In MASC, each dimension of sustainable development has its criteria: (1) the

economic dimension is based on criteria such as profitability, adventices, product quality, economic efficiency... (2) The **social dimension** is evaluated according to the contributions of the system to employment, the work difficulty... And (3) the contribution to **environmental dimension**, is estimated with criteria such as soil erosion, water consumption, and diversity (Craheix et al., 2011)

Box 3. MASC: the model selected by the C.A. to assess cropping system sustainability

According to Sadok et al., 2009, the main advantages of this tool are related to: (1) the scale of study, it is adapted to smaller units than farming system scale and (2) the fast ex ante assessment of sustainability; MASC enables measurement of cropping system sustainability *a priori*. Fast ex-ante methods enable to test a large range of possibilities. It is required to implement innovative cropping system (Sadok et al., 2009). Indeed, fluctuation of price, uneven production, changing consumer demand and environmental context makes the pre-selection necessary (Munier-Jolian et al., 2008; Sadok et al., 2009; Le Gal et al., 2011). MASC is an arborescence model builds up on 39 holistic criteria including social, economic and cultural facts. MASC is based on holistic and mixed elementary criteria rating cropping systems (Sadok et al. 2009). Farmers (or their representative) identify which are the main factors to be considered to improve sustainability and adapt to their local constraints.

At the beginning, two version of MASC were existing, one for organic and another for conventional. They have been gathered and finally, MASC 2.0 estimates sustainability for both. MASC was tried through two projects. One directed by ITAB which aimed to characterize rotations performances *a posterior*. The other one used MASC as a decision-aid tool. For both studies, a comparison of available tools was carried out to select the most promising (Colomb et al., 2010). The different models were selected on six criteria:

(1) Evaluation scale; (2) Target; (3) Indicators relevance; (4) Integration of experts knowledge; (5) Aggregation capacity and (6) Possibility of finest analyse for sensitive criteria.

MASC was the most appropriated model according to those criteria. Results showed that it enables a relevant selection of cropping system if economic and environmental dimension are sufficiently different. The C.A. fixed MASC because its application matches with the finality of the mission. But the main argument in favour of MASC was the ex-ante evaluation and the scale of study. In addition, the C.A. wanted to address at the same time qualitative and quantitative data. MASC is holistic and treat mixed data (Bockstaller et al., 2008). It is user-friendly and transparent for user (Craheix et al., 2011). This argument is not negligible while the model is used by learner.

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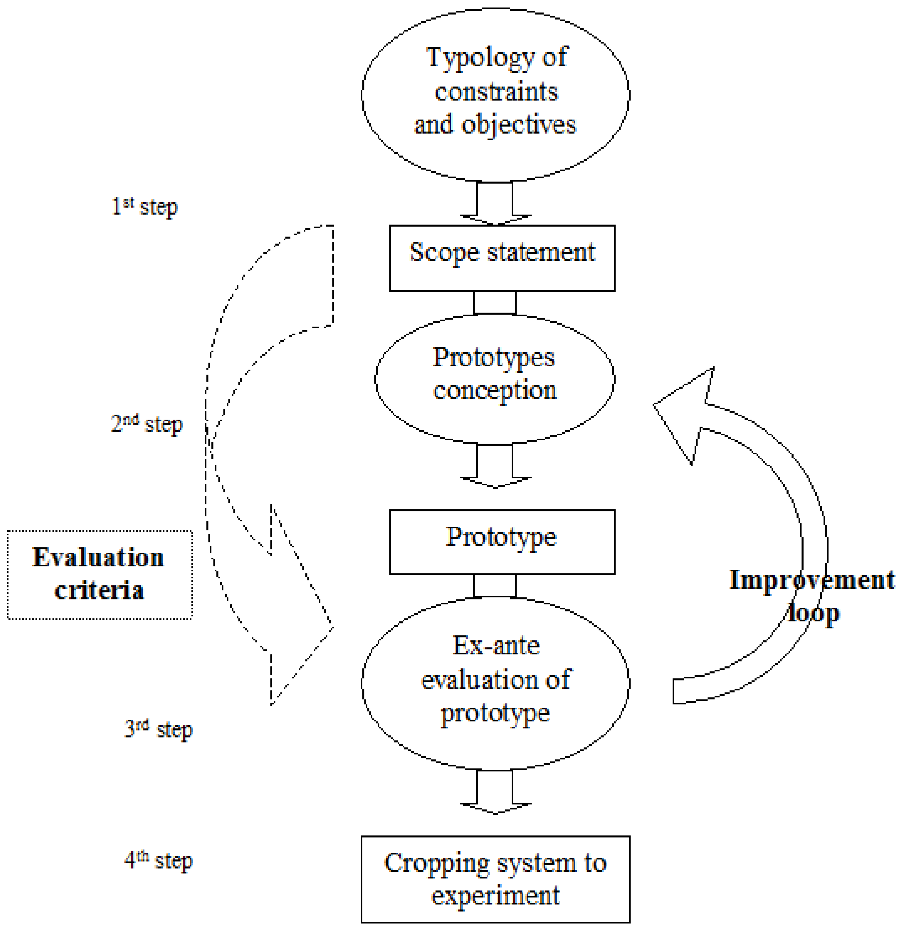
Appendix 2: Prototyping methods



Prototyping approach based on expert knowledge: development of the scope statement, conception of prototypes and selection of the prototype to be experimented after ex-ante evaluation. (Translated and adapted from Lançon et al., 2008)

Appendix 3: Document complémentaire fournit aux agriculteurs lors du workshop

Mise en place d'un essai en système céréalier biologique

Co-conception des systèmes de culture innovants et durables

Le contexte de l'essai

Aujourd'hui la surface de céréales biologiques représente 1.6 % de la SAU en céréales de Bretagne (IBB, 2011). La majorité de la production est destinée à l'alimentation animale (l'inter profession bio Bretagne estime que 87 % de la production part vers les élevages). Dans les années à venir, la demande pour les céréales et protéagineux biologique devrait augmenter. La conversion en grande culture biologique demande des connaissances techniques et pratiques. Les Chambres d'agriculture de Bretagne soutiennent les professionnels souhaitant développer des systèmes de culture innovants et durables. C'est pourquoi des systèmes d'expérimentation sont mis en place pour l'optimisation des systèmes céréaliers.

Les objectifs de l'essai

- **Optimisation de la rentabilité économique du système de culture**

⇨ Amélioration des marges/diminution des coûts de production

- **Optimisation des rendements en céréales et protéagineux**

⇨ Contrôle des paramètres ayant un impact négatif sur les rendements et leur stabilité dans le temps. Les principaux challenges : gestion de mauvaises herbes et de la fertilité.

- **Assurer une productivité à long terme**

⇨ Utilisation durable des ressources naturelles/ conserver des sols productifs pour les générations à venir et ne pas endommager l'outil de travail.

Cette action doit permettre de répondre à la problématique concernant les moyens d'optimisation de la production céréalières AB. Cela implique de :

- maintenir des hauts rendements sur le long-terme ;
- gérer les adventices et la fertilisation durablement ;
- assurer une stabilité économique pour l'exploitant.

Pour l'élaboration de ce système de culture, nous avons mobilisé les connaissances des techniciens bios des Chambres d'agriculture de Bretagne, afin de mettre au point des stratégies répondant aux objectifs de l'essai. Nous mobilisons maintenant les agriculteurs pour améliorer et concevoir les systèmes de culture.

Les stratégies envisagées

Stratégie « étouffement »

- Production de biomasse
- Succession culturale favorisant la plante cultivée/adventices
- Culture nettoyante : sarrasin, chanvre
- Couverture des sols à l'inter-culture
- Désherbage mécanique en complément : faux semis/herse

Témoignage : Jean-Martial Poupeau, Agriculteur bio à St-Aubin des Châteaux (44).

« Auparavant, j'utilisais classiquement la herse étrille mais dans mes sols limoneux battants, son efficacité était souvent limitée, surtout après les hivers humides. Le binage permet d'écroûter plus facilement le sol et autorise des interventions plus tardives jusqu'à l'épiaison. Le binage est très peu adapté aux sols pierreux (casse des socs et du temps pour enlever les pierres). »

Le travail en agriculture biologique. Chambre d'agriculture

Stratégie « mécanique »

- Gestion de l'enherbement par le désherbage mécanique:
  - ⇨ Avant la culture : Faux semis/labour (non automatique)
  - ⇨ Sur la culture : hersage et binage (des céréales)
- Couverture des sols en hiver

Stratégie « couverture permanente »

- Semis direct sous couvert vivant/mulch

Quelles techniques pour le couvert permanent ?

- Gestion des inter-cultures

Faux semis ou couvert végétal?

Couvert permanent (semis sous couvert, semis direct)

- Optimisation de la couverture des sols tout au long de la rotation ; Limiter la concurrence des mauvaises herbes ; Appuyer la compétitivité des plantes cultivées.
- Gestion du couvert :
  - ⇨ Destruction
  - ⇨ Durée de vie
  - ⇨ Choix du couvert : nettoyant, fertilisant..

Séquence de permaculture

Association de cultures : Semis de céréales dans trèfle/semis de trèfle sous couvert de céréales => On ne maîtrise pas actuellement ces techniques : quels type d'essai pourrait-on réaliser ?

Stratégie « pérenne en tête de rotation »

- Légumineuse en tête de rotation :

Les cultures fourragères pluriannuelles (prairies, luzerne, trèfle violet…) présentent de nombreux avantages agronomiques et jouent un rôle important dans le système grandes cultures biologiques

- Gestion de la rotation après une pérenne :

- Rotation très céréalière (blé, avoine, triticale)
- Culture nettoyante : sarrasin

Enquête de l'ITAB* sur Les légumineuses en tête de rotation

Les intérêts agronomiques :

- apport d'azote dans le système ;
- rupture des cycles biologiques des adventices - annuelles, mais aussi des vivaces (3 années semblent nécessaires)- , ravageurs et maladies.

La valorisation:

- **Alimentation animale** : sur l'exploitation ou élevage à proximité : transferts entre fermes (échange avec du fumier ou du compost).
- **La déshydratation** : les usines valorisent les coupes de luzerne biologique ;
- Certains agriculteurs implantent la luzerne et la broient. Dans ce cas, elle est mise en place uniquement pour ses **intérêts agronomiques**.

(Projet RotAB : Rotations pratiquées en grandes cultures biologiques en France : état des lieux par région, 2011)
*ITAB : Institut technique de l'agriculture biologique.

Qu'en pensez vous?

Critère durabilité
Économique (rentabilité, autonomie…)
Social (temps de travail, débouchées…)
Environnemental (consommation d'énergie, fuites d'azote…)
Critère faisabilité

Qu'est-ce qui vous paraît réalisable, intéressant…. ?

Le système « idéal »

- rendement optimisé
- production de céréales et de protéagineux
- gestion des mauvaises herbes et de la fertilité par les techniques culturales et la logique de la rotation
- système de production peu coûteux en énergie non renouvelable
- econome en temps de travail

=> *Système durable sur les points économique, social, environnemental.*

La co-conception d'un système de culture

Les agriculteurs sont les piliers de la connaissance pratique. La Chambre d'agriculture de Bretagne intègre des agriculteurs dès la conception de l'expérimentation afin de partager les connaissances et les mettre à profit de l'essai système de culture.

Nous ne voulons pas limiter la créativité des agriculteurs et souhaitons garder l'esprit ouvert pour des propositions innovantes. Nous estimons que l'innovation peut porter sur le choix :

- des cultures (avec les panels de variétés, familles…)
- des pratiques (travail du sol, désherbage, couverture du sol…)

mais la liste n'est pas exhaustive.
Nous proposons ici un appui technique sur certaines cultures et pratiques. Il ne s'agit pas d'orienter mais bien de proposer.

Quelques cultures à envisager

Le chanvre

Cette culture autrefois bien implantée en Bretagne revient au goût du jour. Le chanvre présente un potentiel agronomique intéressant dans des rotations AB :

Culture peu exigeante : ne nécessite ni fertilisation, ni désherbage ; étouffante/nettoyante : diminue la pression de certaines vivaces ; croissance rapide ; couverture du sol en 3 semaines (cycle végétatif 120 jrs)

Cependant, cette culture est sensible à l'asphyxie racinaire et nécessite un travail important à la récolte.

Les débouchés: - Graines : huile de chanvre/tourteaux pour alimentation animale
- Paille : fibres (textiles, isolants…)

Le sarrasin

Cette culture parfois considérée comme une culture de rattrapage mérite qu'on réfléchisse à son intégration dans la rotation. Elle est un bon précédent pour les céréales : effet très positif sur le salissement d'une parcelle. Elle présente des intérêts agronomiques non négligeables.
Ses grands atouts :

Culture **peu exigeante** : Pas de fertilisation ni désherbage; **Nettoyante** ; à cycle court (Juin-Octobre)

Quelques contraintes à avoir à l'esprit :
Mauvais précédent pour culture de printemps ; Sensible à la verse et au gel ; La récolte peut nécessiter d'être séchée/ventilée ; rendement aléatoire.

La caméline

Cette culture montre tous ses avantage en association. Effectivement elle joue un rôle de tuteur et limite la concurrence en occupant la place. Culture peu exigeante, elle s'associe à des céréales de printemps, pois, sarrasin, lentilles…
Elle peut être utilisée comme inter-culture. Cependant la cultiver seule n'est pas évident. La maîtrise des adventices est plus efficace lorsque la culture est associée. Bien que son pouvoir allélopathique puisse compenser quelque peu, la culture seule paraît risquée en AB. Deuxième point sensible, le débouché. Les graines de la caméline sont riches en huile mais leur pressage nécessite une filière proche.

Association Caméline/Pois

D'autres idées ?

Soja, Lupin, Luzerne, légumes de plein champs, haricots, pois, pomme de terre….

L'essai en bref

Type de production : Grandes cultures

Date de mise en place : 2012

Surface : 6 hectare

Echelle : Système de culture

Gestionnaire de l'expérimentation :
Aurélien DUPONT, Chambres d'agriculture de Bretagne, Station expérimentale de Kerguéhennec

Partenariat : INRA et Université de Rennes, ISARA de Lyon, IBB, ITAB …

Site d'expérimentation

- Localisation

La parcelle d'étude se situe à Kerguéhennec, à la station expérimentale de recherche appliquée en agronomie-productions végétales des Chambres d'agriculture de Bretagne. Kerguéhennec est situé sur la commune de Bignan, dans le département du Morbihan.

- Situation climatique, topographique

Situé à une altitude de 115 m, le site bénéficie d'un climat océanique tempéré, généralement doux et humide. Avec une pluviométrie moyenne annuelle de 891 mm sur 171 jours de pluie, ce sont principalement les automnes et les hivers qui sont les plus arrosés. Les températures annuelles sont douces avec une moyenne de 11,5°C sur 30 ans. C'est en janvier que la température mensuelle moyenne est la plus faible (avec 6,5°C) et en juillet/août qu'elle est la plus élevée (avec 17,6°C). On note l'existence de 47 jours de gelées en moyenne avec un risque important de novembre à mars.

L'essai est en place en conduite agrobiologique depuis 1996. Cette parcelle de plus de 6 ha est sous l'influence de deux pentes. L'essai a été mis en place sur la partie haute de la parcelle et les 3 blocs sont disposés perpendiculairement à la pente la plus marquée (pente de 6 % en moyenne pour l'essai).

- Type de sol

La profondeur de sol dans la parcelle varie entre 50 cm et 1 m avec une moyenne de 80 cm. Une hétérogénéité de profondeur existe donc sur l'essai, ceci du fait du caractère festonné de l'altérite. Le sol repose sur des micaschistes. Selon le Référentiel Pédologique Français (1995), il est classé comme brunisol oligo-saturé et comme cambisol dystique selon la classification FAO (1998).
4 horizons le composent :

- Horizon de labour L : caractérisé par une couleur « brun foncé » sur les 30 premiers centimètres en moyenne, liée à la présence de matière organique (MO).
- Horizon structural S : « brun jaunâtre », organo-minéral de texture limoneuse, sans trace d'hydromorphie. Il descend jusqu'à 60 cm de profondeur en moyenne. La matière organique est concentrée dans des pédotubules ou incorporée dans de plus larges zones de couleur « brun foncé ». L'activité biologique y est importante. A noter également la présence de graviers de schiste et de cailloux de quartz.
- Horizon S/C : intermédiaire entre les horizons S et C.
- Horizon C : au-delà de 80 cm de profondeur, c'est un horizon minéral d'altération de couleur « jaune brunâtre ». Il conserve en partie la structure de la roche qui a subi une fragmentation importante et/ou une altération géochimique (altérite de micaschiste).

Les sols sont très bien pourvus en MO avec plus de 4 % de MO sur les 30 premiers centimètres. C'est également un sol riche en phosphore et potassium. En moyenne la teneur en potassium (K_2O) est de 190 mg/kg. Dans ce type de sol, cette valeur est supérieure à la teneur seuil d'impasse proposé par le COMIFER (1997) pour les cultures d'exigence faible (T_i= 150 mg/kg) et moyenne (tel que le pois protéagineux) (T_i=180 mg/kg). Cette valeur se trouve également supérieure à la teneur seuil renforcé (Tr=170 mg/kg) pour les cultures de forte exigence. En terme de teneur en phosphore (P_2O_5 Dyer = 363 mg/kg sur l'essai), la teneur d'impasse est très largement dépassée et ce, quelle que soit l'exigence de la culture mise en place (T_i=150-160 mg/kg selon l'exigence de la culture). Aucune fumure de fond n'est donc nécessaire. Enfin, les caractéristiques physiques permettent de conclure à une texture limono-argilo-sableuse (loam) (47,5 % de limon ; 32,3 % de sable ; 20,2 % d'argile) et à un indice de battance de 0,8, caractéristique d'un sol faiblement battant.

Les techniques culturales experimentées

Les techniques de travail du sol

- Principe du dispositif

Le dispositif choisi pour l'étude de 4 modalités est de type bloc complet avec 3 blocs constituant 3 répétitions. Les blocs sont séparés par des bandes de 15 m de large. Dans chaque bloc, il y a 4 parcelles élémentaires de 300 m² (12 m x 25 m) sur lesquelles les modalités ont été allouées par tirage aléatoire.

- **Modalités testées**

L'essai porte sur l'étude d'un seul facteur : le travail du sol. Les 4 modalités suivantes sont comparées :

⇒ ***Labour classique***

Cette modalité sert de témoin à l'expérimentation. Le labour est réalisé à l'aide d'une charrue 3 corps réglée pour travailler le sol sur 25-30 cm.

⇒ ***Labour agronomique***

Il s'agit d'un labour peu profond qui pourrait, d'après Y. Gautronneau, être mieux adapté au sol limoneux et fragile de la région. L'idée est de retrouver la fonction de lutte contre les adventices sans les inconvénients des labours profonds qui vont notamment diluer la MO sur des profondeurs plus importantes. Ce travail peut être réalisé à l'aide d'une charrue classique dépourvue de rasettes et réglée pour une profondeur de 12-15 cm ou par une « charrue agronomique » équipée de versoirs de plus petite taille.

⇒ ***Travail superficiel***

Cette modalité n'implique aucun retournement du sol mais uniquement une fragmentation par un outil à dents, le chisel ou canadien qui travaille le sol sur les 12-15 premiers centimètres.

⇒ ***Travail très superficiel***

Au démarrage de l'essai, cette modalité était un semis direct sous couvert. Cependant, compte-tenu des difficultés pour gérer à la fois le salissement et la concurrence du couvert (trèfle banc), cette modalité est passée peu à peu en travail très superficiel (7 cm).

***a** : charrue 3 corps pour le labour classique ; **b** : charrue 3 corps pour le labour agronomique ;*
***c** : chisel pour le travail superficiel ; **d** : semoir spécifique utilisé initialement pour le semis direct*

Appendix 4 : MASC criteria arborescence

This arborescence takes back all the basic criteria of MASC and their aggregated level. It can helps the reader to understand how indicators are evaluated and which are resulting from an aggregation.
In this figure, I used colours and sign to represent some specific indicators or criteria:

Criteria fixed by the objective of the experimentation or the station equipment

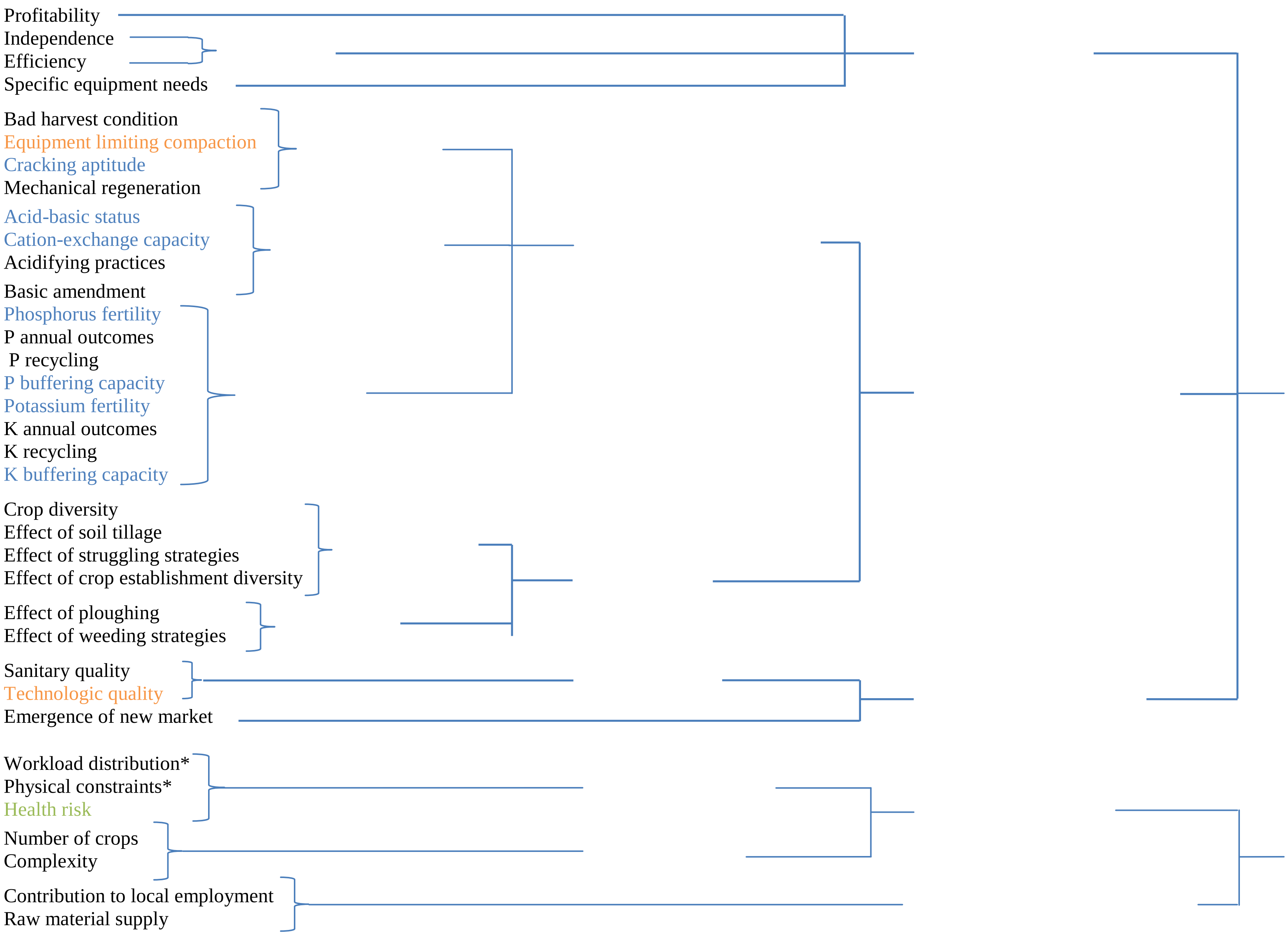
Criteria fixed according to the experimental plot (soil analysis)

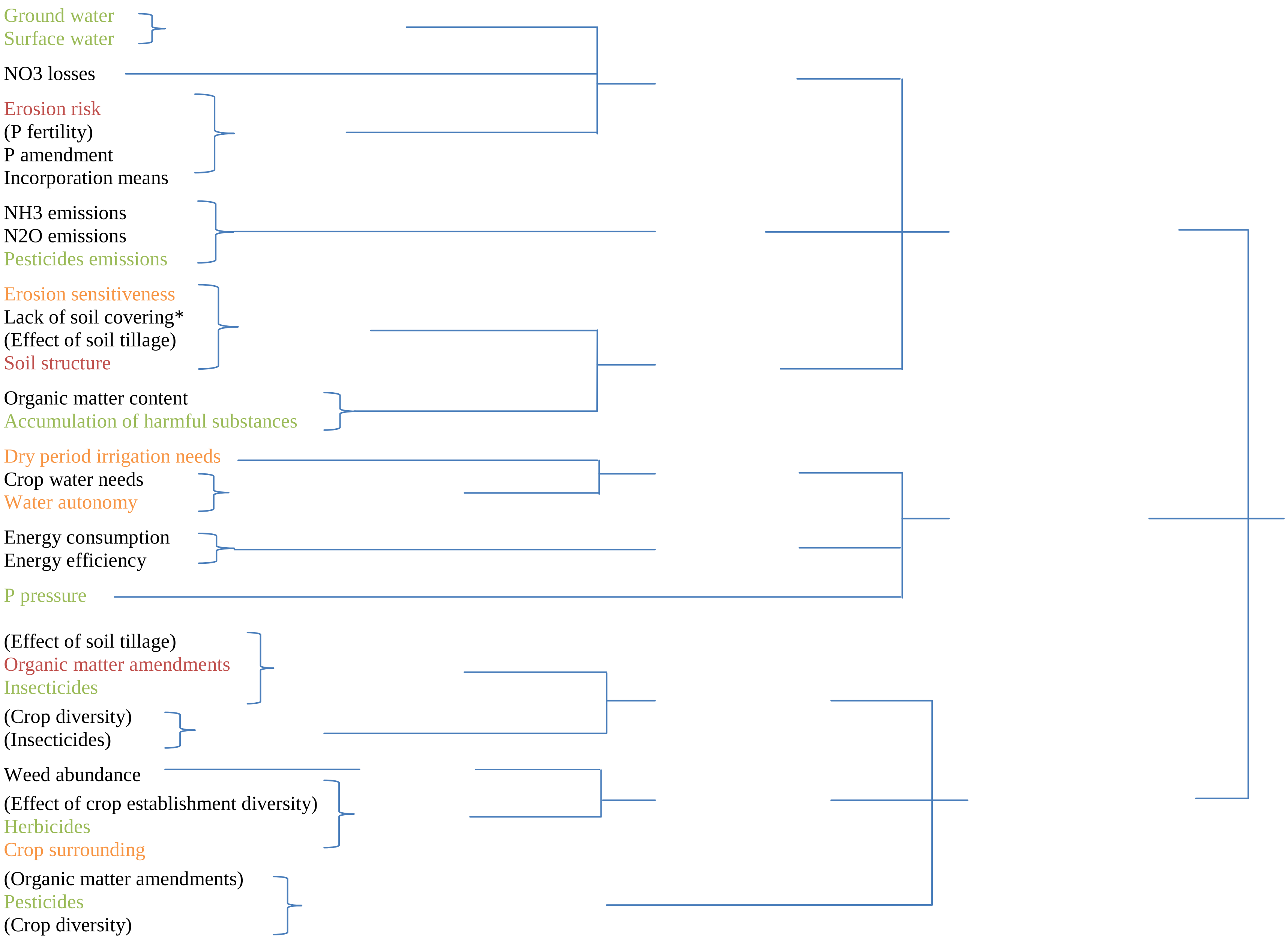
“Critere linked”

Criteria corresponding to the use of chemical inputs

() already filled once

*Estimated with experts


Profitability
Independence
Efficiency
Specific equipment needs
Bad harvest condition
Equipment limiting compaction
Cracking aptitude
Mechanical regeneration
Acid-basic status
Cation-exchange capacity
Acidifying practices
Basic amendment
Phosphorus fertility
P annual outcomes
P recycling
P buffering capacity
Potassium fertility
K annual outcomes
K recycling
K buffering capacity
Crop diversity
Effect of soil tillage
Effect of struggling strategies
Effect of crop establishment diversity
Effect of ploughing
Effect of weeding strategies
Sanitary quality
Technologic quality
Emergence of new market
Workload distribution*
Physical constraints*
Health risk
Number of crops
Complexity
Contribution to local employment
Raw material supply



Ground water
Surface water
NO3 losses
Erosion risk
(P fertility)
P amendment
Incorporation means
NH3 emissions
N2O emissions
Pesticides emissions
Erosion sensitiveness
Lack of soil covering*
(Effect of soil tillage)
Soil structure
Organic matter content
Accumulation of harmful substances
Dry period irrigation needs
Crop water needs
Water autonomy
Energy consumption
Energy efficiency
P pressure
(Effect of soil tillage)
Organic matter amendments
Insecticides
(Crop diversity)
(Insecticides)
Weed abundance
(Effect of crop establishment diversity)
Herbicides
Crop surrounding
(Organic matter amendments)
Pesticides
(Crop diversity)

Appendix 5: Fixed criteria

This table summarize fixed criteria. It gave the qualitative class fixed for criteria that were similar from one cropping system to another. The justifications of the class were given in the column "comments". Three categories were proposed:

- Criteria fixed according to the experimental plot (soil analysis)
- Criteria fixed by the objective of the experimentation or the station equipment
- Criteria corresponding to the use of chemical inputs

CRITERIA	References proposed by MASC	Qualitative class	Comments
Cracking aptitude	Categories 4 and 5 3 2 1	very low low to medium medium to high very high	Aptitude categories according to soil texture *Kerguehennec: silt 40%/clay20%*
Initial acid-basic statu	pH <= 6 6< pH <=7 pH >7	low medium high	*pH initial Kerguehennec = 7*
Buffering capacity (CEC)	CEC < 8 8 < CEC < 14 CEC > 14	low medium high	*CEC mep/100g entre 8 et 9*
Initial P fertility	Satisfy every plant exigency Satisfy only medium exigency Can satisfy only low exigency	high medium low	
P buffering capacity	silt sand medium silt Clay, clay silt, sandy clay silt	low medium high	*Depends on soil texture* *Kerguehennec: soil texture: sandy clay silt*
Initial K fertility	Satisfy every plant exigency Satisfy only medium exigency Can satisfy only low exigency	high medium low	
K buffering capacity	silt sand medium silt Clay, clay silt, sandy clay silt	low medium high	*Kerguehennec: sandy clay silt*
Erosion risk	Sealing: 0.8 = low risk for sealing Slope: between 0 and 0.5% Annual rainfalls: 1018mm => Q3/4	Very low risk	Evaluated with MASC model
Technological quality	Quality objective reach only 1 year/3 Quality objective reach 1 year/2) Quality objective almost also reach	0 1 2	<1.5 low 1.5<=TQ<2 medium 2 high *Objective: animal feeding. Low quality. No risk to not reach objective*
Effect of equipment on soil compaction	no specific equipment Low pressure tire..	low high	*No specific equipment*
Dry period irrigation needs	IRRC = Ipcl/n Ipcl = quantity of water given to the crop	very low	*No irrigation equipment*

Water autonomy	Auto water =100% 100% > AW >= 85% 85% > AW >= 75% AW >75%	very high high medium low	*No irrigation on the plot* Autonomy is calculated by the ratio between quantity of water and crop demand
P pressure	PSPH <= 20 20 < PSPH <= 40 40 < PSPH <= 60 60 < PSPH	very low low to medium medium to high very high	PSPH: Quantity of P coming from non-renewable resource
Crop surrounding	No difference with the plot Extensive system Cultivation of flower…	Low Medium High	*Hedge around the plot*
Health risk	TOX < 1 1< TOX <2 2 < TOX	low medium high	*Organic farming = no use of toxic products*
Pesticides losses in Ground water	MPES<4 4 < MPES < 7 7 < MPES < 9 9 < MPES	very low low to medium medium to high very high	Very high = very high control over pesticides pollution into water
Pesticides losses in Surface water	MPES<4 4 < MPES < 7 7 < MPES < 9 9 < MPES	very low low to medium medium to high very high	
Pesticides emissions	MPA<4 4 < MPA < 7 7 < MPA < 9 9 < MPA	very low low to medium medium to high very high	
Control of accumulation of harmful substances	No accumulation of toxic elements	very low low to medium medium to high very high	It is supposed that organic farming to no cause accumulation of toxic elements. If some toxic such as copper can be imported to the system it is few amounts and to not account compare to conventional farming.
Insecticides	Treatment frequency = 0 btw 0 and 0.75 btw 0.75 and 1.25 > 1.25	zero low medium high	*No use of insecticides*
Pesticides	Treatment frequency = 0 btw 0 and 3 btw 3 and 5 > 5	zero low medium high	*No use of pesticides*
Herbicides	Treatment frequency = 0 btw 0 and 1 > 1	zero medium high	*No use of herbicides*

Appendix 6: Prototyping and conception. Experts' management strategies. The presentation of the strategy is supported by a crop rotation that could achieve the objectives.

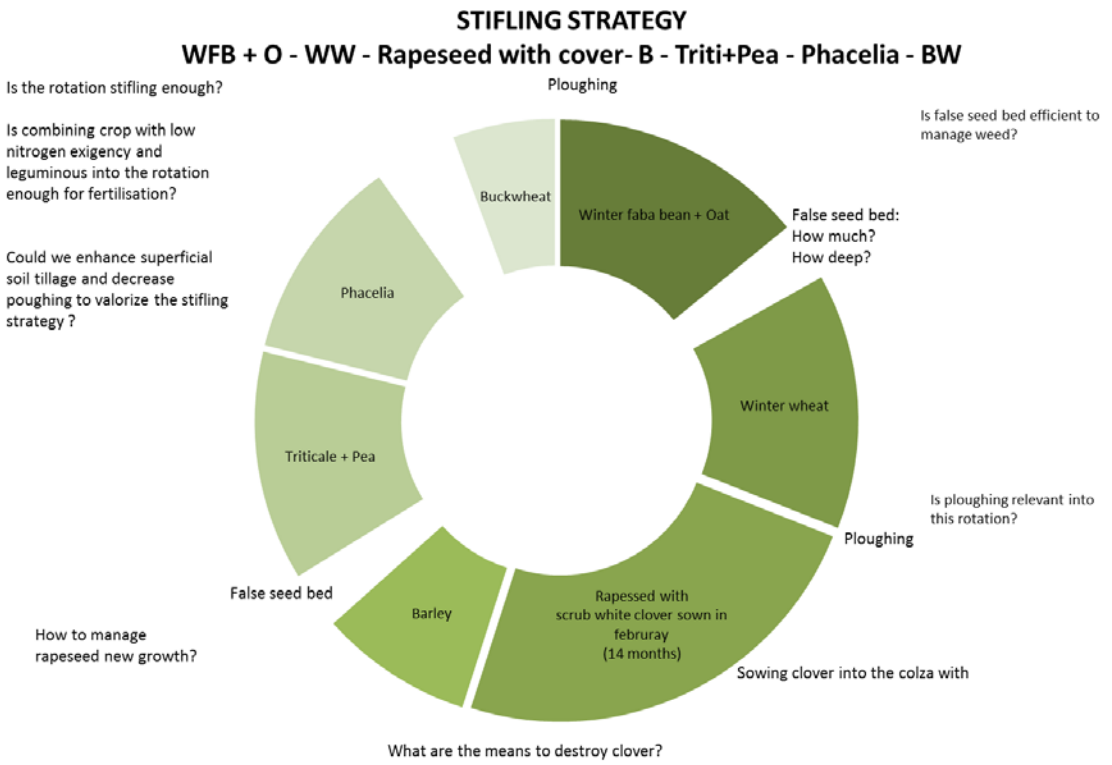


Figure 2: Strategic succession of stifling crop (6 years). Soil tillage: Ploughing to manage Poacaea. Fertilisation management: demanding crop => need organic manure. Cover crop management: cover crop kills at spring time / false seedbed. Weed management: mechanical control if needed / stifling strategy.

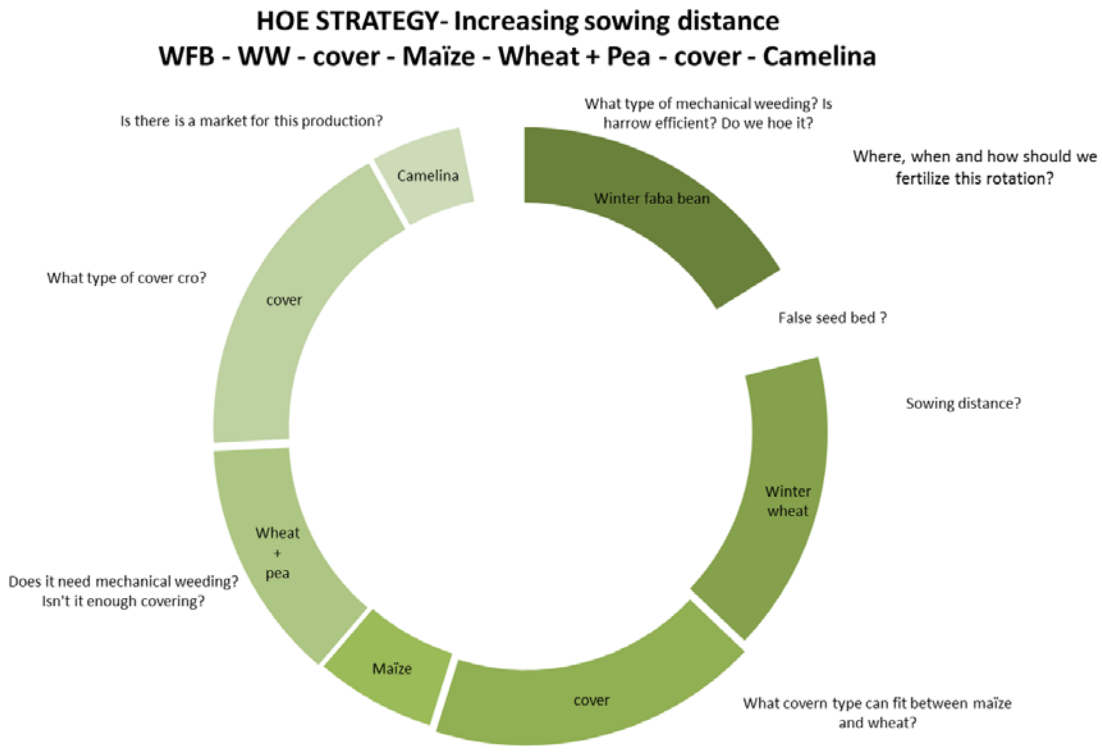


Figure 3: Informative crop succession adapted to the hoe. Soil tillage and fertilisation were not defined. But this rotation will need ploughing and animal manure to be productive. Cover crop for winter because of legislation but not defined yet.

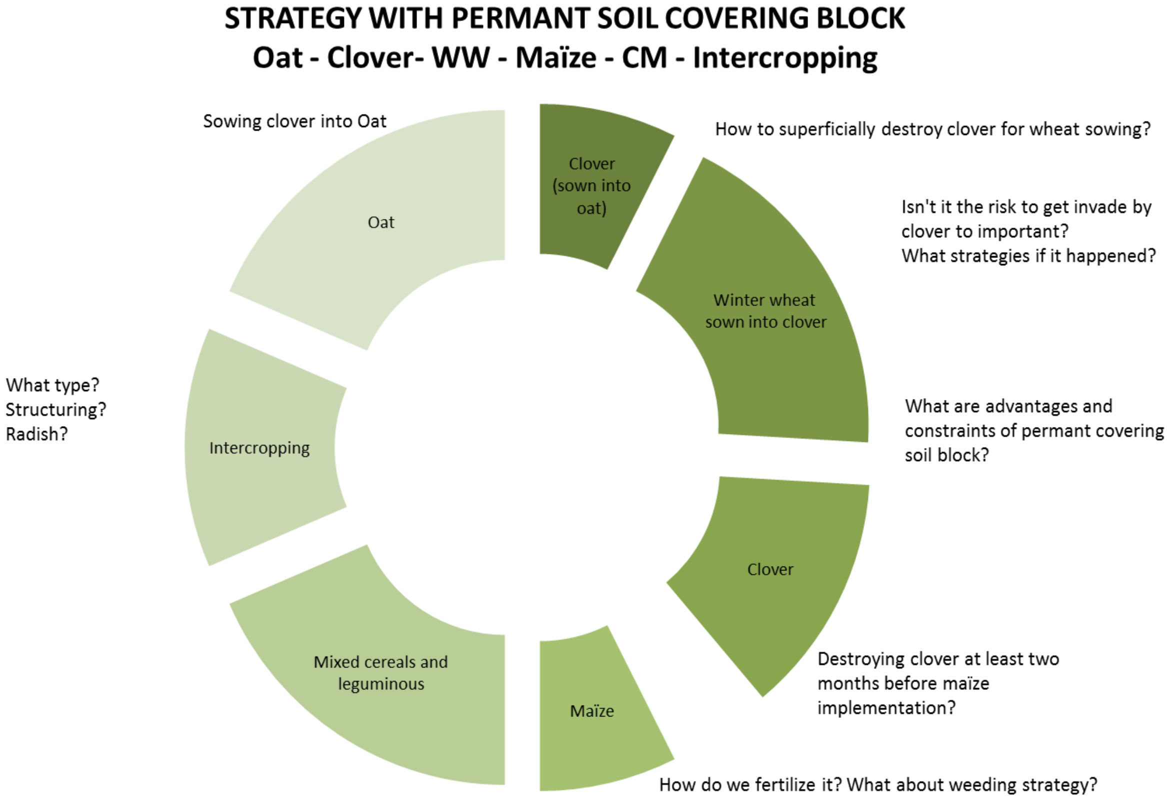


Figure 4: Crop rotation with permanent block. Innovative technique that is not well master in organic farming. Destruction of the secondary crop is the main challenge of this type of rotation.

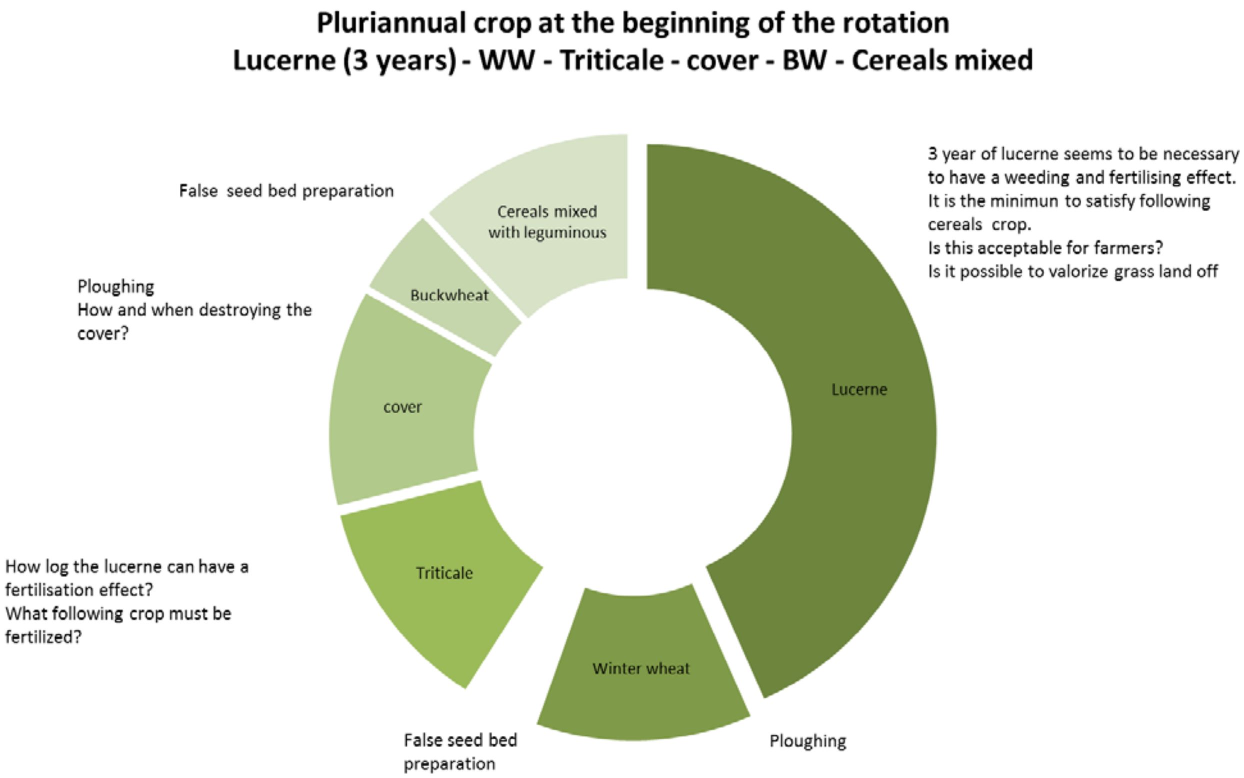


Figure 5: Cropping system with pluriannual. 3 years devoted to grassland for soil structure, nutrients furniture and adventices. Hypothesis: the two following crop do not need intervention (either fertilisation or weeding). Succession devoted to cereal productio . Strategy that may not be regular but occasional when needed.

Appendix 7: SWOT analysis strategy by strategy

Table 1. Stifling strategy

	Strengths	Weaknesses	Opportunities	Treats
EXPERTS	Covering soil to limit weeds Limit intervention into crop (working time)	Not enough to control weed Mechanical complementary strategy Need crops adapted to local condition To be complemented with manure	Association of crop Production of protein	control over secondary crop To be combined with other strategies to be efficient
FARMERS	Covering soil to limit weeds Limit intervention into crop (working time)	Not enough to control weed Mechanical complementary strategy Crop association are not optimized to furnish nitrogen and cover soil - need to be improved	Association of crop Production of protein Allelophatic plant	control over secondary crop Hamp crop are too difficult to harvest
TECHNICIANS	Covering soil to limit weeds Clean soil Nitrogen and carbon furniture Soil quality Limit nitrogen leaching	Accept to grow crop not harvested Shorter sowing period	Association of crop Production of protein	Control over secondary crop Protein not enough concentrated

Table 2. Mechanized cropping system: Hoe strategy – Increasing sowing density

	Strengths	Weaknesses	Opportunities	Treats
EXPERTS	Control weed on the row Reassuring tool Winter cover can be sown in spring (after the last hoe) Model for conventional in conversion Efficient tool	Inter-row weeding Increase sowing space No effect on weed quantity Investment	Effect on the rotation soil structure Water infiltration Nutrients Mineralisation	No insight / experiences Miss references Can damage roots
FARMERS	Control weed on the row More efficient tool Hoeing cereals = model for conventional in conversion to organic	Investment	Effect on the rotation Soil structure	Model for conventional in conversion to organic No insight / experiences
TECHNICIANS	Rotate mechanical weeding (only harrow = Weed resistance) Limit weed hardiness (Harrow alone not enough efficient. Limits appears 10 years later) Winter cover can be sown earlier (with the last hoe passing)	Investment	Effect on the rotation Soil quality Faba bean	No insight / experiences

Table 3. Pluriannual crop at the beginning of the rotation

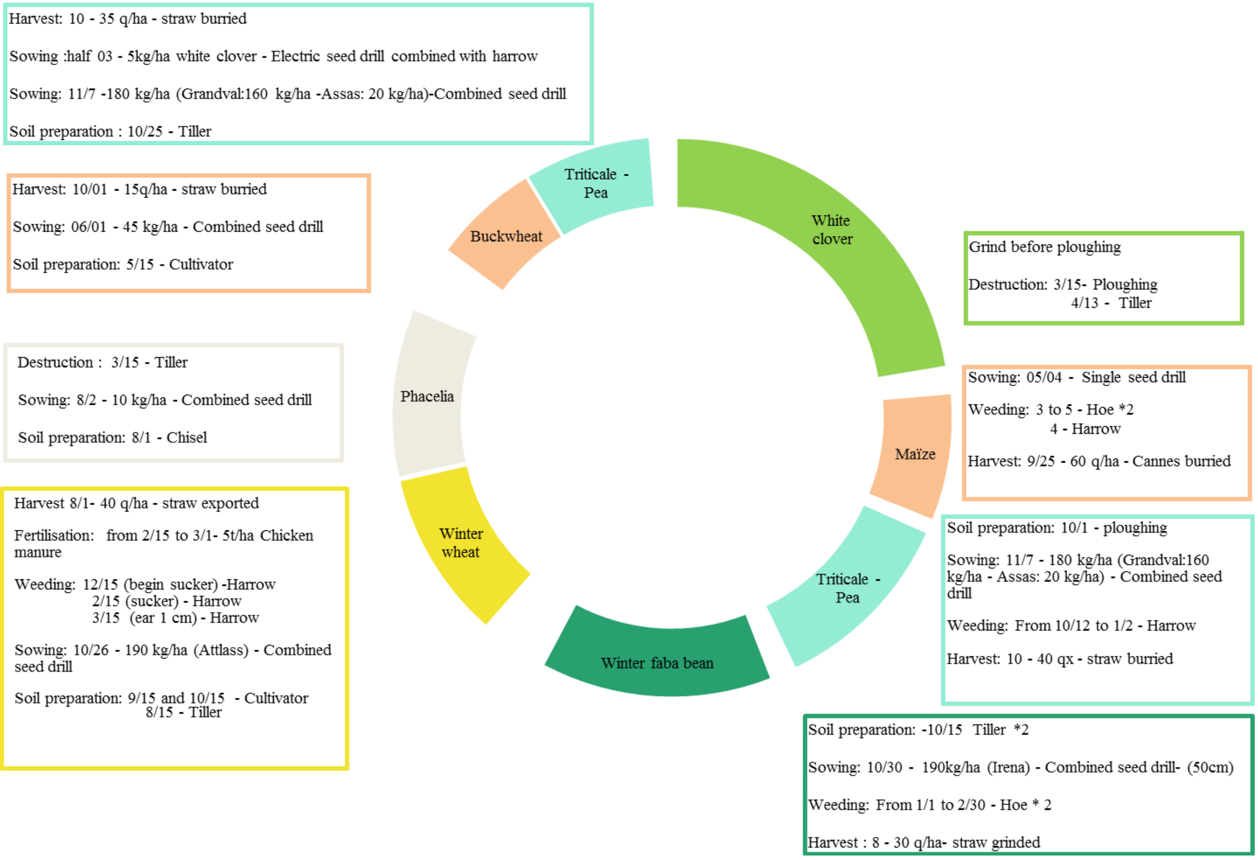
	Strengths	Weaknesses	Opportunities	Treats
EXPERTS	Efficient to manage weed and soil fertility Rest for soil Increase crop productivity over the rotation	Non-productive crop Additional work (harvest and mow)	Valorisation of grass Production of biomass	Harvesting time
FARMERS	Efficient to manage weed Increase soil fertility Increase crop productivity over the rotation	Non-productive crop Law for grass land destruction	Valorisation of grass Production of biomass Increase yield	Up to 6 years after grass, crop are no more productive Grass crop must be valorised
TECHNICIANS	Efficient to manage weed and soil fertility Indispensable to manage cereals production Extend crop succession Increase crop productivity over the rotation	Lucerne need calcareous soil	Valorisation of grass Production of biomass	Harvesting time

Table 4. Strategy with permanent soil covering block

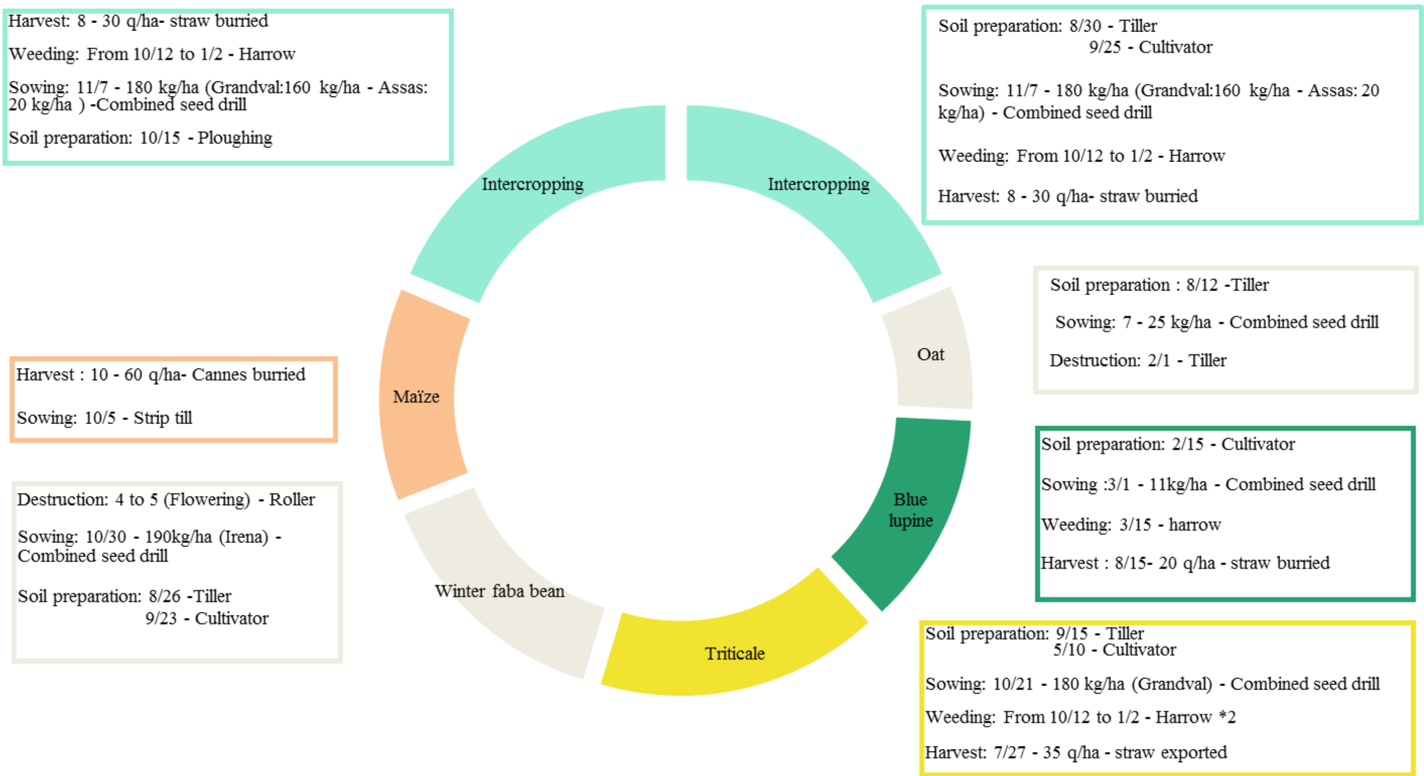
	Strenght	Weaknesses	Opportunities	Treats
EXPERTS	Optimizing soil covering Soil tillage limited to the sowing row Long term crop implantation	Need investment for superficial tillage tools Not possible to combine with mechanical weeding	Autonomous system Mulch	Cover must be sown early to be well developed Competition between cash crop and secondary plant N leaching
FARMERS	optimizing soil covering No tillage Limit adventices growth Increase soil biodiversity	Need investment for superficial tillage tools Time and investment for cover crop Control of the secondary plant Difficult to find nip plant	Autonomous system Mulch	Cover must be sown early to be well developed Competition Weed development
TECHNICIANS	optimizing soil covering limit N leaching soil tillage limited to the sowing row long term crop implantation	Need investment for superficial tillage tools Status law for winter leguminous cover	Nitrogen furniture Clover species adapted	Cover must be sown early to be well developed Competition Mix clover

Appendix 8: Description of the prototype (crop succession and corresponding cultural practices

Cropping system 2: Short perennial at the beginning of the rotation



Cropping system 3: Autonomous



Cropping system 4: Hoe on cereals

Harvest: 10/22 - 15q/ha - Straw burried

Sowing : 05/10 - 25 kg/ha (Harpe) - Combined seed drill

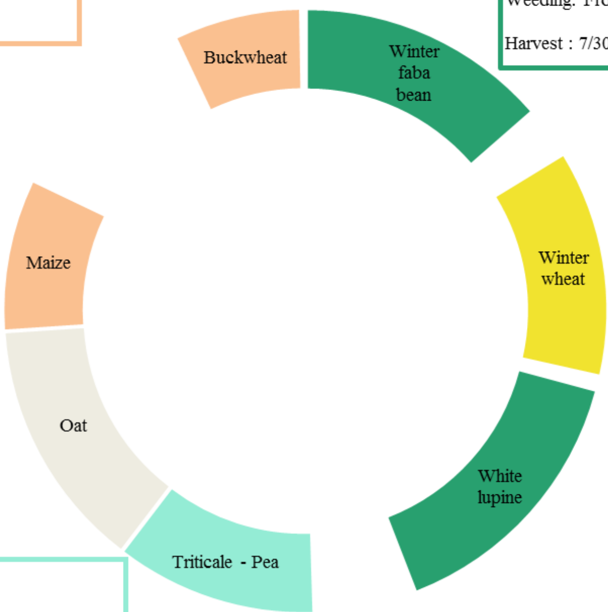
Soil preparation: 4/15 - 5/15 - Cultivator
3/20 - Tiller

Soil preparation: 10/15 - Tiller

Sowing: 10/30 - 190kg/ha (Irena)- Combined seed drill (50cm)

Weeding: From 3 to 4 - Hoe *2

Harvest : 7/30 - 30 q/ha - straw burried



10/15 - Tiller

Harvest : 10/1 - 60q/ha - cannes burried

Weeding: 5/12 - harrow *2
4/30- hoe *2

Sowing: 4/24 - Single seed drill

Soil preparation: 8/15 - Tiller
9/15 Cultivator

Sowing: 10/20 - 170kg/ha (Attlass) -Combined seed drill - (25 cm)

Fertilisation: 3/10 - 3t/ha chicken manure

Weeding: 3/15 - 5/15- Hoe
4/1- 5/1- Harrow

Harvest: 7/25 - 40q/ha - straw exported

Soil preparation: 3/1 - Tiller
3/15 - Ploughing
4 - Cultivator

Fertilisation : 2/15 - 6t/ha Chicken manure

Sowing: 7- 25kg/ha - Combined seed drill

Soil preparation: 7/28 - Tiller
8/15 - Cultivator

Sowing : 8/20 - 11kg/ha - Combined seed drill

Weeding : from 10/15 to 11/15 - Harrow

Harvest: 7 - 25 q/ha - straw burried

Soil preparation: 8/1 - Tiller
8/15 - 9/15 - Cultivator

Sowing: 10/16 - 180 kg/ha (Grandval:160 kg/ha - Assas: 20 kg/ha)- Combined seed drill

Weeding : From 12/10 to 2/1 - Harrow

Harvest: 08 - 30 q/ha - straw burried

Cropping system 5 : Late sowing

10/26 - Disc harrow

Harvest: 10/22 - 15q/ha - Straw burried

Sowing : 5/10 - 25 kg/ha (Harpe) - Combined seed drill

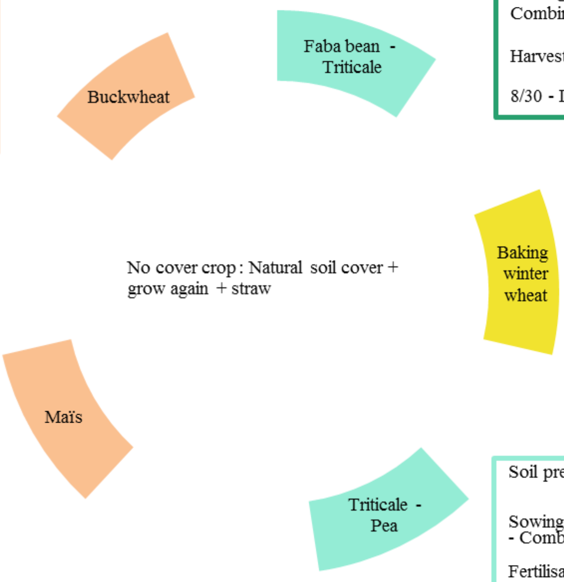
Soil preparation : 3/15 - Ploughing
2/15 - Disc harrow

Soil preparation: 1/30 - Disc harrow
2/15 - Ploughing (30cm)

Sowing: 2/26- 200kg/ha (140 kg/ha Grandval - 60 kg/ha Maya) - Combined seed drill

Harvest: 8/25 - 35 q/ha - straw burried

8/30 - Disc harrow



Soil preparation: 1/30 - Disc harrow
2/15 - Ploughing (20cm)

Sowing: 2/25 - 220 kg/ha (Renan) - Combined seed drill

Fertilisation and weeding benefit from previous crop

Harvest: 8/25 - 30 q/ha - straw exported

8/30 - Disc harrow

9/30 - Disc harrow

Harvest: 9/25 - 60 q/ha - Cannes burried

Weeding : 3 to 5 - Harrow *2
- Hoe *3

Sowing: 05/10 - Single seed drill

Fertilisation: 4/15 - Chicken manure 8t/ha

Soil preparation : 4 - Cultivator (8cm)*4
3/15 - Ploughing
2/25 - Disc harrow

Soil preparation : 1/30 - Disc harrow
2/15 - Ploughing (20cm)

Sowing: 2/26- 200kg/ha (Bienvenue:180 kg/ha - Assas: 20 kg/ha) - Combined seed drill

Fertilisation: 2/25 - 2t/ha - Chicken manure

Harvest: 8/30 - 35 q/ha - straw burried

8/30 - Disc harrow

Cropping system 6: Stifling

Ploughing: 10/10

Sowing: 11/15 - 190 kg/ha (Irena) + Oat : 10 kg/ha - Combined seed drill

Weeding: From 12/10 to 02/01 - harrow *2

Harvest: 8/25 - 30 q/ha - straw burried

Soil preparation: 09/15- Tiller
10/15 Cultivator

Sowing 10/25 - 190 kg/ha (Attlass)- Combined seed drill

Weeding : half 12 (begin sucker) - harrow
half 2(sucker) - harrow
half 3 ear 1 cm - harrow

Fertilisation: 2/15 to 3/1- 5t/ha - Chicken manure

Harverst:8/1- 40 q/ha - straw exported

Soil preparation : 8 - Chisel
8/15: Ploughing

Sowing: 8/20 - 4 kg/ha (kalif) - Combined seed drill
8/20 - roller

Sowing: 10/15 - Dwarf white clover - 4kg.ha - Electric seed drill combined with harrow

Fertilisation : 3/15 - 15 m3 of pigg slurry

Harvest 7/5 - 15 q/ha - straw burried

Clover destruction : 2/ 1 - Chisel

Harvest: 8/25 - 30 q/ha - straw exported

Weeding: Harrow - 4 and 5(sucker)

Sowing: 3/15 - 161 kg/ha (Vanessa) - Combined seed drill

Soil preparation: 2/10 Ploughing
2/21 - 03/10 Cultivator

Harvest : 7/27 - 40 q/ha - straw burried

Weeding : from 10/12 to 1/2 - Harrow

Sowing: 11/7 - 200kg/ha (Grandval 180kg/ha - Assas 20 kg/ha) - Combined seed drill

Soil preparation: 9/15 and 10/20 - Cultivator

Destruction : 3/15 - Tiller

Sowing: 8/2 - 10 kg/ha- Combined seed drill

Soil preparation : 7/30 - Tiller

Harvest: 10/22 - 15q/ha - Straw burried

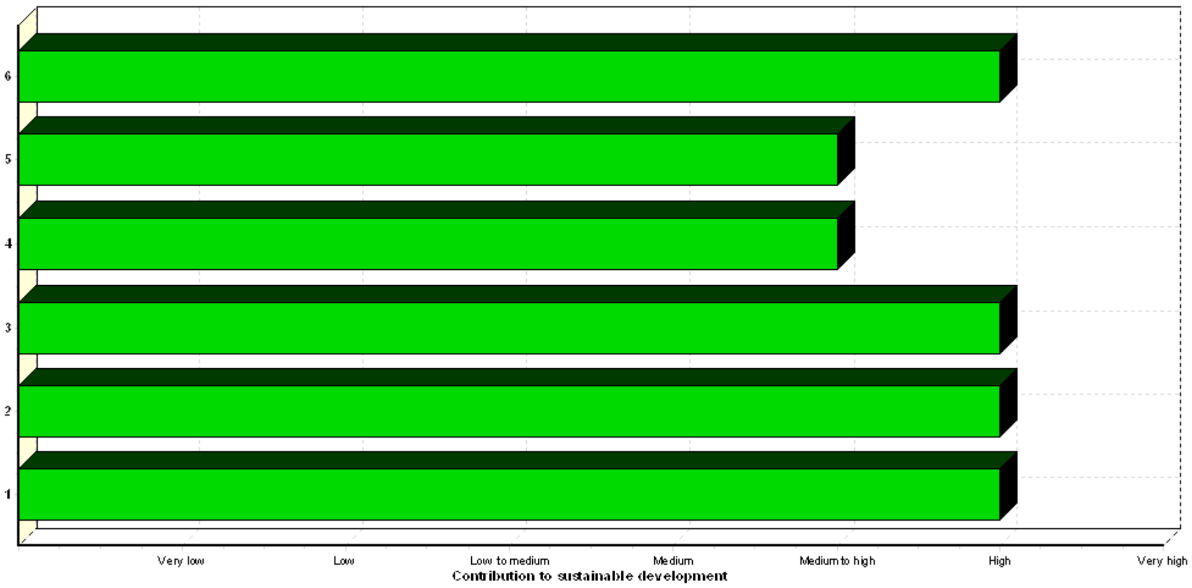
Sowing : 06/01 - 25 kg/ha(Harpe) - Combined seed drill

Soil preparation : 04/15 and 05/15 - Cultivator

Appendix 9 : Representation of the contribution to the three dimension of sustainability (economic, social and environmental)

Those charts were obtained with MASC. They represente the contribution to sustainable development for the 6 prototypes tested. This criteria is too general and depends on too much indicators that it is not a satisfying level for interpretation.

Contribution to sustainable development for each prototype.



Appendix 10: Example of calcul to estimate K outcomes and recycling for the prototype 1

Annual Outcomes $_K$ = (K bringing in - (Yield * Content $_K$))/year				
	K *(kg/ha/year)*	Yield *(t or q)*	K content *(t or q)*	AO_K
Lucerne	0	=3*5t MS	6,3	=0-(15*6,3)
W wheat	0	45	1,7	=0-(45*1,7)
Straw	0	=0,75* 4,5 t of straw	0,65	=0-(3,375*0,65)
Maize	=10t/ha of compost * 2,2	60	0,6	=22-(60*0,6)
Pea-wheat	0	40	=Pea(0,48*0,8)+Wheat(0,52*0,65)	=0-(40*0,722)
Buckwheat	0	15	0,22	=0-(15*0,22)
Pea-wheat	0	40	=Pea(0,48*0,8)+Wheat(0,52*0,65)	=0-(40*0,722)
		Rotation	=sum/nb of years	= - 26 kg K/ha/year

Recycling residues $_K$= (Qt of residue * content $_K$)/year			
	Residues *(t or q)*	K content *(t or q)*	Rr $_K$
Lucerne	5	6,3	=5*6,3
Radish	3	1,7	=3*1,7
Maize	3	1	=3*1
Pea-wheat	3	=(0,48*2,1)+(0,52*1,7)	=3*1,892
Oat (CC)	1	3	=1*3
Buckwheat	=0,75*1,5	0,22	=1,125*0,22
Pea-wheat	3	=(0,48*2,1)+(0,52*1,7)	=3*1,892
Rotation	=sum/nb of year	= 6,8 kg of K recycle/ha/year	

The calculation of P and K fertility is made out of the estimation of the "annual outcomes" and the "recycling residues" of P and K.
Annual outcomes consist of an evaluation of exportation of P and K by the plant including the incomes of organic manure.
Recycling residues consist of an evaluation of P and K recycling into the soil by management of crop residues.

Appendix 11: Ranking and weighting criteria according to the C.A. preferments

	Long perennial	Short perennial	Autonomous	Hoe	Late sowing	Stifling
(1) Economic results	+	-	+++	++	---	-
(2) Economic dimension	++	++	++	---	--	+++
(3) Weed management	+++	++	+	--	---	+
(4) Soil fertility	---	++	--	+	++	+++
(5) Long term productive capacity	+	+	---	+	++	+++
(6) Farmers' satisfaction	---	+++	++	+	+	--
(7) N leaching	+++	+++	+++	-	--	---

Table 1. Point allocated for each criterion

Criteria	Point
(1) Economic results	7
(2) Economic dimension	6
(3) Weed management	5
(4) Soil fertility	4
(5) Long term productive capacity	3
(6) Farmers' satisfaction	2
(7) N leaching	1

Table 2. Point allocated for each color

Colours	Point
Red	0
Orange	1
Yellow	2
Green (light)	3
Green (dark)	4

Appendix 12: MASC arborescence

For each prototypes tested, MASC furnished an aggregation tree. It made clear weakness and strength. Those figures were used for the interpretation of the figures obtained and to classify prototype. It was also use for the translation of the organization of hierarchy into colors.

In this appendix are presented the results for the 6 prototypes.
Colour correspond to:

Sustainability :				
very low	low	medium	high	very high
very low	low to medium	medium to high	very high	
low	medium	high		

7 classes	5 classes	4 classes
1 /7	1 /5	1 /4
2 /7	2 /5	2 /4
3 /7	3 /5	3 /4
4 /7	4 /5	4 /4
5 /7	5 /5	
6 /7		
7 /7		

Mark obtained according to the class

Warning: Colour depends on the number of classes! All colour are not always present.

Appendix 12 a) Results of the ex-ante evaluation of the prototype 1 (Long perennial)

4 /4	Profitability (656.4)					4 /4	Economic results	5 /5	Economic dimension	6 /7	Contribution to sustainable development
4 /4	Subsidices independancy			3 /4	Economic Autonomy						
2 /4	Economic efficiency										
2 /3	Specific equipment needs										
3 /4	Soil Acid-base status			2 /4	Physical and Chemical fertility	3 /4	Long term productive capacity				
2 /4	Soil compaction										
1 /4	P-K fertility										
4 /4	Pests control			4 /4	Pests and Weeds control						
4 /4	Weeds control										
2 /3	Sanitary quality			3 /4	Products' quality	3 /4	Economic development				
3 /3	Technological quality										
2 /3	New supply chain emergence										
1 /4	Employment contribution					2 /4	Society's satisfaction	3 /5	Social dimension		
3 /4	Supply of raw material										
4 /4	System complexity			4 /4	Implementation	3 /4	Farmers' satisfaction				
1 /3	Technical monitoring										
1 /3	Workload distribution			2 /4	Working conditions						
3 /4	Pesticides use risk										
2 /3	Physical difficulty										
4 /4	Ground water	4 /4	Water pollution	4 /4	Water quality	4 /4	Contribution to envriomnent quality	5 /5	Environmental dimension		
4 /4	Surface water										
4 /4	NO3 Losses										
3 /4	P Losses										
4 /4	NH3 volatilisation			4 /4	Air quality						
4 /4	N2O emissions										
4 /4	Pesticides emissions										
4 /4	Acc. Tox. Elements			3 /4	Soil quality						
2 /4	Organic matter content										
4 /4	Soil erosion										
3 /4	Dry period irrigation needs			4 /4	Water	4 /4	Pressure on resources				
3 /4	Dependency on water										
3 /4	Energy consumption			4 /4	Energy						
3 /3	Energetic efficiency										
4 /4	P conservation										
4 /4	Flyings insects			3 /4	Macro fauna conservation	3 /4	Biodiversity conservation				
2 /4	Soil Macro fauna										
1 /4	Abundance			2 /4	Flora conservation						
4 /4	Diversity										
3 /4	Soil micro-organisms										

This prototype had a high contribution to sustainable development (6/7), to economic (5/5) and environmental (5/5) dimension. Nonetheless, one should consider that profitability of this prototype relies on market opportunities for Lucerne. Apparently, it only failed the contribution to social dimension (3/5) because of workload distribution, number of intervention and crops. Lucerne harvest requires lot of intervention: 4 mows per year and 3 swathes. Moreover, this prototypes failed P, K fertilisation indeed exportation are very important for this crop: 6, 3 kg of P / T of Lucerne produced and 26,3 kg of K/T of Lucerne. If fertilisation was brought to the rotation, then P, K fertility and organic matter content would reach better level. This would increase soil fertility and long term productive capacity.

Appendix 12 b) Results of the ex-ante evaluation of the prototype 2 (Short perennial)

Score	Indicator	Score	Sub-group	Score	Sub-criterion	Score	Criterion	Score	Dimension	Score	Overall
3 /4	Profitability (562.6)					4 /4	Economic results	5 /5	Economic dimension	6 /7	Contribution to sustainable development
4 /4	Subsidices independency			3 /4	Economic autonomy						
2 /4	Economic efficiency										
3 /3	Specific equipment needs										
3 /4	Soil acid-base status			2 /4	Physical and chemical fertility	3 /4	Long term productive capacity				
1 /4	Soil compaction										
4 /4	P-K fertility										
4 /4	Pests control			4 /4	Pests and weeds control						
4 /4	Weeds control										
2 /3	Sanitary quality			3 /4	Products' quality	3 /4	Economic development				
3 /3	Technological quality										
2 /3	New supply chain emergence										
1 /4	Employement contribution					2 /4	Society's satisfaction	3 /5	Social dimension		
3 /4	Supply of raw material										
3 /4	System complexity			2 /4	Implementation	3 /4	Farmers' satisfaction				
1 /3	Technical monitoring										
3 /3	Workload distribution			4 /4	Working conditions						
3 /4	Pesticides use risk										
2 /3	Physical difficulty										
4 /4	Groud water	4 /4	Water pollution	4 /4	Water quality	4 /4	Contribution to environmentquality	5 /5	Environmental dimension		
4 /4	Surface water										
4 /4	NO3 Losses										
4 /4	P Losses										
4 /4	NH3 emissions			4 /4	Air quality						
4 /4	N2O emissions										
4 /4	Pesticides emission										
4 /4	Acc. Tox. Elements			3 /4	Soil quality						
2 /4	Organic matter content										
4 /4	Soil erosion										
3 /4	Dry period irrigation needs			4 /4	Water	4 /4	Pressure on resources				
3 /4	Water dependency										
3 /4	Energy consumption			4 /4	Energy						
3 /3	Energetic efficiency										
4 /4	P conservation										
4 /4	Flying insects			3 /4	Macro fauna conservation	3 /4	Biodiversity conservation				
2 /4	Soil macro fauna										
1 /4	Abundance			2 /4	Flora conservation						
4 /4	Diversity										
3 /4	Micro-organisms										

With a high contribution to global sustainable development (6/7), this prototype also presented high contribution to economic and environmental dimension (5/5 for both), but lower in the social one (3/5). To improve long term productivity, fertilisation should be more efficient, regular or important. Nonetheless, it should not damage profitability and decrease gross margin. Even if it responded well to objectives, its profitability was medium, it could limits improvement possibilities. This prototype also seems to be complex with a weak technical monitoring.

Appendix 12 c) Results of the ex-ante evaluation of the prototype 3 (Autonomous)

Score	Indicator	Score	Sub-indicator	Score	Sub-criterion	Score	Criterion	Score	Dimension	Score	Overall
4 /4	Profitability (723.7)					4 /4	Economic results	5 /5	Economic dimension	6 /7	Contribution to sustainable development
4 /4	Subsidices independancy			4 /4	Economic autonomy						
3 /4	Economic efficiency										
2 /3	Specific equipment needs										
3 /4	Soil Acid-base status			2 /4	Physical and chemical fertility	3 /4	Long term productive capacity				
3 /4	Soil compaction										
1 /4	P-K fertility										
2 /4	Pests control			3 /4	Pests and weeds control						
3 /4	Weeds control										
2 /3	Sanitary quality			3 /4	Products' quality	3 /4	Economic development				
3 /3	Technological quality										
2 /3	New supply chain emergence										
1 /4	Employment contribution					2 /4	Society's satisfaction	3 /5	Social dimension		
4 /4	Supply of raw material										
2 /4	System complexity			2 /4	Implementation	3 /4	Farmers' satisfaction				
1 /3	Technical monitoring										
3 /3	Workload distribution			4 /4	Working conditions						
3 /4	Pesticides use risk										
2 /3	Physical difficulty										
4 /4	Ground water	4 /4	Maîtrise des pertes pesticides	4 /4	Water quality	3 /4	Contribution to environment quality	4 /5	Environmental dimension		
4 /4	Surface water										
4 /4	NO3 Losses										
3 /4	P Losses										
4 /4	NH3 emissions			4 /4	Air quality						
4 /4	N2O emissions										
4 /4	Pesticides emissions										
4 /4	Acc. Tox. Elements			2 /4	Soil quality						
1 /4	Organic matter content										
4 /4	Soil erosion										
3 /4	Dry period irrigation needs			4 /4	Water	4 /4	Pressure on resources				
3 /4	Water dependency										
3 /4	Energy consumption			3 /4	Energy						
3 /3	Energetic efficiency										
4 /4	P conservatopn										
3 /4	Flyings insects			2 /4	Macro fauna conservation	2 /4	Biodiversity conservation				
2 /4	Soil macro fauna										
2 /4	Abundance			3 /4	Flora conservation						
4 /4	Diversity										
2 /4	Micro-organism										

Even with a global sustainability characterize as high (6/7), this system did not satisfy social and environmental dimension. With the highest gross margin (724€/ha/year), this prototype had very good economic results. It failed because of soil fertility and thus long term productive capacity. The objective beside this prototype was to propose a cropping system more autonomous for N, P, K fertilisation. Thus there is no organic manure but natural nitrogen fixation. Apparently, N fixing crop are not enough efficient to furnish crops' growth and maintain organic matter content.

Appendix 12 d) Results of the ex-ante evaluation of the prototype 4 (hoe)

Score	Indicator	Score	Sub-indicator	Score	Sub-criterion	Score	Criterion	Score	Dimension	Score	Overall
4 /4	Profitability (603.1)					4 /4	Economic result	3 /5	Economic Dimension	5 /7	Contribution au développement durable
4 /4	Subsidies Independancy			3 /4	Economic Autonomy						
2 /4	Economic Efficiency										
3 /3	Specific Equipment Nedds										
3 /4	Soil Acid-base Status			2 /4	Physic-Chemic fertility	3 /4	Long term productive capacity				
1 /4	Soil compaction										
4 /4	P-K Fertility										
4 /4	Pests Control			4 /4	Pests and weeds controls						
3 /4	Weeds Control										
1 /3	Sanitary quality			1 /4	Products' quality	1 /4	Contribution to the local economic development				
3 /3	TechnologicalQuality										
2 /3	New supply Chain Emergence										
1 /4	Employment Contribution					1 /4	Satisfaction des attentes de la societe	3 /5	Dimension Sociale		
2 /4	Supply of Raw Material										
4 /4	System complexity			4 /4	Facilite de mise en oeuvre	4 /4	Satisfaction des attentes de l agriculteur				
1 /3	Technical monitoring										
2 /3	Workload Distribution			3 /4	Qualite des conditions de travail						
3 /4	Pesticides Use Risk										
2 /3	Physical Difficulty										
4 /4	Surface Water	4 /4	Maîtrise des pertes pesticides	4 /4	Contribution à la qualité de l'eau	3 /4	Contribution à la qualité du mlilieu	5 /5	Dimension Environnementale		
4 /4	Groundwater										
4 /4	NO3 Losses										
3 /4	P Losses										
3 /4	NH3 emissions			4 /4	Contribution à la qualité de l'air						
4 /4	N2O Emissions										
4 /4	Pesticides Emissions										
4 /4	Acc. Tox. Elements										
2 /4	Organic Matter Content			2 /4	Préservation de la qualité du sol						
3 /4	Soil Erosion										
3 /4	Dry Period Irrigation Needs			4 /4	Pression Eau	4 /4	Pression sur les ressources				
3 /4	Dependency On Water										
3 /4	Engery Consumption			3 /4	Pression Énergie						
3 /3	Energetic Efficiency										
4 /4	P Conservation										
4 /4	Flings Insects			3 /4	Conservation de la macrofaune	3 /4	Conservation de la biodiversité				
2 /4	Soil Macrofauna										
2 /4	Abundance			3 /4	Conservation de la flore						
4 /4	Diversity										
3 /4	Soil Micro-Organisms										

This prototype was the one with the lowest contribution to sustainable development (5/7). This result was explained by a low contribution to economic and social dimensions. Even with high profitability (603 €/ha/year) this system is not performing in the global economic dimension. Its major weak was the products' quality. We can expect this prototype to be productive on short term but to quickly present sanitary problems. In organic farming it is very important to manage pests and diseases because there are not yet performing protection against. To be more efficient, improvement should focused on economic efficiency, long term productivity and sanitary quality but also on environment quality, supply of raw material, working conditions quality... Indeed, this prototype presented lot of criteria to be improved in order to make it acceptable for farmers.

Appendix 12 e) Results of the ex-ante evaluation of the prototype 5 (Late sowing)

Score	Basic criterion	Score	Intermediate criterion	Score	Sub-criterion	Score	Criterion	Score	Dimension	Score	Overall
4 /4	Profitability (598.6)					3 /4	Economic results	4 /5	Economic dimension	6 /7	Contribution to sustainable development
1 /4	Subsidices independency			2 /4	Economic autonomy						
3 /4	Economic efficiency										
3 /3	Specific equipment needs										
3 /4	Soil acid-base status			3 /4	Physical and chemical fertility	3 /4	Long term productive capacity				
2 /4	Soil compaction										
4 /4	P-K fertility										
3 /4	Pests control			3 /4	Pests and weeds control						
2 /4	Weeds control										
2 /3	Sanitary quality			3 /4	Products' quality	3 /4	Economic development				
3 /3	Technological quality										
2 /3	New supply chain emergence										
1 /4	Employement contribution					2 /4	Society's satisfaction	4 /5	Social dimension		
3 /4	Supply of raw material										
4 /4	System complexity			4 /4	Implementation	4 /4	Farmers' satisfaction				
2 /3	Technical monitoring										
2 /3	Workload distribution										
3 /4	Pesticides use risk			3 /4	Working conditions						
2 /3	Physical difficulty										
4 /4	Ground water	4 /4	Pesticides in water	4 /4	Water quality	3 /4	Contribution to environment quality	4 /5	Environmental dimension		
4 /4	Surface water										
4 /4	NO3 Losses										
3 /4	P Losses										
1 /4	NH3 emissions			3 /4	Air quality						
4 /4	N2O emissions										
4 /4	Pesticides emisions										
4 /4	Acc. Tox.Elements			2 /4	Soil quality						
1 /4	Organic matter content										
3 /4	Soil erosion										
3 /4	Dry period irrigation needs			4 /4	Water	4 /4	Pressure on resources				
3 /4	Water dependency										
3 /4	Energy consumption			3 /4	Energy						
2 /3	Energetic efficiency										
4 /4	P conservation										
3 /4	Flying insects			2 /4	Macro fauna conservation	2 /4	Biodiversity conservation				
2 /4	Soil macro fauna										
3 /4	Abundance			3 /4	Flora conservation						
3 /4	Diversity										
2 /4	Micro-organisms										

The general contribution to sustainable development is high (6/7). But the contribution to economic, social and environmental dimension is medium to high. This prototype did not particularly satisfy one dimension. In average, the level of satisfaction is medium. That means that optimising this cropping system would require to improve almost all basic criteria. Apparently, this prototype would not be economical efficient and would not permit to manage weed issues. Prototype 5 had a high level of farmers' satisfaction. It is mainly due to good working conditions and low complexity of implementation. This prototype had a high capacity to maintain soil fertility because of the regular organic manure and occasional straw exportation. In addition, the weeding method proposed was innovative and could deserve to be further explored.

Appendix 12 f) Results of the ex-ante evaluation of the prototype 6 (Stifling)

Score	Indicator	Score	Sub-criterion	Score	Criterion	Score	Theme	Score	Dimension	Score	Overall
3 /4	Profitability (478)					4 /4	Economic results	5 /5	Economic dimension	6 /7	Contribution to sustainable development
4 /4	Subsidces independency			3 /4	Economic autonomy						
2 /4	Economic efficiency										
3 /3	Specific equipment needs										
3 /4	Soil acid-base status			4 /4	Physical adnd chemical fertility	4 /4	Long term productive capacity				
4 /4	Soil compaction										
4 /4	P-K fertility										
4 /4	Pests control			4 /4	Pests and weeds control						
3 /4	Weeds control										
2 /3	Sanitary quality			3 /4	Products' quality	3 /4	Economic developmet				
3 /3	Technological quality										
2 /3	New supply chain emergence										
1 /4	Employment contribution					1 /4	Society's satisfaction	2 /5	Social dimension		
2 /4	Supply of raw material										
3 /4	System complexity			2 /4	Implementation	3 /4	Farmers' satisfaction				
1 /3	Technical monitoring										
2 /3	Workload distribution			3 /4	Working conditions						
3 /4	Pesticides use risk										
2 /3	Physical difficulty										
4 /4	Groud water	4 /4	Water pollution	4 /4	Water quality	4 /4	Contribution to the quality of the environment	5 /5	Environmental dimension		
4 /4	Surface water										
3 /4	NO3 Losses										
4 /4	P Losses										
3 /4	NH3 emissions			4 /4	Air quality						
4 /4	N2O emissions										
4 /4	Pesticides emissions										
4 /4	Acc. Tox. Elements			3 /4	Soil quality						
2 /4	Organic matter content										
4 /4	Soil erosion										
3 /4	Dry period irrigation needs			4 /4	Water	4 /4	Pressure on resources				
3 /4	Water dependency										
3 /4	Energy consumption			4 /4	Energy						
2 /3	Energetic efficiency										
4 /4	P conservation										
4 /4	Flying insects			3 /4	Macro fauna conservation	3 /4	Biodiversity conservation				
2 /4	Soil macro fauna										
2 /4	Abundance			3 /4	Flora conservation						
4 /4	Diversity										
3 /4	Micro-organisms										

This system is well satisfying global sustainability. At this scale of analysis, the main weak is the social dimension (2/5). If we go into deeper level of aggregation, see that beside a high contribution to economic dimension, this prototype is not highly profitable (478 €/ha/year). In addition to its lower economic results, prototypes 6 did not satisfy farmers' working conditions and environmental dimension. In Bretagne, there is an on-going issue about nitrogen losses. In these conditions it would be out of context to propose a rotation with a risk of leaching. Fertilisation was a condition to permit the stifling strategy but it implies too much risk.

Appendix 13. Discussion of cropping system removed

About late sowing prototype (5):

This prototype is innovative and makes a mockery of the forwarding sowing date technique. MASC did not evaluate this method as a performing one. In addition this technique presents a risk of uneven implementation. In Bretagne, climate is wet and there are few workable days. To illustrate this, I took the measurement of rainfall from the first of February till the fifteen of March and I looked at the numbers of days without rain:

Table 2 Rainfall on the region of Bretagne for the selected period of the three last years(specific location: Bignan, 56)

Year	Rainfall on the period from 1/02 to 15/03 (mm)	Annual rainfalls	% of rain for the period	Days without rain	Days without rain in February
2011	101,4	1088	9	13	9
2010	149,6	962	15	18	6
2009	80,5	824	9	11	5
Average:	110,5	958	11	14	6,7

Table 12 shows that in average, there is 110 mm of rain for this period; it represents around 10% of the annual rainfall. During this period, there is 14 days without rain (potentially workable), but in average, half of those "without rain" days occurred after the first of March. The prototype purpose is to implement crop before march so, this method can be implemented only favourable years. The prototype was based on the willingness to limit intervention during the growing period, to do so, farmer combined two practices: the late sowing and the non-covering in winter. He argued that this helped to decrease weed seed bank, actually, he let weeds grow and plough everything before to sow. It may be an innovative to diminish weeds vivacity nonetheless, it is illegal to let the soil uncover during winter. .MASC pointed out a risk of soil degradation and did not assess the efficiency of this weeding method.

About the hoe prototype (4):

The rotation is not complex and reassuring for farmers. The hoe is an efficient tool and farmers agreed - even if they lack some results on this technique- that it may be interesting to rotate weeding tools on cereals. Nonetheless hoe for cereals are specific. Surprisingly, the main treat is not gross margin but one should considered that investment may be under evaluated regarding to the precision of MASC indicator concerning this subject. To achieve properly this system, farmers should invest and in reality it may affect farm's viability. This rotation also presented the treats to not include enough crops diversity and cover crops. It may have negative consequence on crop sanitary quality. The hoe, implies to grow pure crop and to enlarge sowing distance therefore, it represents a risk. Hoe is reassuring but it cuts two ways. Indeed, when farmers increase sowing distance, they are exposed to a risk of weed overgrowth. If conditions do not permit intervention into field and force farmer to skipped weeding, then may encounter weeds issues.

About long perennial prototype (1):

This rotation had one of the highest contributions to sustainable development. It includes different agro ecological practices such as: leys, alternation of winter and summer crops, alternation of grain and root crops, cover crops, allelopathic crop, covering crop (intercropping) and also rotate weeding tools (see fig.8 and table.11). Even if leys were discriminatory for the C.A., one should be aware that in practice, farmers introduce it sometimes. When weeds overgrowth reaches too high level, the only solution to break down weeds cycle is a long cycle crops. It is also a building fertility crop as it permits to fixe nitrogen for the following crop. In condition of N deficiency, it must also be considered (complemented with P,K fertilisation).

About short perennial prototype (2):

The prototype came to the same tragic end as long perennial prototype. Nonetheless, it should be noticed that I evaluated this one in condition where farmers would not sale the clover (while they would sale Lucerne), it appears that it has an impact on the profitability but it is less damaging than if Lucerne is not sale. In other words, the consequence of implanting 2 years of clover is less damaging economy than 3 years of Lucerne. The effect of 2 years of clover is not proved yet, nonetheless it is assumed that it is a fertility building leys and may have a positive effect on weed cycle. Thus, if farmers face too much problems and need to introduce a leys crop, maybe they should orient their choice towards clover instead of Lucerne. The choice for Lucerne or clover depends on objective. Clover may be used regularly as weeding method while Lucerne is more depending on decision rules. The effect will not stretch as long as a regular clover to break down weeds clover nonetheless it is conceivable that 3 years of Lucerne may permit to have proper soil.

Appendix 14. Innovative crops removed from the cropping system

RAJOUTER LES PREMIERS (RETOURVER VIEILLE VERSION RAPPORT)

Even if **rapeseed** seems to be economically interesting, organic farmers hesitate to grow it. Two major problems are drawn; first, winter oilseed rape is difficult to manage without pesticides. This crop tends to be massively attack by insects Second, -point expressed by the local people- is the management of rapeseed grows again. Indeed, there is little literature about this challenge in organic farming. Research focused more on fertilization and pests' management. In Bretagne it seems that the risk to be overwhelmed with rapeseed plant all along the rotation is too important to be considered into the experimentation. The main reason is that rapeseed seeds are very small and can easily return to the soil if harvest is not done in very good conditions (without wind, FRAB, 2009). The organic farmers' union of Bretagne (FRAB) supported the hypothesis that irregular ploughing may help to manage grow again, and they emphasize that plough must be avoid right after harvest (FRAB, 2009). In addition, it was proposed to implement it with clover, it would imply a tillage intervention to destroy clover (usually ploughing) and this is contradictory with the FRAB recommendation. In addition, the efficiency of such association still have to be proved. Lupine was proposed as innovative crop interesting for farmers because it is easy to implement and manage compare to rapeseed. However, it may be complicated to valorize it either for food or feed: Lupine was proved to be allergen for humans (like it is for peanuts) and Lupine contains anti-nutritional factors for feed. Studies on animal feed and feed components had shown that it was not really appreciate by animals. Lupine can be introduced into fish and pigs feed , theoretically up to 20%

They are not references concerning other breeding animals. I must take into account that this crop can be difficult to sale.

Intercropping is not innovative nonetheless it is an essential element of the future development of organic farming. Intercropping are autonomous, rustic, covering and have a high added value (due to the protein). They can be characterized as "High value with little investment" (Pelzer et al., 2012). The gross margin of pea-wheat unfertilized intercrops is higher than for wheat sole crop (Pelzer et al., 2012). The intercropping was proved to be more profitable not only on economic but also in terms of soil nitrogen content compare to pea sole crop and energetic efficiency (Pelzer et al., 2012). Intercropping, in my case are mainly pea-triticale mixtures. It would be interesting to propose other association or proportion (cereals/leguminous) of crop that could be more efficient. I would recommend the C.A. to go deeper into experimentation on those crops. Moreover, the C.A. already planned to run experimentation on varieties, proportion, harvest date and synchronization of growth. It could be relevant to work on the proportion of each species to reach a maximum N fertility for cereals and protein production.

Appendix 15. Interesting crop sequences:

According to the recommendations we saw above concerning weeds management and fertilisation, the best system should:

- Favour stifling crops: triticale, intercropping, buckwheat, Faba bean (sown in association)
- Use allelopathy effect of crop: Buckwheat, rye.
- Rotate winter and summer crop
  - ➔ Winter crop: Intercropping, Faba bean[6], wheat, triticale, rapeseed
  - ➔ Summer crop: Maize, barley, blue lupine, buckwheat, Faba bean
- Rotate grain and root crop: Root crops were not included into prototype 6 or 3. It could be introduced through a cover crop such as radish.
- Rotate nutrient depleting – building crop
  - ➔ Nutrient building: crops able to fixe N atmospheric (leguminous crop, intercropping, leys)
- Include leys: In our case, it would be possible to include it within a strategy of under sown crop.
- Hoeing cereal. Before flowering, wheat can be hoe to control weeds on the inter-row. It allows an alternation of weeding tools. In addition, participants presented it as beneficial for the soil structure and water infiltration. It may be an efficient tool for soil quality in case of reduced tillage. Bàrberi., 2001 proposed to sow row in pairs. It could actually be interesting to manage weeds on the row. It meets the principle of stifling strategy.

[6] Faba bean must be sown with another plant such as oat (cheaper) to cover soil between the time Faba bean loose its leaves (one month before harvest) and harvest. It permits to not open soil and good conditions for weeds to grow.

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Abstract: Beyond the positive effect of organic agriculture, its recent growth led to modernization and specialization of organic farming systems. The most appropriated system for organic is mixed farms, nonetheless, crop land area increased. High price and high demand for organic cereals are pushing up conversion of cropping system to organic. However, farmers are quickly facing technical issues such as weeds management and soil fertility. Arable organic farm is limited because fertility building elements (leguminous leys) have most often no economic value. The challenge is to design innovative systems to handle organic issues in respect of farms' viability. Conception of sustainable and innovative cropping systems is most often based on expert and theoretical knowledge. Nonetheless, I assumed that some innovative techniques found there origins on farm. We will see that including farmers into the designing step provided a precious source of technical information and essentials decisions rules to success crops rotation. Importance is given to the consideration of end-users. On the basis of experts and farmers' criteria of sustainability, I evaluate 6 prototypes of cropping systems. All the prototypes co-designed were more sustainable than the national average. The selection of the most promising cropping system for on-station experimentation was more depending on the specific context and vision of sustainability than on the results provided by the evaluation tool.

Résumé: L'agriculture biologique (AB) a connu un essor mondial ces dernières années. L'effet positif sur l'environnement et les conditions sociales des agriculteurs n'est plus à démontrer. On observe cependant une tendance à la modernisation et à la spécialisation des systèmes de production. Les systèmes de type « polycultures élevage bovins » sont les plus répandus et le mieux appropriés au mode de production de l'agriculture biologique. Mais aujourd'hui les exploitations de grandes cultures biologiques se développent aussi. Les prix et la demande pour les céréales AB sont élevés poussant de plus en plus à la conversion des exploitations céréalières. Cependant les agriculteurs font vite face à des soucis techniques de gestion de la flore adventice ou de fertilité des sols. Les agriculteurs sont donc en recherche de solutions techniques innovantes pour leur système de culture. La Chambre Régionale d'Agriculture de Bretagne souhaite mettre en place un essai système en grandes cultures biologiques. Le système de culture doit répondre à des problèmes techniques sans pour autant détériorer les conditions socio-économiques des agriculteurs. En partant du postulat que de nombreuses innovations naissent chez les agriculteurs, j'ai proposé d'intégrer des agriculteurs dans la phase de co-conception des systèmes de culture. Nous verrons, qu'ils ont été la source d'informations techniques adaptées au contexte local. Sur la base des critères de durabilité définis au cours de la conception, j'ai évalué 6 prototypes de système de culture différents. Tous les systèmes co-conçus ont obtenu une note de durabilité supérieure à la moyenne nationale. Nous verrons que la sélection du plus prometteur en vue d'une mise en place en station expérimentale a été plus dépendante du contexte et de la vision de la durabilité que les résultats bruts de l'outil d'évaluation.

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