Norwegian University of Life Sciences

<table>
<tr><td colspan="2">
BIBLIOGRAPHIC NOTICE
AUTHOR: Teatske BAKKER
Promotion : 2008-2009 Thesis supervisor : Anne AVELINE, Charles FRANCIS
Report characteristics : Innovation processes and sustainability of farmers' practices in minimum tillage: a qualitative survey in Brittany; 92 pages ; 19 tables ; 20 figures ; 29 pages bibliography ; 12 appendices.
Key words : Minimum tillage, agronomy, sociology, innovation, sustainability, Brittany.
</td></tr>
<tr><td></td><td>ABSTRACT</td></tr>
<tr><td>INDICATIVE OUTLINE</td><td>Introduction
Context and background, literature study
Material and methods
Results
Discussion and limits
Conclusion</td></tr>
<tr><td>OBJECTIVES</td><td>This study aims answering the demands of the Regional Chamber of Agriculture and the SUSTAIN project: review farmers' practices in minimum tillage related to basic sustainability indicators, and highlight the innovation proces behind changes of practices in Brittany, in order to reveal farmers' expectations towards advisory services.</td></tr>
<tr><td>METHODS & TECHNIQUES</td><td>The study was based on 29 qualitative interviews with farmers.
1) the description of cropping practices allowed to build a typology of crop management sequences for winter wheat and maize, which were linked to modifications in cropping systems (on cover crops management and rotations), resulting in three agronomic coherence classes. Farmers' caracteristics in each class were described.
2) focus was put on sociological aspects by means of open-ended questions about motivations, information sources and and perception of other stakeholders of the innovation.</td></tr>
<tr><td>RESULTS</td><td>1) A difference appeared between farmers using deep tillage and the others, whereas the systemic approach of farmers with superficial tillage and no-tillage were rather similar. The type of farming system and the pedo-climatic conditions did not influence the classification, whereas socio-economic differences appeared, as well as evolutions in the perception of soils.
2) Farmers enter a learning dynamic which bring them to reconsider their conception of soils and to adapt general principles of minimum tillage to their own specific context. The key point for accompanying innovation in tillage practices is to put farmers and their knowledge in the center of the interactions with other stakeholders, namely advisors. Considering complex cropping systems requires a joint effort from farmers and advisors to make the whole cropping system evolve.</td></tr>
<tr><td>CONCLUSIONS</td><td>The diversity of crop management sequences and modifications of the cropping system reflect different stages of the learning process. However, farmers are pragmatic and are not necessarily motivated to transform their systems all the way to no-tillage due to agronomic, economic and social brakes. Group dynamics appear suitable, as they allow farmer to exchange experiences. Multiplying the approaches (group meetings, personnal advice, conferences and demonstrations) and perspectives appears relevant to reach the targetted audience</td></tr>
</table>

<table>
<tr><td colspan="2">

NOTICE BIBLIOGRAPHIQUE

AUTEUR : Teatske BAKKER
Promotion : 2008-2009 Patron de mémoire : Anne AVELINE, Charles FRANCIS
Signalement du mémoire : Processus d'innovation et durabilité des pratiques en non-labour: une enquête qualitative en Bretagne, 92 pages ; 19 tableaux ; 20 figures ;29 pages de bibliographie ; 12 annexes.
Mots-clé : Techniques Culturales Sans Labour, agronomie, sociologie, innovation, durabilité, Bretagne.

</td></tr>
<tr><td></td><td>RESUME D'AUTEUR</td></tr>
<tr><td>PLAN INDICATIF</td><td>Introduction
Contexte et situation initiale, revue bibliographique
Matériel et méthodes
Résultats
Discussion et limites
Conclusion</td></tr>
<tr><td>BUTS DE L'ETUDE</td><td>Cette étude vise à répondre à la demande de la Chambre Régionale d'Agriculture de Bretagne et du projet SUSTAIN : un aperçu des pratiques de TCSL en lien avec des indicateurs de durabilité, et la mise en évidence du processus d'innovation sous-jacent, pour comprendre les attentes des agriculteurs envers le conseil.</td></tr>
<tr><td>METHODES & TECHNIQUES</td><td>L'étude est basée sur 29 entretiens avec des agriculteurs.
1) la description des pratiques culturales a permis de construire une typologie des itinéraires techniques pour le blé et le maïs, qui a été liée aux modifications du système de culture (gestion des intercultures et rotations), résultant en trois classes de cohérence agronomique. Les caractéristiques des agriculteurs de chaque classe ont été décrites.
2) les aspects sociologiques ont été étudiés avec des questions semi-directives sur les motivations, les sources d'information et la perception des autres acteurs de l'innovation.</td></tr>
<tr><td>RESULTATS</td><td>1. Une différence est notable entre les agriculteurs en travail profond et les autres, tandis que l'approche au niveau du système de culture est assez similaire entre les classes de travail superficiel et de semis direct. Le type d'exploitation et le contexte pédo-climatique n'influencent pas la classification, tandis que des différences socio-économiques apparaissent ainsi qu'une évolution de la perception des sols.
2. Les agriculteurs entrent dans une dynamique d'apprentissage qui les amène à reconsidérer leur conception des sols et à adapter les principes généraux du non-labour à leur propre contexte. Une des clés pour accompagner l'innovation consiste à replacer l'agriculteur et son savoir au centre des interactions avec d'autres acteurs, notamment les conseillers. La prise en compte de systèmes de culture complexes requiert un effort conjoint des agriculteurs et des conseillers pour faire évoluer l'ensemble d'un système.</td></tr>
<tr><td>CONCLUSIONS</td><td>La diversité des pratiques culturales est le reflet de différents stades de ce processus mais cependant les agriculteurs sont pragmatiques et rencontrent différents freins agronomiques, économiques et sociaux. Les dynamiques de groupe apparaissent appréciées, car elles permettent l'échange d'expérience entre praticiens, mais aussi la production de nouvelles connaissances. La multiplication des approches (réunions de groupe, conseil co-construit, conférences, démonstrations) semble adaptée pour toucher le public ciblé.</td></tr>
</table>

Aknowledgements

I would like to express my gratitude to Djilali Heddadj, my research supervisor, for his availability and his patient guidance, his enthusiastic encouragements and our valuable discussions on this research work.

I thank my thesis supervisors Anne Aveline and Charles Francis for their comments and inputs on this project, from the very beginning until the final reviewing.

My thanks are also extended to Bastien Dannevoye, his help and insights on the sociological part allowed me to gather, interprete and restitute the ideas farmers expressed.

I thank Patrice Cotinet and David Meallet for the answers and coffee they provided during the internship, as well as the whole staff working at the Kerguehennec research station for their their kindness and availability. My thanks go especially to Morgane, Valentin, Antonin and Louise for our constructive exchanges and their motivation in our little office.

I also thank my parents for their support and our exchanges, their point of view as farmers and minimum tillage practioners has been very helpful.

And finally, I thank all the farmers for their warm welcome and the time they kindly dedicated to answer my questions.

Outline

List of figures

List of tables

Abbreviations

ADEME	French Environment and Energy Management Agency
AWU	Annual Working Unit
BASE	Biodiversité, Agriculture, Sol & Environnement
CA	Conservation Agriculture
CAP	Common Agricultural Policy
CMS	Crop Management Sequence
CRAB	Regional Chamber of Agriculture of Brittany
CV	Cover crop
DRAAF	Direction Régionale de l'Agriculture, de l'Alimentation et de la Forêt
EARL	Exploitation Agricole à Responsabilité Limitée (Limited liability agricultural holding)
GAEC	GroupementAgricole d'Exploitation en Commun (Collective farming grouping)
GHG	Greenhouse Gas
ha	Hectare
INRA	Institut National de la Recherche Agronomique (national institute for agricultural research)
kg	Kilogram
km	Kilometer
LHV	Lower Heating Capacity
MASC	Multi-attribute Assessment of the Sustainability of Cropping systems
Max	Maximum
MT	Minimum Tillage
Min	Minimum
NT	No-tillage
OM	Organic Matter
PhD	Philosophiae doctor
SOM	Soil Organic Matter
SUSTAIN	Soil functional biodiversity and ecosystem services, a transdisciplinary approach
TCS	Techniques Culturales Simplifiées (Simplified Cropping Practices)
TFI	Treatment Frequency Index
TMT (CV)	Technical Monitoring Time (for Cover crops)
UAA	Utilised Agricultural Area
USDA	United States Department of Agriculture
USA	United States of America
WP	Working Package
ZES	Zone d'Excédent Structural (Structural Excess Zone)

A English-French glossary of the technical terms can be found in appendix 1.

Introduction

« This tractor does two things : it turns the land and it turns us off the land »
John Steinbeck, *The grapes of wrath*, 1939.

In the years 1930, the « Dust Bowl », a severe wind erosion caused by droughts and poor crop management, played an important role in the Great Depression. John Steinbeck, in his book the *Grapes of wrath*, highlighted the links between an agricultural and environmental disaster and the economic and social consequences. Indeed, the agricultural depression forced banks to close, and thousands of farmers lost their livelihoods and property. The unemployement and massive migration resulting created major social strife in America. This example illustrates the necessity of a multi-faceted approach of agricultural activities, combining environmental, social and economic aspects.

Nowadays, driven by an increased awareness of the issues sustainable agriculture has to address and incitations received from agricultural networks, politics and citizens, farmers are proactive in the evolution of their practices and innovate by themselves. In a complex and uncertain situation, innovation is frequently defined as the abundance of new material, social and intellectual forms and will allow a permanent and unpredictable adaptation to a moving context, which is also evolving though the innovation itself. (Faure & Compagnone, 2011). Farmers' innovations lead to a large variety of systems, which are not always coherent.

In the present report, our focus is put on innovative cropping systems using minimum tillage, which encompass a wide range of ploughless crop management sequences (all based on a non-inversion of the soil, in opposition to ploughing) and associated practices in the cropping system. Moreover, the study was conducted in Brittany, in North-West France, where 26% of the farms implemented annual crops without ploughing in 2010 (Agreste Bretagne, 2012-a). As a public institution supporting farmers, the regional Agricultural Chamber is interested in getting an overview of the implemented minimum tillage techniques and a better knowledge on the innovation process undergone by farmers, in order to adapt its advisory services to innovative farmers. Moreover, in a larger context of knowledge production on minimum tillage for scientists and policy-makers, the SUSTAIN project aims at assessing the sustainability of minimum tillage, and more specifically, on socio-economic aspects.

Therefore, this study aims at giving an overview of farmers' practices in minimum tillage and link their results with basic sustainability indicators, and to gain knowledge on the innovation process and its determinants in Brittany, in order to reveal farmers' expectations towards advisory services and research.

To provide answers to the issues at stake, we will first delimit the subject by means of a literature review, detailing successively the concepts linked to innovation and sustainability, and the practices encompassed under the terms “minimum tillage” and “conservation agriculture”. Afterwards, we will detail our methodology and present our results in two parts: first we established a typology of crop management sequences for winter wheat and maize, that we linked to modifications in the cropping system in order to make a typology of minimum tillage practices, which we then described. In a second time, our focus was put on the innovation processes and the tracks for improvement of advisory services to this new conception of cropping systems. To conclude, we tried to establish links with previous studies and crossed our agronomic and sociological results.

1. Literature study

1.1. Overview of the topic: innovation, sustainability and minimum tillage

In the following part we will be detailling the matter of the present report. First, we will provide a conceptual framework to understand the need to focus on innovation in cropping systems when considering sustainable agriculture. Then, we will describe the different kinds of tillage operations which can be found in France and afterwards the techniques generally associated to Minimum Tilage (MT) and included in the denomination “Conservation Agriculture” (CA). A brief history of the development of these practices in the world and in Europe will conclude this section.

1.1.1. Conceptual framework around innovative cropping systems.

Agriculture has engaged in an evolution process in the past decades in regards of the more and more shared statement of its unsustainability. As a matter of fact, it was very successful in meeting a growing demand for food during the latter half of the 20th century, as scientific advances and technological innovations enabled a production boost. Nowadays, the techniques, innovations, practices and policies involved during that period have also undermined the basis for productivity (Gliessman, 2006). Natural resources have been degraded and agriculture in industrialised countries became dependant on non-renewable resources, namely fossil fuels, but also phosphorous.

The Brundtland comission (1987), in it report named “our common future”, defines sustainable development as a “"development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Another largely accepted definition is the one proposed by the IUCN (International Union for Conservation of Nature, 1980), stating that sustainable development takes environemental, economical and social aspects into account, which are the three cornerstones of this concept.

We can namely highlight that this last definition places the social dimension as an inevitable element and on the same level than environment and economy. As Gendron (2005) summarizes, “ecological integrity is a condition, the economy, a mean, and social and individual development, a purpose of sustainable development”.

The concept of sustainable development represents an evolution in the vision of development because it takes into account the finite nature of natural resources available in the biosphere. In addition, with the idea of irreversibility it introduces long term concerns in decisional processes which were beforehand focused on the present situation (Gendron, 2005). More specifically, sustainable development in agriculture appears crucial not only because of its unique place upstream of food systems and networks, but also because of the impact of its activities on landscapes (Craheix & al, 2012). Facing these issues, studying farmers practices at the level of the crop management sequence (CMS) in a given plot is not relevant and a larger spatial and temporal scale is required: the cropping system, the farming system and up to the territory level. Indeed, systemic approaches in agriculture consider farms as whole, taking all interrelations into account within the system and with its environment. A cropping system is thus defined by the type of crops and their succession, in addition to the CMS applied to each of the different crops (Sebillotte, 1990).

Nevertheless, sustainability is difficult to assess in practice. Since the Brundtland report in 1987, a great number of definitions of sustainability have been given, which remains a complex and contested concept (Pretty, 1995). As a complex concept, with multiple dimensions and case-specific, it is uneasy to assess and boundaries are blurred (Sadok & al, 2009). However, sustainability has become a quality criterion to describe agricultural systems and implement improvements (Meynard, 2008). Systems research imply holisitic methods and considers the three dimensions of sustainability. Economic criteria are not sufficient to assess the global sustainability of a cropping system, and therefore mixed data (quantitative and qualitative) are being used (Sadok & al, 2009).

To address the issues of sustainable agriculture, it has been acknowledged that there is not a unique pathway for improvement, but on the contrary an abundance of systems, ranging from agroforestry systems, to mixed systems with crop and livestock or aquaculture, also including conservation agriculture systems and precision agriculture. The variety of systems is adapted to the diversity of agroecological and socio-economic contexts (Pretty & al, 2010).

Emerging from the movement towards sustainable agriculture, agroecology aims at putting the concept of sustainable agriculture into practice, through the design and management of ecosystems with ecological principles. (Gliessman 1998). Sustainability in an agricultural system can be defined as the ability to produce enough food without deteriorating on the long term the conditions making this food production possible.

We can thus say that there are different ways to improve the sustainability of a system, but all require innovation. Indeed, two dynamics occur in parallel. On the one hand, the current knowledge and practices are adapted to new conditions, and on the other hand, innovation is also necessary to answer actively to existing or emerging issues (Compagnone, 2011).

Driven by an increasing awareness of the challenges for a more sustainable agriculture, and lucid about the necessity to innovate, farmers have questionned their practices, namely in crop management and tillage. Associated to the idea of integrated production (defined by Viaux, 1999), innovative cropping systems have emerged, combining existing crops and techniques with new crops and techniques (Meynard, 2008). Ploughless techniques such as minimum tillage, reduced or no-tillage and conservation agriculture belong to these innovative cropping systems, and one of the aims of our study is to get an overview of these practices as they are implemented in Brittany.

1.1.2. Definition of key words and mentioned techniques

The following description of the tillage techniques found in France is based on a reference document in this field: the report written in 2007 by Labreuche & al for the ADEME (French environmental and energy management agency), depicting the state of knowledge on environmental impacts of ploughless techniques in France.

1.1.2.1. Classification of soil tillage operations

According to ADEME (2007), three criteria can be used to qualify a soil tillage operation:

I- Depth of tillage. A tillage operation is called superficial if it does not exceed 15 cm depth, and deep if it affects the whole topsoil layer (generally between 20 and 30 cm depth).

II- Presence or absence of surface reversing: ie. an inversion and combination of soil horizons. Crop residues on the surface are buried without mixing with the soil in the tillage bottom, leaving the surface bare.

III- Degree of horizon mixing: soil horizons are combined, crop residues on the surface are more or less buried, resulting in a dilution of the elements which were initially concentrated at the surface (organic matter for instance).

From this classification, ploughing refers to a tillage operation with soil inversion and combination of soil horizons. Including ploughing into Crop Management Sequences (CMS) is motivated by the results of soil inversion on the burying of crop residues, on weeds, pests and diseases control and on soil loosening. In Europe, ploughing techniques are mainly based on mouldboard ploughs, associated with other tillage operations as it is difficult to sow directly in a ploughed soil.

In opposition to “conventional systems” defined by CMS including ploughing operations, Minimum Tillage (MT) techniques can not be defined by a peculiar CMS but include very diversified techniques. MT describes all CMS without soil inverting, and with various tillage depths. Indeed, it can be a deep tillage operation without inversion (eg. topsoiling) substituting to ploughing. Moreover, crop management sequences without deep tillage often require one or more superficial tillage operations (8 to 15cm) fulfilling the functions of stubble tillage, stale seedbed and preparation of seedbeds. Sowing with a combine drill, even without prior tillage, is also included in this category of CMS.

No tillage (NT) consists in positioning directly the seeds in a soil that has not been tilled, thus limiting the tillage only to the sowing line, at 2-3 to 10 cm depth maximum. Use of specific seeddrills (usually with discs) is required for a good seed placement, except for broadcast sowing. According to ADEME (2007), the practice of no-tillage *sensus stricto* is somewhat uncommon in France. No-tillage seeddrills are mainly used after a stubble tillage operation (superficial tillage).

In between MT and NT, strip-tillage is an American technique aiming at tilling the soil only on strips of 10 to 15cm wide, thus on a greater width than the sowing line only (strip-tillage therefore differs from no-tillage). Tillage is superficial, usually mixing soil layers without reverting. This technique is namely suitable for maize cropping (and other root crops), and allows to decrease the sensibility of the inter-row to erosion while creating favourable development conditions for the plant thanks to the tillage on the sowing row.

Table 1 summarizes the different crop management sequences found in MT techniques. In practice, a wide variety of MT practices can be observed in the fields, as a consequence there are also great differences in the level of simplification. On the one side, MT management sequences can include several passes (associating deep and shallow cultivation, all without inverting the soil). On the other side, no-tillage, also called direct drilling, avoids all tillage passes except for seeding (with specific material).

Table 1 : Soil tillage typology (from ADEME, 2007)

		Typology				
		Residues burial			Soil coverage	Tools
Practice	**French translation**	**Dilution depth (cm)**	**Inversion and/or mixing**	**Soil tillage localisation**		**Examples (categories)**
Mouldboard ploughing	Itinéraire avec labour	25 cm (15-40 cm)	Inversion and mixing	Whole surface	Total incorporation	Classic tools, stubble tillage/ ploughing/ secondary tillage/seedbed preparation/sowing
Non-inversion	Itinéraire avec pseudo-labour	15-40 cm	Mixing	Whole surface	Strong incorporation	Non-inverting tillage tool + superficial tillage tool + conventional/combined /specific sowing tool
Topsoiling	Ititnéraire avec décompactage	0-15 cm		Whole surface	Low to medium incorporation	Superficial tillage tool + topsoil cultivator + conventional/combined /specific sowing tool
Superficial tilage	Travail superficiel	0-15 cm	Mixing	Whole surface	Low to medium incorporation	Superficial tillage tool + conventional/combined /specific sowing tool
No-tillage, direct drilling	Semis direct			Sowing row	No incorporation	Specific sowing tool

The term “Reduced Tillage” (RT) is sometimes used in opposition to “No Tillage” (NT), suggesting that reduced tillage necessarily includes tillage. In our study, we used the term “Minimum Tillage” (MT) because it gathers all crop establishment methods without soil inverting and constitutes a rather neutral denomination (not conjecturing on positive technical and agronomical aspects of all these practices).

1.1.2.2. Conservation Agriculture and MT associated practices

Conservation Agriculture is a concept developed since the nineties in the USA, and which has been a harmonised definition in 2001(« First World Congress on Conservation Agriculture : a worldwide challenge », Madrid, Spain) that includes 3 principles for a complete implementation (Derpsch, 2001):

- Absence of deep soil reversal (no inverting, no ploughing) and/or crop establishment with direct drilling.
- Permanent vegetal soil cover (living or dead),
- Relevant crop rotation (variety of crops, length, but also fertility management and introduction of legumes)

In the USA, the Department of Agriculture (USDA) set in 2005 a soil coverage rate of at least 30% of the surface after sowing in order to limit water erosion of soils (NRCS, 2011).

Conservation agriculture thus goes beyond a simple change in tillage practices and takes interrelations within the cropping system into account over the whole rotation.

Strategies and choices made for the CMS and the rotation impact the management of the period between two main crops, which can be left as a bare soil (tilled or not) or sown with an intermediate crop (ADEME, 2007). The establishment of a cover crop aims at protecting the soil against surface sealing, runoff and erosion, namely in case of long periods between two main crops (for instace late sowing of a spring crop). Cover crops also provide habitats to micro- and macro-fauna (including game). Moreover, as whole Brittany is declared as “Structural Excess Zone”, its legislation obliges farmers to establish a catch crop in vulnerable conditions (Préfecture Bretagne, 2010), in order to fix nitrates and avoid their lixiviation in autumn.

Green manures, which contribute to soil fertility thanks to an organic matter supply and eventually fixing of atmospheric nitrogen in the case of legumes, are forbidden (CRAB, 2009). They nevertheless favour biological activity and soil structuration.

Second crops are harvested cover crops, and go along with the idea of double cropping. It can be a cash crop with a short cycle (for instance buckwheat) or fodder (for example Ray Grass sown after a cereal and harvested in spring before sowing maize). Fertilisation of harvested catch crops is allowed, even in the case of legumes, unlike other kinds of intermediate crops (CRAB, 2009).

Finally, undercover sowing is the combination of no-tillage sowing of the main crop and conservation of intermediate crops.

1.1.2.3. History of the development of MT practices

The development of MT techniques first took place in Northern and Southern America in answer to growing soil erosion problems (Holland, 2004 ; Lahmar, 2010). Rapid intensification of agriculture in the USA caused the “dust bowl” phenomenon, aeolian erosion of the arable layer, and had striking social impacts described in “*The grapes of Wrath*” in 1939 by Steinbeck. In the same time the eastern part of the USA had to face severe hydraulic erosion in humid area. Thus, the “soil conservation service” was created in 1935 by President Roosevelt (Robert & al, 2004). Cropping systems decreasing the number of tillage operations, sometimes to null, appeared efficient to battle erosion and its consequences. Progressively, MT techniques spread to other countries, like Australia, Brazil and Argentina also with the spread of Paraquat herbicide in the 1970's (Basch & al, 2009).

Moreover, while European farmers beneficiated of strong market price thanks to the development of market support systems with the common agricultural policy (CAP), farmers in numerous regions of South America were exposed to world market price fluctuations. They had little choice but to make MT techniques evolve and find solutions to weed control and residue management. (Basch & al, 2009). The American continent has thus been a driver for the development of MT, which have almost become the norm nowadays (for example in Brazil) and agricultural machinery manufacturers have designed a variety of specific tools and drills adapted to local contexts.

MT techniques are also being implemented in other regions of the world, for instance in Northern China to battle wind erosion and dust clouds resulting in Pekin, or against hydraulic erosion in Norway or in Czech Republic (ADEME, 2007).

Development of MT techniques in Europe and more specifically, in France, is not a new tendency. Indeed, the first trials took place at the end of the 1960's, and research at the experimental stage took place with the long duration trial in Boigneville (Arvalis, started 1989). Reduction of establishment costs is the main driver, soil erosion or degradation was not identified as a major concern by European farmers (Basch & al, 2009). However, the development is hindered by the production oriented vision of agriculture at that period, with lower yields than conventional systems. The surfaces decreased and are almost insignificant in the 1980's. The next decade sees a renewal of interest towards MT techniques as a consequence of the CAP (Common Agricultural Policy) reform in 1992, combined to an increasing awareness of environmental problems (water pollutions by pesticides, losses of silty soils, effects of land reparcelling…). Research focus shifted towards means to limit the impacts of modern agriculture on the environment (transfers of chemicals, nitrogen and phosphorous leaching…).

Drawbacks in the development of MT in France, and more generally in Europe, can thus be explained by historical reasons, in addition to less stronger economic and institutional incentives, and psychological brakes (weeding, soil structure…) (Le Garrec, 2003)

Nevertheless, the implementation of MT techniques has strongly increased in the last decade. In France, they are used throughout the territory, indistinctively of crop, soil type or region (ADEME, 2007). Research nowadays considers new perspectives on this topic, such as soil fertility management, input optimization and interrelations within the cropping systems, using more favorable soil conditions with diverse crop rotations, appropriate drills… (Basch & al, 2009)

1.2. Significance of the modifications implemented with minimum tillage

Soils are, on the same account as water and air, a fragile and non-renewable resource. Good soil quality is crucial for establishment of agricultural crops. Until recently in history of farming, arable land has been exploited using inversion tools and methods like ploughing. However, these practices have lead to extreme situations under intensive agriculture: soil structure degradation, compaction, erosion and on the long run loss of soil fertility. Holland (2004) stated that a large proportion of Europe's arable land is prone to soil degradation. The surge of interest in sustainable farming and food production in the past 30 years lead to reconsider soil management, as the latter were degraded by human activities, especially agriculture. In 2009, the IAASTD report (International Assesment of Agricultural Knowledge, Science and Technology for Development) identified conservation agriculture as a mean of action towards a more sustainable agriculture, namely in regards of climate change and soil fertility losses mitigation.

In the following section, we will first detail the mechanisms operating under MT techniques and the benefits or drawbacks resulting in a European context. We will then shift focus towards socio-economic impacts, and the attitudes of farmers towards adoption of these techniques. Finally, we will highlight challenges hindering development of MT in France.

1.2.1. Minimum tillage processes, benefits and drawbacks for European agriculture.

Reducing tillage intensity, in addition to adapted rotations and soil cover between two main crops as recommended in principles of Conservation Agriculture (CA) implements a few essential mechanisms which can have a wide range of interrelated effects on soils and at the scope of the agro-ecosystem (ADEME, 2007):

a. The essential impact of MT and CA are an improvement of the organic matter (OM) content at the soil surface, observed as a consequence of slower mineralisation and in specific cases, of a decrease in erosion. It also benefits from carbon inputs of cover crops. This localisation has various benefits ranging from soil aggregate stabilisation and surface protection against erosion and aggressions, to habitats and feed enhancing biological activity and diversity (earthworms, arthropods, gasteropods…), along with an improvement in soil functions of transformation and filtration. A mulch and OM in superficial horizons also favours adsorption of plant protection products and limits their dispersal, but can make the complete elimination more difficult and decrease the pesticide efficiency.

b. Although a tendency to decrease soil porosity can be observed, the impacts of MT on soil compaction are globally positive. Indeed, soil porosity decrease is limited and moreover mechanism of porosity creation and structural stabilisation are enhanced. Along with the presence of a mulch or cover crops, this results in an attenuation of the risks of erosion, surface sealing and water run-off. Soils are also less sensitive to severe compaction caused by machinery, except in humid conditions.

c. Modifications and increases in soil biodiversity are observed in interrelation with the two previous effects: an increase in surface OM content favours biological activity, which in turn influence the porosity. Communities are modified in the composition and structure in the whole food chain of agro-ecosystems, until birds and mammals. A rise in microbial activity results in a faster degradation of pesticides.

Originally, MT techniques were developed as an answer to erosion problems, and their efficiency as mean to fight wind or water erosion has several times been proven around the world.

In France, results show that in most cases MT is useful to battle erosion. However, the impact strongly relies on how the technique is being implemented. Indeed, soil coverage and surface organic matter are two cornerstones in reducing erosion. However, the pedo-climatic context also influences the impacts of MT, with variations between climatic years and between different kinds of soil texture.

While MT techniques have only a minor effect of transfers of nitrate to water, it appears that agronomic knowledge on soils is very important for other hydraulic transfers of pollutants. Indeed, when the risk of run-off is important, MT globally show a positive impact on total phosphorous, plant protection products and suspended solids. However, during drainage MT techniques can increase transfers of phosphorous and pesticides. Water quality preservation thus requires to pay attention and to preferably use low mobility pesticides and avoid their application during drainage periods. Furthermore, in case of run-off, a trade-off has to be found between an important soil coverage and the intensity of tillage, which can be increased for weed management for example.

An increased dependency to plant protection treatments, namely herbicides, has been pointed out in some studies (Robert & al, 2004), as weed management seems more difficult than with ploughing. However, the ADEME report (2007) concludes that reducing tillage intensity neither has significant impacts on inputs consumption (not including energy), nor on crop fertilisation (nitrogen, phosphorous, potassium).

It has also to be mentioned that a repeated deep tillage can lead to a dilution in depth of the OM, and thus invalidate many of the previously quoted benefits. More generally, most conclusions are made associating MT with adapted crop rotations and soil cover in the period in between two main crops, therefore a partial application of these principles may not lead to the same extent of benefits. In addition, impacts of MT strongly differ according to the pedo-climatic context.

Three main mechanisms are thus the source of all the environmental advantages and drawbacks described previously, which were summarized by Holland (2004) in the scheme Figure 1.

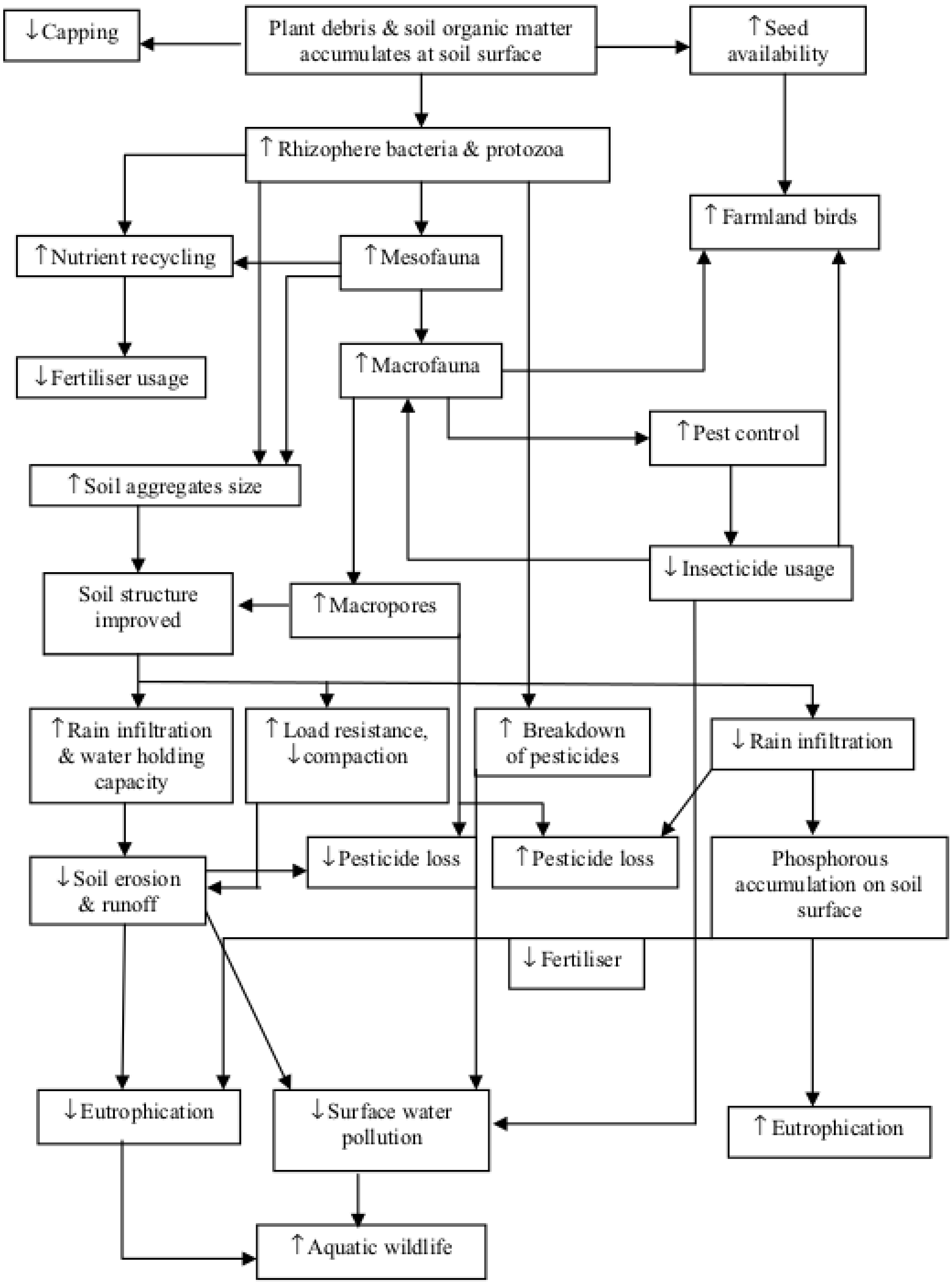


Figure 1: Interactive processes through which conservation tillage can generate environmental benefits (from Holland, 2004).

1.2.2. Agronomic and environmental results in Brittany

Located in the center of Brittany (30 km north-east of Vannes, in Morbihan) the trials in Kerguehennec are managed by the department of applied research in agronomy of the Regional Agricultural Chamber. They aim at monitoring the evolution of plots (soils and crops) conducted with three modalities of tillage : ploughing, reduced tillage (RT) and no-tillage (NT). The « agronomic » trial crosses the three tillage modalities with different fertilisation conditions (mineral, poultry manure, bovine manure (only on maize), pig slurry). A second trial focuses on water run-off (quantities, transfers of pollutants and suspended matter) comparing the three tillage modalities. Results after 8 years were compiled in a report in 2011 (PRIR, 2011).

First, concerning macrofauna (earthworms), microfauna and consequences on soil structuration, it appears that under NT, earthworm communities are densified and increased (anecic and endogeic earthworm species are especially favoured). Indeed, given their sensibility to soil properties and tillage management, earthworms can be used as indicators for soil biological quality and the suppression of ploughing is decisive to restore earthworms' communities (Piron & Cluzeau, 2009). Results of MT on soil biology are similar to those observed in other regions, and earthworms' response to MT techniques varies according to the type of practice, intervention dates and pedo-climatic conditions.

Moreover, biophysical structuration of soils after the cessation of ploughing was also observed, resulting from the mentionned densification of earthworm communities, but also from combined climatic and biological factors. Earthworms' activities also intefers with microbial activities as they modifies soil physical properties and induce the mixing of organic components. On a global scale, suppression of ploughing allowed, after 8 years of differenciation, to double microbial biomass in the surface horizon and to increase carbon content by 20 % in comparison to the initial measure. Organic products revealed a positive influence on fungal communitiess in laboratory conditions. However, a strong temporal variability appears in aggregates' structural stability.

In addition, it has been aknownledged in literature that one of the first effects of the suppression of ploughing is to induce soil compaction and thus decrease water infiltration capacity. However, on the long run, resulting from the stimulation through earthworms (tunnels and dejections), macroporosity and pores connectivity are expected to rise again and improve MT soils hydraulic connectivity. Results in Brittany show that after 8 years, despite an important earthworm activity and an increased structural stability, that macroporosity in NT remains lower than compared to ploughing.

Furthermore, no interaction between tillage and fertilisation (mineral, poultry manure, bovine manure (only on maize) and pig slurry) were observed in the trials conducted in Brittany. The fertilisation modality had a significant impact on soil mineral nitrogen content, whereas tillage modalities did not impact this indicator. Moreover, whilst the quantity of soil organic matter (SOM) stored in the surface horizon increased under MT, the overall SOM quantities stored in the soil profile did not show any evolution.

Concerning Greenhouse Gas (GHG) emissions, trials revealed that N_20 fluxes under NT are potentially more important compared to ploughing. This could be explained by a stronger soil anoxia favoured by soil compaction and increased water retention for soils in NT.

The trial in Kerguehennec also investigated the impacts of soil tillage on water run-off, transfers of pollutants and sediment. After four years, it appears that these phenomenon are rather rare, and that the impact of tillage depends on the season. Indeed, in winter water run-off is less important under ploughing than under MT modalities, and thus, transfers of herbicides and erosion (suspended matter) are also lower for ploughing than for MT. However, in spring and summer, the more important degradation of surface conditions under ploughing leads to more run-off. MT techniques are beneficial in both periods for the reduction of concentrations of suspended matter in run-off waters, compared to ploughing.

1.2.3. Socio-economic impacts and the attitude of farmers towards adoption of minimum tillage

Although decreasing operational costs and labour time seem to be farmers' main motivations to adopt MT and CA (ADEME, 2007), it appears that this topic has been less investigated than the environmental impacts of MT in the available body of literature. Nevertheless, one should bear in mind that questioning intensive soil tillage affects both general public, concerned by ecological and environmental issues, and farmers via the economic and life quality related interests (Tebrügge, 2001).

It is namely difficult to quantify the extent of MT in France and quantitative data on the socio-economic impacts of MT (potential savings in time, consumptions, etc...) is scarce and often controversial. Resulting from the long term trial in Boigneville (Arvalis) started in 1989, the fuel savings with MT techniques can range from 20 to 40%. However, if ploughless cropping patterns are not sufficiently simplified, savings are not as interesting for farmers

Determinants for adoption of minimum tillage, and more widely of conservation agriculture practices, are very variable, and little common agreements or consensus emerge from literature. As agro-ecological and socio-economic settings differ, these practices can not be promoted as a ready-to-use package, but have to be adapted to local conditions (Giller & al, 2009). However, the following section tries to summarize the main tendencies arising from European studies. Table 2 summarizes the main constraints and drawbacks evoked in literature, in a European context, about adoption of MT or CA practices which will be successively detailled.

Table 2: main constraints and drawbacks evoked in literature, in a European context, about adoption of minimum tillage or conservation agriculture practices.

Motivations	Constraints
Reducing costs and labour (ADEME, 2007)	Knowledge intensive techniques (Friedrich & Kassam, 2009)
Need to find solutions to difficulties (Friedrich & Kassam, 2009)	Widespread tradition of ploughing (Soane & al, 2012)
Awareness and concerns about soil problems (Knowler & Bradshaw, 2007)	Time consuming technical adaptation process (Lahmar, 2010)
Pioneer farmers testifying, involvement of advisors (Lahmar, 2010).	Financial brakes, especially for small-scale farms (Wandel & Smithers, 2000)
	Inapropriate structures, lack of support of agri-supply and advisory services (Friedrich & Kassam, 2009)

- **Constraints to adoption of MT and conservation agriculture:**

– MT techniques, and by extension CA, are knowledge intensive practices and contradict both farmers own experience and his agricultural education (Friedrich and Kassam, 2009). Successful adoption of these practices is influenced by the exposure to information and education level (Knowler and Bradshaw, 2007). Obviously, farmers do not want to change if they are not familiar with them and if they have not been properly presented (Lahmar, 2010). This stresses the importance of a multi-level communication, towards farmers, advisors and also the public. The understanding of the interrelations in an agricultural system and its holistic management is a complex process undergone by farmers, and therefore CA is not a ready-to-use package (Friedrich and Kassam, 2009). It requires involvement of all the stakeholders, farmers, researchers and extension agents to adapt the principles to specific contexts (Giller & al, 2009).

- Soane & al (2012) stated that in developed countries reducing tillage can be difficult because of the importance of ploughing, which is widely practiced and traditional. It can also become a social issue because the image the new practice gives to others (neighbours for example) is sometimes uneasy to admit (Friedrich and Kassam, 2009). A change in cropping practices seems to have more chance to succeed when there is an awareness of all farmers of a region, support from technical advisors and communication about the subject (Lahmar & al, 2010).
- Although interesting results (cf. 1.1.2.3.) are described worldwide, practices have to be well-adapted to local conditions to minimize technical and agronomic problems, and this process takes time. Weed management, crop residues management and soil compaction can become problematic during the transition period (Lahmar, 2010, Friedrich and Kassam, 2009).
- From a financial point of view, although theoretically profitability of the farm is not affected, and even improved, by a shift in tillage practices, capital is needed for investments (namely in specific machinery). As an evidence, one can observe the size of farms reducing tillage: big farms are more prone to adopt MT, as they might have a better investment capacity and ability to absorb the risk of change (Wandel & Smithers, 2000). Long term labour and costs savings are other evoked reasons, linked to intensification in capital (Lahmar, 2010). Soane & al (2012) described European farmers as Cartesians, switching to CA only for the immediate benefits it can bring, and hindered by the high cost of the first investment. Moreover, shifting tillage practices can appear challenging because it implies to find a new equilibrium and eventually to support large investments. However, investments are not a *sine qua non* condition for successful shift towards MT, and the Agricultural Chambers in Brittany for instance recommend to start with machinery available on the farms (D. Heddadj, personal communication).
- A last brake to evolution of cropping practices can lie in inappropriate infrastructures. As a matter of fact, MT represents a turning point for farmers, but also for the agri-supply sector. Indeed, it can seem uneasy because both stakeholders are waiting for the other to undergo the process of change in practices. Appropriate products, equipments of advisory services have long been lacking in farmers' opinion. As an example, equipments for direct seeding remain very expensive in Europe because they often have to be imported.

Machinery manufacturers were not willing to enter this market as long as it MT techniques were not widespread. The low availability of certain inputs and technologies required hinders the adoption (Friedrich & Kassam, 2009, Basch & al 2009).

- **Motivations to shift towards MT and conservation agriculture :**

- In France, farmers first evoked reason to decrease tillage intensity are socio-economic: MT decreases machinery costs (fuel, equipment wear) and saves labour time (ADEME, 2007). This can also be verified nowadays in a global context of soaring prices of agricultural inputs. Moreover, farmers facing difficulties are likely to be more open to change and willing to find new solutions (Friedrich & Kassam 2009). However, this motivation can be double-edged, because the possibility that farmers only take the opportunity of short term benefits (cost reductions, labour savings) and revert back to ploughing if the economical situation gets better is not excluded (Kessler, 2006).

- Awareness and concerns about soil problems are a significant driver for adoption of soil conservation practices (Knowler & Bradshaw, 2007). Farmers also search for more resilient farming systems as an increase in drought occurrence is expected in Southern Europe, while in Northern Europe wetter soils in autumn are forecast : both situations encourage farmers to reduce tillage so as to maintain yield stability (Soane & al, 2012).

However, environmental concerns on their own rarely appear as decisive drivers for European farmers changing their tillage practices. Lahmar (2010) stated that farmers having experienced important problems on the farm are more likely to adopt conservation agriculture practices. Economic and organizational benefits are playing a more important role in their decision.

- Pioneer farmers and acknowledged neighbours also trigger adoption of new tillage practices, as well as the involvement of advisors. The organisation of events and demonstrations seems to be efficient to spread new practices (Lahmar, 2010).

SUMMING UP

Originally developped to battle wind and water erosion in Northern and Southern America, MT techniques also enter in a sustainable approach of farming. Indeed, they enhance biological mechanisms in soils (surface organic matter, porosity, biodiversity) which have beneficial environemental impacts (water quality, soil compaction). In addition, the techniques allow farmers to save time and decrease some of their operational costs. However, the impacts are strongly dependent on the context in which they are implemented and scientific controversies are still ongoing. There are also a few drawbacks to consider, for example in case of drainage. While savings on time and operational costs are farmers main motivation to stop ploughing, several constraints to farmers' adoption of conservation tillage have also been identified in litterature.

1.3. Background situation in Brittany

The next section is meant to give an overview of the agricultural context in Brittany, through a presentation of its main pedo-climatic features and a review on the importance of agriculture, that shapes its economy but also the territory. In a second part our focus will be restrained to the development of MT techniques in Brittany, detailing successively the expansion of the technique in the region, and the state of the current knowledge on farmers' practices and socio-economic characteristics.

1.3.1. Agriculture in Brittany

The general overview of Brittany is shown in Figure 2: in the western part lies the Finistère, the centre is divided between Côtes d'Armor and Morbihan, and Ille-et-Vilaine is the most eastern "département". The Rennes basin is a rather homogenous area around Rennes.

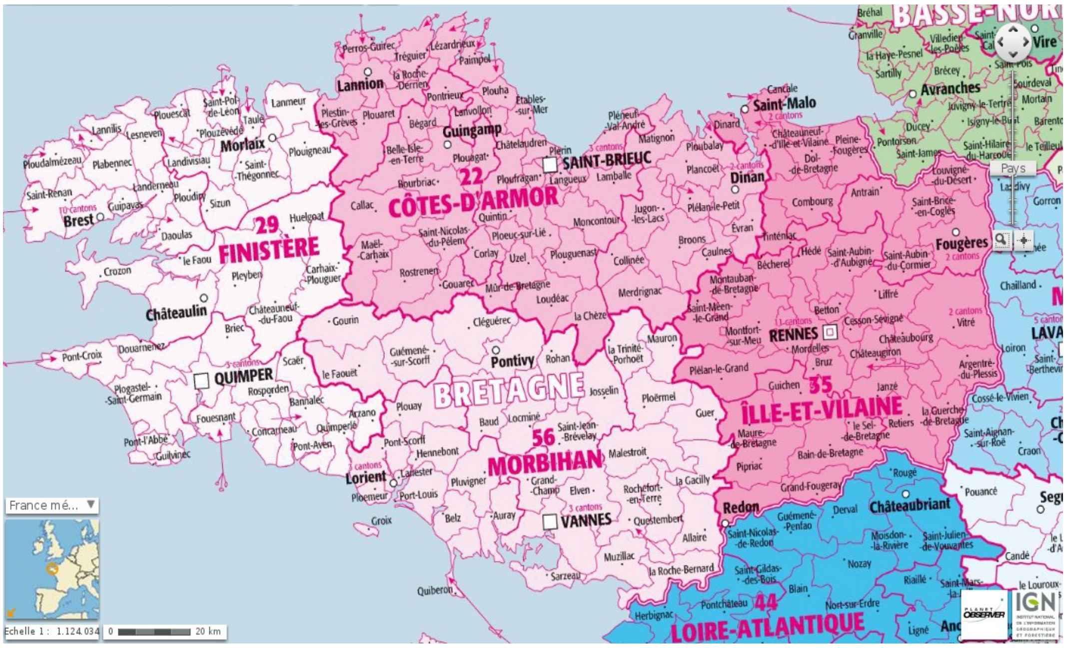


Figure 2: General overview of the territory in Brittany (Geoportail)

1.3.1.1. Pedo-climatic context

Brittany is an ancient and eroded mountain range (Amorican massif) and its subsoil is made of granites and schists. Lermercier (2010) highlighted that soils are mainly silty (from wind inputs and from bedrock alteration) and acidic (due to the high silica content in the rocks and the oceanic climate) throughout the territory. Nevertheless this apparent homogeneity conceals a remarkable diversity of soils which results from interactions with climatic conditions and landscape elements such as topographic and hydrologic factors and humans activities.

Diaz & Gachet (2002) identified four large-scale categories of soil, among which deep silt soils (1 to 2 m) are the most frequent. Rather sensible to surface sealing (low clay content), this type of soil is present in the North of Brittany and in the Rennes basin. In the centre part of Brittany, very clayey soils on schists can be found but they are quite rare, just like brown soils on granites, mainly composed of permeable sands. Soils in the Southern part of Brittany are rather shallow and rich in organic matter.

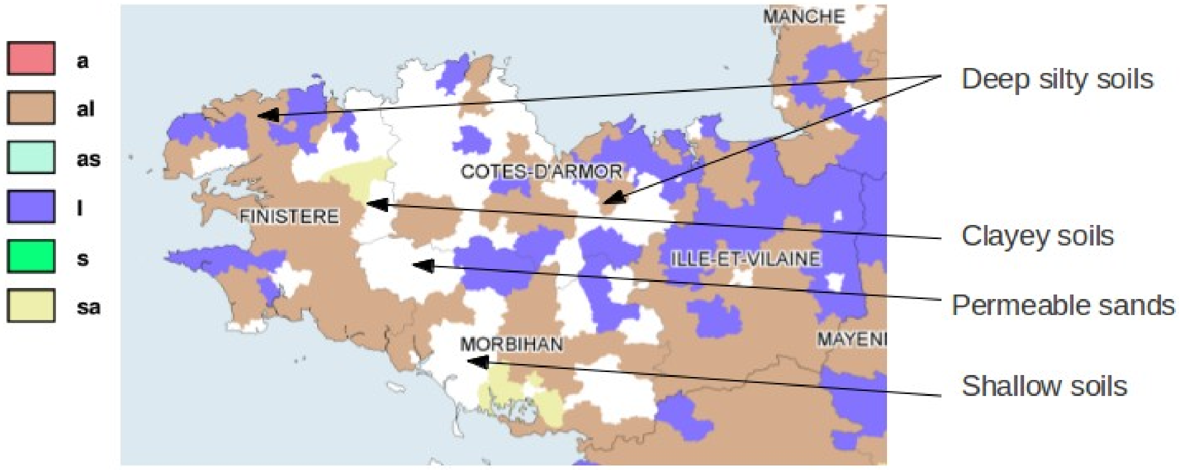


Figure 3: Simplified map of the soil type in Brittany, with highlight on the four main soil type zones. [legend: a: clay; al: silt and clay; as: clayey sands; l: silt: s: sands, sa: sandy clay] (Diaz & Gachet, 2002)

The four soil main four types are shown in Figure 3 and we can thus observe that silty soils predominate, and that there a gradient in organic matter from East (2% in the Rennes basin) to West (7-8% in Finistère).

Silty soils present a low structural stability: the impact of raindrops can lead to the formation of a structural crust. In the Rennes basin for example, soils are silty and poor in organic matter, and are therefore very sensible to surface sealing when intense rains occur. They are also more susceptible to runoff as the hydraulic conductivity decreases. On the other hand, soils of the Western part, developed on granites, more sandy and rich in organic matter, present less risks.

Globally, the climate in Brittany is oceanic and temperate. Rainfalls are frequent but not very abundant. The average sunshine period is depending on the distance from the sea and the latitude. Temperature variations (diurnal and seasonnal) are evened out through the currents and oceanic winds. Detailled maps on climatic indicators (annual total rainfalls and temperatures, number of frost days) troughout the territory can be found in appendix 2.

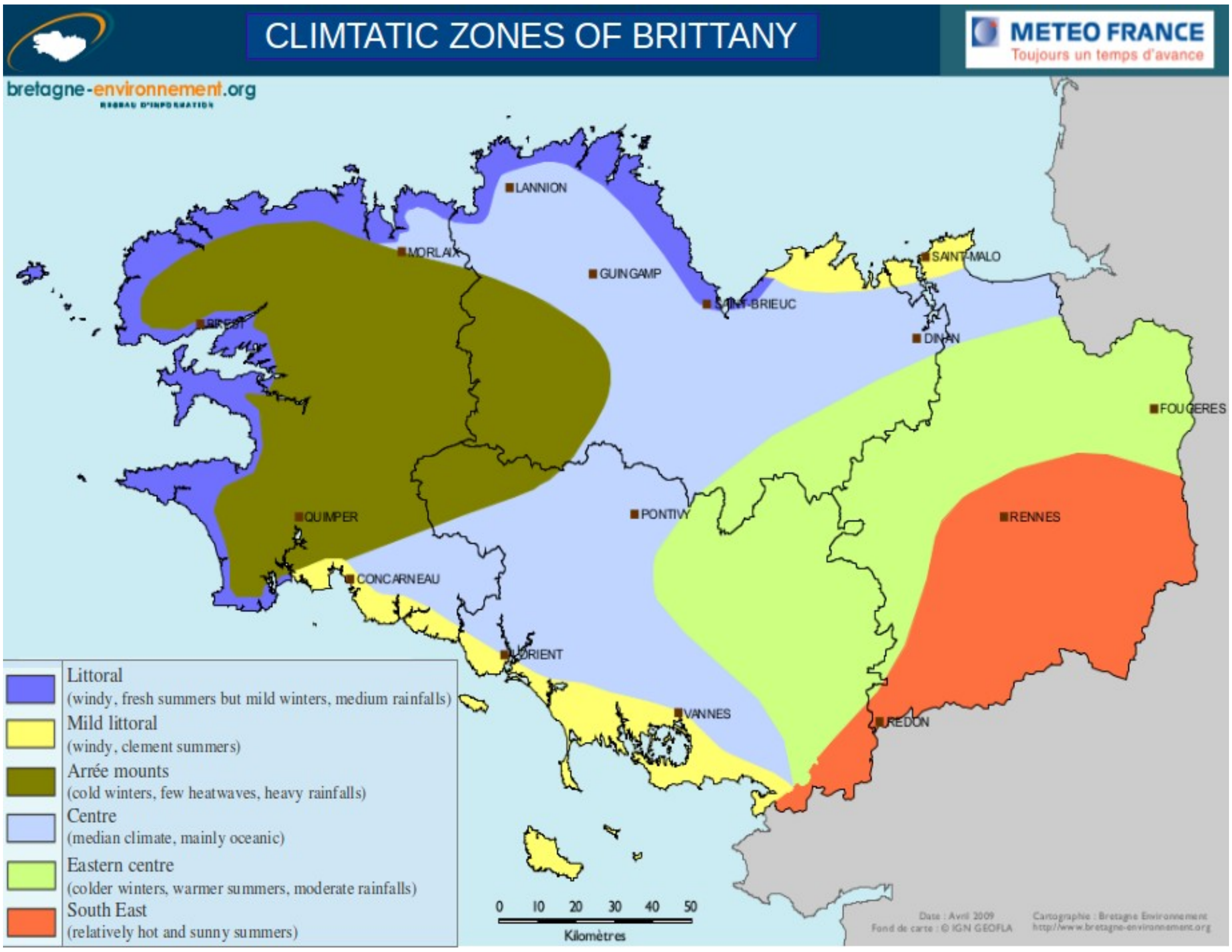


Figure 4: Map of the six climatic zones observed in Brittany (GIP Bretagne Environnement).

On an infra-regional scale, six climatic areas can be distinguished based on the pluviometry, the seasonal temperature evolutions, the sunshine period and the wind frequency, as shown in Figure 4. We can namely observe pronounced differences between the Eastern and the Western parts of Brittany: coastal areas are favoured, with milder winter and sunnier summers, compared to the inland. Hilly areas receive more rainfalls. Different micro-climates have important consequences in agriculture (for example on sowing dates). The strong and frequent winds from oceanic origin (oriented West/SouthWest) also influence the vegetation (GIP Bretagne Environnement, 2010).

1.3.1.2. Agriculture in Brittany (CRAB, 2012-a)

Historically, farming played an important role in Brittany. Nowadays, it is still prominent, as Brittany is the first agricultural region of France and produces 12% of the standard gross production. This activity occupies 60% of the territory and employs directly 58200 persons (whole-time equivalents) in 34500 farms. It is also an important region for food industries, which employed 56375 persons in 2012.

Animal productions are predominant and concerns mainly dairy, pork and poultry productions. Brittany is in addition the first French region for vegetable production.

Field crops are partly dedicated to animal production, but also sold on various markets. 619 000ha were dedicated to major crops (cereals, peas, oilseed) in 2011, among which 92% of cereals.

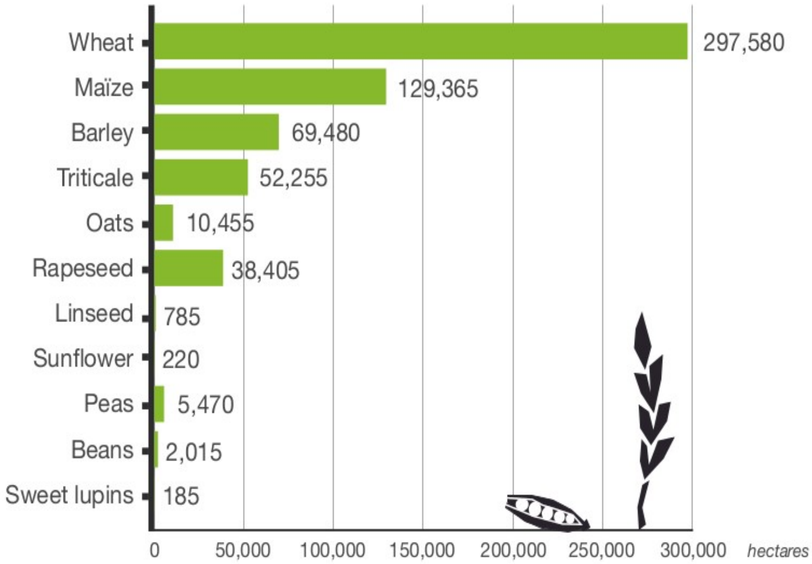


Figure 5: Surfaces covered by the main crops grown in Brittany in 2011 (CRAB, 2012-b).

As we can see on figure 5, winter wheat and silage maize are the main crops, followed by barley (spring and winter), whereas other cereals (triticale, oats) are marginal. Rapeseed is the main oleaginous and covered 38400ha in 2011, the half of which was dedicated to diester production. Protein crops have been declining, due to numerous technical constraints, and represented 7671ha in 2011, mainly peas.

However, the face of Brittany’s agriculture has changed a lot in the last decades. Indeed, the number of farms decreased for a third between 2000 and 2010, and in this same time period profound modifications in work organisation occurred: legal structures in the form of companies expanded and professionalization of farms increased. One farm out of ten is bigger than 100ha, and these farms represent 31% of the Utilised Agricultural Area (UAA). The average farm size is however below the national average area (48ha in Brittany, versus 58ha for France). Farms growing less than 50ha represent more than 40% of the farmers.

Brittany also faces issues linked to its farming activities that impact the whole territory and its population. As it is a region with a lot of intensive animal breeding, a problematic situation has emerged since 1970 from the management of animal manure, namely regarding nitrates and phosphorus. Erosion and water runoff also concern a large part of the territory, due to the nature of the soils and the climate (GIP Bretagne Environnement, 2010). The first actions started in nineties and continue nowadays, for instance bringing livestock buildings up to environmental standard, or promoting of bocage and hedgerows (CRAB, 2009). The fourth Action Program, started in 2009, makes soil cover mandatory during winter to limit the risks of nitrogen leaching, by means of winter crops, second crop or with catch crops. In addition, the destruction of cover-crops should be mecanical (through tillage operations) except for vegetables and for farmers using MT techniques. This measure is meant to limit the use of total herbicides (Préfecture Bretagne, 2010).

Figure 6 displays a map with the Structural Excess Zones (ZES), which are areas where total produced nitrogen by livestock exceeds 170kg per spreadable hectare and per year.

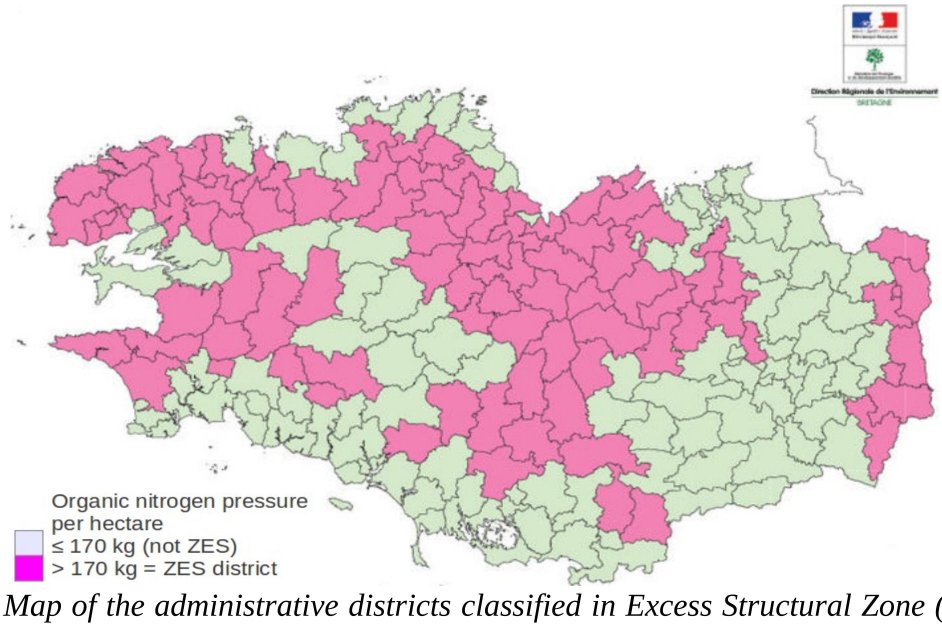


Figure 6: Map of the administrative districts classified in Excess Structural Zone (ZES) in 2009 (Préfecture Bretagne, 2010)

1.3.2. Minimum tillage in Brittany

1.3.2.1. Development of MT techniques in Brittany

In Brittany MT techniques have been expanding strongly in the past years and the proportion of the area of the main crops (winter wheat, barley, maize) sown under MT or NT reached 21% in 2006 (Heddadj, 2008) and 24% in 2010 (M. Filippi, personnal communication). Figures from the 2010 Agreste survey have not been publicised yet, however the percentage of farms sowing annual crops without ploughing reached 26% in 2010 (Agreste Bretagne 2010-a), which is slightly above the national average (24% of farms). Figure 7 shows the evolution of the surfaces in France and in Brittany and illustrates the scope of MT development in the last decade. It has also to be mentioned that in regions specialised in grain production, the proportion of farms implementing MT techniques can reach 40% in 2010.

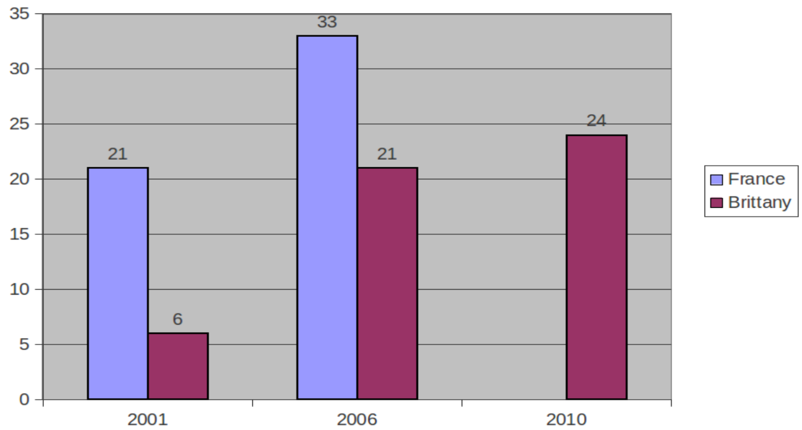


Figure 7: Areas grown without ploughing in Brittany and in France in 2001, 2006 and 2010 (Heddadj, 2008; M. Filippi, personal communication).

The implementation of simplified tillage often goes along with evolutions in the crop rotations and cover crop management. In Brittany, only 6% of the annual crops were conducted in monocropping for the last 3 years, covering 52800ha. Furthermore, 83% of the surfaces implemented with spring crops (namely maize, which accounts for 30% of the utilised agricultural area (UAA) in Brittany) had a cover crop established in winter, whereas in 2000, only 26% of the surfaces with spring crops were covered in winter. This figures includes cover crops (implemented on 58% of the farms), second crops (on 24% of the farms) and crop residues. Considering that in Brittany spring crops account for 30% of the UAA, the total soil cover ratio on agricultural land reached 96% (Agreste Bretagne 2010-a).

Various factors can explain this expansion. Since 2000, several programs have focused on the recovery of good water quality, namely at the watershed scale. Actions have been undertaken namely about soil cover in winter to limit nitrogen leaching, with the obligation, since 2009, to establish a cover crop on bare soils in winter (Préfecture Bretagne, 2010). Some farmers have then noticed the beneficial effects on these plants on soil structure and investigated this technique (Corbel, 2009). In parallel, farmers have become more and more aware of the environmental issues.

1.3.2.2. State of knowledge about the MT practices implemented in Brittany

To gain understanding on MT practices in Brittany, one can rely on the study carried out by Perche & al (2009), on a sample of 107 farms throughout the territory using a closed-ended and multiple choice questions, and data from this study was also analysed by Munin (2009). Another source of information comes from Agreste (Ministry of agriculture, food industries and forestry) which carries out every 5 years an inventory of agricultural practices on 5 main crops in Brittany. Moreover, two student reports were carried out in Brittany: Quenea (2006) made a technical and environemental analysis of farmers practices in a network of 18 farms comparing ploughing and MT. Corbel (2009) carried out a case study on 30 farms in the Leff watershed (Côtes d'Armor) mainly using MT techniques.

First, Agreste confirms that the occasional use of MT is predominant in Brittany, as ADEME (2007) stated at the national level. In the study of Perche & al, 45% of the surveyed farmers have completely stopped to plough all their areas in wheat and maize. This study also revealed similarities between wheat and maize in the use of MT techniques: the proportions of farmers that keep ploughing, use alternatively ploughing and MT, or use only MT techniques are relatively close.

The main result we can retain from the previous studies in Brittany is that there is a large diversity of crop management sequences. Quenea (2006) showed that the use of a topsoil cultivator is very widespread for maize establishment. Munin (2009), using data from the study of Perche & al, calculated that 19% of the farmers do topsoiling every year, and 20% every 2 or 3 year.

This variability is also linked to the diversity in machinery used. Perche & al stated that 66% of the MT farmers did not have a specific MT drill, and that 99% of the farmers with less than 5 years of experience in MT are using classic sowing tools.

Knowledge on rotations and cover crops is more scarce. Quenea (2006) demonstrated that white mustard and phacelia were the most widespread species used as cover crop. In the study of Corbel (2008) it appears that rotations are mainly organised around wheat and maize, the two major crops in Brittany.

The Agreste study (Agreste Bretagne 2010-a) identified a few constraints to implementation of MT in Brittany. As a matter of fact, several days of dry weather are required before sowing and this fact could mean that the climate in Brittany is less adapted to MT than in other French regions. Moreover, whereas in regions specialized in cereal and crop productions, the percentage of crops sown without tillage can reach 40%, the high proportion of grasslands in Brittany could explain a lower prevalence of MT. According to Agreste, grasslands cover 40% of the UAA in Brittany and the fields are smaller than in other regions specialized in grain production. This could also explain that farmers in Brittany are more reluctant to buy specific machinery because they have fewer crops concerned by this investment. Munin (2009) also stated that if MT techniques are proven to be a mean to save working time, technical limits appear against extreme simplification in the pedo-climatic context of Brittany, with mainly silty soils and a mild and humid climate. These limits require to adapt tillage case-specifically, be it deep tillage (decompaction) or superficial (stubble tillage, residue management).

However, in the study conducted by Perche & al (2009), 20% of the farmers said that they had not encountered specific problems since they started using MT techniques. For the other surveyed persons, the main problems mentioned are difficulties in weed management (39%), followed by crop damages due to pests (26%). Farmers also evoke cereal contamination by mycotoxins (12%), technical sowing problems (11%) or poor soil warming in spring (7%).

Farmers pointed out numerous issues to solve and make MT techniques evolve. Among them, the use of total herbicides was quoted by 38%, followed by improvements concerning stubble tillage, weeding strategies and use of slug poison.

1.3.2.3. State of knowledge about the socio-economic determinants in Brittany

A survey was conducted in 2007 on farms crop management sequences for autumn cereals after maize and maize establishment after a cereal in order to estimate (according to farmer’s declaration) the labour time (excluding transportation times and manure spreading times) (Munin, 2009). It illustrated a large variability in the total labour time spend per hectare, which can be linked to the wide range of practices implemented, but globally in favour of MT techniques. Indeed, for wheat a difference reaching 1h/ha was observed, and the establishment time was in average 1h40/ha (versus 2h10/ha in average for establishment with ploughing). For maize establishment in spring, the average time reached 3h20/ha using MT techniques (4h/ha with ploughing) and the total crop management time differed of 2h/ha between both modalities. Establishment time appeared to decrease even more with the use of specific tools and drills.

Another study took place so as to compare mechanisation costs of two homogenous groups (UAA > 60ha with 80% of UAA cropped, and UAA > 60ha with 60-80% UAA cropped) between ploughing and MT (Castel, 2009). Although there was a wide dispersion, global mechanisation costs appeared very close between ploughing and MT, because savings with MT techniques are mainly done during crop establishment, which represents only one quarter of the total mechanisation costs. Moreover deep non-inversion tillage brings little savings. Mechanisation costs ranged from 900€/ha to 300€/ha, the lowest figures were generally achieved by farmers using superficial or no-tillage, showing that MT techniques are compatible with low costs.

Furthermore, we know so far that big farms are more prone to adopt conservation tillage (Agreste 2010-b). The 107 farms in the study of Perche & al (2009) displayed a higher average AWU (98ha) than the regional average (56ha). Munin (2009) also noted a tendency to speed up time savings, linked to an evolution of the UAA/AWU ratio: it increased from 13 ha/AWU in the 90’s to 23ha/AWU in 2000, and was estimated at 27 ha/AWU in 2007. Farmers have less and less time available per hectare for the field work. Therefore, they also implement other tools to decrease working time per hectare: delegation, plot organisation, combined sowing tool, tool width…

More information of the profile of farms converting to MT can be found in the study of Perche: societies as legal structure are more frequent (81% in that study versus 53% in average in Brittany) and the sample of this study also appeared rather young: 51% of the surveyed persons were between 35 and 45 years old (versus 32% in Brittany).

Concerning farmers motivations to adopt MT techniques, Corbel (2009) revealed that a reorganisation of farmers' working time was the main reason to adopt MT, linked to a decrease in available labour and an increase in the size of farms.

Globally, farmers were satisfied about their conversion to MT techniques. In the study of Perche & al (2009), the main positive criteria evoked (by more than 75% of the farmers) were global working time, fuel consumptions, soil quality and mechanisation costs. Only 5% of the 107 farmers backtracked about their MT techniques. It is also interesting to note that 60% of farmers did not observe an evolution of their crop gross margin.

It appears from this overview of the available data that most knowledge on MT techniques implementation in Brittany comes from quantitative studies, and therefore not able to detail precisely the argument farmers develop in order to adapt their cropping system to their new practices. Moreover, qualitative studies have been carried out but they restrained to a limited area such as a watershed in the case of Corbel's study. Information on farmers practices, linked to the soil types and farming types at the scale of Brittany is thus lacking, as well as description of farmers' rotations and cover crops.

SUMMING UP

The territory in Brittany is profoundly impacted by farming activities, the latter also employ a consequent portion of the population, directly or indirectly (namely food industries). Because of its pedo-climatic caracteristics and the orientations of its agriculture, Brittany is susceptible to soil degradation problems, runoff and pollutant transfer.

Knowledge on the surfaces concerned in Brittany is rather scarce, however a development of MT techniques has been observed in the last years. It has been shown that there is a large variety of practices. Adoption might be dificult given the specificities of the climate in Brittany.

Concerning socio-economic determinants, savings on labour as well as on operating costs appear the main drivers. In some specific regions, it has also been demonstrated that farmers adopt MT in order to solve specific soil problems.

1.4. Demand addressed

In the following section, we will briefly present the stakeholders involved in this study, the research team of the Sustain project and the Regional Agricultural Chamber of Brittany (CRAB) and the reflection at the origine of this study. We will then rephrase the issues at stake and decline the hypotheses and associated research questions.

1.4.1. Snowman network and Sustain project

The SNOWMAN Network is a European group of research funding organizations and administrations in the field of Soil and Groundwater. Whereas soil protection is a thematic strategy of the EU, insufficient awareness, and thus lacking knowledge and efficiency of research activities was observed on soil and groundwater topics. Aiming at connecting policies and research to societal developments linked to soils, Snowman partners defined multi-sectoral and multi-disciplinary approaches in order to develop and share relevant knowledge for the sustainable use of soil and groundwater. A wide variety of topics is covered, ranging from knowledge on ongoing processes in soils (soil functions, interactions with hydrological systems) to the assessment of the impacts of various threats (contaminations, climate change) or beneficial mechanisms (biodiversity, soil fertility) to sustainable agriculture, including socio-economic aspects (Snowman Network, 2013).

The SUSTAIN project (Soil functional biodiversity and ecosystem services, a transdisciplinary approach) fits into the 3rd call for research of Snowman. Initiated in October 2011, its purpose is to provide knowledge and answers 1) on functional soil biodiversity and the integration of soil ecosystemic services in decision making, and 2) on the impacts on soil quality of agricultural and forest practices, and the role of soil in processes of mitigation and adaptation to climate change taking place in European agricultural and forestry sectors. More specifically, Sustain aim at understanding the impact of reduced tillage practices on essential soil functions and its biodiversity, as well as quantifying the consequences of MT systems in terms of soil ecosystemic services for food production and GHG mitigation. Moreover, research teams will investigate the socio-economic sustainability of MT systems. On a global scale, developing and disseminating tools such as soil disturbance indicators or system sustainability evaluation. Research is conducted as a partnership between France (Rennes 1 University, INRA (French agronomic research institute), and Regional Agricultural Chamber of Brittany*)* and the Netherlands (Wageningen University) (Sustain, 2011).

Among the seven working packages (WP) composing the Sustain project and detailled in Figure 8, the present study belongs to WP 5, the economic and sociologic assessment.

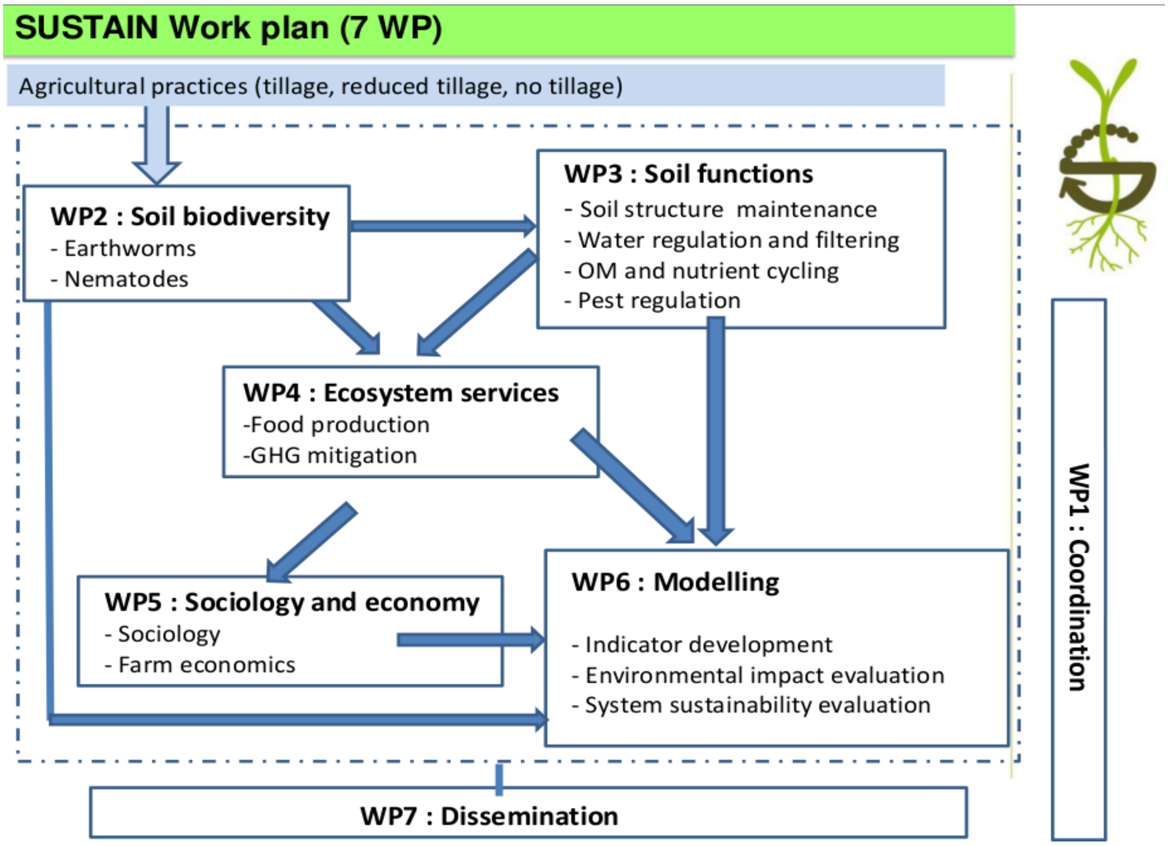


Figure 8: Organisational scheme of the 7 Working Packages (WP) of the Sustain Project (Sustain, 2011).

This task aims at analysing the innovation processes undertaken by farmers modifying their agricultural systems. Therefore, the study focus is put on closely linked components: farmers practices, their networks and information sources, their learning dynamics and their perception of MT practices (working conditions, relations to society, identity). In order to understand farmers evolutions when they change their practices, WP5 thus implements an integrated approach that combines agronomy, meaning the description and assessment of the technical choices, with social sciences, understood as the human dimensions linked to these changes. The economic performance of the studied farms is also targetted. The multi-faceted study designed to answer WP5 is entirely detailled in the methodology section (page 34).

1.4.2. Regional Agricultural Chamber of Brittany (CRAB)

In France, Agricultural Chambers are public institutions created in 1924, and aim at representing all economic stakeholders involved in agriculture (farmers, landowners, employees, agricultural organisations such as cooperatives, unions, syndicates) and help farmers in the development of their activity. Departmental agricultural chambers (94 in total) had an important educative role in the development of modern agriculture after the Second World War. Nowadays, they still accompany evolutions of agriculture and its related sectors, and have broadened their expertise to topics linked to environment, rural and territorial development and since 2010, forestry. Representatives of the departmental chambers are elected every 6 years among all categories of agricultural stakeholders, and will internally constitute the head of the regional agricultural chambers. Regional Chambers play a role coordination and planning of the agricultural development at the regional scale, make the link between departmental chambers, and interact with state institutions, for instance the prefecture.

In Brittany, 180 elected representatives and 650 technicians and engineers work in the AgriculturalChambers, and are the link between farmers, communities and society. Six priorities have been identified for Brittany: ensure farmers competitiveness, adapt the sectors to their markets, guarantee renewal of labour force, promote an ecologically intensive agriculture and preserve agricultural real estate. A considerable impact on this global strategy comes from the progressive withdrawal of the French state, resulting in the delegation of new assignments to the Agricultural Chambers (CRAB, 2013).

Besides its activity of advisory and supporting activities, the CRAB also runs an applied research organ, divided into three departments: agronomy, herbivorous and pigs and poultry. Indeed, one of the assignments of the Agricultural Chambers is to produce technical references in order to guide farmers and communicate to general public and policy makers.

The department of applied research in agronomy is composed of a specific research team and an organisation in the field, by means of three experimental stations and a network of stakeholders all over the territory. Concerning MT, it has identified a number of questions and constraints arising from the diversity of situations and the innovative nature of these practices. Therefore, trials are carried out since 2000 at the experimental station in Kerguehennec (Morbihan) in order to compare three tillage modalities (ploughing, reduced tillage, no-tillage) about soil structure and crop development and water run-off and transfers of substances (Heddadj, 2008). Moreover, the departement is a partner of the SUSTAIN project and is associated to the different working packages (WP) described previously. The aim is to gain knowledge on sustainability of MT systems at a larger scale (namely by means of cooperation between research teams in the Netherlands and in France) and help to develop sustainability assesment tools.

In addition to their role of production of local references in the experimental stations, the department of applied research in agronomy became aware of the necessity to adapt the advisory services they offer to farmers using MT practices. Therefore, they expressed the need to gain knowledge on farmer's profiles and crop management practices, and expect from the present study recommendations for a better support of innovative farmers interested in soil conservation practices.

1.4.3. Problem, hypotheses and research questions

As detailed in the literature study, MT could potentially answer to many questions for a sustainable future agriculture, as they were identified by Pretty & al, 2010, especially regarding water resources, soil nutrition and erosion, biodiversity and ecosystemic services. Farming and food systems have engaged in an evolution process in the past decades and a wide range of innovations and adaptations have emerged worldwide, based on innovation processes.

Among them, MT techniques are based on a decreased tillage intensity, in answer to problematic situations created by ploughing (erosion, loss of soil fertility...). Several environmental benefits of the techniques are reported, however one needs to consider a few drawbacks, controversies and above all lacking knowledge in various fields, linked to the very context-dependent results. Moreover, concerning farmers adoption of MT techniques, socio-economic motivations are the most common, but several constraints might hinder the switch of technique.

From the American continent, this innovation spread to France and in 2010, 26% of the farms in Brittany established all or part of their crops without ploughing. Noticing this growing interest for MT, the Agricultural Chamber wishes to accompany farmers through the process of changing tillage practices. Therefore, there is a need to get an overview of the profile of these farmers and to gain knowledge on the practices they implement and their determinants.

Moreover, the Sustain project aims at producing knowledge about MT techniques and raise awareness among scientists, politics, farmers and general public on the necessity to consider soils. The aim of WP5 is to understand farmer's evolution accompanying their innovation process and get a multifaceted overview by means of an integrated approach combining both agronomic and social approaches.

Thus, considering the specificities of MT systems and of the context in Brittany, we are trying to determine what evolutions can be observed in the sustainability of farming systems when a change of tillage practices towards MT techniques occurs. We will also investigate if the characterisation of various involvement levels in this innovation highlights a two-speed evolution of farmers' visions and systems' sustainability. Finally, the report aims at assessing the extent of the impacts of the revealed innovation processes on strategies of advisory services and consequently, providing lines of thought to adapt and improve advisors' approach of innovative farmers. In order to answer these questions and meet the issues at stake, we established hypothesis based on our literature study and matching research questions in the following table.

Table 3: Hypotheses and research questions.

Hypothesis	Research question
The diversity of crop management practices in MT is not linked to the diversity of pedo-climatic contexts and farming types.	Can we establish a typology of crop management practices? Can it be linked to the pedo-climatic context? To the type of farm?
Conversion to MT rather reflects a systemic vision of the farmer than simply a shift in tillage tools.	Does a conversion to MT systematically modify the cropping system and the farming system? Can we establish a typology of cropping systems in MT?
There is a difference between the motivation of experimented farmers in MT and those who adopted these techniques recently.	What are farmer's motivations to start using MT techniques? Can we observe an evolution?
Conversion to MT is linked to the social network of the farmer	What is the importance given by farmers to the different socio-technical networks? What are farmers' information sources? Do they express expectations?
Economic, social and environmental impacts of MT differ according to the degree of tillage simplification.	What are the results of basic economic, social and environmental indicators ?

2. Material and methods

2.1. General process

As detailled in the previous section, the aim of the present study is to grasp the global scope of innovation processes carried out by farmers on their change towards minimum tillage practices through a study of different closely linked components: technical changes, relationships and information networks, learning dynamics, representation and identity of farmers.

The reflection for the conception of the present study takes its roots in a network of 11 coupled farms (ploughing / RT) used in 2006 to compare these two tillage intensities (Quenea, 2006). However, as the SUSTAIN project aims at taking the diversity of pedoclimatic situations and farming types of Brittany into account, it requires to scale up from plot to farm level, including its direct surroundings and farmers' networks. Coupling ploughing and MT farms then appeared less relevant, so it was decided to scale the sample size up to 30 farms.

In 2013, it was decided to create a MT and NT group inside the Agricultural Chamber of Brittany. It is composed of 4 local field advisors (one for each department) and two applied research engineers and aims at enhancing exchanges and activities at a regional scale among field advisors and researchers. D. Heddadj, researcher specialised in environmental impacts of MT and member of the SUSTAIN project team, proposed to associate the regional advisor group to the survey. As a matter of fact, field advisors are in close contact with farmers and are a relay in the fields, and the same time they interact with stakeholders from the Agricultural Chamber and are thus able to prioritize the questions to address during the survey. Therefore, the group of advisors was associated to the project and gave advice on different steps :

- suggestion of themes for the questionnaire and the definition of the sample
- feedback on the questionnaire formulation
- providing a list of names of farmers to contact

In return, this group expected to gain knowledge on the profile of farmers using MT and their practices, but also on their information sources and expectations from advisory services.

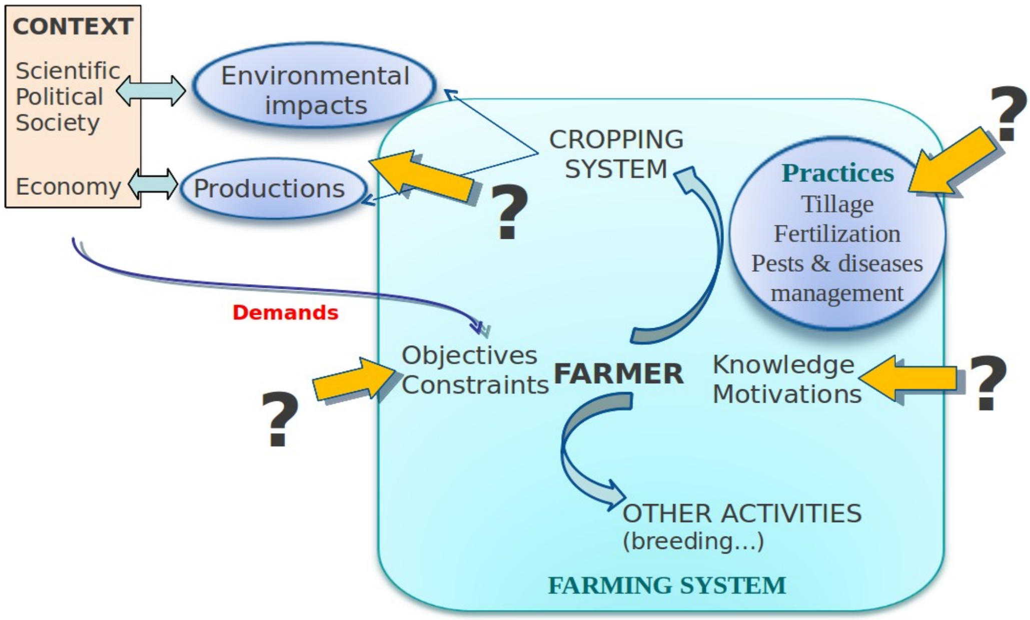


Figure 9: Scheme summarizing the focus of the study (arrows with question marks = main focus points).

Figure 9 summarizes the focus of our study: in the center of the scheme we can see the farmer. He has his own motivations and knowledge, but also objectives and constraints he has to deal with. The farming system surrounding him is composed two parts: we are mainly focusing on the cropping system, but of course the other activities on the farm (namely animal breeding) also influence the farmer in his choices. The farmers use a set of practices in their cropping system, according to their knowledge, motivations and constraints. In return, there are two outcomes: the productions and environmental impacts (externalities). These outputs interact with the context surrounding the farm at different levels: at local (immediate environment, network) or national scale (laws). The economy is of great importance for the productions. The context is addressing demands to farmers, which can turn into constraints or objectives.

Our focus points (arrows with question marks) in the present study are numerous: we will focus on farmers' practices, as well as his results (the outcome of the cropping system), but also on the farmers motivations and information sources, and the constraints and problems he might have to face.

The survey progressed according to the calendar presented in table 4.

Table 4: Simplified calendar of the survey progress.

Month	Operation
1	Meeting with the regional Minimum Tillage group , literature study, writting of the questionnaire
2	Feedback on the methodology and the questionnaire from various stakeholders, sample composition
3 – 4	Interviews, transcript
5 – 6	Data analysis and interpretation, writting of the report

2.2. Construction of the questionnaire

A meeting with the regional group of advisors validated the general process and allowed to identify the themes to cover in the questionnaire. The discussion highlighted the need to work both at the scope of crop management sequence (understood as the logical and ordered combination of techniques implemented of a plot in order to obtain a production (Sebillotte 1974)) and at the cropping system level, which combines crop successions and crop management sequences (Sebillotte 1990). We chose to detail the Crop Management Sequence (CMS) of wheat and maize, which are by far the most frequent crops in Brittany (CRAB, 2012-a)

The questionnaire, visible in appendix 3, was written taking inspiration from the questionnaires of the Agreste study and previous studies (Quenea, 2006; Perche & al, 2009).

Various stakeholders were requested to react on the project and their inputs lead to a questionnaire divided in 2 parts:

- part I with technical and economic focus : productions on the farm, implemented cropping practices, inputs, machinery, crop yields, incomes (selling prices), operating costs, and estimated working times. This part is composed of closed questions, tables and multiple choice questions, including a table for the description of the CMS in wheat and maize.
- A sociological part : farmer's profile, trigger for change and motivations, assistance and social networks, information sources, learning dynamics and expectations from agricultural stakeholders and institutions. This second part consists of open-ended questions and follow-up suggestions to identify farmers' trajectories in MT techniques.

2.3. Sample composition

After discussion with local field advisors the sample was divided in 2 distinct groups:

- 15 farms conducted with MT techniques for more than 5 years, in order to get informed about the practices of experimented users, as well as their decision criteria (eg. CAP reform in 1992), their process, and the benefits they obtain nowadays.
- A second group of similar size composed of MT users for less than 5 years, so as to cover the diversity of decision criteria of these more recently converted farmers and evolutions of the context surrounding these techniques (difficulties, information sources...)

Each of the four local field advisors transmitted a list of farmers with their coordinates, the type of farming system and the experience (duration in years) in MT.

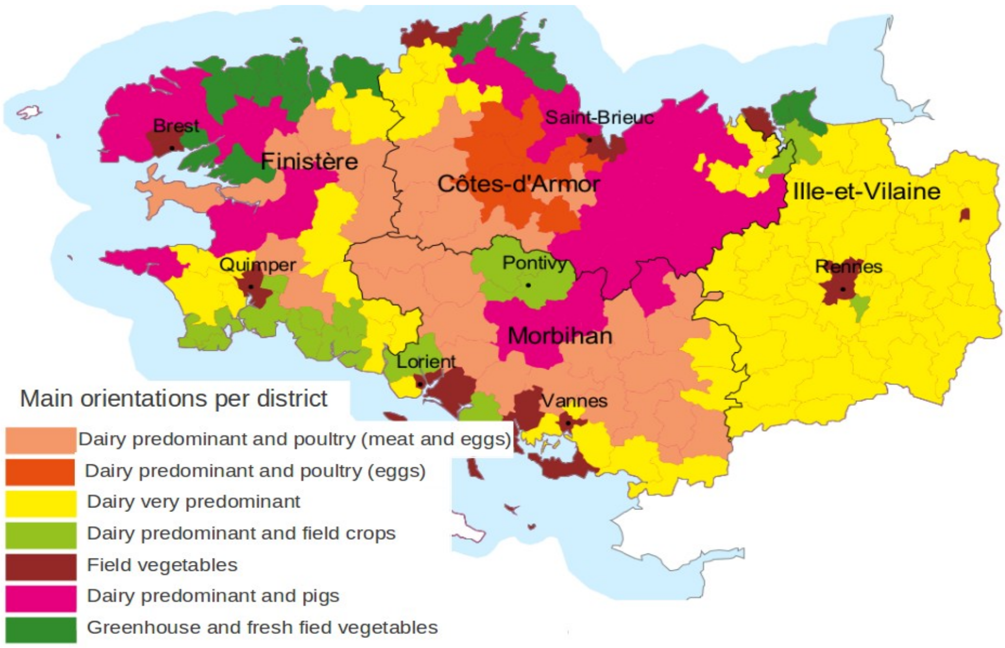


Figure 10: Map of the main farming types in Brittany (Agreste Bretagne, 2010-b).

Using the map (Figure 10) of the main farming types found in Brittany (Agreste Bretagne 2010-b), four key profiles of farms were selected: soilless breeding (pig or poultry production), bovine (milk or meat production), multiple livestock (soilless and bovine) and crop.It was decided to dismiss farms calling on agricultural services supply for the soil tillage operations.

Then, the farms were pinned on the « physiographic entities » map (Lemercier, 2010), showing the distribution of identified pedo-climatic contexts in Brittany (Figure 11). This allowed to see the distribution of the farming types throughout the pedo-climatic contexts and make a first selection targeting farms to contact in priority.

Figure 11: Distribution of the total list of farmers displayed on the map of Brittany's physiographic entities (Lemercier, 2010).

2.4. Realisation of the interviews

First, two « test » interviews were carried out in Ille-et-Vilaine on 02/28/2013 and 03/04/2013, in order to finalise the formulation of the questionnaire and the attitude to adopt during the interview.

Then, a letter explaining the whys and wherefores of the study (appendix 4) was sent to the first selection of farmers. Each of the farmers received a phone call between 3 and 7 days after the estimated date of reception so as to enquire about their interest and make an appointment if appropriate. In case of refusal, the letter was sent to another farmer on the list.

In practice, interviews were carried out between 03/11/2013 and 04/22/2013. Lasting from one hour to 3h30, they were recorded if the interviewed agreed, and guaranteed anonymous. The discussions were individual and in a quiet place every time this was possible, to allow the interviewed person to talk freely, and they were sometimes followed by a visit of the farm, a plot or equipment.

2.5. Data analysis

2.5.1. Tools and software

The collected data was analysed with the standard Excel software. For the indicators, we used MASC indicators and STEPHY software. MASC (Multi-attribute Assessment of the Sustainability of Cropping system) is a multi-criteria assessment tool of the sustainability of cropping systems which “conceptualizes the sustainability assessment problem through a decisional approach based on a division of the overall problem into the three dimensions that make up sustainability (social, economic and environmental)” (Craheix & al, 2012). 39 qualitative evaluation criteria are aggregated in a tree-like structure presented in appendix 5.

STEPHY is a result from the national program Ecophyto 2018 for the reduction of the use of plant protection products. We used a guide and a calculator for multiple croppings systems aiming at designing cropping systems that would be more efficient and require less phytochemicals (Guide Stephy, 2011). The indicators used in this approach can be found in appendix 6.

2.5.2. Agronomic and technical information

Modalities of decision-making in a cropping system, combining crop successions and CMS, can be analysed in regards of farmer’s general objectives, decision rules about technical operations, crop structure in time and space and practices implemented in case of competition for resources (Aubry & al, 1998 in Chantre & al, 2010).

Chantre & al (2010) transferred to field crop farms the approach initiated by Madelrieux & al (2002) and Moulin & al (2008) in farms specialized in animal productions. Going further than the simple analysis of the impacts of a change or innovation, and then the notion of "evolution trajectory" (Capillon, 1993, in Madelrieux & al, 2002) which compares two states without investigating the way the change from one to the other occurs, the approach of studying processes behind a changement allows to take interrelations within a system into account. As Chantre & al (2010) underline, change of practices belong to exceptional changes (questioning the farm strategy and its configuration) whereas structural changes (minor but continual modifications or adjustments) can be linked to the context in which changes of practices take place. The authors of the study, which focuses on changes of practices aiming at decreasing phytopharmaceutical use, describe for each farm agronomic coherence phases, the latter being defined as "phase in the life of a farm during which agronomic practices and decision rules on the initiation of those practices are stabilised" (Chantre & al, 2010). The succession of coherence phases on a farm is called "trajectory of the change of practices" and their comparison among a group of farms enables to describe a typology of trajectories.

In the scope of our study, we will limit to determining the actual agronomic coherence phase of each farm, understood as the coherent organisation in a cropping system of the cropping practices described by the farmer.

Therefore, in a first step, we highlighted the logic behind the technical choices of crop management sequences in winter wheat and maize, the two main crops in Brittany (Agreste Bretagne, 2010-b). The crop management sequences were then classified in five levels and based on the following indicators:

- depth of tillage (based on ADEME, 2007)
- Number of passes for crop establishment
- Total number of passes
- Number of passes for plant protection treatments (based on Chantre & al, 2010)
- energy use efficiency[1] (indicator estimated with the STEPHY guide, 2011)

[1] Standard formula: Energy Use Efficiency = ∑ (LHVcrop i * yield crop i / Energetic Cost crop i) / n
with: Energetic Cost = ∑ (cost intervention i * nb intervention i)/n + total N units provided * energetic cost of 1 unit + total quantity of provided water * energetic cost of 1 m^3 + energetic cost of P for 1 T of product * yeild + energetic cost of K for 1 T of product * yield. E*nergetic costs from INRA, ADEME 1999*
and: LHV (Lower Heating Capacity) of products and by-products from *INRA, ADEME, 1999*

In a second step, we enlarged the scope of analysis to the whole cropping system and took into account the way farmers implemented crop rotations and cover crops. Indeed, the latter form, with a minimum soil tillage, the three cornerstones of Conservation Agriculture. Cover-crops and adaptations in the rotation play an essential role for a successful reduction of tillage intensity, acting on soil structure and organic matter, but also weed management, water storage capacity.

We used the Technical Monitoring Time (TMT), a MASC indicator based on the number of different crops found in a rotation (shown in table 5), and thus reflecting the additional knowledge, observation and management adaptations required by a high crop diversity. We developped the same indicator for cover-crops (TMT CV) based on the same classification.

Table 5: Technical Monitoring Time (TMT) classification (from Craheix & al, 2012)

	Low	Medium	High
Number of crop species	TMT ≤ 3	3 < TMT ≤ 6	TMT > 6

Finally, we described the distinctive features of the farmers making up each class, in order to determine if the type of farming system and the pedo-climatic conditions influence farmers' adoption of MT. We have also been highlighting what classes had in common and their differences on four themes: knowledge on soils and ecosystemic services, implementation of changes in cropping practices, socio-economic results and difficulties farmers might have encountered.

During our survey, we aimed at collecting inputs on the plant protection treatments (type and dose) that farmers applied, so as to establish the Treatment Frequency Index[2] (TFI) for each farmer. As a matter of fact, the TFI has been approved as a relevant indicator of the environmental burden of farming activity (Guide Stephy, 2011). However, we managed to gather enough data to calculate the TFI in wheat for only 5 farmers, and 6 in maize. Therefore, it was decided to use the number of passes for plant protection treatment in the construction of the classes, even though it does not necessarily reflect the TFI (one farmer can do several passes at reduced dose, or one pass with full dose). The TFI was placed in the section describing the agronomic classes.

[2] TFI= (applied dose of active substance * treated surface) / (accredited dose of active substance * total plot surface)

2.5.3. Sociological questions

The second part of the questionnaire was valorised with the ESA qualitative survey methodology (Herault & al, 2010). Bastien Dannevoye (ARC – Fructis research group, University of Liège), PhD student on sociological aspects of RT, contributed on the methodology and the interpretation of the sociological questions.

First, all of the answers to sociological questions have been transcribed, so as to, in a second time, read them through and identify quotations belonging to essential themes. Afterwards, all quotations were coded and sorted out theme by theme. Finally, a transversal lecture of the different themes allowed to interpret the ongoing dynamics, in link with literature.

2.6. Feedback to involved stakeholders

A presentation of the conclusions and recommendations arising from our study will take place on 09/09/2013, with special attention given to the reactions of the regional advisor group. A synthetic document was sent to the surveyed farmers.

Figure 12 summarizes the different methodological steps of our survey.

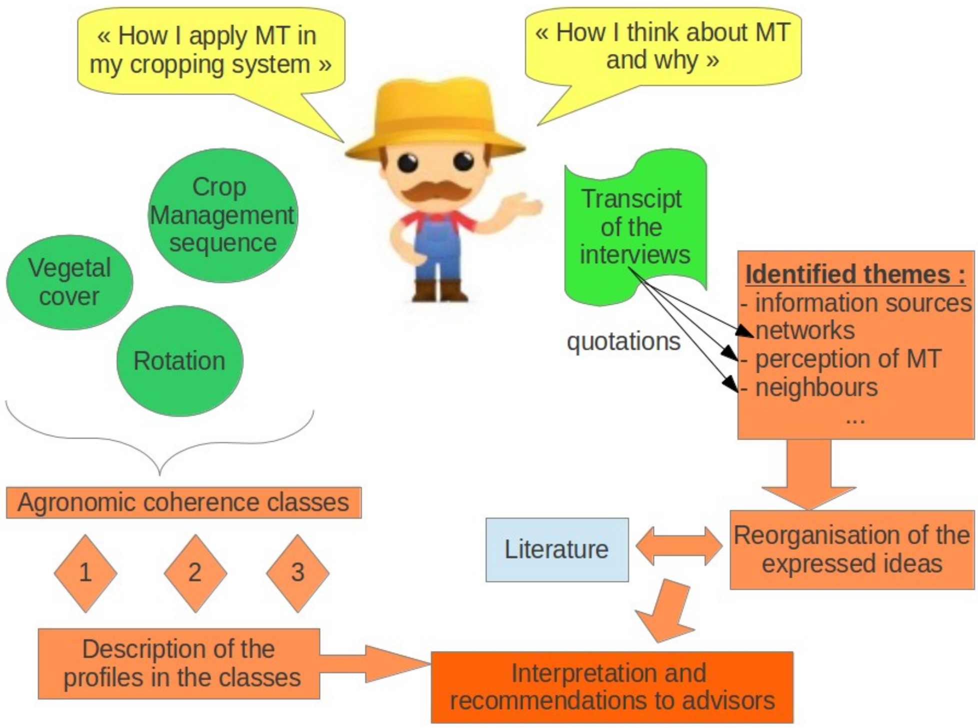


Figure 12: Scheme summarizing the methodological approach of the survey analysis.

3 Results

3.1 Sample caracteristics

In total, 29 interviews were carried out between the 02/28/2013 and the 04/22/2013. Lack of time has been the main reason evoked by farmers declining the interview.

Only 26 farms were taken into account for the analysis of agronomic practices, and all 29 interviews were used for the sociological aspects. Some mistrust towards the Agricultural Chamber appears in the rejection of 2 persons, and also in the discourse of 2 interviewed farmers, as they did not want to detail their agronomic practices. Farmers attitude towards the institution will be analysed in part 3.3. Moreover, one farmer was unable to describe completely his agronomic practices because he is currently going back to ploughing after several crop failures.

3.1.1 Spatial distribution

As we can see on figure 13, the spatial distribution of the farms allows to cover a wide range of climatic conditions and soil types in Brittany. Farms are located on the whole area excepted in Monts d'Arrée (which is also a less agricultural area) and the centre of Brittany (Ploermel area).

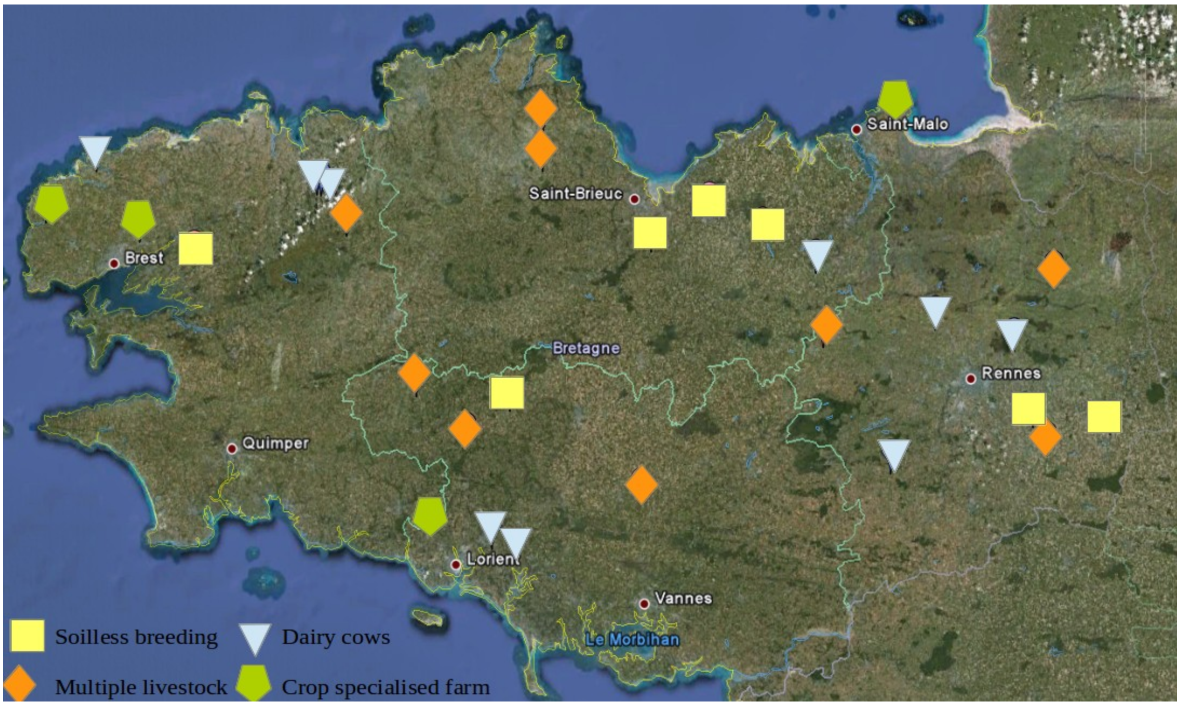


Figure 13: Map of the geographical distribution of the 29 surveyed farms.

Moreover, it appears that the different farming types are spread throughout the surveyed zone. This allows us to suppose that pedo-climatic conditions and farming types are not linked: if the study highlights any trend in a peculiar pedo-climatic condition, it cannot be explained by the type of farming system, and vice versa.

Two farms are found in a “green algae” watershed, a third one in a contentious watershed and a fourth one in a drinking water catchment area. These farms are sometimes subject to specific legislations or environmental incentives.

3.1.2 Production systems distribution

- Farming types

Even if the size of our sample is not statistically significant, we wished to get a distribution of farmers close to the figures of Brittany, into account, in order to interview farmers with various concerns. Table 6 shows the distribution of interviewed farms among the four main farming types, and table 7 details the productions encountered.

Table 6 : Distribution of the sample depending on the farming type.

Farming type	Surveyed sample		Data Brittany 2010 (%)
	Number	%	
Field crops	4	14	9
Dairy cows	8	28	38
Other bovines (meat and dairy)	2	7	7
Pigs and poultry livestock	8	28	31
Multiple livestock	7	24	10

Table 7 : Distribution of the different productions within the farming types.

Poultry	Pigs	Dairy	Bovine meat	Crops
2	12	13	4	4

We observe that the sample distribution is relatively close to the overall dispersal in Britanny, except for multiple livestock systems which appear over-represented.

One farm is certified organic (field crops and vegetables), and 4 farmers combine two activities (employee of a machinery sharing ring, agricultural services supply or more). It is also to notice that 4 persons are involved in local or professional circles (associations, syndicates, local representative).

- Farm size

The average utilised agricultural area (UAA) in the surveyed farms reached 92.3 ha (n= 27, min= 21 ha, max= 202 ha): it is above the average area of medium to large sized farms in Brittany (occupying 95% of the agricultural land) which reached 60 ha in 2010 (Agreste Bretagne, 2010-b). Tables 8 and 9 show the average production capacities on dairy and pig farms.

Table 8 : Characteristics of pig farms (specialized or with other breeding activities).

Pigs	
Average number of farrow-to-finish places (n=9)	244
Average number of fattening places (n=3)	487

Table 9 : Characteristics of dairy farms (specialized or with other breeding activities).

Milk production	
Average quotum (n=11)	580000L
Average headcount (n=11)	70 cows
Average milk production Brittany	346150L

According to the Agricultural Chamber (CRAB, 2012-a), only 30% of the pig farms having a breeding activity ("farrow-to-finish" systems), representing 1085 farms, hold 200 sows or more. Again, we notice that the farm size is above average for the two main productions in Brittany.

- Legal structure and labour

As shown in figure 14, companies (Collective farming groupings (GAEC) and limited liability agricultural holdings (EARL), etc…) outnumber individual farms.

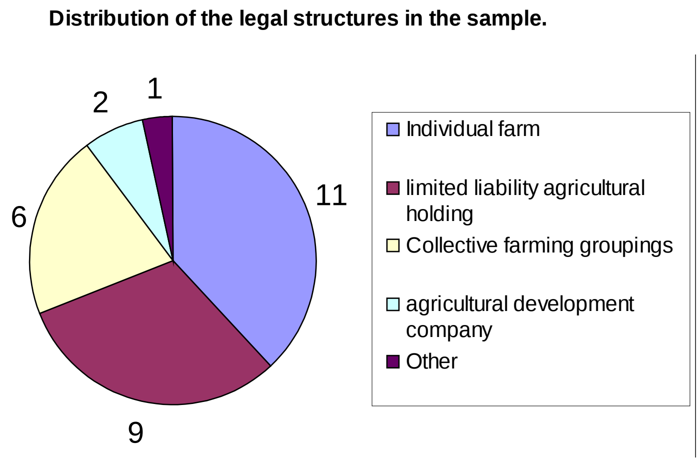


Figure 14: Distribution of farms' legal structures in our sample (n= 29).

In Brittany, the proportion of farms as companies is higher than at the national level (46%, versus 31% in France) (Agreste Bretagne, 2012-b) and the last decade saw these kinds of legal structures grow rapidly. They represent 70% of the large size farms in Brittany (as well as in France). We can therefore link the prevalence of company structures to the globally bigger farm size in our sample.

Furthermore, the average annual work unit (AWU) observed on the surveyed farms (2.3 AWU) can be compared to the average AWU for medium to large sized farms in Brittany (2.1 AWU, Agreste Bretagne 2012-b). Our sample reached the maximum of 5 AWU (on 2 farms) and 4 AWU (4 farms). However, the AWU devoted to crops presents an average of 0.7 AWU and rarely goes above 1 AWU (1 farm at 1.5 AWU, 9 farms at 1 AWU). The proportion of time devoted to crops is sometimes very low: the minimum is 0.3 AWU (on 5 farms) or 0.5 AWU (11 farms). This observation must be qualified as farmers mention that they sometimes benefit from occasional assistance (which is not included in this estimation). Nevertheless we can link this result to the fact that breeding is the major activity and generates the biggest income (except for the 4 crop farms).

3.1.3 Sociological features

- Age

The average age of farmers reaches 45 years, and can be linked to the distribution of the number years since farmers started their activity, displayed in figures 15 and 16. We notice that there is only one person under 30 years old.

These results are close to the regional average age of a medium to large sized farm manager is 46.9 years old (Agreste Bretagne, 2012-b).

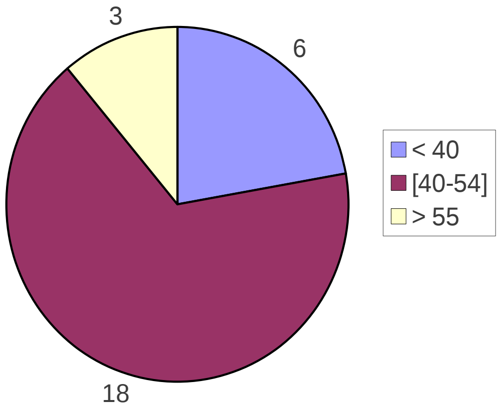


Figure 15: Age distribution in the sample (n=29)

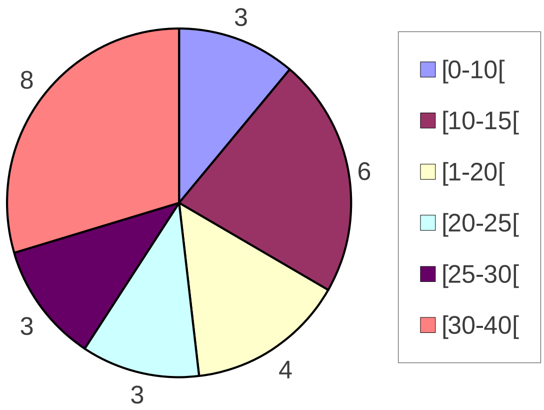


Figure 16: Distribution of the number of years farmers have started their activity (n=29).

Moreover, 55% of farmers are aged between 40 and 54, whereas 26% are 55 years old or more and 20% under 40. A crossed curve of farmers' age, number of years as farmer and number of years using MT techniques is available in appendix 7 and shows that no specific link between a farmer's age and his experience in MT can be established.

- Experience in MT

As figure 17 shows, there are mainly two waves of conversions to MT: in the 90's and in the following decade. We can also notice that the two farmers that started MT more than 20 years ago are two "pioneers" and locally acknowledged as such.

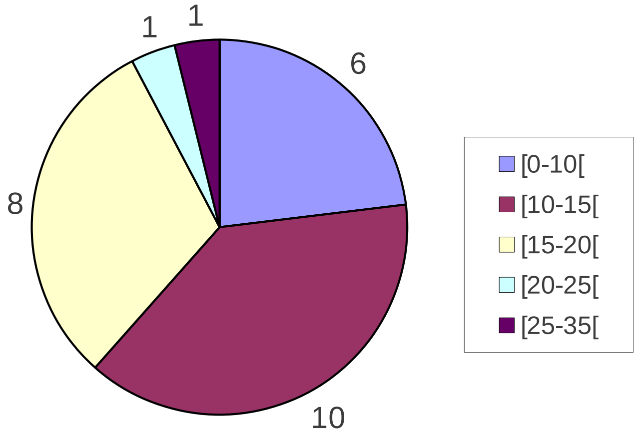


Figure 17: Distribution of the number of years since farmers started using MT techniques (n=29).

This unequal distribution clearly shows the difficulties encountered during the survey to find farmers that recently started using MT techniques.

SUMMING UP

- Companies are prevalent in our sample
- The utilised agricultural area (UAA) in our sample is above average, and so are the production means for dairy and pig farms.
- No significant trend appears between the age or the number of years as farmer and the experience in MT techniques.

These observations inform us on the surveyed sample and can be considered as first results in this study. Indeed, they provide details on the farms likely to implement MT in Brittany.

3.2. Analysis of agronomic practices

In this part we focus on the 26 farms that provided a complete description of their agronomic features and their MT techniques. As detailed in the methodology, we proceeded in 2 steps: first, we focused on crop management sequences, and in a second time, we analysed the cropping system. This allowed to build agronomic coherence phases, which will be described in the third part of this section.

3.2.1. Classification per crop management sequence (CMS)

We adapted to our current survey used the tillage intensity description made in the ADEME report (2007) based on the tool used and the depth of the tillage operation. The number of passes for crop establishment (from destruction of the cover-crop to the sowing operation) the total number of passes and the number of plant protection treatments were used as further criteria, as well as farmers' estimations of the working time for crop establishment (not including manure or slurry spreading). In addition, the energy use efficiency was estimated with the Stephy calculator.

As a result, we were able to classify the crop management sequences (CMS) into 3 main levels, displayed in tables 10 and 11.

A CMS of level 1 applies to a deep and intensive tillage (several passes for crop establishment) with a high level of inputs. The decision rules for plant protection treatments belong to almost systematic treatments.

CMS of the second level encompass tillage depths between 15-8 cm and above 8 cm, on the whole soil surface.

CMS of level 3 always match with the lowest tillage intensity, located on the sowing line or a larger strip (strip-tillage), but can be more or less integrated concerning inputs, as some farmers apply principles of agronomic weed, pests and disease management.

- **Wheat**

Table 10 : Classification of the levels of wheat crop management sequences (CMS).

CMS LEVEL	W1 : Intensive soil tillage	W2 : Medium intensity soil tillage		W3 : no-tillage or low intensity tillage	
		a) deep tillage	b) shallow tillage	a) input intensive	b) decreased inputs
Depth of soil tillage	> 15 cm	8-15 cm	< 8 cm	Tillage only on the sowing row	
Number of passes for crop establishment	3 to 5	2 to 4		1 (maximum 2)	
Total number of interventions	7 to 13	8 to 11		8 to 10	5 to 7
Energy use efficiency	< 10	>10		> 8	> 10
Plant protection treatments (nb of passes)	4 to 6 *	3 to 5		3 to 6	1 to 3
Estimated working time (h/ha)	> 3,7	2,5 - 4		1,5 – 2,7	**≤ 2**
Number of farmers	*3**	*7*	*8*	*4*	*3*

* Except for one organic farmer (which thus did not bring fertilisers nor phytopharmaceuticals)

- Level W3: Wheat establishment with one pass (6 farmers) is done with a direct drill and one farmer is adding a a pass with a total herbicide beforehand. An additional distinction appear inside this category. Indeed, some farmers put strategies in place so as to decrease the use of pesticides, whereas other farmers, with the same level of tillage intensity apply rather systematically plant protection treatments (namely fungicides), resulting in a total number of passes close to the previous class.
- Level W2: Medium intensity shallow tillage (< 8cm) can be done in with 1, 2 or 3 passes of a superficial tillage tool (disc stubble tiller or a disc harrow), with (4 farmers) or without (3 farmers) a herbicide treatment before sowing. One farmer uses mechanical soil cover destruction. One farmer is doing only one pass as he combines a spring tine harrow to his combined seeder. In total, 6 farmer sow with a combined drill and 2 farmers with a direct drill.
- Medium intensity deep tillage (8-15cm) is done with one pass of deep tillage (disc stubble tiller, tine tool, disc harrow) before sowing. One farmer is adding a herbicide treatment before sowing. One other farmer is doing differently: after a mechanical cover

crop destruction, he does one superficial tillage and then one deep tillage and sowing. Only one farmer in this group uses a direct drill.

– Level W1: Finally, the deep (> 15cm) and intensive tillage group is composed of 2 farmers with a similar tillage: after a herbicide treatment, they do one pass of deep tillage (coil-spring tine cultivator or spring tine harrow) before sowing. A third farmer is a more specific case because it is an organic farm. This farmer does 3 passes with a cultivator at 12-15 cm to create a false seedbed and then one pass at 15-20 cm deep, before sowing. All three farmers use a combined drill.

◆ **Maize**

Table 11 : Classification of the levels of maize crop management sequences (CMS).

MAIZE* CMS				
CMS LEVEL	**M1 : Intensive soil tillage**	**M2 : Medium intensity soil tillage**		**M3 : no-tillage or low intensity tillage**
		a) deep tillage	**b) shallow tillage**	
Depth of soil tillage	> 15 cm	8-15 cm	< 8 cm	Tillage only on the sowing row
Number of passes for crop establishment	5 to 6	5 to 7	4 to 5	3
Total number of interventions	8 to 9	7 to 11		5 to 6
Energy use efficiency	> 14	> 7	> 15	> 15
Number of farmers	*5*	*8*	*9*	*2*

* Three of the surveyed farmers for wheat do not grow maize.

– Level M3: What is striking here is the reduced number of farmers really sowing maize without tillage and a tendency to increase tillage intensity in comparison to wheat establishment. Indeed, only two farmers are doing low intensity tillage. The first farmer destroys mechanically his cover crop and then brings organic fertiliser, whereas the second brings mineral liquid fertiliser and a herbicide treatment. Both farmers then sow the maize combined a strip-tiller to the drill with a starter fertiliser input.

– Level M2: For medium intensity shallow tillage (< 8cm), in general farmers bring organic manure and combine it with two superficial tillage operations, first to incorporate and the second to prepare the seedbed. One farmer adds a herbicide treatment to this sequence, and another brings urea in addition to manure. One farmer implements a different maize establishment: after two superficial tillage operations, he brings successively 3 times slurry, then tills again superficially, and sows. Shallow tillage is done with a disc harrow, a rotary harrow, a stubble tiller or alternative tools (like a harrow with ground driven spades). For the sowing, 3 farmers used a combined drill (and two of them also bring starter fertiliser), two farmers use a single-seed drill and one a direct drill (with discs).

- For medium intensity deep tillage (8-15 cm), three farmers destroy chemically their cover crop, and three more mechanically. Afterwards, there is one or two organic fertiliser inputs followed by a superficial tillage for incorporation , a deep tillage (with a tine tool or a rotary tiller) and another superficial tillage for seedbed preparation. Shallow tillage can be done with a disc harrow, a rotary harrow, or a drill (Horsch or direct drill with discs).
- Level M1: Farmers in the deep intensive tillage group (> 15 cm) combine one or two organic fertiliser inputs with a deep tillage operation (top soil cultivator, chisel) and a superficial tillage operation (tine tool, disc stubble tiller, sunrake tiller) for seedbed preparation. Sowing is done with a combined drill, except for two farmers using a single-seed drill (one of them also brings started fertiliser).

We can explain the fact that farmers are more reluctant to simplify their tillage techniques for maize with different factors. First, maize is key for livestock, be it sillage maize for cows or grain maize for pigs and poultry. Moreover, its root system is more sensititve to compaction than wheat, which encourages farmers to till in order to securize their yields. Risks in maize establishment are also more important because there is no recovery phenomenon possible (in comparison to cereals' tillering) and the vegetative cycle is short.

3.2.2. Systemic analysis and construction of the agronomic coherence classes

In order to investigate the scope of the modification of the cropping system, we used three indicators: a typology of the corp rotations, the technical monitoring time (TMT) based on the crop diversity of each farm and the technical monitoring time for the cover-crops (TMT CV). This allowed us to establish three main agronomic coherence classes.

- **Crop rotations**

Each farmer implements up to three different crop rotations on his farm. In total 52 rotations have been described and collected. A fundamental distinction can be made between rotations including pastures or meadows and rotations without, and this criterion is often linked to type of farm (grasslands are found in ruminant farms). Rotations were then discriminated according to their duration in years and the number of different crop species they contain.

Table 12: Classification of the rotations

Duration	**R1- Short or medium rotations**		**R2- Long rotations**		
Presence of grassland	a) without grassland	b) with grassland	a) with grassland	b) without grassland	c) with grassland
Diversification	Undiversified (< 4 species)		Undiversified (< 4 species)	Diversified (≥ 5 species)	
Effective (total = 52)	*25*	*9*	*2*	*8*	*8*
Example	Maize/wheat /maize/ wheat/barley	Maize/ triticale/oats/ Rye Grass	Maize/wheat/ rape/alfalfa (4 years)	Wheat/ Barley/ Maize/ Field peas/ Rapeseed	Maize/barley/ second crop (oats, clover, rye)/ field peas/ undercover wheat/ Rye Grass and clover
	Barley/rape/ wheat/maize /maize	Maize/wheat / Rye Grass			

As we can see in table 12, there is a large variety of practices and this already shows that not all farmers in MT have modified their rotations. It also highlights that a lot of rotations without grasslands (soilless breeding activities for instance) are short and little diversified, whereas this tendency cannot be found in rotation with grasslands.

- **Technical monitoring time (TMT)**

The TMT reflects the time dedicated to crop monitoring and results from the number of different crops (not including cover crops) present on a farm (table 13). It was used as an additional indicator to gain overview of the crop diversity on each farm, and consequences for farmers. Indeed, the more different crops, the more knowledge and know-how is required from the farmers, which has thus to spend more time to inform and observe. In our study, it ranges from "low" (a farm with maize monoculture and pastures) to "high" (a farm with long and diversified rotations with more than 10 crop species)

Table 13: Distribution of farm in the technical monitoring time (TMT) modalities.

	Low TMT	**Medium TMT**	**High TMT**
Number of species	TMT ≤ 3	3 < TMT ≤ 6	6 < TMT
Number of farms	6	17	3

- **Cover crop diversity**

In order to complete the overview of the efforts required to implement changes in a cropping system, we investigated the number of species used as interculture. Indeed, permanent soil cover is one of the cornerstones of conservation agriculture, and establishing a cover crop brings several benefits such as soil tillage through root biomass, nitrogen fertilisation in the case of legumes, as well as organic matter inputs, soil protection against compaction, erosion or nutrient leaching. (ADEME, 2007). Thus, enquiring the importance given to cover crops helps to understand their role in farmer's MT practices.

Most farmers surveyed are using multiple species mix (21 farmers out of 27). Similarly to crops in the rotation, we defined a TMT for cover crops (TMT CV) displayed in table 14.

Table 14 : Classification of the types of cover crops (CV) implemented according to the technical monitoring time (TMT CV).

TMT CV	**CV 1- Low**		**CV 2- Medium**	**CV 3- High**
	a) single species	b) multiple species (TMT CV ≤ 3 species)	3 < TMT CV≤ 6	TMT CV > 6
Species	phacelia, diploid oats*, white mustard, Italian RG, clover		CV1 + radish, vetch, spring peas, faba beans, sunflower, black oats, nyger, brown mustard	CV 2 + Crimson clover, Chinese radish, vetchling, lentils, turnip rape, buckwheat, berseem, fenugreek, rapeseed
Effective	*6*	*8*	*7*	*6*

* *Avena strigosa*

- Low TMT CV: this group represents farmers (a total of 6) using only one plant species as cover crop. In addition, 8 farmers are mixing 2 or 3 of the mentioned species, for example the farmer n° 28 which is using phacelia + mustard together.
- Medium TMT CV: the 7 farmers in this category mix between 4 and 6 plant species for their cover crops. One can mention as an example farmer n°25 and his association of radish + phacelia + diploid oats + vetch. This way, the blends are balanced between different crop types.
- High TMT CV: in this last group, the mixes encompass 6 species or more, and are used by 6 farmers. A wide range of plants are evoked in the associations. An illustration is given by farmer n° 15, whose mix is composed of oats + vetch + Crimson clover + diploid oats + white clover + Chinese radish + mustard.

It is also a result in itself that cover-crop composition is very diverse, and although the same species occur regularly, the associations are each time different and seem to answer farmer's own determinants, for instance costs reduction, soil compaction, possibility to be grased or harvested, etc...

- **Construction of agronomic coherence phases**

From the wheat and maize management sequences and the analysis of rotations and cover crops arises a classification of the cropping systems. The characteristics of these agronomic coherence phases are detailed in table 15. The aim of the approach is to establish a classification of farmers based on the level of inclusion of conservation agriculture principles in the cropping system. Thereby, we try to determine if a distinction can be made between the single suppression of the ploughing operation and transformations of the cropping system linked to a systemic vision.

This classification is primarily based on the tillage intensity and the number of changes implemented, however in some case boundaries are blurred. Indeed, it appears that many of the surveyed farms use multiple species cover-crops, and also short and medium length rotations (R1a) are numerous and can be found in almost all classes. However, we used the TMT for the farm to gain an additional overview of the crop diversity on the concerned farms.

Tableau 15 : Description of the modalities of the agronomic coherence classes

CLASS	1	2a	2b	3a	3b
	Suppression of ploughing operation	Modifications of CMS, and to a certain extent, of the cropping system		Changes at the scale of the cropping system	
Main feature	Deep tillage (< 15 cm) without reversal	Medium depth tillage (8-15 cm)	Shallow tillage (> 8 cm)	RT and no-tillage combined	No tillage
Wheat CMS level	W 1 : deep intensive tillage W2b, W2a : medium intensity (deep or shallow)	W2a : deep medium intensity tillage	W2b : shallow medium intensity tillage	W3a,W 3b : no-tillage	
Maize CMS level	M1 : deep intensive tillage M2a : deep medium intensity tillage	M2a, M2b : medium intensity tillage (deep or shallow)		M2b : shallow medium intensity tillage	M2b : shallow medium intensity tillage M3: no-tillage
Rotation	R1a, R1b : short or medium length, little diversified	R1a : short or medium length, little diversified R2a: long, little diversified	R1a : short or medium length, little diversified R2b : long & diversified	R1a, R1b: short or medium length, little diversified R2b: long & diversified	R2b, R2c : long & diversified
TMT CV	CV1a : single species cover crop CV1b : low diversity (≤ 3 species)	CV1a, CV1b : single species or low diversity (≤ 3 species) 2,3 : medium to high diversity associations (> 3 species)		CV2 : medium diversity mix (3-6 species)	CV2, CV3 : medium to high diversity mixes (> 3 species)
Optional features	Low to medium TMT				
Class size	*7*	*5*	*7*	*3*	*4*

To summarize, it appears that difference between class 1 and the two other classes are more important than the difference between class 2 and 3. Indeed, the changes relative to cropping systems have been implemented in rather similar ways in these two classes, and the main distinctive feature is the tillage intensity.

SUMMING UP

- For wheat CMS, a large diversity of practices can be observed. Tillage at medium depth (8 – 15 cm) or superficial tillage (< 8 cm) are the most common, with a combined sowing tool. Seven farmers are establishing wheat with no-tillage (one or two passes).
- Maize CMS are less diversified, only two farmers are establishing maize with low intensity tillage (strip-tillage). The others favour techniques with 4 to 7 passes, for instance a first pass in order to incorporate manure, and a second one for seedbed preparation.
- There is also a large variety of rotations, and only systems already optimised for tillage techniques and cover crops have made their rotations evolve. Many short rotations without grasslands are undiversified (< 4 species).
- Concerning cover crops, most farmers have made changes in their practices. Associations of species are very diverse and answers specific objectives for each farmer.
- Based on soil tillage intensity for winter wheat and maize, in addition to cropping system analysis (on cover crop and rotations), three agronomic coherence classes were established. The first class (deep tillage) can be distinguished with the absence of changes at the scale of the cropping system (only suppression of the ploughing operation).

3.2.3. Description of the agronomic coherence classes

We will now detail the most outstanding differences and similarities between the classes, and table 18 (page 60) summarizes these observations

3.2.3.1. General overview

The following factors are common to all classes and do not seem to influence farmer's distribution among the classes:

- The age of the surveyed farmers being quite homogenous, it is not possible to underscore a benefit of experience in the choice of a tillage technique. For instance, young farmers (under 40) can be found in class 3 as well as in classes with deep tillage operations.
- Furthermore, the number of years using MT techniques neither is a cohesion factor in groups of practices, and we observe that it is possible to stop ploughing at all stages of a farmer's career.
- Very homogenous in our sample, it appears that the education level of a farmer does not allow anticipation of the agronomic class he belongs to.

- As shown in table 16, no clear tendency emerges from the dispersal of the farming types between the classes and one can find back almost every farming type in each class. We can simply notice that there is no farm with multiple livestock activities in the classes 3a and 3b.

Tableau 16 : Distribution of the agronomic coherence classes among the farming types.

Farming type	Class 1	Class 2a	Class 2b	Class 3a	Class 3b
Bovines (dairy and meat)	2	1	1	1	2
Soilless breeding	2	2	3	1	1
Multiple livestock	2	2	2	0	0
Crops	1	0	1	1	1

- Moreover, the crossing of physiographic entities between members of the same class does not allow to draw conclusions concerning a concordance between a kind of MT technique and peculiar pedo-climatic conditions: farmers from the same class cover a wide range of contexts, as visible in figure 18. Detailled maps for each class can be found in appendix 8.

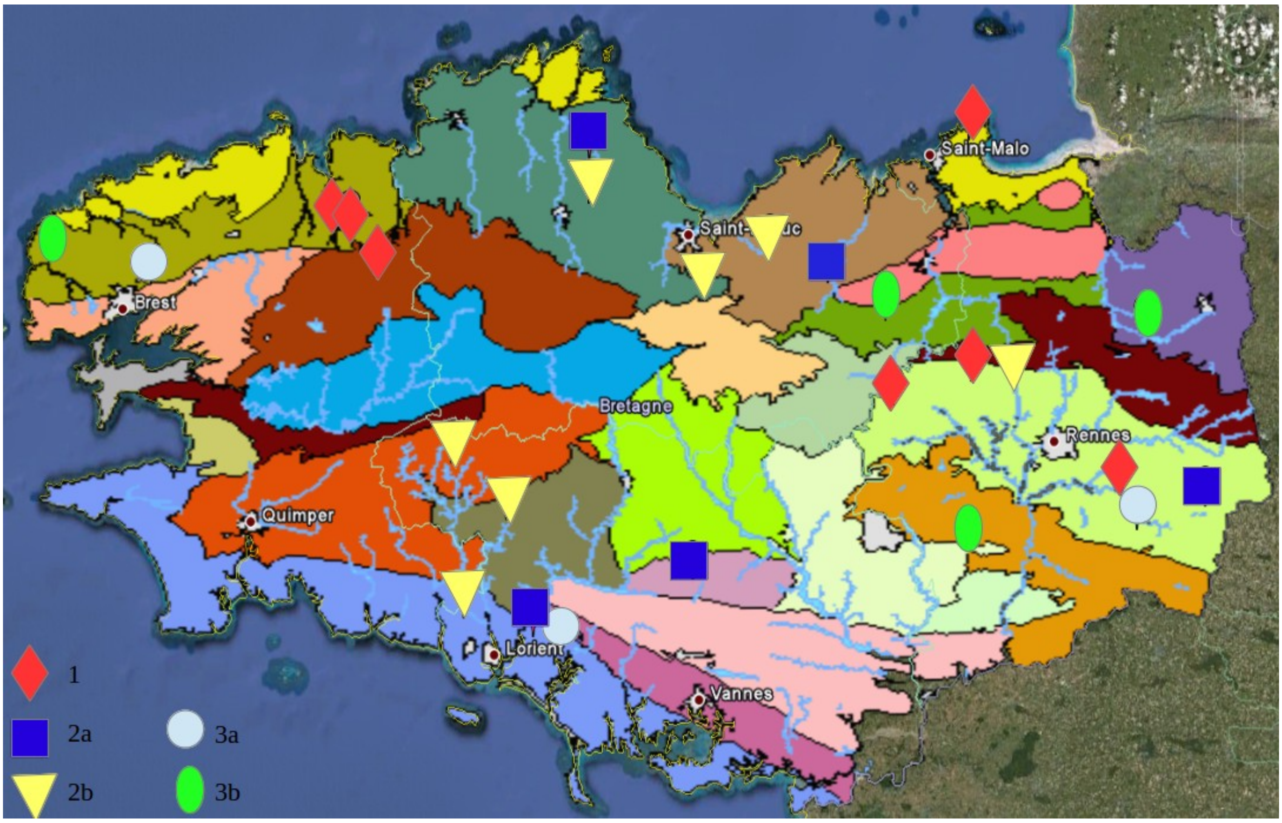


Figure 18: Map of the distribution of the agronomic coherence classes according to the type of farm and the physiographic entity (Lemercier, 2010).

- The type of determinant mentionned for the choice of the crops, as displayed in table 17, cannot be linked to the agronomic class. Livestock is a significant driver for type of crops implemented, as well as the selling price. Except for farms with strong geographical constraints, the distance between a field and a farm does not play a central role.

Table 17: detail of farmer determinants in the choice of their crops

	Determinant in the choice of crops	Number of farmers mentioning it in first place	Number of farmers mentioning it in second place
Economic reasons	Direct remuneration	5	1
	Needs of the breeding activity	7	3
Plot caracteristics	Potential of the plot, nature of the soil	2	4
	Distance of the plot from the farm	2	1
Crop sequence	Time lapse before a crop comes back *(potato, rape...)*	3	1
	Alternating crops	2	3

3.2.3.2. Differences between classes

- *Soil description and knowledge on ecosystemic services*

We tried to do a brief and concise diagnosis of farmers knowledge and perception of their soils. Therefore we investigated 1) the rigour and precision of their speech and 2) the veracity of their soil descriptions. In addition, we also investigated farmers' knowledge on ecosystemic services.

First, concerning soil descriptions, 3 farmers from class 1 are using vague terms ("soft soil", "light soil"), whereas in all the other groups farmers give precise descriptions of the type of soils they have on their farm. By saying this, we encompass that farmers know the type of texture of their soils, the depth and they are able to give a precise estimation of the organic matter content. In addition, 5 farmers gave indications about the spatial heterogeneity in soil texture between their different plots, and 3 farmers knew precisely the percentage of clay in their soils. We can thus see that in general farmers have a good knowledge of the composition of their soils.

Globally, we notice that classes 2b, 3a and 3b employ an abundant and diverse vocabulary to talk about the physical and biological processes in soils and stress the importance of soil observation in their techniques (for instance the spade test). The list of modifications in the soil that farmers perceived since they implemented MT is richer in class 3 than for the previous classes (as visible in table 18). This illustrates that farmers have better knowledge to talk about their soils and observe its evolution. This could also be explained by the fact that in class 1 and 2, 5 farmers are still using the plough.

In a second step, we compared farmers descriptions with soil typology established by Sols de Bretagne (Lemercier, 2010) for the speed of drainage and drying, the sensibility to surface sealing and the proportion of stones. It has to be recalled that this is farmers' estimation, and moreover it would be hasty to conclude on farmers knowledge based on this superficial description of their soils. However, this might be useful to assess if farmers express a lack of information on soils physical properties.

First, we observe that only 7 farmers describe their soils as very sensitive to surface sealing whereas 18 farmers are susceptible to have soils exposed to surface sealing (silty soils for instance). We can thus make the hypothesis that farmers have seen an evolution in their soils regarding surface sealing and base their comparison on the state of ploughed soils (before they stopped ploughing or their neighbours' fieds).

In class 1, with one exception, farmers describe rather shallow soils, not sensitive to surface sealing and with rapid soil drainage and drying. In classes 2 and 3, two groups of soil physiographic entities appear, on the one side soils with high agricultural potential (brown soils in the basin of Rennes, silts) and on the other hand, more difficult areas of diverse kinds (hydromorphic soils in basins, coastal areas with drying soils). As a result, both categories encompass very diversified soil types, with various depths, drying speed or sensibility to surface sealing. Therefore, we can say that MT techniques can be adapted to various pedo-climatic contexts and different soil kinds.

Although this would need a more in-depth study because of the numerous parameters to take into account and the spatial variations, we can say that globally, farmers descriptions are in adequation with the physiographic entity they belong to. Moreover, farmers did not express the need to gain knowledge on soil types and properties, but all without exception were interested in soil biological processes.

Finally, in farmers' answers to the question “To you, do reduced tillage techniques provide services to society?” we observed a gradient in the number of mentionned ecosystemic services. Indeed, all farmers in class 3 were able to cite 3 to 6 ecosystemic services, whereas it ranges from 1 to 3 services mentioned in class 1, and 1 to 4 in class 2.

	1a (n= 7)	2a et 2b (n= 12)	3a et 3b (n= 7)
Age and number of years in activity	No clear trend.		
Number of years in RT	No clear trend.		
Type of farming system	No clear trend.		
Localisation	No clear trend.		
AUU/AWU	39 ha/AWU (min= 25, max= 58)	48.7 Ha/AWU (min= 20, max= 177).	58.3 ha/AWU (min= 21, max= 120)
Operating costs	Wheat : average 426.9€/ha (n= 6, min= 315, max= 515) Maize : average 507.8 €/ha (n= 5, min= 462, max= 543)	Wheat : average 394.4 €/ha (n= 8, min= 288, max= 482) Maize: average 494.1 €/ha (n= 8, min= 423, max= 634)	Wheat : Average 263.6 €/ha (n= 4, min= 186, max= 450) Maize: average 411.8 €/ha (n= 4, min= 303, max= 485)
Soil description	Vague terms (« soft soils ») or technical description	Very diverse soil natures but precise descriptions (type of texture, depth and estimation of the organic matter content)	
Perceived modifications	Few perceived modifications (0 to 4), mainly bearing capacity and earthworms	Several modifications perceived (2 to 6): bearing capacity, earthworms, water infiltrations…	
Equipments	- Investments in specific RT machinery are not systematic - All have at least a chisel or a decompactor	- Investments in specific RT machinery are various and not systematic.	- Possession of a stubble tiller is not systematic - some own strip-till machinery
Change of practices	- Shifting sowing dates is not systematic - Highest sowing densities	- Systematic shift in sowing dates - Intermediary sowing densities	- Systematic shift in sowing dates - Lowest sowing densities
Encountered problems	- Soil compaction (after grain maize) - slugs, large predators - fusarium wilt - weeds (couchgrass, goosegrass, speedwell, bindweed…)	- technique (sowing, fertilisation) - slugs (6 farmers) - fusarium wilt, eyespot, take-all, glume blotch, rust)	- technique (sowing) - slugs (5 farmers) and pests (wireworms, voles) - few diseases evoked
		Evolution of weed populations : Poaceae, dock, goosegrass, speedwell, couchgrass…	
Implemented solutions	- ploughing (2 farmers) - resowing (2 farmers) - modifications in the rotation - chemicals, resistant varieties	- slug poison (2) or not (2) - resistant varieties, fungicides - changes in the rotation - herbicides, soil cover optimisation	- choice of the sowing tool - slug poison (2) or not (3) - herbicides, undersowing, changes in the rotation
Ecosystemic services	0 to 3 services mentioned, mostly decreasing GHG emissions	0 to 4 services evoked, mostly soil protection and water quality preservation	3 to 6 services mentioned with a wide variety of topics

Table 18: Similarities and differences between the agronomic coherence classes

In addtion, one person in class 1 did not mention any service, and this was also the case for two farmers in class 2. The persons who did not talk about this subject explained they were not interested or they did not know In class 1 (n= 7), four farmers mentioned the decrease in Green House Gases (GHG) emissions resulting from MT and three farmers evoked the positive role played by MT in battling erosion and protecting soils. In group 2 (n= 12), this last concerns is also important, as six farmers talk about it. Another concern arising from this group is the preservation of water quality and regulation processes (floodings, deepwaters) which is mentioned by 5 farmers. In group 3 (n= 7), all ecosystemic services are evoked at least once, and no service can be considered as more important than the others. All farmers mention water quality preservation, and five farmers talk about erosion concerns.

- *Evolutions in cropping practices*

- In order to cope with a different dynamic in soil warming, due to less tillage, farmers change their sowing dates: earlier sowing for winter wheat in autunm and later sowing in spring for maize. These changes in sowing dates appear widespread, except for 4 farmers in class 1.
- Moreover, in group 1, two farmers resorted to ploughing, namely in order to solve sowing problems in humid conditions after grain maize. One could suppose that more than one farmer had to face difficult sowing conditions for winter cereals because of the humid autumn in 2012,nevertheless only this class seems to have used ploughing. The second case is more specific as it relates to an organic farmer aiming at controlling weed infestation. Indeed ploughing in commonly used in organic farming for this purpose.
- We noticed that sowing densities also follow a gradient, for both surveyed crops. As the agronomic coherence classes are not linked to pedo-climatic conditions, we can say that sowing densities are also independent from a specific pedo-climatic context. For maize the differences are not very pronounced, as it ranges from 95200 plants/ha in class 1 (n=6, min= 75000, max= 10200) to 90200 plants/ha in class 3 (n= 6, min= 80000, max= 99000). This figures match the densities commonly practiced in Brittany.

  For wheat, group 1 shows a higher average density (150kg/ha, n= 5, min= 140kg/ha, max= 150kg/ha) than the other classes (133kg/ha in class 3, n= 7, min= 120, max= 160). We can thus observe a strong variability, but there was no specific question about the reason for such choices. Many factors enter into account in the choice of the sowing density : to the initially targetted number of plants per square meter (based on the soil type and the sowing date) should be added the estimated loss rate at emergence (based on the proportion of stones, the sowing depth, the seedbed conditions). One should also consider the weight per thousand seeds of the chosen variety.

A table of advised sowing densities for wheat in Brittany according to the sowing date and the soil type can be found in appendix 9. Considering the observed sowing densities and the fact that farmers declared to sow in an early period in autumn, we can say that the densities are rather high compared to ploughing. This can mainly be explained by the higher loss rate at emergence. Integrated cropping practices, based on decreased sowing densities leading to reductions in inputs (less lodging or fungal diseases) compensating yield reductions in the gross marging calculation, appear difficult to apply to MT techniques. We can also make the hypothesis that farmers in group 1 feel more the need to securize their yields with a higher sowing density, taking losses at plant emergence into account.

- Concerning crop rotations, it is interesting to note that while all farmers of class 3 mentionned evolutions in their rotations, it is not systematical in classes 1 and 2 (respectively 4 (n=7) and 7 (n=12) farmers made changes). In total 18 farmers redesigned their rotation, doing one or more changes.As shown on figure 19, the modifications can be done either on lengthening the rotation with the introduction of a new crop (thus one more year in the rotation), either by means of a reorganisation of the crop sequence. Farmers in class 3 have made changes of the different kinds and tend to detail general principles they apply for the design of their rotation such as for example: avoiding growing wheat after maize, alternate spring and winter crops, or also introduce legumes or other peculiar crops (buckwheat, flax).

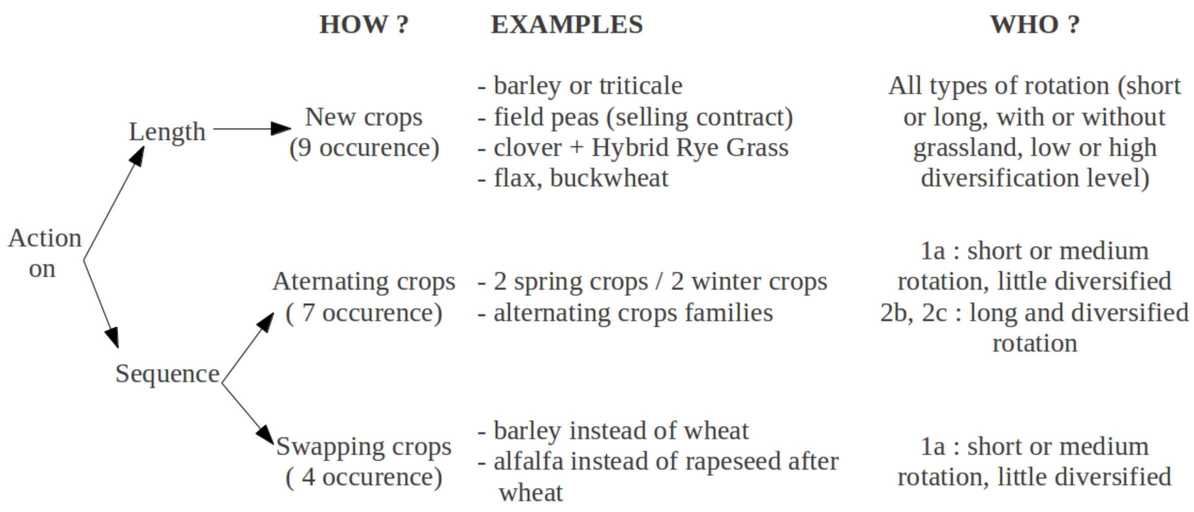


Figure 19: Arborescence of the changes made in the crop rotations by farmers (n=18).

It is dificult to estimate the scope of these changes in the rotation (for instance on the length of the rotation) given that the survey did not enquire on the initial rotation. However, this can already be considered as a result on the action principles farmers implement when the reconsider the design of their rotations.

- Concerning the Treatment Frequency Index (TFI), we had difficulties to collect complete data for many farms. Moreover, most farmers able to provide their TFI figures are already engaged in an approach of reduction of their use of phytochemicals (5 farmers in our sample are engaged in Agro-Environmental Measures contracts) and therefore it does not necessarily reflect the reality. We can nevertheless point out that 2 farmers in class 3 manage to grow wheat without using any fungicide, which is thus in opposition to the fear of more occurences of fusarium (and mycotoxins) on wheat grown with MT. Appendix 10 displays the data we were able to collect concering the Treatment Frequency Index (TFI): already calculated indicators or applied doses of plant protection products in order to determine it by ourselves. In comparison to the references in Brittany (2008), no significant trend arises: for wheat the farmers in our sample are below the average (2 farmers) or at a similar level (3 farmers), whereas for maize, farmers appear above average (3 farmers) or below (3 farmers).
- Another indicator that can be used to describe farmers practices is the way to destruct the cover crop before maize sowing. We observe that in all classes priority is given to mecanical destruction (15 farmers in total). The input of manure combined to tillage operations is the most common way to proceed (11 persons), and 2 farmers add a pass with a roller. One farmer uses a duckfoot tine. Furthermore, concerning total herbicides, farmers use doses between 1L/ha and 2,5L/ha, be it as first operation for cover-crop destruction (4 farmers) or in addition to a previous tillage (5 farmers).

- *Socio-economic differences*

- Concerning yields, as visible in table 19 (next page), we observed no variation concerning maize, be it grain or silage maize. Indeed, for grain maize, the average yields range from 8,6 T/ha in class 1 to 8,3 T/ha in class 2 and 8,4 T/ha in class 3. These figures are close to the results obtained in Brittany for the harvest of 2012 (Ministère de l'agriculture). It is even more difficult to conclude for silage maize because of the small population size (7 farmers are growing silage maize). Yields range from 12,8 T/ha (a farmer in class 2) to 15,5T/ha (a farmer in class 3), and no specific trend was observed.

Table 19: Yields obtained in the different agronomic coherence classes for wheat and grain maize in comparison to average yields in Brittany in 2012. (Ministère de l'agriculture).

	Class 1	**Class 2**	**Class 3**	**Brittany 2012**
Grain maize	Average 8,6 T/ha (n=4, min= 7, max= 9,8)	Average 8,3 T/ha (n= 7, min= 6,7, max= 10)	Average 8,4 T/ha (n= 4, min= 7,5, max= 9,2)	Average 8,5 T/ha
Winter wheat	Average 7,0 T/ha (n= 6, min= 5,5, max= 9,2)*	Average 7,3 T/ha (n= 11, min= 6,4, max= 8,7)	Average 6,5 T/ha (n= 7, min= 5,4, max= 6,7)	Average 7,0 T/ha

** The organic farmer is not included.*

On the opposite, we can easily calculate yields for wheat, and we can observe that the highest average is reached in class 2 (7,3T/ha) and is relatively close to the result in class 1 (7T/ha) but different from class 3 with an average 6,5 T/ha. Class 3 is also below the average yield in Brittany.

- We notice that investments in specific machines for MT are not systematic, namely in classes 1 and 2a, in total the existing material on the farms is used in 8 farms out of 19. Interesting fact, these farms have recently started with RT, except for 2 farmers who explain that it is a choice for them not to invest.
- Moreover, the equipment of farms in group 1 is very similar to the equipment of “conventional farms”. Unlike the other classes, all farmers in 1 own at least either a chisel, either a decompactor. On the contrary, in classes 3a and 3b, possession of a stubble-tiller (disks or tines) is not systematic. The latter are also the only groups having strip-till equipments.
- The distribution of the UAA does not show a clear tendency: the highest average UAA can be found in class 2 with 94ha (min=53, max= 172). Class 1 shows in average 88,1 ha (min= 30, max= 120) and class 3, 76,9ha (min= 21, max= 120). One can notice the extreme variations of UAA between farms. However, the ratio UAA/AWU allows to go further and shows how much time can be dedicated to crops per hectare; we observe a gradient from the average in class 1 (39ha/AWU) to 3 (58ha/AWU). We can understand this result as an increase in time-savings (Munin, 2009). Presumably, this trend arises from choices made by the farmer or on the contrary the time saved in MT makes farm extensions possible, resulting in new time constraints
- We observe a gradient in the opertating costs visible for both wheat and maize. Although the average figure has to be put in perspective given the small size of the groups, it ranges from 426.9€/ha for wheat (n= 6, min= 315, max= 515) in class 1 to 263.6 €/ha in average in class 3(n= 4, min= 186, max= 450), with class 2 at an intermediary level. The same dynamic is

shown for maize: reaching 507.8 €/ha in average in class 1 (n= 5, min= 462, max= 543), it goes down to 411;8 €/ha (n= 4, min= 303, max= 485) in class 3, and class 2 is again in between this two figures.

- *Difficulties mentioned*

- Technical difficulties occurred for 7 farmers, spread over all the classes, namely at sowing (seed positioning and depth, closing of the seed row…). The choice of the sowing tool may help to solve these shortcomings.
- Many farmers (15 in total) evoke damages due to slugs, and it is interesting to see the variety of answers implemented: among them, some used slug poison (three farmers in class 2, two farmers in class 3, on the contrary other farmers refused (two farmers in class 2, three farmers in class 3), explaining that they wanted to preserve beneficial insects which normally attack slugs.
- Weed management difficulties have been mentioned by 19 farmers. Evolutions of the weed flora have also been observed, according to some farmers, there are more Poacae at the expense of dicotyledonous (bromegrass, goosegrass, wild oats, tuber oat-grass…). The main answer given is the use of herbicides (one farmer in class 1, five farmers in class 2, two farmers in class 3), as well as optimisation efforts of soil coverage in classes 2 and 3 (two farmers in class 2, three farmers in class 3).
- Difficulties in fungal diseases management are mentioned by six persons (two farmers in class 1, three in class 2 and one in class 3), mainly concerning increased fusarium wilt infections. A few farmers (six farmers) had to face other pests (game, maize flea beetle, wireworm).

SUMMING UP

- Farming types are distributed among the different agronomic coherence classes, and the same observation can be made for the physiographic entities. Therefore, the type of farm or the pedo-climatic context are not linked to the kind of tillage practices used.

- The surveyed farmers know their soils well: they are able to talk about it with precision (4 exceptions in class 1) and are globally in adequation with the the analysis performed by Sols de Bretagne (Lemercier, 2010). Farmers show an interest in biological processes in soils. Knowledge on ecosystemic services appeared increasing from class 1 to class 3.

- Farmers have adjusted their cropping practices to ploughless techniques, as they have changed their sowing dates (earlier in autumn, later in spring) and sometimes sowing densities (namely for wheat). Some have also modified their rotations. Conserning the encountered problems,

damages caused by slugs and evolutions in weed flora are the most frequently quoted difficulties. n class 1, using the plough is not excluded.
- Yields are close to the average in Brittany, with the exception of class 3 for winter wheat. However, the operating costs in this class are also lower than in the two other classes. Investments in specific equipments are not systematic, excepted in class 3. Finally, the ratio UAA/AWU shows that the time dedicated to crops per hectare is decreasing, with the lowest value in class 3.
A scheme summarizing the main differences between the classes is available in appendix 11.

3.3. Sociological questions

3.3.1. How does innovation happen?

3.3.1.1. Innovation as an answer to unsatisfactory situations

In a complex and uncertain situation, innovation allows a permanent and unpredictable adaptation to a moving context (Faure et Compagnone, 2011). Thus, innovation appears to be an answer to difficulties or to an unsatisfactory situation, and farmers' statements about their motivations to convert to reduced tillage corroborate this idea.

Indeed, the first reason mentioned (25 farmers) often refers to economic and social improvements, such as savings on working time and costs. Farmers have encountered difficulties, namely in the case of a short time window for cereals sowing after late grain maize harvests. For three farmers it has been a consequence of a sudden decrease in labour availability (accident) or material (broken plow). A reduced tillage intensity can also decrease operating costs (machinery wear, fuel consumptions...) while maintaining yields at a similar level. But as farmer n°5 expresses below, it can also be a strategical choice in the farm management, namely in cases where the breeding activity is the most profitable activity on the farm.

« When it's expensive, you pay attention! It's under a constraint that you become intelligent, that you start paying attention! [*laughing*]" (farmer n° 22)
« It saves time. The planning is easier to manage. " (farmer n° 20)
"Basically we are more stock breeders, our cows are what we like most. […] Time is something important in dairy farms nowadays. Because we're always having more milk to produce and we do it." (farmer n° 5)

In addition to socio-economic motivations, 6 farmers mentionned they have also faced specific problems on their fields, for example compaction, poor water reserve capacity, drainage, low pH levels or loss of organic matter. This has increased their awareness of soil processes and they had everything to gain by trying a change in practices. For two more farmers, having a”living soil” was the main reason to start.

« My soil analyses drew my attention, the organic matter content was dropping, I thought something was wrong” (farmer n° 19)
“… the environment also behind, because even about leaching from slurry and so on, everybody is talking about it… phosphorous and all that, farmers are responsible… (farmer n° 21)

Many farmers with socio-economic motivations (11 out of 25) express an evolution in their motivations: they have stopped ploughing for economical reasons and gradually became aware of the impacts their tillage practices could have on the soil biology and on the environment. Among them, 6 persons talk globally about their concerns on “agronomy” or “life in the soil”, whereas the 5 others express the idea of responsibility towards the environment. All gradually became aware of a wider system with its interconnections, that their own farming system.

“ It’s not only about decreasing the costs, we know that the more we move the soil, the more we are disrupting everything” (farmer n° 23)
“After the organisational aspects, I saw that benefits on the soil took place and little by little I started reflecting on my crop rotation, on this notion of diversity, of rotations, and also diversity of cover crops.” (farmer n° 29)

Sociological studies have described the details this process (Goulet & Vinck, 2012, Stassart & al, 2013): from technical questions, the supression of ploughing evolves and the field of concerns is enlarged to the soil management, which is no longer considered as simply a production support. Farmers talk about “living soils” and go towards a systemic transformation of the interpretation of the function accomplished by the soil.

Finally, we observed no difference of motivation between farmers that recently converted to MT (less than 10 years) and more experimented farmers. In both cases, socio-economic motivations are predominant, and farmers express a shift of their concern linked to their new conception of soils.

3.3.1.2. A variety of attitudes towards the reduced tillage technique

- **Observed attitude toward neighbours**

We can generally see that the surveyed persons express a differentiation between those who plough and those who don't. Farmers become deviant in their neighbour's eye and also consider themselves different according to a number of criteria.

Indeed, many of them (11 persons) talked about a cold enthusiasm of their neighbours for their techniques, and 8 felt they were considered as "fools". This can influence technical choice, namely in regards of residues left on the fields, but can also turn out to be an obstacle for more farmers to convert to MT.

(*imitating*) "You'll see you will return to ploughing, in 2 years you'll return to ploughing!" […] So after it was also a motivation too so as not to take back the plough" (farmer n° 5)
"even if we're convinced of what we're doing, there is still the outside eye, because I'm the only one in my municipality to do it, and even if we don't talk about it, I know they are still waiting to pounce" (farmer n° 8)

Farmers adopt various attitudes to differenciate themselves from "those who plough", ranging from the denunciation of the absurdity of some practices (example below) and the conditions in which they are done (13 occurences), to the differences in economic reasonments (6 farmers point out the fact that high selling prices will not lead farmers to reconsider their crop management, 6 others think that they do not look enough at their margin per hectare). In addition, 16 farmers mention the questioning they went through themselves, and thus deploring it is not more widespread. However, nine farmers reveal that they feel a rising awareness among their neighbours about the benefits from MT, be it economic or agronomic approaches.

"People bring their dejections and stuff, they till the soil, and in some cases the soil looks fine, it seems ready to sow. And on this, no, they re-plough, then they come back again to refine everything and afterwards they sow, and I thought "no, impossible, it doesn't make sense, it's an aberration" (farmer n° 14)
"I know some guys, they only see the soil from the cab of their tractor!" (farmer n°19)
"A majority of people is more a mere executor than anything else, and that suits them probably. They need to have securised systems." (farmer n° 16)

- **Attitude towards other farmers using RT**

Moreover, it appears that farmers also make distinctions between the different approaches of MT techniques: 12 persons distinguish farmers making an opportunistic use of MT techniques from those using implementing associated CA practices and/or NT techniques.

"Everybody doesn't practice in the same way, for some it's purely economic, it's only about " I'll do one passing less, we'll see what happens" but they are not convinced at all about generalizing it" (farmer n° 25)
"In the region, people that aren't ploughing we're still starting to see some, but many haven't reconsidered their crop rotation" (farmer n° 19)

Therefore, a double distinction arises from the difference made not only between plough users and MT users, but also within the circle of MT techniques, between farmers using MT in a less systematic and/or systemic way than others might do. At first glance, the approach of MT practitioners might seem dogmatic, as the following quotation demonstrates.

"Today there is no questioning to have, either the guy doesn't want to get there and he ploughs, either he moves directly to no-tillage, but methods in between… no, that's not interesting, end of the story." (farmer n° 12)

- **Evolution of farmers' attitude**

However, a pragmatic approach of MT predominates and farmers put things into perspective, namely because farmers alone support all the risks. This last point explains why intermediary MT systems are the most prevalent compared to NT and evolutions are, in most cases, very gradual. Indeed, the idea that the change of tillage practices takes time is expressed 7 times, and 10 more farmers explained that the machinery is not the most important for a successful implementation (whereas 3 persons explicitely told machinery was crucial).

As a consequence, 5 farmers also consider the plough as part of their tool box, and 3 farmers actually plough systematically for some or their crops (spinach, green beans).

"Some people are lucid, I have a neighbour… he says, and I also recognize myself in his words namely with the chisel sometimes, he said "I don't plough but pffff! I do an intensive RT which is almost the same". (farmer n° 6)
"We got some backlashes as we wanted to go too fast […] we thought that the dogma had to be applied… that the dogma was stronger than everything else, in fact." (farmer n° 11)
"I'm not closed, meaning that it is not strict RT as some practice, where it's a religion and you do only that because you entered the system… No, I say you need results every time and at some point one should be know to go back to the classical techniques and yes, adapt them." (farmer n° 7)

Every step requires reflection and the will to ensure yields (because of the livestock forage needed, or the income the crop provides) makes it difficult to take risks. One additional brake to taking risks is pointed out by recently started farmers (four of them expressed this idea) : having little buffer, they cannot afford a difficult year.

“But we can’t convert overnight. […] It’s not easy to implement, because today you have a capacity… you don’t have room for error either.” (farmer n° 21)
« the problem is that we are alone, so when you give it a try and when you suffer a failure, you'd go « ok, wait, I'll stay quiet for a little while now" and then you don't make any progress". (farmer n° 24)

This has been the reason one farmer has decided to go back to ploughing in his fields. Recently started in dairy production, he tried to implement MT for six years but did not manage to cope with agronomic problems (poor crop establishment, pests...). One of the main problems expressed during this interview was the lack of support in his surroundings : he felt abandoned by the technician of the cooperative who was not convinced by MT, his neighbours and the local machinery sharing ring were also distant with these techniques. He also talked about a gap between experienced farmers, whose reasonments and concerns are far from those a beginning farmer might have.

- **Particularisation process and adaptation of the innovation to the local context**

The wide range of practices observed in the first part thus results from adaptation of the innovation to a large number of constraints and local specificities. Brives & De Tourdonnet (2010) distinguish two kinds of farmers: farmers able to extract from a local situation knowledge they could apply to their own context while others remain at a stage where innovations elsewhere loose their validity “at home”. In our study, it is not possible to judge and classify farmers in these two categories based on a single interview, nontheless 6 farmers spontaneously expressed this need.

“There is a trial near Rennes. Yes, but Rennes, the world doesn’t end there, we have 200km more to be in Brest” (farmer n° 22)
“We don’t know, in fact, what to do, we hear everything and nothing, every time we go to a meeting we hear “yes, that’s not bad” but after you have to adapt it to your own system” (farmer n° 8)

Farmers produce and request pragmatic knowledge, but according to their ability to translate localized facts into generalities, their expectations from advisory services will be different.

In short, we can see an evolution of farmers departing from dogmatic statements as they start having doubts. This increased consciousness about the limits of their own system leads to a adaptation process of the innovation. Innovation is thus not a linear process but it is particularised: as we revealed in the agronomic part, there are a variety of tools, a wide range of soil types on the farms and differences in the way to manage the crops. (Stassart & al, 2013).

3.3.1.3. Innovation involving the Agricultural Chambers

In this section we will try to investigate the example of Finistère compared to the other departments of Britanny, as a strong local dynamic has been revealed through the interviews. However, the aim of this section is not to induce a competition between departements, nor to minimize the actions engaged by the local advisors elsewhere. Its purpose it to propose a lecture of the elements that seem to have contributed to the emergence of farmers interest and implementation of MT practices in Finistère, in order to lead advisors to a reflection on their activities.

In total, 7 farmers were interviewed in Finistère, and 4 of them belong to the group animated by an advisor of the Agricultural Chamber. First, the observed group dynamic in Finistère relies on the fact that the facilitator and the group learned together at the same rate, as a farmer points out:

"They are very advanced, they have reflections that… the common man doesn't have at all. It's logical, this group, it's a pioneer group, they know each other, they all started more or less at the same time, so they have progressed a little all at the same time. (farmer n° 14)

The local group has been identified as a driver for innovation by other famers (from the departement of from other departements in Brittany).

"There was some research, on varieties and so…They were a driving force. And we miss that, but not a soft thing, something that would really pull us " (farmer n° 6)
"it's true that we have a good group dynamic in Finistère, which allows us to move forward on a lot of issues" (farmer n° 29)

More specifically about the group facilitator, it appears that it's both his availability and accessibility as individual advisor and the group dynamic he contributes to install that are appreciated by farmers:

"If you have a doubt about things, you have our advisor who is quite… he masters and we manage to reach him" (farmer n° 23)
"The whole thing afterwards is about finding people with the skills and the will to do fieldwork […] I think that to vulgarize this kind of techniques, one needs guidance and to do so you have to be hands-on." (farmer n° 29)

Farmers in Finistère express the prevalence of the function of group coordinator (4 persons), and to a lesser extent of personal advisor (mentioned only one time), played by the local employee of the Agricultural Chamber.

From there, one can wonder about the difference with other regions. In Côtes d'Armor, there is no group currently, although there has been an attempt to create one, as the farmer below explains. Farmers feel a little isolated because they cannot relate to farmers having the same practices in their area.

« What I regret, it's precisely that this group we tried to create did not work out.. Well, I think we could made reduced tillage evolve a bit by this mean, emulation between farmers, make trials within the group, or look for something else... Some have information that others don't have, so they bring it... That's an information source I trust. » (farmer n° 19)
« It's a little bit annoying that I am isolated in my type of activity, in my rotation, and in my area... I don't have information from neighbours and that's a pity. » (farmer n°26)

In Ille-et-Vilaine and Morbihan, there are already groups dedicated to crop management, but they do not seem to have a major importance according to farmers. Only 2 farmers mentioned that these group were determinant in theiir decision to adopt MT techniques. Farmers state that the Agricultural Chamber is behind to accompagny them in these practices.

Because, well, now you have « crop groups » but to go to a field visit and ok, is it necessary to treat ? … Pfff, it's ok. It's not for managing things that we know more or less how to manage that we need advice, no, it's more to think outside the box and let's go ! (farmer n° 6)

In Finistère, based on action principles and decision rules, a co-constructed advice emerges in accordance with the constraints and objectives of the farmer, and helps them to master their cropping patterns. Encouraged to develop their own research skills and make good use of various information sources, farmers develop a large variety of practices. In addition, the group contributes to create references (varieties and cover crops testings) and teaches farmers how to make trials and interpret them. Combining different tools (group meetings, personalized advice, diffusion of information…), farmers acquire knowledge and skills to construct and adapt their cropping systems to multiple specificities of agriculture in Finistère (pedo-climatic conditions, productions, labour availability…).

In a context where more and more farmers depart from the scope of classic advisory services (Compagnone, 2011) and institutions withdraw from technical support, it appears that some advisors managed to answer the new expectations of innovative farmers, whereas in other departments where groups exist they do not appear attractive or innovative enough to farmers. Farmers also feel isolated when they cannot really exchange with their neighbours.

3.3.1.4. Innovation with other partners.

- **Attitudes towards the Agricultural Chambers**

The attitudes towards the Agricultural Chambers are often ambivalent and namely influenced by history and nowadays the withdrawal from certain fields and the growing number of charged services (Compagnone, 2011). As a matter of fact, more than half of the interviewed sample (16 persons) pointed out the backwardness and absence of the Agricultural Chambers in the movement of CA and MT.

"They have missed the boat, it's obvious, and so they didn't step in on time and the farmers are doing without them. […] People reflected by themselves, because there was nobody." (farmer n° 11)

However, having made this statement, some farmers (4 of them) reject all inputs from the institution, whereas most of them (12 persons) strongly insist on the role Agricultural Chambers could have to play in the spreading of MT techniques. When there are expectations, some people (6 persons) express a vague feeling (first quotation) whereas others (7 persons) clearly phrase them (second quotation). The expectations of this second group concern the Chamber's role of communication and information to farmers, its ability to set up and animate farmers groups, and also its research function, within the experimental station to produce references as well as expected measures on farmers' fields so as to precise the role of MT in environmental problems (nitrogen leaching, water run-off, erosion...).

"Nowadays I feel that the orientation of Agricultural Chambers rather tends to a quite organic discourse so… anyhow we are also in that approach" (farmer n° 7)
"all the associations we've got, they won't have a role of vulgarization. That's why I remain committed to keep important links with the Agricultural Chamber, with all institutions, economic structures, be it cooperatives or something else, because they stay, and to expand sales forces, we need intermediaries" (farmer n° 29)

- **Information sources**

Each farmer declared combining information from two to five sources which we will succinctly describe.

- **BASE Association** : 13 farmers declared to be members of this MT techniques association, some of them since its very beginning about ten years ago(6 in Ille-et-Vilaine, 4 in Côtes d'Armor, 2 in Finistère, no significant trend linked to the type of farm). Among them, two are also participating in a group of the Agricultural Chamber.

« I joined the BASE network and that allowed me to meet a lot of other people really involved in the process and I discovered new ideas" (farmer n° 19)

Readers of "TCS magazine" (MT tillage, written by BASE members) are also numerous (21 persons) and it represents an important information source for farmers.

- **Cooperatives** can play a paradoxal but nonetheless important role in Brittany. On the one hand, these organisations can influence negatively farmers conversion. Indeed, 3 farmers are growing vegetables (spinach, green beans), and all 3 report that cooperative technicians advise against the use of MT (fear of residues for example). In addition, 5 farmers growing field crops also talked about a negative point of view or a lack of knowledge from their cooperative technicians about MT techniques.
- However, on the other hand 3 farmers have been coached in their conversion to MT by technicians from cooperatives and private companies. Indeed, along with the withdrawal of public institutions from technical advisory services, private stakeholders have arisen, especially in the field of MT (Goulet, 2011).

"There is the guy from Triskalia, who is quite into MT techniques though. Well, in the beginning, we made some mistakes because we weren't vigilant enough. […] But he was well informed, because if we had had a technician completely against, maybe he wouldn't have given good advice" (farmer n° 5)

This leads also to questions concerning the orientation (commercial or territorial imperatives) of this type of support to innovation. (Goulet, 2011) However, farmers also mark a clear distinction between them and the "conventionnal' type of advisory services, and some (6 farmers) insist on their autonomy towards technicians and the commercial nature of their advisory services.

« About technical advice, I want to say –and I won't seem very humble to you- but the few technicians I know… it happens more often that they take my advice, than the contrary" (farmer n° 19)
"It's still very heavy for people a bit novice in agronomy, technicians are mostly used to sell chemicals, fertilisers… […] We depart from the technical training towards systemic notions, and that's completely different because you're talking about transversality, pluridisciplinarity, and that changes a lot of things." (farmer n° 29)

Strategies of agribusiness companies in innovation and farm advisory services have therefore evolved and tend to valorise the knowledge of the farmer and minimize the commercial character of their approach (Goulet, 2011).

- **Neighbours** are also an influent information source that shouldn't be underestimated, namely for farmers that started more recently (example of a pioneer). Indeed, 8 persons described the positive influence a leading person had on their process of adoption and successful implementation of MT practices.

" My neighbour, just there. It's mainly there that we saw, he's innovative in MT. He's the one who started around here » (farmer n° 21)

- **Other actors/medias**: Finally, 9 farmers also find their information in specialised agricultural magazine (not specific to MT), which can also play the role of first contact with MT techniques. Internet (website or magazine) is a relatively recent communication media, nevertheless it has an important influence for 5 of the surveyed persons. Three farmers also rely on private advisors.

« It's clearly by means of the internet forum that I learned these new techniques ». (farmer n° 12)

- 7 farmers started in MT from a personal reflection or because of a local blank in the MT networks, this is especially true for the people using MT techniques for more than 10 years without necessarily belonging to a group in the beginning. These persons them joined BASE (4 persons) or a group of the Agricultural Chamber (1 person). Two of them still are not officially engaged in these network, although they might use them to get information (reading "TCS magazine" without being a BASE adherent, for example).

"I didn't really have any information source at the beginning, it's me who reflected." (farmer n° 13)
"I have a basic principle: if you ask a farmer, so as to do a good job, to be guided by 3 or 4 engineers, you'd better ask directly to the farmer to have the level of an engineer and sort it out on his own" (farmer n° 11)

Globally, farmers declared that they had enough access to information, and that their main obstacle was the lack of time to read or go to meetings and analyse all this information.

3.3.1.5. Attitudes towards research

In our questionnaire, we asked farmers what was globally their feeling about research and if they had specific expectations. It appears that highlight a lack of knowledge on the environmental impacts of MT techniques, rejoining the observations made in the ADEME report (2007). More specifically, the peculiar situation concerning nitrates, phosphorous and water quality in Brittany seems to weigh in farmers concerns. Indeed, 6 farmers state that there should be more measures on environmental impacts. Linked to this expectation, there is the will to gain recognition from politics about the benefits MT techniques could provide and to communicate to general public and to sceptical farmers.

« Figures are lacking today. Because we base our techniques on convictions stating that « yes, there are less pesticides, less nitrates in waters » but afterwards there should be figures into the bargain. We have some with drainage water but that's not enough » (farmer n° 29).
« I think that if we give figures really.... but region per region, not at a national level, it has to be local. Every one says « yes but it's working there, but here it's not the same so it won't work » whereas if we have figures to support what we say... » (farmer n° 14).

In our sample, 9 farmers express criticisms on the research on MT. According to them, this field of research has been restrained, research is biased and experiment design can be improved. From this statement, 3 farmers comment that it is difficult to interprete results from experimental research station and that these results are not complete enough.

4 more farmers also express their disinterest from research and state that innovation is primarily done by farmers.

« Anyways, 80 % of innovations are done by farmrs, the 20 % come afterwards... » (farmer n° 22)
« We're talking about systems, no longer about technique, and so there are a lot of parameters to take into account, and the French research, today, is not able to develop a model for a system. We know how to work on a variable, a parameter, we make it variate and we can compare. But when you're talking about systems it is very difficult to have comparison elements […] there are too many parameters and interactions and finallyit is hard to assess and model the functioning of a soil, an ecosystem. » (farmer n° 29)

As suggestions for improvement, farmers suggest monitoring in a network of fields, redesigning experiments in order to be closer to farmers practices. Five persons felt there was a positive evolution of research towards the field of MT.

« I think the research is moving in this direction, given the proportion of surfaces that aren't ploughed nowadays » (farmer n° 7)

SUMMING UP

- Innovation appears as an answer to a non satisfactory situtation. Socio-economic motivations (decreasing labour time and costs) are prevalent to stop ploughing. Afterwards, with the increasing awareness of impacts of soil tillage (on biological or environmental processes), farmers' motivations evolve.
- Farmers make a distinction with “those who plough” but also inside the group of MT practioners. They depart from dogmatic statements and evolve as they face the need to secure their yields. Their awareness of the limits of their system leads to an process of adaptation of the innovation to their own farm.
- In the cases where innovation happen with the Agricultural Chambers, the observed dynamics is mainly engaged by the joint learning of a group of practioners and its coordinator.
- The other farmers point out the backwardness of the Agricultural Chambers concerning MT techniques, however they insist on the role the institution could play in terms of vulgarisation (information, building groups of farmers) and production of references.
- Most information sources used by farmers have as common point the exchanges between practioners (BASE association, networks of neighbours...). Cooperatives can have a negative influence as well as a positive influence, but farmers insist on their autonomy towards the commercial approach of this source of information.
- Concerning research, farmers express the need to have more studies and measures available on the environmental impacts of MT techniques. On the long run, they would appreciate recognition from politicis and general public concerning the benefits of these techniques.

3.3.2. How to adapt advisory services?

3.3.2.1. Leaving behind the top-down approach

As detailled in the literature study (cf part I) the concept of a system, usually defined as a collection of interconnected parts where properties emerge from the whole, is usually placed in opposition to reductionism (which is considering that the whole equals the sum of its parts). Emerging after the Second World War, reductionist agriculture was based on farmers supervision (top-down approach) to modernize farms with industrialized and mechanised technologies, in order to produce food for a growing population (Goulet, 2011)

We can observe that 22 farmers make this opposition between them and “conventional” farmers which they associate with a reductionist practices.

“And then you have the technician coming and he says “hey! Some fertiliser is lacking” so you and get some, you apply it and it’s ready! (*laughing*) He’s selling you the products and that’s it. And you’re not wondering, you don’t have worries! (*laughing*) (farmer n° 21)
“Today, each time there is an intervention in a plot, we think about the consequences. For example, a guy, a neighbour who is ploughing, we imagine what is happening underground” (farmer n° 12)

Moreover, more than one farmer (8 farmers) said he felt MT techniques were a way to take control again over their profession. This attitude can be linked to their will to be autonomous. Farmers also consider themselves as pioneers, or as open-minded followers, in link with their feeling of being different from their neighbours. They emphasis on their independence and reject top-down approaches, which they assume institutions and scientists adopt.

“We take back our profession a little bit, we begin to gain interest in how things happen and we’re no longer subordinates.” (farmer n° 16)
“The logic is to place themselves (*Agricultural Chambers*) above and inform masses. Well… there a so-called aspect of « master and vassal »… » (farmer n° 11)

3.3.2.2. Taking the particularisation process into account

- **For the farmer**

As detailed previously, the farmer enters in a process of adaptation of the technique to the conditions on his own farm.

“You have to adapt to the local context. That’s what is a bit difficult, because not everybody has the temperament to try out, some people like well-framed things, well established, and no, I wouldn’t be able to give a procedure to anyone.” (farmer n° 19)

- **For the advisor**

However, a farmer willing to use MT is not the only one ongoing a process of adaptation. Indeed, soils have for long been left aside in research focuses and only considered as an “inert” support for crop production by farmers and advisors (CSEB, 2003). Paradoxically, as Baveye & al (2011) point out, humans are in contact with soils everyday and critically depend on them to survive, allowing us to consider soils as the “most underappreciated, least valued, and yet essential natural resource.” (Montgomery, 2007, in Baveye & al, 2011). Thus, although the shift towards the consideration of soils as living organisms has been initiated for a few years, advisors, and more generally institutions such as the Agricultural Chambers, need to review the importance given to soils in their worldview (CSEB, 2003) and adapt their activities to the pedo-climatic context.

3.3.2.3. Considering learning dynamics

The advisor should realise the heritage of the post-war boom years on the vision of agriculture, and go beyond towards a systemic vision. In fact, one could say that the farmer and the advisor have to undergo the same learning process (Goulet, 2011) Thus, this stresses out the importance for each of them to consider the learning dynamic of the other : farmers enter in a learning dynamic of trial and error, so do the advisors.

« When I have a bad yield, I'm also always wondering « what did I do wrong ? ». I analyze what I did, I open my notebook, I write everything down. […] It's with mistakes that you move forward" (farmer n° 2)
"We're always having questions, that's normal, otherwise we don't question ourselves and we're not evolving". (farmer n° 16)

This new conception of the relations between advisors and farmers has important consequences. Indeed, farmers can't expect from the advisor to know everything, and on the other hand advisor should take farmers' inputs into consideration. It is no longer one working for the other, but rather both persons reasoning together on a situation (Desjeux & al, 2009).

This trend has already been highlighted in a study of the dynamics taking place in a MT group of a cooperative (Brives & De Tourdonnet, 2010). Indeed, beside a collective evolution inside the group, a co-evolution with the advisors occured in the same time.

3.3.2.4. Challenges linked to evolutions in agricultural advisory services

- **More and more charged services in Agricultural Chambers**

The Agricultural Chambers too take part in the development of a service economy (Mundler 2006). As a consequence, one could assume that when farmers pay for a service, they expect a clear answer and a more or less easily applicable, "ready-to-use", solution. This is for example what a farmer expresses about the articles in "TCS magazine"

"When you read TCS magazine, it's easy and all but pfff! When you try, you say "Oh! Normally it should work but it doesn't!" "(farmer n° 6)

From this assumption arises a potentially problematic situation, because MT techniques are complex and multiple, therefore they need to be adapted to local conditions. There is thus a need to clarify this with farmers, communication with the advisor is vital to establish that the farmer is paying for the ability to evolve rather than a "ready-to-use" solution.

- **Advisor, coordinator (promoter) or instructor?**

Advisor can have different meanings , according to Faure & Compagnone (2011):

- First, the basic understanding of "Advisor" rather refers to personalised advice, and in a certain way, to a top-down approach. In out sample, 5 farmers expressed an interest towards this type of advisory service.

"There are never two farms alike. Everybody has to adapt […] it's good also to have a personalised advice. To have somebody mastering the subject, he comes on the farm, we tell him how we work […] and then how we can make our system evolve. Both approaches are complementary I think." (farmer n° 14)
"we need concrete things, what can I adapt to my situation?" (farmer n° 6)
« If I am looking for advisory services nowadays, it's personalised advice […] it can be completed by field visits of course, but I think every farm has its own specific needs." (farmer n° 7)

- On the other hand, the term "coordinator" matches with the role played in a group of farmers: orienting the debate, inviting stakeholders, organising field visits… in order to stimulate the exchange of experiences and the fact that farmers learn from each other, and find answers to their questions in their exchanges.

"In this kind of approach, you need to be guided, that's essential. And I think that the revolution has to be first and foremost in the head" (farmer n° 29)
"(*the group*) allows us to exchange about what the ones and the others are doing. Everybody is making little trials at home and so it allows to exchange views on what is working and what isn't." (farmer n° 8)

In our interviews, 13 farmers told they were interested in group meetings. Their would mainly go for the possibility to exchange with other farmers, the support a group provides when starting with MT techniques. In addition, experimentations and trials within a group of farmers is also very motivating for 4 farmers.

– Finally, the aim of an "instructor" is to lead farmers so that their practices satisfy environmental and regulatory requirements. This part of the advisory work has strongly been decreasing the past decades (Compagnone, 2011) and we observe that none of the interviewed farmers is interested in this service.

At least 4 farmers showed an interest in combination of group coordination and personalised advisory services. We can see that farmers' expectations vary, thus continuing to propose a wide range of tools is a good solution: from personalised advice based on co-active research of solutions to group coordinator promoting networking of peers in order to confront directly their experiences. This statement can be linked to Compagnone (2011): an advisor's work could be defined as "supporting farmers and helping them to build a network".

- **Multiplying the approaches and perspectives**

Goulet (2011) analysed the approach of private companies and cooperatives in advisory services and highlighted a strategy that tends to minimise the commercial character of the approach and instead valorise the farmer and his knowledge. Nevertheless, the tools used by the technicians are relatively similar to the ones used by advisors of Agricultural Chambers (group meetings, personal advisors...). This leads us to the conclusion that the used tools appear adequate, whereas the scheme of the relation between advisor from the Agricultural Chamber and farmer has to be redesigned: it is no longer the first one working for the second, but both working and making progress together.
Moreover, the same author emphasis the need to enlarge the scope of issues to other entities such as the soil in socio-technical networks about MT. (Goulet, 2011) Indeed, as described in part 3.2.3.2., farmers show interest in biological processes taking place in soils. They also expressed clear expectations on a few subjects such as hardy varieties (namely maize variety with a good starting vigour) and fertilisation. The general context around water pollutions (nitrates, phosphorous, pesticide residues) is also present and farmers are interested in scientific measures in order to clarify the impacts MT techniques can have.

We observed a strong interest of farmers in group meetings, however different modalities have also been detailed. Indeed, most farmers would like local groups, but one farmer (already in a local group) also expressed the idea of a regional group in order to federate farmers and build a network. Furthermore, it appears crucial to make groups of farmers with a similar level, and 6 farmersexpress the idea that there can be a gap between the most advanced farmers and their own level of experience. Indeed, for the first approach of MT, it is difficult, and even dissuading, to consider the reasonments of more experienced farmers. Farmers that recently stopped ploughing are most likely looking for answers to their specific concerns. For a farmer using MT for several years, coming back to a more basic level can also be disappointing. Therefore, on a regular basis it would be better to make groups of farmers on the same level. Nevertheless, opportunities for experienced farmers and beginners to exchange should not be banned, as both can learn from each other.

> "It will scare them. I think that in the beginning, if we want to start something, you have to put in the same area people on the same level in the same time... because otherwise I think it can be scary!" (*laughing*) (farmer n° 14).

In addition to the answers farmers can get from other farmers with the group dynamic, experiments carried out in a group appear also popular. Indeed, it allows farmers to understand the impacts of practices, but also to produce knowledge in the fields, for instance with trials of cover crop association, or comparisons of different tillage tools.

> "Every company, be it a big firm or a small or medium business, dedicates a portion of its budget for research and development, so that they can make progress. Well, here it's the same. If every company or farm made some reasearch and development […] and it's not a big budget, we're not a big farm here, right... Then we could progress!" (farmer n° 22)

Moreover, farmers also showed interest in field visits and machinery demonstrations, and regret that they always meet the same persons at these events. This could suggest that communication to attract new farmers might need improvements. Conferences, with specialists, experienced farmers or foreigner stakeholders (as it is done in the BASE network) also interest farmers.

SUMMING UP

- To adapt advisory services to innovative farmers, it is important to replace the farmer and his knowledge in the center of the relation scheme with the advisor. Therefore, it is necessary to depart from a top-down and reductionnistic approach.
- Soils, which have long been considered only as an inert support to agricultural production, are a central concern in MT techniques. This requires from advisors to enter a particularisation and adaptation process of the innovation to the context of each farmer.
- Moreover, the systemic vision in MT techniques lead to a learning process for the farmer, but also for the advisor. The consequence is that each stakeholder should consider the learning dynamic of the other: the farmer cannot expect from the advisor that he knows everything on the subject, because of the complexity of these systems. On the other hand, the advisor has to build the advice while taking the knowledge of the farmer into account.
- Large scale evolutions of advisory services lead to the emergence of new challenges. The growing proportion of charged services within the Agricultural Chambers requires a clarification on the nature of the relations between farmer and advisor: the advisory service concerns the ability to make a system evolve rather than a “ready-to-use” solution. Moreover, the advisor has nowadays to fulfill two functions: first, personalised advice, and on the other hand the role of group coordinator.
- The tools used by the Agricultural Chambers appear adequate to play these different roles, but the relation scheme between farmer and advisor has to change. Group dynamics are appreciated but some farmers are interested in a combination of different kinds of advisory services. The multiplication of the approaches and perspectives thus appears as a solution to meet a large audience.

A scheme summarizing the main caracteristics of this analysis is visible in appendix 12.

4. Discussion, limits and perspectives

4.1. Comparison with previous studies for the cropping practices

First, we pointed out a few singularities of the farms composing our sample. It appears that the same distinctive features can be found in the study of Perche & al (2009) and Corbel (2009) : the farms surveyed about MT are bigger than the average farm in Brittany. One could make the hypothesis that bigger farms have more the necessity to save time. Moreover, farms as societies in their legal structure were also more present in the sample studied by Perche & al. However, in that study, the surveyed persons tend to be rather young farmers (51 % between 35 and 45) while our sample followed the age distribution found in Brittany among farmers. Finally, concerning the lack of correlation between MT techniques and a peculiar farming type, this result is also confirmed by Perche & al and Quenea (2006).

On the one hand, Quenea (2006) established two group of practioners for wheat establishment. First, a group using deep tillage with rather similar crop management sequences to the ones presented here, except that the use of p.t.o animated tool (Horsch type) appears more widespread. The second group using superficial tillage is identical to the first category in our classification.Munin (2009) observed rather similar crop management sequences in a small scale study in Côtes d'Armor (direct sowing ; stubble tillage and sowing or topsoiling and sowing).
Munin (2009) also analysed data from the large scale study in Brittany in 2008, and revealed that the number of passes for wheat establishment after maize reached in average 5,7 passes, whith large variations as it ranged from 3 (9 farmers) to 4-5 (32 farmers), 6 (22 farmers) or 7 and more (35 farmers).
On the other hand, for maize establishment, direct drilling appears very limited (only one farmer) in the study of Quenea (2006), and this is confirmed in our survey. However, superficial tillage was absent from the described crop sequences in that study and all the other farmers were using top soil cultivators. On the contrary, in the present survey 9 farmers were using medium intensity shallow tillage for maize. In the study of Munin (2009) in Côtes d'Armor, there were also three types of CMS of maize establishment : direct seeding, reduced tillage and deep tillage. This could possibly show an evolution since 2006 in the sense that more farmers dare to decrease tillage in maize or else that the MT techniques have been improved. Quenea also highlighted that the strategical importance of maize (for animal feed) and the specificities of this plant (short

cycle, root system sensitive to compaction...) hinder the development of MT techniques in comparison to wheat.

We can thus conclude saying that farmers in MT have a tendency to increased soil tillage (deep and/or repeated tillage) for maize establishment, with the dual purpose of incorporating organic fertilisers and manage weed infestation, whereas they generally establish wheat in a more simplified way.

Furthermore, we investigated cover crops and rotation implemented by farmers in Brittany. In the study of Quenea (2006), the diversity of crops was similar between the MT and the ploughing group) but a significant difference could be observed between farms with soilless breeding activities and the other farms (with ruminants or specialised in crop production). This leading effect of the type of livestock of the crop diversity was not observed in our study.

Moreover, concerning cover-crops, in the study of Quenea mustard and phacelia were the two main species used, and only 3 farmers out of 18 were using multiple species mixes. This result is strongly contrasting with our study, and we can make the hypothsesis that farmers practices and knowledge about the associations of species have evolved, whereas in 2006 the establishment cover crops in winter was not yet mandatory (it became compulsory with the fourth Action Plan in 2009). Perche & al (2009) recorded that 12 % of the surveyed farmers made a modification in the type and the management of their cover-crops, a low proportion compared to our study where most farmers implemented multiple species association in cover crops.

Concerning the description of agronomic classes, it is not always easy to compare since this approach has not been used before. Nevertheless we can compare the main trends expressed in previous studies. Corbel (2009) reported that farmers mainly noticed an increase of soil bearing capacity, especially since that study was conducted in a watershed with silty and clayey soil, rather sentitive to soil compaction. However, this improvement could as well be linked to the use of cover-crops because even farmers ploughing every other year report this modification (thus benefits from non-inversion of soils can not explain this change). On a larger scale, our study proved that farmers had a good general knowledge of their soils. We saw differences in the number of mentionned soil modifications, but improvements in soil bearing capacity also turned out to be the most frequently qutoted. In addition, we investigated farmers' knowledge about ecosystemic services, and it appeared that in class 3 knowledge was widespread, whereas the number of services evoked in class 1 and 2 differed.

Quenea (2006) was able to show that farmers having invested in a specific MT drill and having more years of experience in MT enter in a global approach of costs reduction, visible through lower consumption of plant protection treatments and mineral fertilisers than farms using the plow. However, the author points out that this decrease in the use of mineral fertilisers and plant proctection products is not systematic. In the present study, we saw that changes in farmers practices regarding sowing dates (earlier in autumn and later in spring) were widespread whereas sowing densities remain globally high for wheat (in comarison to recoomendations for early autumn sowing), and show no significant trend for maize. Evolutions in crop rotations were systematic in class 3 and variable in class 1 and 2. Though we were not able to draw conclusions concerning the Treatment Frequency Index, we could see that some farmers have indeed entered in an approach of reduction of their inputs (Agro-Environmental Measure Contract for instance).

In addition, regarding socio-economic characteristics, Perche & al (2009) highlighed the high proportion of farmers (66 % in their study) which does not use specific seeding tools, and Quenea (2006) made a similar statement. This trend is also confirmed in our study. Quenea also stated that savings on fuel, working time and mecanisation costs in MT strongly depend on tillage depth, pulling power and number of passes required for crop establishment. In his study, the CMS classified as « reduded tillage » are distinctively detached from the CMS in ploughing, whereas « deep tillage » CMS, which most of the time use topsoiling operations, show fuel consumptions for crop establishment similar to those obtained with ploughing. Some farms using deep tillage had similar fuel consumptions or mecanisation costs to ploughing techniques, however this statement not be generalised because of the great variability of ploughless crop management sequences for maize, resulting in a wide range of consumptions. Nevertheless, « deep tillage » allowed farmers to meet the goal of reducing labour peaks and mechanisation costs.

The savings on time and fuel appeared significant for the farmers chosing to go further in the simplification of their CMS. However, difficulties linked to this decreased tillage intensity can appear (especially in maize establishment) on an agronomic and economical (yields losses) level. Munin (2009) showed that the establishment time logically decreased with the level of simplification of the tillage. However, between 2 farmers practicing the same CMS, this study demonstrated that the time spent per hectare for each operation can vary a lot, and thus the labour required for crop establishment also. The time spent per hectare can vary of 1hour for autumn cereal establishment, and up to 2 hours per hectare of maize for similar CMS. Castel

(2009) stated that mechanisation costs in MT are almost at the same level than with ploughing because savings made at crop establishment only represent one fourth of the global costs, and in addition, deep tillage does not allow important savings. However, this study was onlu conducted on mechanisation costs and did not take working time into account.
Finally, regarding the obstacle farmers have to face, weed management is the first difficulty mentioned in the study of Perche & al (2009), by 39 % of the surveyed farmers. Corbel (2009) also reported an increase in weed pressure, which they manage with plant protection products or an optimisation of cover crops. This trend is also visible in our study, along with damages caused by slugs, which we can link to the wet climatic conditions in 2011 and 2012.
Pests are also the second problem in the study of Perche & al (26 % of the farmers), followed by mycotoxins in cereals (12 %) and sowing irregularities (11%). These results are rather similar to ours.

4.2. Links with literature in sociology

We highlighted a dynamic starting with the questioning about the relevance of ploughing and thus, that conversion to MT occurs in answer to an unsatisfactory situation. This trend is also expressed in the study conducted in 2009 by Perche & al in Brittany. Likewise, Corbel (2009) in a study on 30 MT farms in the Leff watershed (Côtes d'Armor) pointed out that MT allows farmers to be more flexible, in a contxt of labour planning reorganisation (decrease in workforce, less resort to agricultural) in parallel to an intensification in capital of the farms (increased size of the cropped area or of the breeding activities). It is interesting to note that in Corbel's study farmers express strong motivations to use MT in order to reduce constraints of their biophysical environment (soil drainage, compaction and/or soil cohesion in dry periods) whereas this trend appears only secondary in our study. We might explain this with the specificities of the surveyed area in the Leff watershed, where some areas show very clayey soil texture and hydromorphic conditions.
Then, we described the range of attitudes farmers adopt towards plough users but also within the circle of MT farmers. As Goulet (2008) explains, a double processus is engaged : on the one hand stakeholders with similar practices and worldviews associate, on the other hand they dissociate themselves towards others. Riousset (2011), in a caracterisation of the influence of a support forms on cropping practices, talks about « double deviant » no-tillage farmers : they are

different in their neighbours' eye but also within the group of MT users. A strong collective identity is emerging from dissociations (Goulet, 2008). Given the fact that the study of Riousset (2011) was conducted in South West France, with groups of private stakeholders, we can thus bring evidence that this idea can be transferred to a different context in Brittany.

Furthermore, we drew a parallel between our interviews and the work of Goulet & al (2008): innovation is a not a linear but a swirling process. Indeed, farmers go through a particularisation process which can explain the wide variety of implemented practices given the large range of tools, soil types on the farms and differences in the way to manage the crops. (Stassart & al, 2013)

In the following part of our reflection, we tried to gain understanding on how farmers innovate with the Agricultural Chamber. We observed that in Finistère, a group dynamic started more than 10 years ago, where the coordinator and the group learned together at the same rate. This distinctive feature can also be found in studies of group dynamics in other regions and organisations studied byCompagnone (2011). This author points out the strong decline of the role of instructor (helping farmers to comply with legislation) in advisory services, in favour of the functions of group coordinator and personal advisor. Goulet & al (2008) stated that farmers innovate for and by themselves. Indeed, we observed an ambivalent attitude of farmers towards the institution the Agricultural Chamber represents, which can be linked to history, the progressive withdrawal from certain fields and the growing number of charged services (Compagnone, 2011). Nevertheless, the technico-economic context plays an important role in the development of MT techniques. Corbel (2009) could observe correlation between the date a farmer became member of a specific private advice office and the date where farmers stopped ploughing. Moreover, while cooperatives are a widespread information and technical advice source in Brittany, their representativity in her study remained rather limited, which was also the case in the present survey, and explanations on this reluctance are similar (fear of mycotoxins in cereals). Finally, the association BASE was considered as an important source of information in both studies, mainly for its action of diffusion of farmers' experiments and the exchanges within this circle. Corbel noticed that these two aspects also take place in an informal way in the field, namely between neighbours and farmers confirmed this trend in our study.

4.3. Crossing agronomic and sociological analysis: main tracks for improvements of advisory services

Farmers enter learning dynamic as they progressively gain a more systemic view of the interactions between soils and the other components of their cropping system, and they start a particularisation process of the innovation (to stop ploughing) to their own local context. We can say that the agronomic classes reflect different stages of this process.

One could think that the aim of a farmer is to evolve, to start in class 1 and progressively evolve until class 3. In fact, this has been the case for some farmers. However, as we detailed, farmers can stay in class 1, whilst others started MT already in class 2 or 3. Therefore, it is necessary to take the many brakes farmers encounter into account. Indeed, farmers enter in a learning dynamic and start questioning many topics they have learnt, experienced or they see neighbours doing. Agronomic uncertainties (namely regarding maize), economic risk management and social differences can hinder the development of MT.

Time is a key component of this process. Many farmers stop ploughing because it saves time, but the time they might save has to be reinvested into the search for information or training. Furthermore, the adaptation process is very slow, as farmers can only do one trial per year, at crop establishment. Exchanging experience allow them to make faster progress, and to dilute a little the risks. Finally, farmers stress the temporality of the learning process (over several years) which leads them to a new conception of soils and of what can be called a “good” cropping practice. This process has also been pointed out in sociological studies (Stassart & al, 2013).

Farmers reject a top-down approach from scientists and advisors, in which their role would be limited to the implementation of the techniques proned by their advisor. This need to reconsider interactions among agricultural stakeholders has been stated worlwide many times, as Le Gal & al (2011) demonstrated. The scheme (figure 20) displays the two conceptions of the innovation process at stake and highlights the interconnections in an interactive frame for innovation support.

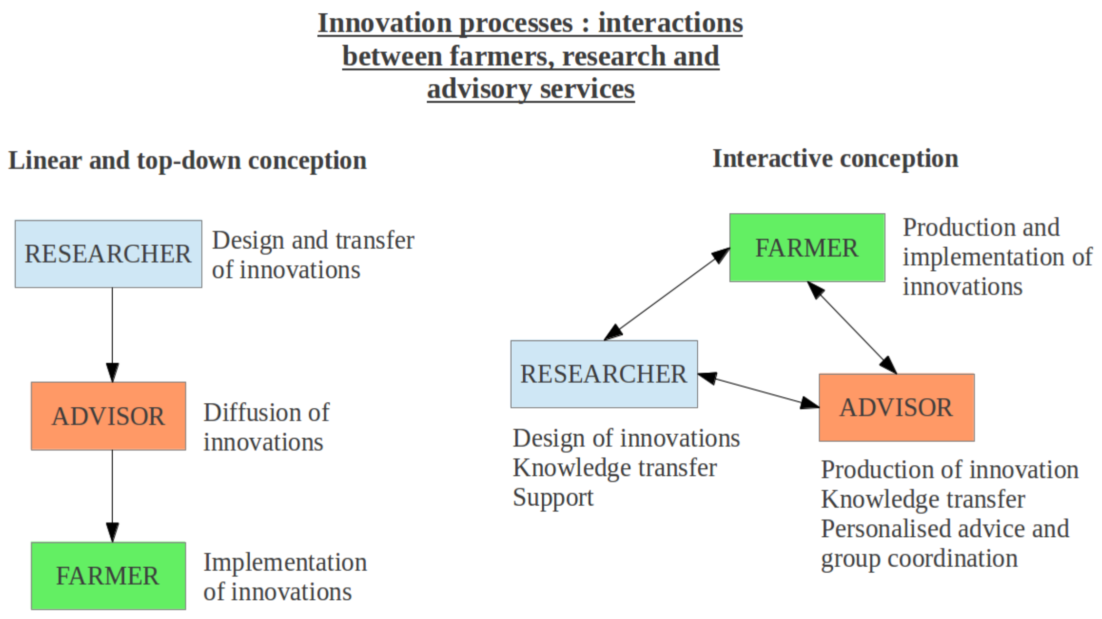


Figure 20: Interactions between researchers, farmers and advisors in top-down and interactive innovation processes (adapted from Le Gal & al (2011)).

It appears also important to understand that the type of advice farmers receive can influence the technique they adopt (Riousset, 2011). All farms are different, and shape different farmers, nevertheless various typologies have been established in literature. Among them, Cerf & al distinguished two types of farmers, those who are able to adapt knowledge from a local situation, and the farmers who are requesting advice for that, be it from an advisor or from a colleague. The two groups will have different expectations in terms of advisory services, and we can make the hypothesis that the second group would be more likely to be interested in personal advice, starting from a review of farmers situation and need to adapt the advice. Nevertheless, group dynamics seem to be very appreciated, and this trend was also highlighed in previous studies (Corbel, 2009, Riousset, 2011). It allows farmers to echange on their experience, thus avoiding errors, overcome difficulties and confirm or spread some practices. These practices appear successful when the coordinator of the group enters the same learning process than its members.

Given the particularities of the subject and the targetted audience, multiplying the approaches and perspectives seems the best solution. Indeed, it is difficult, and even dissuading, for a farmer that recently stopped ploughing to follow the reasonments of more experienced farmers, and he needs answers to his specific concerns, which can come from a farmers' group at his level, a general guide or a personalised and co-constructed advice. Moreover, it can also be disappointing for a farmer using MT for several years to come back to the beginning of the process. Nevertheless, opportunities for experienced farmers and beginners to exchange should not be banned, as both can learn from each other (by means of testimonies or field visits for example), but on a regular basis it would be better to make groups of farmers on the same level.Farmers also expressed interest in field visits, conferences and machinery demonstrations, but point out that available time is a strong constraint for them, and therefore they rather seek efficient advice. .

4.4. Limits and perspectives

Desjeux & al (2009) stated that although a relative consensus emerges towards a reorientation of the role of advisors and farmers, few propositions are made concerning new models and advisory services. With the present report, a few answers have emerged. However some limits to the used methodology have to be considered. First, our survey was qualitative and although we aimed at covering a wide range of pedo-climatic contexts and farming types, the representativity of the situation in Brittany remains partial. Moreover, the figures presented in the analysis of the agronomic practices have also to be considered carefully, given the size of our sample (26 farmers for this part, 29 for the sociological part). Finally, our sociological part is based only on perspective of farmers, and there has been no interview of advisors.

If this survey had to be replicated in a near future, it could be relevant to separate both parts. One the one hand, the survey on agronomic practices could be carried out on a larger sample, allowing statistical comparisons. One could for example think of a questionnaire sent out by mail or on Internet, or the use of the Agreste network to spread it. On the other hand, the sociological part could be carried out on the same sample size, and as it would be disconnected from the agronomic questions, it would give more time for the interview. The questions could also be precised in order to confirm the trend observed in the present study, and look for explanations. It could also be interesting to study more in-depth the different approaches of advisors from the Agricultural Chambers on this topic, as well as investigating the visions of other

To conclude, it would also be interesting to look at farmers' innovation processes at a larger scale, because of the international origins of MT and the transboundary networks established nowadays. Although the resilience of MT systems is demonstrated, especially on the American continent, an approach of the flexitbility and adaptation processes farmers implement in Brittany could possibly teach a lot in order to improve the advice given to farmers that start using MT techniques. Finally, the question of the ability of MT and more generally conservation agriculture to make conventional agriculture evolve towards more sustainable systems also remains unanswered in a European context.

Conclusion

In this study, we tried to bring answers to the demands expressed by the Regional Agricultural Chamber of Brittany and the SUSTAIN project team : review farmers' practices in minimum tillage and explain the innovation process behind these practices and its determinants in Brittany, in order to understand farmers' expectations towards advisory services and research and propose tracks for improvement. .

Minimum tillage techniques have developped rapidly in Brittany during the last decade, however knowledge on the practices and motivations of farmers was so far limited to quantitative or very localised studies. Therefore, we established a survey methodology based on a questionnaire in two parts. First, a questionnaire on farmers agronomic practices and the detailled description of their cropping system. The second part, by means of open-ended questions, allowed us to study different sociological components such as information sources and networks, learning dynamics and the representation and identity of farmers.

The description of the practices and the operated technical modifications reveal a large variety of know-how, and allowed us to establish three main agronomic coherence classes. Nevertheless, it appears that neither the pedo-climatic context, neither the farming type influence the type of practices adopted by the farmer. It is noticeable that the first class uses a deep and intensive tillage, shows higher input consumptions and less knowledge on soils and ecosystemic services than the two other classes. Generally, farmers appear more reluctant to simplify maize establishment than for wheat, and this can be explained by the will to ensure the yields of a crop without possibility of revovery and essential to breeding activities.

In the second part, we highlighted the learning dynamic engaged by farmers. Initially motivated by economic aspects (decrease working time, operating costs), farmers become progressively aware of agronomic and environemental benefits of soil tillage simplification. The specificities of Brittany from an environemental point of view plays a rôle in this evolution. Moreover, the surveyed farmers describe a particularisation process, which leads them to adapt the innovation to their own farm and to relativise generalistic or even dogmatic discourse. This dynamic results in two kinds of practitioners : those able to extract action principles from a local situation, and on the contrary farmers considering that a situation encountered far away cannot apply to their own context. Time is a key component of this process, and exchanges of experience inside a group allow to make progress, and thus to dilute a little the risks for each farmer.

Summing up, farmers expectations towards advisory services differ and multiplying the approaches (group meetings, personalised advice, other tools and supports) allow to broaden the targetted audience. Group dynamics are appreciated, at the condition that they respect the level of each farmer. The function of an advisor becomes richer with the role of group coordinator, and this requires to enter in the same process of adaptation and to consider the stage of each farmer in his learning dynamic. Departing from top-down approaches, advisory services become the ability to co-construct the evolution of a system thanks to the sharing of knowledge between the advisor, the farmer and a group of practitioners.

LIST OF BIBLIOGRAPHIC REFERENCES

ADEME (LABREUCHE J., LE SOUDER C., CASTILLON P., OUVRY J.F., REAL B., GERMON J.C., DE TOURDONNET S. :coordinators); 2007. Evaluation des impacts environnementaux des Techniques Culturales Sans Labour en France. ADEME-ARVALIS Institut du végétal-INRA-APCA-AREAS-ITB-CETIOM- IFVV. 400 p. Available at http://www2.ademe.fr/servlet/getDoc?cid=96&m=3&id=51256&p1=00&p2=11&ref=17597 [Retrieved 27/08/2013].

AGRESTE BRETAGNE ; 2012-a. Résultats définitifs du recensement agricole 2010 : vers une meilleure prise en compte de l'environnement en agriculture. Direction régionale de l'Agriculture, de l'Alimentation et de la Forêt (DRAAF), Service Régionale de l'Information Statistique et Economique (SRISE). 4 p.

AGRESTE BRETAGNE ; 2012-b. Mémento de la statistique agricole : Spécial résultats du recensement agricole 2010 (données définitives). Direction régionale de l'Agriculture, de l'Alimentation et de la Forêt (DRAAF), Service Régionale de l'Information Statistique et Economique (SRISE). 32 p.

AGRESTE ; 2010. Les dossiers n° 8 : Grandes cultures. Statistique recensement agricole 2006. 37 p.

ARVALIS-INSTITUT DU VÉGÉTAL; 2009. Implantation des céréales. Paysan Breton n° 2824 (pages spéciales). 38p.

BRUNDTLAND COMMISSION;1987. Report of the World Commission on Environment and Development: Our Common Future. 300p.

BASCH G., GERAGHTY J., STREIT B., STURNY W.; 2009. No-tillage in Europe: State of the Art, constraints and perspectives. IN: GODDARD T, ZOEBISCH MA, GAN YT, ELLIS W, WATSON A, SOMBATPANIT S (eds) No-till farming systems. Special Publication No. 3. World Association of Soil and Water Conservation (WASWC), Bangkok, 159–168

BAVEYE P.C., RANGEL D., JACOBSON A.R., LABA M., DARNAULT C., OTTEN W., RADULOVICH R., CAMARGO F.A.O. ; 2011. From Dust Bowl to Dust Bowl: Soils are Still Very Much a Frontier of Science. Soil Science Society of America Journal 75, 2037-2048.

BRIVES H., DE TOURDONNET S.; 2010. Comment exporter des connaissances locales ? Une experience de recherche intervention aupres d’un club engage dans les techniques sans labour . ISDA (Innovation and Sustainable Development in Agriculture and food) International Symposium, Hot topic 3: Learning and being creative: how can different types of knowledge be combined to create innovation? Montpellier, 28/06-01/07/2010.

CASTEL JJ., DOUGUET G.; 2009. Références économiques des TCSL. Forum Agrofutur “sol et vie, le travail du sol en question”. Pontivy, 27/01/2009.

CHANTRE E., CERF M., LE BAIL M.; 2010. Diagnostic agronomique des trajectoires de changements de pratiques en vue de la réduction d'utilisation de pesticides en grande culture: Cas de la Champagne Berrichonne de l'Indre. SFER (Société Française d'Economie Rurale) colloquium “la Réduction des Pesticides: enjeux, modalités et conséquences”. Lyon, 02-03/03/2010.

COMPAGNONE C.; 2011. Quelles formes d’accompagnement des agriculteurs à l’innovation ? Revue Pour 212, 123-128.

CORBEL M.; 2009. Les pratiques de non-labour en Bretagne: diversité, déterminants et impacts sur l'environnement. Etude de cas sur le bassin versant du Leff (22) et étude expérimentale à la station de Kerguéhennec (56). Montpellier: Institut des régions chaudes, Sup' Agro, Mémoire Ingénieur.

CRAB (CHAMBRE REGIONALE D'AGRICULTURE DE BRETAGNE); 2013. Les chambres d'Agriculture de Bretagne **[online]** Available at http://www.bretagne.synagri.com/synagri/les-chambres-d-agriculture-de-bretagne-00023904 [Retrieved 27/08/2013].

CRAB; 2012-a. Economie Agricole Bretonne: Analyse et perspectives édition 2012. Chambre Régionale d'Agriculture de Bretagne. 70p.

CRAB; 2012-b. Agriculture and Food Processing Industry in Brittany. The figures edition 2012. Chambre Régionale d'Agriculture de Bretagne. 52 p.

CRAB , 2009: Référentiel Agronomique régional, guide CIPAN (Cultures Intermédiaires Pièges à Nitrates). Chambre Régionale d'Agriculture de Bretagne. 16p.

CRAHEIX D., ANGEVIN F., BERGEZ J.-E., BOCKSTALLER C., COLOMB B. GUICHARD L., OMON B., REAU R., DORÉ T.; 2012. Multicriteria assessment of the sustainability of cropping systems: A case study of farmer involvement using the MASC model . 10th European IFSA (International Farming Systems Association) Symposium, Workshop 6: Integrated simulation modeling in farming system research. Aarhus, Denmark, 1-4/06/2012.

CSEB (Conseil Scientifique l'Environnement en Bretagne); 2003. Gestion des sols et apports de déchets organiques en Bretagne . Editions du CSEB. 58p.

DERPSCH R.; 2001. Conservation tillage, no-tillage and related technologies, Keynote contributions "First wolrd Congress on Conservation Agriculture; 1-5 octobre 2001", Madrid, ECAF-FAO, 161-170.

DESJEUX Y., FAURE G., GASSELIN P., REBUFFEL P.; 2009. Synthese bibliographique sur le conseil en agriculture . UMR Innovation (Cirad, INRA, Sup Agro). 138p.

DIAZ M., GACHET A.; 2002. Impact des techniques culturales simplifiées sur la qualité du sol et de l’eau en Bretagne. Atelier de spécialisation génie de l’environnement, décembre 2002, Ecole Nationale Supérieure Agronomique de Rennes.

FAURE G., COMPAGNONE C.; 2011. Les transformations du conseil face à une nouvelle agriculture. Transformations et diversification du conseil pour des agricultures en mouvement, Article introductif. Cahiers Agricultures volume 20, n° 5, 321- 326.

FRIEDRICH T., KASSAM A.; 2009. Adoption of Conservation Agriculture Technologies: Constraints and Opportunities . IV World Congress on Conservation Agriculture., New Delhi, India, 4-7/02/2009.

GENDRON C.; 2005. Le Québec à l'ère du développement durable. Options politiques, juillet-août ; 20-25.

GEOPORTAIL. Carte Administrative **[online]**. Available at www.geoportail.gouv.fr/ [Retrieved 27/08/2013].

GILLER K., WITTER E., CORBEELS M., TITTONELL P.; 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view . Field crops Research 114 (1) 23-34.

GIP (Groupement D'intérêt Public) Bretagne environnement ; 2010. Cartes Air et Climat **[online]**. Available at http://www.bretagne-environnement.org/Media/Atlas/Cartes/%28categorie%29/29201 [Retrieved 27/08/2013].

GLIESSMAN S.R. ;1998. Agroecology: Ecological Processes in Sustainable Agriculture. Ann Arbor Press, Chelsea, MI.

GLIESSMAN S.R. 2006 Introduction to Agroecology : the need for sustainable food production systems. In Agroecology: The Ecology of Sustainable Food Systems, 2nd edition. Cleveland : CRC Pr Llc.

GOULET F.; 2011. Accompagner et vendre. Les firmes de l'agrofourniture dans l'innovation et le conseil en agriculture. Cah Agric 20 : 382-6.

GOULET F.; 2008. L'innovation par retrait: reconfiguration des collectifs sociotechniques et de la nature dans le développement des techniques culturales sans labour. Grenoble: Université Pierre Mendès France, Thèse de Doctorat.

GOULET F.; PERVANCHON F.; CONTEAU C.; CERF M.; 2008. Les agriculteurs innovent par eux-mêmes pour leurs systèmes de culture . IN Systèmes de culture innovants et durables. REAU R.; DORÉ T. Dijon, Educagri éditions: 53-69.

GOULET F., VINCK D.;, 2012. L'innovation par retrait. Contribution à une sociologie du détachement. R. française sociol. 53-2, 195-224.

GUIDE STEPHY; 2011. Guide pratique pour la conception de systèmes de culture plus économes en produits phytosanitaires. Application aux systèmes de polyculture. Available at http://www.systemesdecultureinnovants.org [Retrieved 27/08/2013].

HALLAIRE V., MENASSERI S., BOTTINELLI N.; 2009. Effet des TCSL sur les propriétés physiques du sol. Forum Agrofutur "Sol et vie, le travail du sol en question". Pontivy, 27/01/2009.

HEDDADJ D.; 2008. Etats des lieux sur les pratiques de non labour en Bretagne . SPACE conference « Sols agricoles et développement durable » SITMAFGR and FARRE. Rennes, 11/09/2008.

HERAULT C., SIGWALT A., THAREAU B.; 2010. L'analyse de contenu. Ecole Supérieure d'Agriculture, Angers.

HOLLAND JM.; 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agriculture, Ecosystems and Environment 103, 1-25.

IAASTD (International Assesment of Agricultural Knowledge, Science and Technology for Development); 2009. Agriculture at a crossroads. Synthesis report. Washington (DC) : Island Press.

IUCN (International Union for the Conservation of Nature); 1980. World Conservation Strategy.

KESSLER C.A.; 2006. Decisive key-factors influencing farm households’ soil and water conservation investments . Applied Geography 26, 40–60.

KNOWLER D., BRADSHAW B.; 2007. Farmers’ adoption of conservation agriculture: A review and synthesis of recent research . Food Policy 32, 25–48 .

LAHMAR R.;, 2010. Adoption of conservation agriculture in Europe : Lessons of the KASSA project , Land Use policy 27, 4-10.

LE GAL PY.; DUGUÉ P.; FAURE G.; NOVAK S.;2011. How does research address the design of innovative agricultural production systems at the farm level? A review. Agricultural Systems vol. 104, 9, 714-728

LE GARREC L.; 2003. Evaluation environnementale et économique des pratiques agricoles en techniques de conservation des sols. Angers: Ecole Supérieure d'Agriculture, Mémoire Ingénieur.

LEMERCIER B.; 2010. Final report Sols de Bretagne. Available at http://www.sols-de-bretagne.fr/a-telecharger/func-startdown/114/ [Retrieved 27/08/2013].

MADELRIEUX S., DEDIEU B., DOBREMEZ L.; 2002. Modifications de l'utilisation du territoire lorsque des éleveurs cherchent à résoudre leurs problèmes de travail. Fourrages 172, 355-368.

MEYNARD JM. 2008. Produire autrement : réinventer les systèmes de culture. INRA Symposium « Systèmes de culture innovants et durables : quelles méthodes pour les mettre au point et les évaluer ? » ; Paris, 27/03/2008.

MICHOT D., HALLAIRE V., BESNARD S.; 2009. Effet des TCSL sur la circulation de l'eau dans le sol. Forum Agrofutur “Sol et vie, le travail du sol en question”. Pontivy, 27/01/2009.

MINISTÈRE DE L'AGRICULTURE (Ministère de l'agriculture, de l'alimentation , de la pêche, de la ruralité, et de l'aménagement du territoire); 2008. Treatment Frequency Index reference per crop and per region.

MINISTÈRE DE L'AGRICULTURE (Ministère de l'agriculture, de l'alimentation , de la pêche, de la ruralité, et de l'aménagement du territoire); 2012. Yields for wheat and grain maize in Brittany.

MOULIN C-H., INGRAND S., LASSEUR J., MADELRIEUX S., NAPOLÉONE M., PLUVINAGE J., THÉNARD V.; 2008. Comprendre et analyser les changements d’organisation et de conduite de l’élevage dans un ensemble d’exploitations : propositions méthodologiques. IN : DEDIEU B., CHIA E., LECLERC B., MOULIN C-H., TICHIT M. (eds). L'élevage en mouvement, flexibilité et adaptation des exploitations. Paris: Editions Quae, Chapitre 11, 181-196.

MUNDLER P.; 2006. Les conseillers d'entreprise entre guichet et projet. IN : RÉMY J.; BRIVES H.; LÉMERY B. (eds). Conseiller en agriculture. Dijon ; Paris : Educagri éditions ; Inra éditions.

MUNIN V.; 2009. Références "temps de travail" du sans labour. Forum Agrofutur "Sol et vie, le travail du sol en question". Pontivy, 27/01/2009.

NRCS (NATURAL RESOURCES CONSERVATION SERVICE); 2011. Conservation practice standard: mulching. US Department of Agriculture. Available at http://www.nrcs.usda.gov%2FInternet%2FFSE_DOCUMENTS%2Fstelprdb1045720.docx [Retrieved 27/08/2013].

PERCHE S., LEBOSSE D., MUNIN V., TURLIN JP.; 2009. Enquête qualitative sur les pratiques en TCSL. Forum Agrofutur "Sol et vie, le travail du sol en question". Pontivy, 27/01/2009.

PIRON D., CLUZEAU D.; 2009. Effet des TCSL sur la biologie du sol. Forum Agrofutur "Sol et vie, le travail du sol en question". Pontivy, 27/01/2009.

PREFECTURE BRETAGNE, 2010. La déclinaison de la Directive Nitrates en Bretagne **[online]** Available at http://www.bretagne.pref.gouv.fr/Les-actions-de-l-Etat/Environnement-et-prevention-des-risques/L-eau/Cadre-reglementaire/Protection-des-eaux-superficielles/Directive-nitrates/La-declinaison-de-la-Directive-Nitrates-en-Bretagne [Retrieved 27/08/2013].

PRETTY J.;1995. Participatory learning for sustainable agriculture. World development vol 23, n° 8, 1247-1263.

PRETTY J., SUTHERLAND W.J., ASHBY J., AUBURN J., BAULCOMBE D., BELL M., BENTLEY J., BICKERSTETH S., BROWN K., BURKEL J., CAMPBELL H., CHEN K., CROWLEY E., CRUTE I., DOBBELAERE D., EDWARD-JONES G., FUNES-MONZOTE F., GODFRAY H.C.J., GRIFFON M., GLYMANTISIRI P., HADDAD L., HALAVATAU S., HERREN H., HOLDERNESS M., IZAC A-M., JONES M., KOOHAFKAN P., LAL R., LANG T., McNEELY J., MUELLER A., NISBETT N., NOBLE A., PINGALI P., PINTO Y., RABBINGE R., RAVINDRANATH N.H., ROLA A., ROLING N., SAGE C., SETTLE W., SHA J.M., SHIMING L., SIMONS T., SMTIH P., STRZEPECK K., SWAINE H., TERRY E., TOMICH T., TOULMIN C., TRIGO E., TWOMLOW S., VIS J.K., WILSON J., PILGRIM S.; 2010. The top 100 questions of importance to the future of global agriculture . International Journal of Agricultural Sustainability 8, 4.

PRIR (Programme de Recherche d'Intérêt Régional) Bretagne (MENASSERI-AUBRY S., PIRON D., CLUZEAU D., HALLAIRE V. : coordinators); 2011. Evaluer et modeliser la gestion des matières organiques associée a une réduction du travail du sol en vue d'une agriculture durable. Rapport final. 220p.

QUENEA M.; 2006. Analyse technique et environnementale des pratiques sur un réseau d'exploitations des Chambres d'Agriculture de Bretagne. Rouen: ESITPA, Mémoire Ingénieur.

RIOUSSET P.; 2011. Influence du mode d'accompagnement sur les pratiques culturaleset leur durabilité en agriculture de conservation des sols. Paris: Sciences Po, Université Pierre et Marie Curie, Mémoire de Master.

ROBERT M., CAPILLON A., RAUNET M.; 2004. Historique mondial et enjeux environnementaux des techniques sans labour. CORPEN Symposium on minimum tillage techniques (TCSL) 31/03/2004.

SADOK, W., ANGEVIN, F., BERGEZ, J.-E., BOCKSTALLER, C.; 2009. MASC, a qualitative multi- attribute decision model for ex ante assessment of the sustainability of cropping systems. Agronomy for Sustainable Development, 29 (3), 447-461.

SEBILLOTTE M.; 1974. Agronomie et agriculture. Essai d'analyse des tâches de l'agronome. Cahier ORSTOM, série biol. N° 24, 3-25.

SEBILLOTTE M.; 1990. Système de culture: un concept opératoire pour les agronomes. IN : L. COMBE, D. PICARD (eds.). Les systèmes de culture, , Paris: INRA, 165-196.

SNOWMAN NETWORK, Homepage. **[online]** Available at http://www.snowmannetwork.com [Retrieved 27/08/2013]

SOANE B.D., BALL B.C., ARVIDSSON J., BASCH G., MORENON F., ROGER-ESTRADE J.; 2012. No-till in northern, western and south-western Europe: A review of problems and opportunities for crop production and the environment . Soil & Tillage Research 118, 66–87 .

STASSART P., VANKEERBERGHEN A., DANNEVOYE B., SALLETS MP.; 2013. Transition et écologisation de l’agriculture en Région Wallonne: trajectoires en Agriculture de Conservation. 1st interdisciplinary congress on sustainable development “quelle transition pour nos sociétés? Thème 2: Alimentation, agriculture, élevage” Namur, 31/01-01/02 2013.

STEINBECK J. ;1939. The grapes of wrath. New York City : The Viking Press, J. Lloyd.

SUSTAIN; 2010. Research project proposal: Soil Functional Biodiversity and Ecosystem Services, a transdisciplinary approach. SNOWMAN Network, 3rd Coordinated Call for Research.

TEBRÜGGE F.; 2001. No-tillage visions: protection of soil, water and climate and influence on management and farm income. IN: Garcia-Torres, L.; Benites, J.; Martínez-Vilela, A. (eds.) Conservation Agriculture - A Worldwide Challenge. Springer, 2003.

VIAUX P. 1999. Une troisième voie en Grande Culture – Environnement, Qualité, Rentabilité. Dijon : Editions Agridécisions.

WANDEL J., SMITHERS J.; 2000. Factors affecting the adoption of conservation tillage on clay soils in Southwest Ontario, Canada. American journal of alternative agriculture vol. 15, n° 4.

APPENDICES

1. English-French glossary (based on ADEME, 2007)
2. Maps of the climate in Brittany
3. Questionnaire of the survey
4. Letter sent to the surveyed farmers
5. MASC arborescence (Craheix & al, 2012)
6. Indicators used in STEPHY (2011)
7. Crossed curve of the age and the experience of farmers
8. Detailled maps of the distribution of each agronomic coherence class in Brittany.
9. Recommended sowing densities in Brittany (Arvalis – Institut du végétal, 2009)
10. Table of available data for treatment frequency index (TFI)
11. Scheme summarizing the main caracteristics of the agronomic coherence classes.
12. Scheme summarizing the conclusions of the sociological analysis.

APPENDIX 1 : English-French glossary (based on ADEME, 2007)

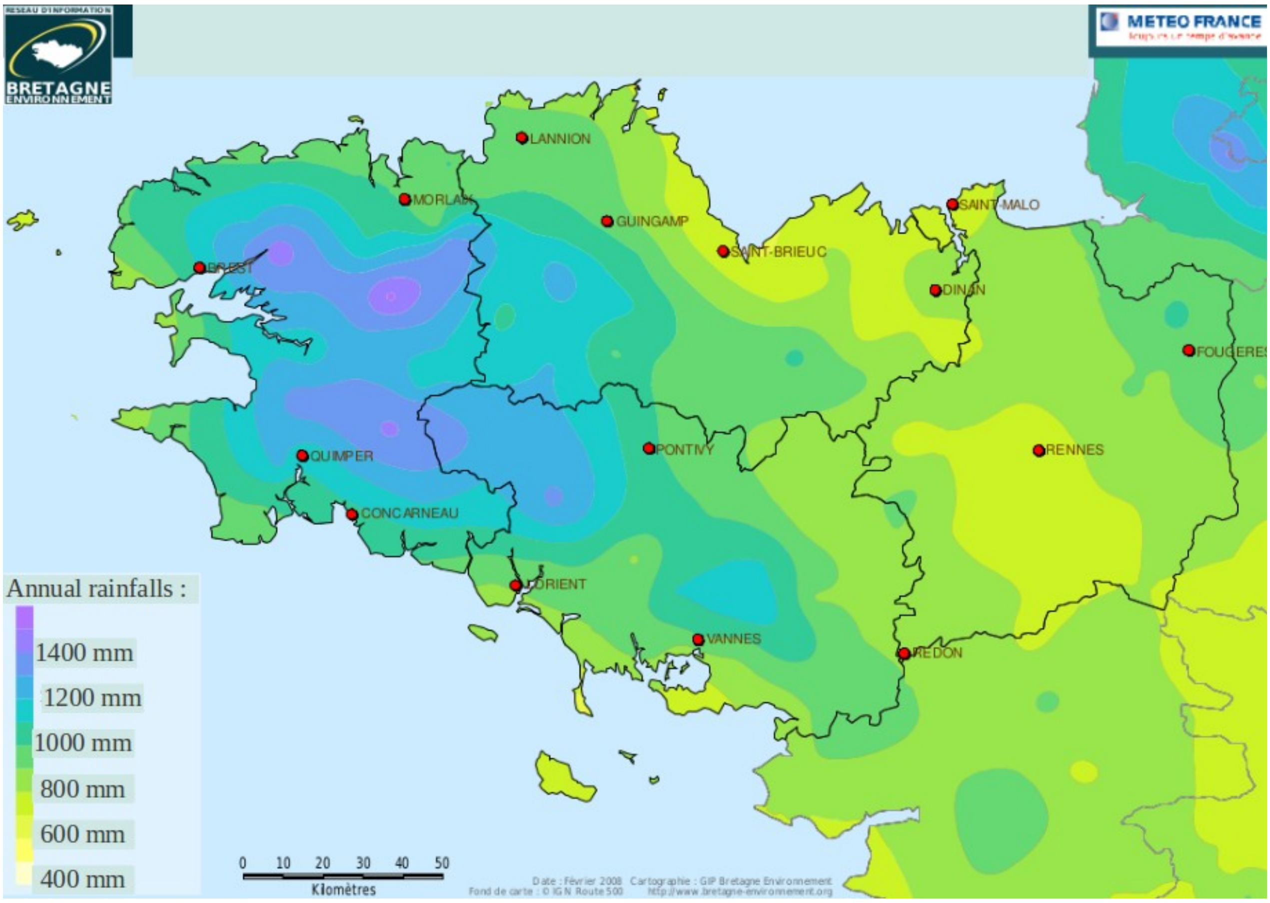
Tools and techniques

English term	French equivalent
Broadcast sowing	Semis à la volée
Chisel	Chisel / cultivateur lourd
Combined drill	Semoir en combiné
Coil-spring tine cultivator	vibro-déchaumeur
Cultivator	cultivateur
Direct drill	Semoir direct
Disc stubble tiller	Déchaumeur à disques
Disc harrow	Pulvérisateur à disques = cover-crop
Duckfoot tine	Soc en patte d'oie
Harrow with ground driven spades	Herse à bêches roulantes
Mouldboard ploughing	Labour conventionnel
Mouldboard plough	Charrue à versoirs
Minimum Tillage (MT)	Techniques Culturales Sans Labour (TCSL)
No-tillage (NT)	Non-labour, Semis direct (SD)
Reduced Tillage (RT)	Techniques Culturales Simplifiées (TCS)
Rotary harrow	Herse rotative
Rotary tiller	Cultivateur rotatif
Seedbed preparation	Préparation du lit de semence
Single-seed drill	Semoir monograine
Spring tine harrow	Cultivateur léger (canadien)
Stale seedbed	Faux semis
Stubble tillage	Déchaumage
Stubble tiller	déchaumeur
Sunrake tiller	Houe rotative
Tine tool	Outil à dents
Topsoiling	Décompactage
Topsoil cultivator	décompacteur
p.t.o. driven seeding tool	Semoir avec prise de force (type Horsch)

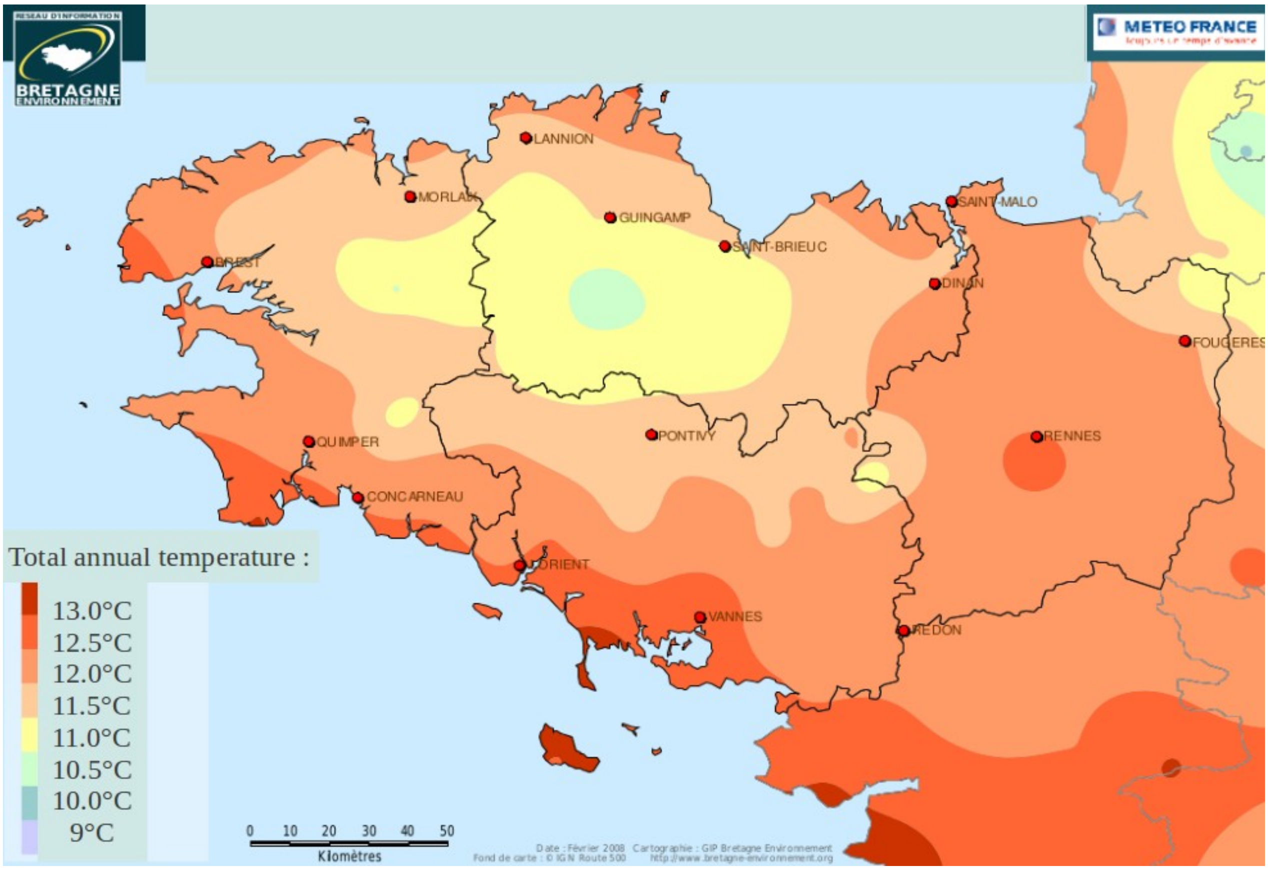
Cover-crops

English term	French equivalent
Catch crop	CIPAN : culture intermédiaire piège à nitrates
Cover crop	Couvert végétal
Double cropping	Double culture (deux récoltes par an)
Green manure	Engrais vert
Intermediate crop	Culture intermédiaire
Main crop	Culture principale
Second crop	Culture dérobée
Soil cover	Couverture du sol
Undercover sowing	Semis sous couverture végétale

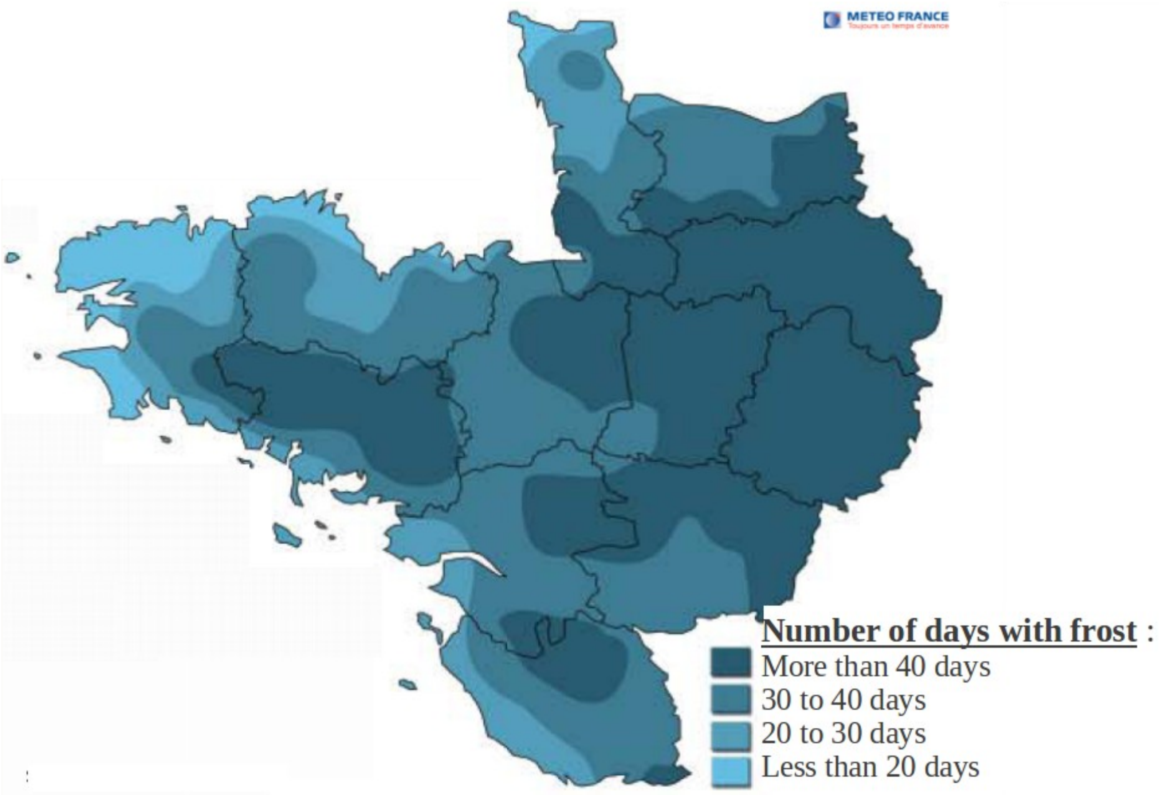
APPENDIX 2 : Maps of the climate in Brittany



Map of the total annual rainfalls in Brittany (GIP Bretagne Environnement).



Map of the total annual temperature in Brittany (GIP Bretagne Environnement).



Map displaying the number of frost days in Brittany (GIP Bretagne Environnement)

APPENDIX 3 : Questionnaire used for the survey

<u>Survey on reduced tillage techniques in Brittany</u>

This interview is composed of 2 parts: first, we will talk on your cropping practices and the results you obtain. In the second part, focus will be on your motivations to stop ploughing.

This interview is anonymous.
The collected data will be used only for the present survey and in a way that does not allow to recognize the surveyed farmers. In any case, this data will be transmitted to control authorities.

With your agreement, I will record this interview. The recordings are only a support to written notes and will be destroyed after use.

General features of the farm

"Can you describe me your farm?"

- **Address**

Last name: First name:
Name of the farm:
Address

- **Structure:** Society/ Individual/Other

Number of agricultural working units (AWU):
  - familial:
  - employees:
  - occasional

AWU dedicated to the cropping system:

- **Activities**

Crops for 2011-2012
Usable Agricultural area (UAA): ha of which natural pastures: ha
Crop rotation

Crop	Area (ha)
Winter wheat	
Maize (grain)	
Maize (silage)	
Rapeseed	
Temporary grassland	

Crop	Area (ha)

% of legumes in the crop rotation:

Breeding activities (average number)

	Number or m²	
Milk production (nb of cows)		Quotum :
Cow meat production Suckler cows Young bulls (indoor)		
Porcs (Effectives or available places to precise) Breeding pigs Piglets Slaughter pigs		Breeder ☐ Breeder – fattener ☐ Fattener ☐
Poultry in m² Table birds Laying birds Breeding hens or turkeys Future breeding turkeys		
Sheep		
Goats		
Other (to precise)		

Other activities (agricultural services…):

- **Environmental constraints**

Contentious watershed:

Area of structural surplus (*ZES*)**:**

- **History of the farm or of the farmer:** main steps (installation, farm expansion, new production, society creation…)

Step	**Date**	**Area (ha)**	**Crop prod.**	**Animal prod.**	**Comments**
Installation					
Extension					
Other					

- **History of reduced tillage techniques on the farm:**

Date	Area (ha)	Involved crops	Soil tillage*	Equipement	Comments
Start of the conversion					

* Ploughing (P) - Sowing with farm tools (FT) – Minimum tillage (MT)- Direct sowing (DS)

Duration of the transition period (in years):

Part of the crop rotation in reduced tillage <u>for 2011-2012:</u> *100% RT* *partially RT* ↓

		Area (ha)	Frequency	Evolution
Winter wheat	- never ploughed			
	- ploughed			
	- deep tillage, decompaction			
Other straw cereals (barley, triticale etc.…)	- never ploughed			
	- ploughed			
	- deep tillage, decompaction			
Maize	- never ploughed			
	- ploughed			
	- deep tillage, decompaction			
Rapeseed	- never ploughed			
	- ploughed			
	- deep tillage, decompaction			

Other :	- never ploughed			
	- ploughed			
	- deep tillage, decompaction			

2. Technical and economical part <u>regarding the plots in reduced tillage</u>

- **<u>Practices:</u>** *“Can you describe me the soil types? (in your plots in RT)”*

What is the nature of your soils in the plots in RT?

○ silty
○ silt loam / sandy loam
○ Clay loam / silty clay loam
○ Other:

○ Heavy soils
○ Light
○ Heterogeneous
○ Other:

How deep is the soil in the plots in RT?

○ <30 cm
○ 30 to 60 cm
○ 60 to 90 cm
○ Heterogeneous

○ Not deep at all
○ Average depth
○ Very deep
○ Other :

Is the depth in your plots in RT different from your other plots? YES NO 100%RT

In the plots in RT, are your soils:

- Sensitive to capping (surface sealing)? *Not sensitive sensitive very sensitive*
- Soil drainage (surface drying): *quickly slowly*
- Sloping? Average slope class: *<3% 3-5% >5%*
- Stony? *A little average very stony*

Is this general or particular to a cluster of plots?

In the plots in RT, do you know :

- The rate of organic matter (%)? *<2% (low) 3 to 4 % (average) >5% (high)*

To sum up, what are the main problems and the main qualities of your soils?

Do you take peculiar measures to avoid soil compaction and to maintain the soil structure in your plots in RT?

- no
- operations in dry conditions
- emptying of the combine-harvester at the end of the field (headlands)
- Passing always on the same tracks
- Reduction of weight of the equipment
- Equipments limiting soil compaction (low pressure tires, twin wheel…)
- Other

Which parameters do you take into account to decide on the date of sowing? Are you deciding of the period of operations (if using common material or agricultural services)? How do you judge the state of soil drainage?

How frequently are you intervening (sowing, harvesting…) in bad conditions (weather, wet soil…)?

Since you stooped ploughing, have you perceived changes in your soils?

○ Soil bearing capacity
○ Earthworms
○ Erosion
○ Activity (microbial, biological)
○ Surface runoff

○ Soil structure
○ Other:

"What are the crop rotations in place on your farm?"

Area (ha)	Distance from the farm*	Examples of crop successions (5 previous years) with **intercropping**				
		2012	2011	2010	2009	2008

N°	* Distance from the farm
1	< 5 km
2	5 to 10 km
3	10 to 20 km
4	20 to 30 km
5	> 30 km

In your crops using reduced tillage techniques, are you using mixtures?

	Winter wheat	Maize	Rapeseed	Other
Varieties : number ?				
Species : which ones ?				

Have your crop rotations evolved since you started using reduced tillage techniques?
If yes, which changes have been practised in the rotation? ***Order according to the importance (1= the most important)***

- ○ lengthening of the rotation → length:
- ○ alternating crop familiers
- ○ intermediate crops
- ○ new crops
- ○ other:

What are your decision rules / the determining facts for the choice of your crops? ***Order the answers***

external elements
- ○ Laws and regulations
- ○ selling prices
- ○ other

Internal elements
- ○ dispersal of the plots
- ○ need of straw or feed
- ○ type of soil
- ○ other:

Are you carrying out tests or trials? *YES* *NO*
If yes, how do you manage them?

Precise details	Trial alone	Trial with a group	Trial with a firm	Trial with an advisor
Sowing dates				
Varieties				
Equipments				
Other :				

Are you **currently** facing **agronomic problems** that are specific to reduced tillage practices?

		Crops involved	Solutions you consider/tried out
Sowing	○ 1- Uneven sowig because of residues ○ 2- Sowing depth ○ 3- Seed/soil contact ○ 4- Other :		○ a) choice of the sowing tool ○ b) increase sowing densities ○ c) sow deeper ○ d) other :
Emergence	○ 1-Late emergence : soil warms up slower ○ 2- Heterogenous ○ 3- slow growing rate of young plants		○ a) repetitive residues burying/ tilling in ○ b) choice of the sowing tool ○ c) other :
Fertilization	○ 1- cereal lodging ○ 2- Nitrogen deficiency ○ 3- Other deficiency ○ 4- Other :		○ a) adjustment of N doses ○ b) growth regulator ○ c) other
Pests	○ 1- Slugs (grey, black, both) ○ 2- other :		○ a) modifiying sowing dates ○ b) harvester with chaff scatterer ○ c) slug poison ○ d) repeated stubble tillage ○ e) other :
Diseases	○ 1- Fusarium wilt ○ 2- cereal eyespot ○ 3- Take-all of cereals ○ 4- Rye ergot ○ 5- other		○ a) resistant varieties ○ b) Fine grinding of maize stover ○ c) change in the rotation ○ d) residues incorporation ○ e) soil coverage ○ d) other :
Weeds	↓		○ a) stale seedbed ○ b) herbicids ○ c) adapted cover crops ○ d) chaff collector ○ e) extension of the rotation ○ f) other :

Couch grass	Brome grass	Italian Ryegrass	Meadow grass	Thistle	Bind-weed	Goose grass	Wild geranium	Docks (rumex)	Ragged robin	Other

Do you know your Treatment Frequency Index (TFI)? *YES* *NO*
If yes, indicate the year

	Reference plot	Not referenced plots
TFI herbicide		
TFI excluding herbicides		

Evolutions in the practices since the conversion to reduced tillage techniques

		Evolution winter wheat: ↑ ↓ =	Evolution maize: ↑ ↓ =	Comments
Sowing (1)		Dates: densities :	Dates: densities :	
Ferti-lization (2)	organic	Dose: Dates of fertilising :	Dose: Dates of fertilising:	
	minéral	Dose: Dates of fertilising : Type :	Dose: Dates of fertilising : Type :	
Chemi-cals (3)	Pests	Pressure : Dose:	Pressure : Dose:	
	Weeds	Pressure : Doses:	Pressure : Dose:	
	diseases	Pressure : Doses:	Pressure : Dose:	
Yields (4)				
Other (5)				

<u>TABLE (next page): CROP MANAGEMENT SEQUENCE</u>

Intervention codes

1	Superficial tillage (< 8 cm)
2	Superficial tillage (8 to 15 cm)
3	Deep tillage without reversal (>15cm)
4	Ploughing
5	Mecanical weeding
6	Sowing combined to soil tillage
7	Sowing without simultaneous tillage
8	Organic fertilization
9	Mineral fertilization
10	herbicide
11	insecticide
12	fungicide
13	Slug poison treatment
14	Growth regulator treatment
15	Other treatment :
16	Harvest
17	Other :

Type of organic fertilization

Type of organic fertilizer	Inputs	Comments
Manure		
slurry		
Compost :		
Poultry manure		
Other :		

Crop management sequence on a plot in reduced tillage techniques for **winter wheat** for the 2011-2012 campaign

Plot area (ha) : Preceding crop : Residues management

category	**date**	**Code**	**Type of intervention**	**Details***
Soil tillage				
Sowing (sowing density)				
Chemicals (precise name, type and dose of product. Precise if alternative techniques are used)				
organic and mineral fertilisers (precise type and dose)				
Harvest (precise yield, harvest conditions)				
Others (ex : irrigation)				

* Details : conditions of intervention / crop stage at intervention / other details

Crop management sequence on a plot in reduced tillage techniques for **winter wheat** for the 2011-2012 campaign

Plot area (ha) : Preceding crop : Residues management

category	**date**	**Code**	**Type of intervention**	**Details***
Soil tillage				
Sowing (sowing density)				
Chemicals (precise name, type and dose of product. Precise if alternative techniques are used)				
organic and mineral fertilisers (precise type and dose)				
Harvest (precise yield, harvest conditions)				
Others (ex : irrigation)				

* Details : conditions of intervention / crop stage at intervention / other details

Machinery

- Tillage and sowing equipements

Brand & type	Code	Crops (***code***)	Depth (***code***)	Tool width (m)	Status (%), Price (€), Rent (€/ha)	Age (years)

Status : P : property ; JO : joint ownership (indicate % owned by the farmer) ; AS: Agricultural services supply ; R: renting

Disk tool for stubble tillage	1
Chiesel	2
Rotalabour	3
Vibrating tine cultivator	4
Rotary harrow + driller	5
Traditional driller	6
Disk harrow	7
Soil decompaction tool	8
Deep working cultivator	9
Rotary harrow	10
Direct seed drill	11
Dragged stubble cultivator with drill	12
Seed drill with seed mill	13
Seed drill with tines	14
Simplified seed drill	15
Other :	16

Tillage depth

< 5 cm	1
5 to 10 cm	2
10 to 15 cm	3
15 to 30 cm	4
> 30 cm	5

Involved crops

Winter crops	1
Spring crops	2
All of them	3

- Pulling, manutention and harvest

Equipment	Brand	Power (ch), number WD	Status (%), Price (€) Rent (€/ha)	Age (years)

Status : P : property ; JO : joint ownership (indicate % owned by the farmer) ; AS: Agricultural services supply ; R: renting

- Fertilization, chemical treatments

Brand and type	Code	width (m), volume (l)	Power (ch)	Status (%), Price (€) Rent (€/ha)	Age (years)

Status : P : property ; JO : joint ownership (indicate % owned by the farmer) ; AS: Agricultural services supply; R: renting

Slurry tanker : nozzle	1
Slurry tanker : spreading bars	2
Slurry tanker : dribble bars	3
Slurry tanker with injection	4
Manure spreader with horizontal shredder beaters	5
Manure spreader with vertical shredder beaters	6
Manure spreader : with spreader table	7
Manure spreader : other	8
Sprayer for pesticide treatments	9
Centrifugal mineral fertiliser broadcaster	10
Row spreader for mineral fertiliser	11
Liquid mineral fertiliser spreader	12
Mechanical weeding : chain harrow	13
Mechanical weeding : rotary hoe	14
Mechanical weeding : hoe	15
Other :	16

Is your equipment a limiting factor for your cultural practices ?

- General data for the <u>cropping system</u> (included delegation of services, and without harvest)

Fuel consumption (L/year or L/ha/year)	mechanisation costs (€/year or €/ha/year)

	Winter wheat	Maize	3rd crop :
Time dedicated to crop establishment (hours/ha)			
Time dedicated to crop management, without harvest (hours/ha)			

- Intercropping

What kind of intercropping are you using of your plots in reduced tillage? A single species or a mix of species?

	Area	**Previous crop**	**Following crop**	**Destruction***
Mustard				
Rapeseed – Turnip rape – Fodder kale				
White Radish				
Phacelia				
Oats				
Diploid oats (Brazilian)				
Hairy vetch – lentil				
Crimson clover (Italian) or Berseem clover (Egyptian)				
Nyger				
Buckwheat				
Sunflower				
Rye - Triticale				
Field beans (*Vicia faba*)				
Italian RyeGrass				
Clover				

* Destruction: Frost (F); Mechanical (M); Rolling (R); Chemical (C); Grazing (G)

- Ecosystemic services

To you, do reduced tillage techniques provide services to society? YES   NO

If yes, in which way?
1 : Food, fiber, fuel… production
2 : Carbon storage, organic matter
3 : Fighting against erosion , soil protection, avoidance of bare soils
4 : Decreased use of chemicals
5 : Decreased use of mineral nitrogen fertilization
6 : Decreased GHG emisisions (directly or indirectly)
7 : Water quality preservation, waterflow regulation (flooding, ground water)
8 : Biodiversity and habitat preservation
9 : Other :

Economy ; we consider only the **cropping system in reduced tillage for the 2011-2012 campaign**

Crop	Winter wheat	Maize
PRODUCTS		
Yield		
Selling price		
Direct subsidies		
COSTS		
Mineral fertilizers (€/ha)		
Organic fertilizers (€/ha)		
Seeds (€/ha)		
Chemicals (€/ha)		
Agricultural services supply (sowing, harvesting…)		
Mechanisation		

Gross margin evolution according to the tillage technique (a- increase, b- decrease, c- no evolution)

Crop	**Gross margin with ploughing**	**Actual gross margin**	**Comments**
Winter wheat			
Maize			

3. Sociological part

After having described your practices, we will now focus on your path in reduced tillage techniques, the reasons behind this choice and your motivations.

First question, if today you had to do it all over again, would you do it?	
	(objectives, method, results)
How did you come accros the idea to stop ploughing ?	
	- How did you first hear about it ? - What were your first information sources ? Which ones were essential to you? - Did you make your decision and start right away ? If not, what was the trigger to start ? - What were your initial motivations? Did you have any apprehension or fear ?
Today, what are the memories you keep from the period you stopped ploughing?	
	- What were the reactions of your relatives (partner, associate(s), family (father), predecessor)? - What were the reactions of your neighbours or farmer colleagues ? (were your practices an opportunity to exchange, to stimulate each other, or on the contrary subject of suspicion ?) Are you comparing your plots? -Have you encountered difficulties at the beginning? - agronomic - économic - « psychological » (stop ploughing)
Have you experienced this change of tillage practices as a personnal adventure or rather a collective adventure?	
	- Have you been accompagnied or followed? (advisor, association, farmer group...)

	- If yes, why ? What did it bring you at the time you stopped ploughing? And nowadays, what does it bring you? How often do you attend meeting? - If no, why ? -Advantages & disadvantages ?
What did this change of practices bring you ? Does it mean a lot to you, or is it just a change among others ?	
	Did you acquire any specific know-how or knowledge? Experience?
Today, how do you consider and manage your cropping system ?	*Current situation*
	- Strenghts/weaknesses ? - Are you still wondering about a lot of subjects ? - Do you have projects, future trials in mind ? How do you consider the future of your cropping system? Do you see ways to improve your system ?
Do you consider that you have access to all resources and information sources you need to make full use of your potential?	
	-What are your main technical information sources ? (*Internet, magazines, neighbours, network…)* Which ones are the most important ? - Do you have enough information ? Support? - Do you have any expectations towards guidance organisms ? (*group meetings and monitoring, personnalized advice, field trip days, written supports and guides, trainings, conferences…)* - Expectations towards research & scientists ? (*reference values, diagnosis tools)*
- Do you have any expectations towards politics ?	
	(recognition, subventions…)

Finally, to sum-up, what is the assessment you draw from your experience in reduced tillage until today?	*Sum-up*
	- Where are you now on your learning curve? Have you finished you transition ? -What idea do you have of a reduced tillage cropping system ? - Would you recommend this change of practices to other farmers?

Self-assessment:

○ How do you rate your quality of life regarding your work, and more specifically your cropping system?

○ How did your working time evolve since you stopped ploughing?

- ○ Your effective working time? The peaks of work?

- ○ The time spent for conception and management of the cropping system?

○ How did your pesticide treatments evolve since you stopped ploughing?

- ○ Quantities and doses?

- ○ The risks you take, your exposure?

○ Further comments on life quality:

Sociological details

- Your age:

- Your education (or equivalent):

○ Professional certificate
○ Baccalaureate
○ Higher technician certificate (2 years)
○ Bachelor (3 years)
○ Master (5 years)
○ Other:

- Main activity on the farm:

- Year of installation, context:

- Have you already considered the transmission of your farm?

APPENDIX 4 : Letter sent to the surveyed farmers (in French)

Station expérimentale de Kerguéhennec, Bignan
Date

Bonjour,

Les surfaces conduites en techniques culturales sans labour ont connu une évolution significative ces dernières années. D'après le dernier recensement agricole de 2010, les terres cultivées en non labour représentent 26% des surfaces de cultures annuelles.

Ces techniques, lorsqu'elles sont optimisées, constituent sans nul doute des leviers agronomiques prometteurs pour aller dans le sens d'une agriculture durable. C'est l'innovation par les agriculteurs eux-mêmes qui est au cœur de la réussite de ces changements de pratiques depuis plusieurs années. Ils ont engagé un processus d'adaptation de leurs techniques et de leurs itinéraires culturaux aux conditions de leur exploitation. Ils contribuent ainsi à faire avancer les connaissances qu'ils partagent le plus souvent auprès de leur réseau.

Aujourd'hui, il y a un besoin de mutualiser les connaissances des agriculteurs et de les faire connaître. Ce processus a déjà été engagé lors des Journées Innovaction de 2012.
Par ailleurs, il est aussi nécessaire d'identifier les contraintes auxquelles font face les agriculteurs dans ces nouveaux systèmes. Cela contribuera à faire remonter vers la recherche appliquée les questions sur lesquelles il faudra travailler.

Pour réaliser cet état des lieux des techniques de non-labour en Bretagne, le pôle Agronomie des Chambres d'Agriculture de Bretagne a décidé de mettre en place une enquête auprès d'un échantillon d'exploitations engagées dans cette démarche depuis un certain nombre d'années. Cette étude sera menée par une stagiaire de l'Ecole d'Agriculture d'Angers (ESA) **entre mars et avril 2013.** Elle sera réalisée sous la forme d'entretiens individuels qui porteront sur 2 volets. Le premier volet concerne les pratiques (travail du sol, fertilisation, traitements phytosanitaires, matériel…). Un deuxième volet de l'entretien concerne les aspects économiques (produits, charges opérationnelles). Cet entretien reste anonyme et les données seront utilisées uniquement dans le cadre de cette étude.

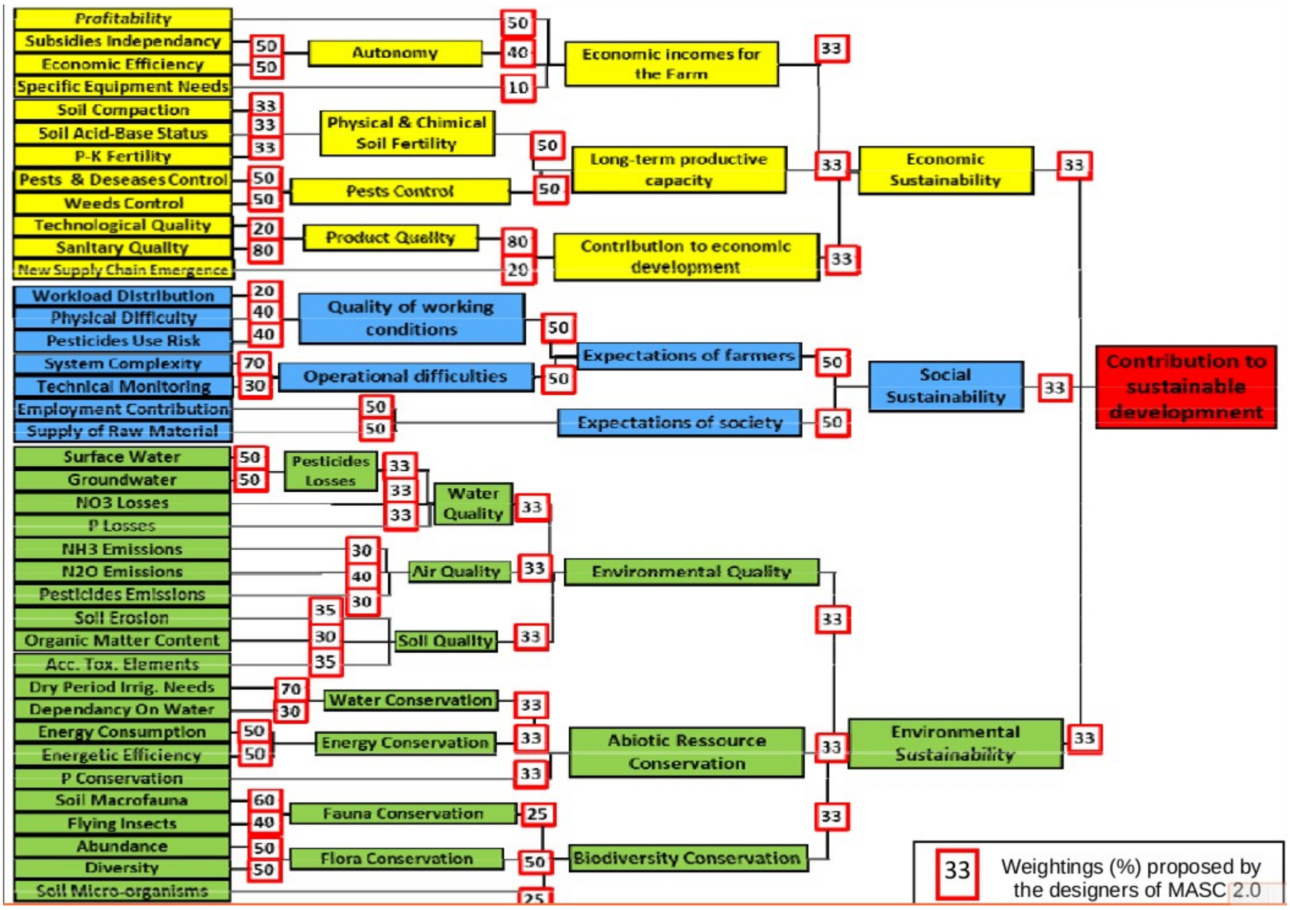
Les principales conclusions de cette enquête vous seront transmises sous forme d'une synthèse de quelques pages envoyée par courrier. Une restitution sera également faite aux conseillers.

La stagiaire Teatske BAKKER vous contactera pour prendre un rendez-vous d'entretien.

Cordialement,

Le/la conseiller(e) Teatske Bakker

APPENDIX 5 : Scheme of the MASC arborescence (Craheix & al, 2012)



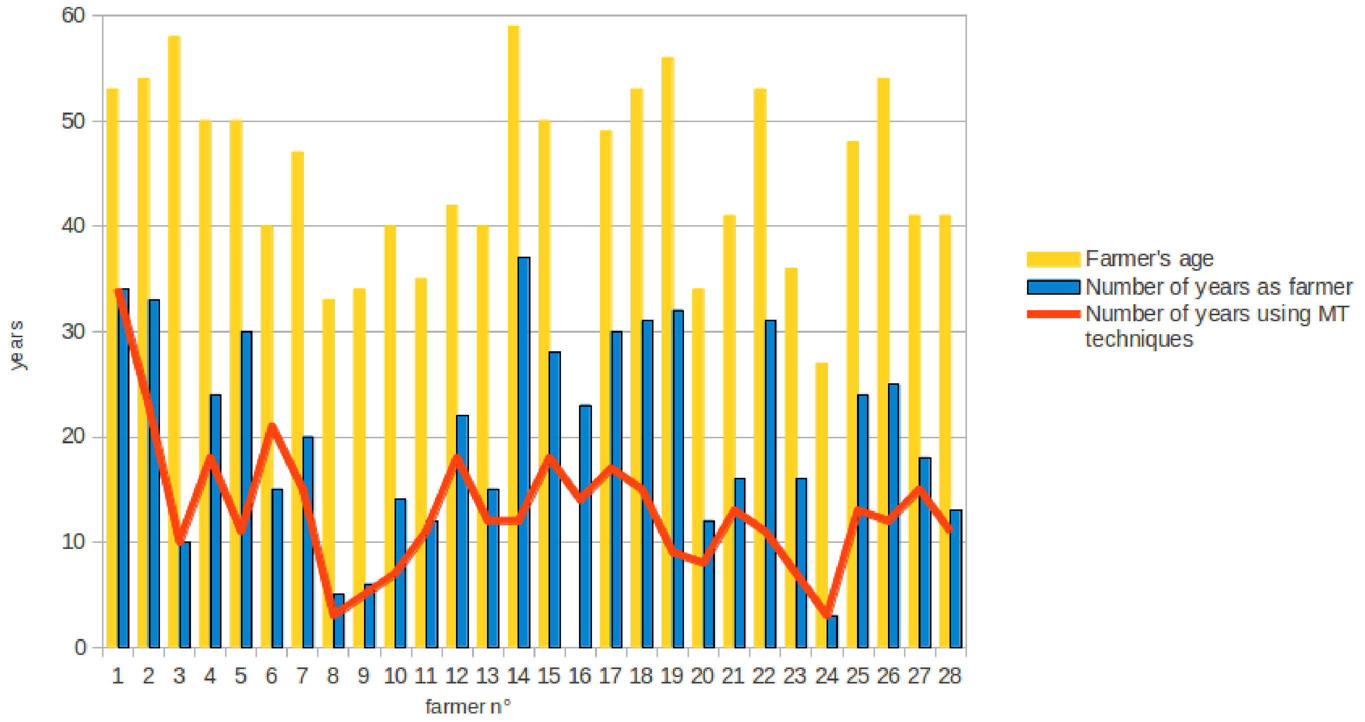
APPENDIX 6 : Indicators used in STEPHY

Indicateur	Mode de calcul	Données à renseigner	Données paramétrées		Sorties
	n = durée de la rotation	Données	Données	Unité	Sorties
IFT (calcul par la calculette du MAP)	IFTculture =Σ [DA/DH x PP] pour toutes les spécialités commerciales utilisées et pour chaque traitement	Spécialité commerciale (SC) Dose apportée (DA) Proportion de la parcelle traitée (PP)	Dose Homologuée (DH) par culture et par spécialité commerciale Sources : MAP	Sans	IFT total IFT herbicides IFT insecticides IFT fongicides IFT autres
IFT	IFT / culture rentrée directement **ou** IFT = charges phytos/coût unitaire IFT pour la culture IFTsdc = Σ (IFTculture)/n	IFTpour chaque culture du SDC ou charges phytos pour chaque culture	Coût de l'unité IFT par culture et par catégorie de produits (Insecticides, herbicides,...) Sources : MAP	€/unité d'IFT	IFT total IFT herbicides IFT insecticides IFT fongicides IFT autres par culture et en moyenne sur le SDC
Traitements des semences	Nombre de cultures avec semences traitées / nombre total de cultures	Utilisation ou non de semences traitées pour chaque culture de la rotation			Fréquence d'utilisation de semences traitées sur la rotation
Coûts énergétiques	Σ (coût interv. i*nb interv. i)/n + nombre d'unités d'N mineral apportée * coût énergétique d'une unité + quantité d'eau apportée * coût énergétique du m^3 d'eau + coût énergétique du P pour 1T de produit * rendement + coût énergétique du K pour 1 T de produit * rendement	Nombre de passages pour : Roulage Labour Travaux superficiels Décompactage Semis Binage/hersage/houe rotative Fauche/entretien Epandage fumier/lisier/engrais minéral Pulvérisation Récolte Fauchage/fanage/andainage/pressage Broyage Rendements Quantités d'eau apportées Quantités d'azote apportées par culture *N.B. : Le nombre de passages peut directement être déduit dans le calculateur en fonction des cultures.*	Consommations énergétiques / type d'interventions Coût énergétique de l'unité d'azote Besoins en P et K forfaitaire par culture + coût énergétique de l'unité de P et de K Coût énergétique du m3 d'eau *Sources : INRA, ADEME, 1999*	MJ/ha MJ/T	Coût énergétique total Par culture et en moyenne sur le SDC
Efficience énergétique	Σ (PCI cult. i/ coût NRJ cult.i)/n		Pouvoir calorifique Inférieur (PCI) des produits et sous-produits *Sources : INRA, ADEME, 1999*		Efficience énergétique Par culture et en moyenne sur le SDC
Bilan Bascule	Σ (apports d'N - coef. d'export. *rendement)/n	Quantité d'azote apportée sous forme minérale et organique Rendement moyen par culture	Coefficient d'exportation par culture *Sources : COMIFER*	kg N/ha	Bilan azoté sur le SDC
Nombre et nature des passages effectués		Nombre et nature des passages effectués			Nombre et nature des passages effectués en moyenne sur le SDC

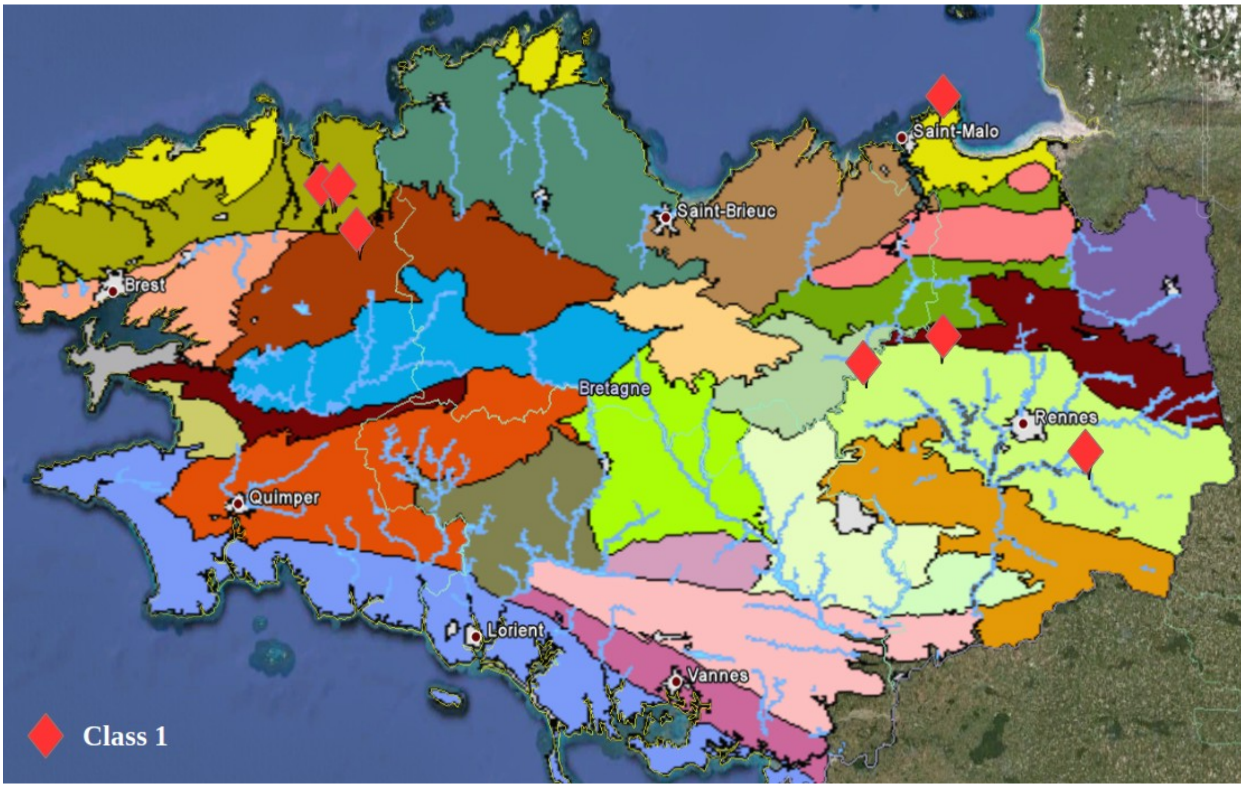
Indicateur	Mode de calcul	Données à renseigner	Données paramétrées		Sorties
	n = durée de la rotation	Données	Données	Unité	Sorties
Produit brut (PB)	Σ (rendement * prix)/n pour toutes les cultures de la rotation	Rendement moyen par culture	Prix de vente par culture	€/ha et €/q	Produit brut en moyenne sur le SDC
Charges opérationnelles (CO)	Σ (qté semences achetées*prix) + Σ (IFT traitement i * coût unité traitement i ou charges phytos) + (quantité d'azote apportée * coût unité d'N)]/n + coût du P pour 1 T de produit * rendement + coût du K pour 1 T de produit * rendement	Quantités semences achetées par culture (en kg) IFT par culture et par type de traitement ou charges phytos Quantités d'engrais apportées par culture Quantités d'azote organique achetées Rendements	Coûts des semences Coûts des traitements / unité d'IFT et par type de traitements Coûts de l'unité d'N Besoins en P et K forfaitaire par culture + coût de l'unité de P et de K	Semences : €/kg IFT : €/ha Engrais minéral (N/P/K) : €/kg Engrais organiques : €/kg	Charges opérationnelles en moyenne sur le SDC
Charges de mécanisation et de main d'œuvre (CMMO)	Σ (Nombre d'interventions i * CMMO pour intervention i)/n	Nombre de passages pour : Irrigation Décompactage Travaux superficiels Labour Semis Epandage Pulvérisation Récolte Broyage Herse	Coûts par type d'intervention *Sources : Barèmes Entraide*	€/ha	CMMO en moyenne sur le SDC
Marge directe	PB - CO - CMMO				Marge directe en moyenne sur le SDC
Achat de matériel spécifique		Achats à effectuer			
Coûts d'apprentissage		Nombre de nouvelles cultures sur la rotation Nombre de pratiques nouvelles sur la rotation			

APPENDIX 7 : Crossed curve of the age and the experience of each farmer in MT techniques.

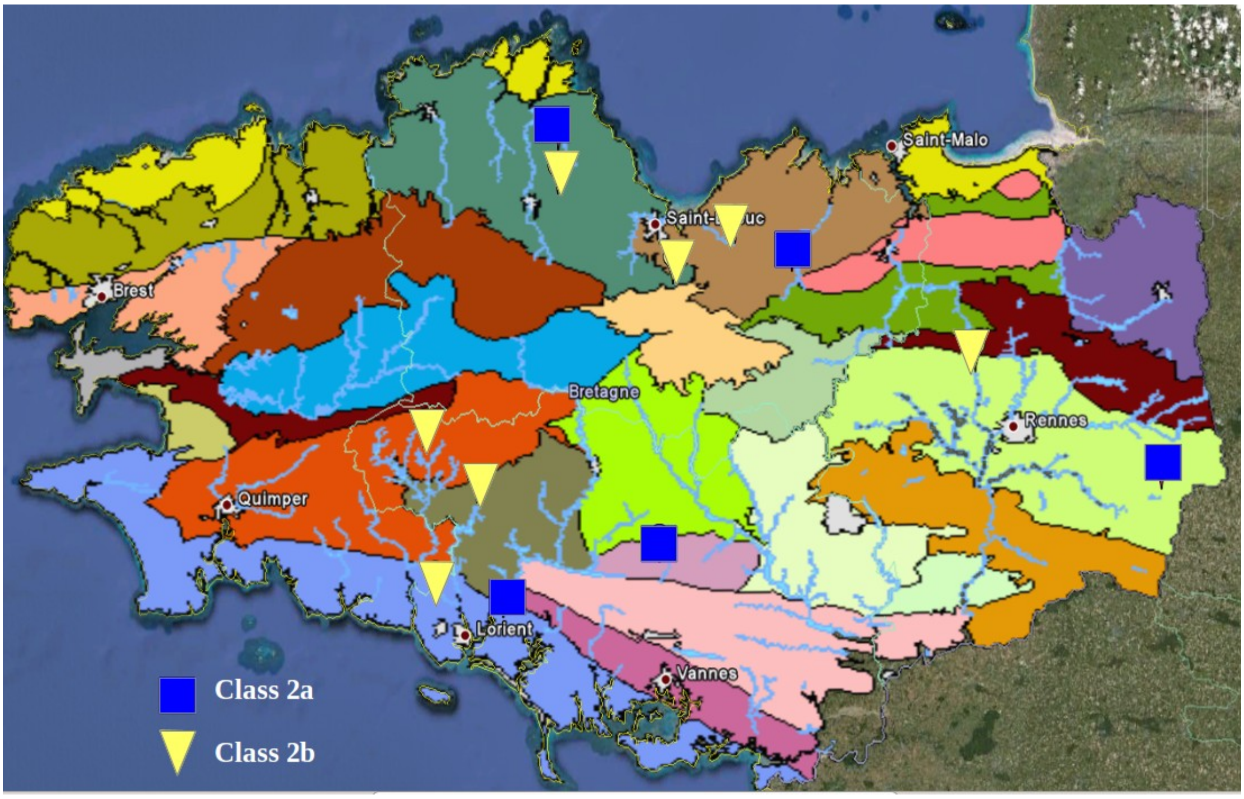
We observe no significative influence of a farmer's age or the number of years as farmer on the date of conversion to MT



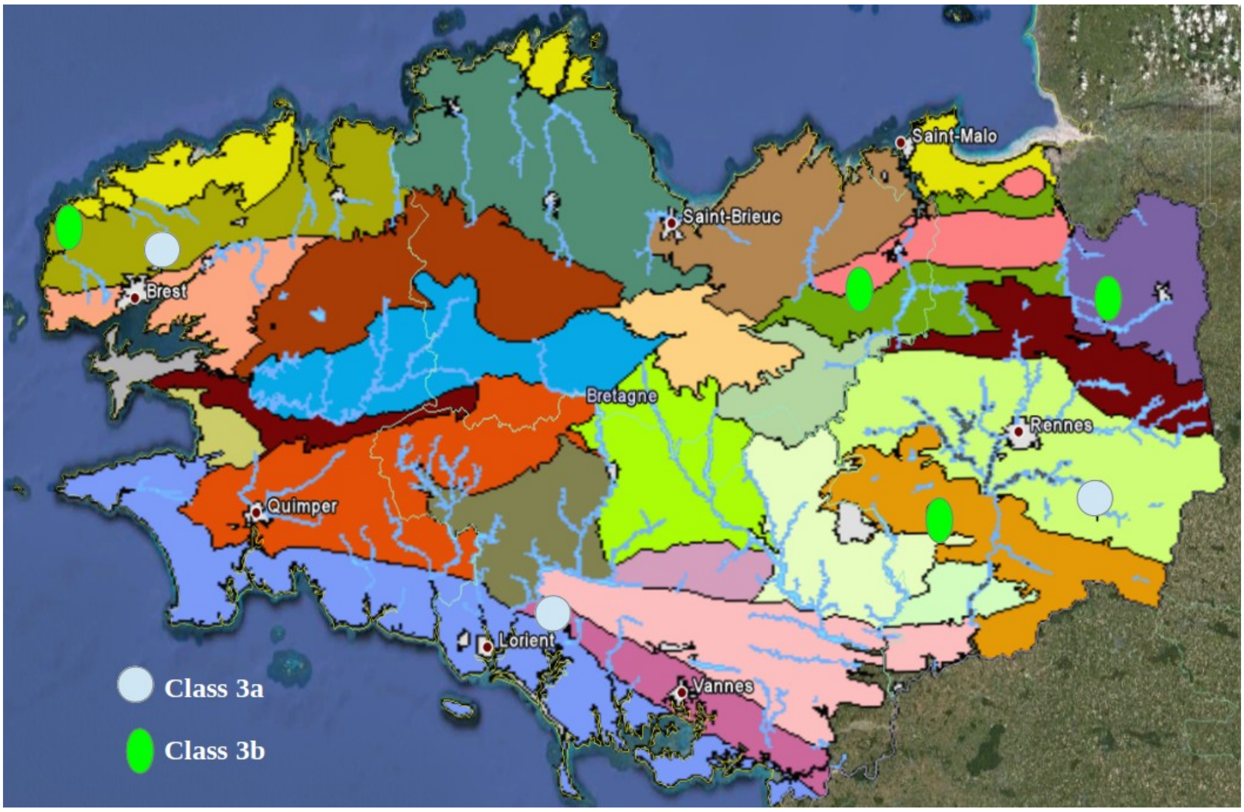
APPENDIX 8: Detailed maps of the distribution of each agronomic coherence class in Brittany.



Map of the distribution of farmers in class 1.



Map of the distribution of farmers in class 2.



Map of the distribution of farmers in class 3.

Legend of the physiographic entities.

APPENDIX 9: Recommended sowing densities in Brittany (Arvalis – Institut du Végétal, 2009)

Recommended sowing densities

Sowing date	October 10 to 20	October 21 to 31	November 1 to 15	November 16 to 30
Dry silty soils (density in grains/m²)	180	220	250	280
Hydromorphic silty soils (density in grains/m²)	260	290	320	350

Equivalence between sowing densities and sowing doses

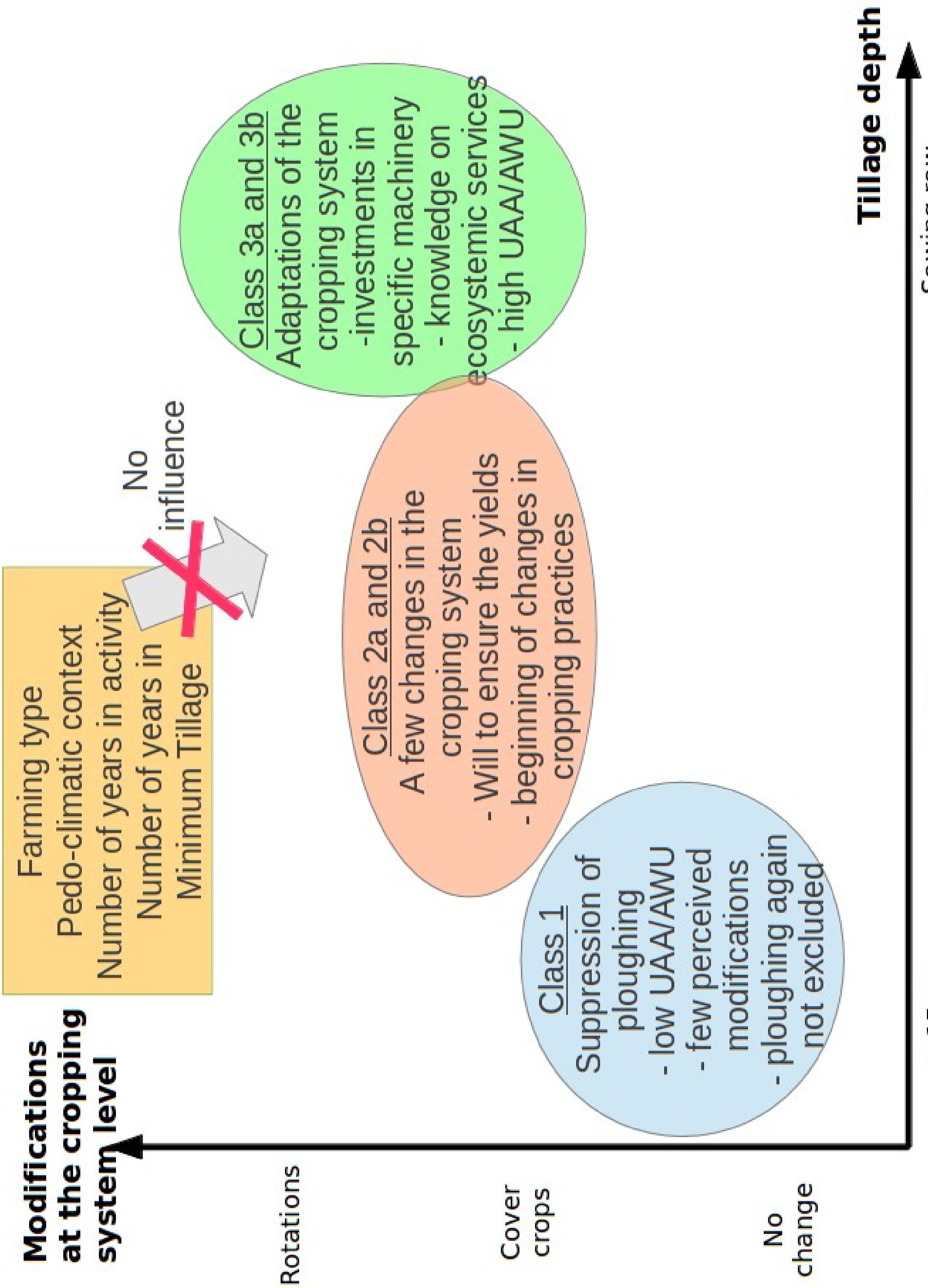
		Thousand seeds weight (g)										
		35	38	40	42	45	48	50	52	55	58	60
Sowing density (grains/m²)	200	70	76	80	84	90	96	100	104	110	116	120
	225	79	86	90	95	101	108	113	117	124	131	135
	250	88	95	100	105	113	120	125	130	138	145	150
	275	96	105	110	116	124	132	138	143	151	160	165
	300	105	114	120	126	135	144	150	156	165	174	180
	325	114	124	130	137	146	156	163	169	179	189	195
	350	123	133	140	147	158	168	175	182	193	203	210
Sowing dose (kg/ha)												

APPENDIX 10 : Table of the avaible data for treatment frequency index (TFI) for wheat and maize crop management [H: Herbicides; HH: not including herbicides].

	Wheat TFI		**Maize TFI***
Class 1	H : Lack of available data	HH : Lack of available data	2 farmers : 2,14 and 1,13
Class 2	H : 1 farmer at 1,52	HH : Lack of available data	2 farmers : 1,84 and 1,71
Class 3	H : 4 farmers :	HH :	2 farmers : 1,21 and 0,85
	- 1,53	- 2,08	
	- 1,46	- no data	
	- 0,78	- 0	
	- 0,88	- 0	
Brittany (2008)	1, 49	2,91	1,66
France (2008)	1,64	3,49	1,75

* Maize TFI HH = 0

APPENDIX 11: Scheme summarizing the main caracteristics of the agronomic coherence classes.



APPENDIX 12: Scheme summarizing the conclusions of the sociological analysis.