Deliverable 1.1 - Appendix A1

Conservation agriculture, organic farming and GM crops in France

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Table of contents

I – Context of development of Conservation Agriculture, Organic Farming and GMO in France

I-1- Repartition and evolution

I-1-1- Conservation Agriculture

The total arable surface in France is 19.5 million hectares. It is difficult to assess the total surface cultivated under Conservation Agriculture because this concept is rather wide (from deep tillage without overturning to direct drilling with permanent cover crop). Moreover, many farmers who practice reduced tillage sometimes introduce ploughing (Barbier and Chevrier, study report, 2002)

According to SCEES (Central Office of surveys and statistics) the **total surface** cropped under no ploughing techniques reached **1,423,800 hectares in 2001** (CORPEN, 2004). There are few areas in direct drilling: between 50,000 and 150,000 hectares (ECAF, 2005).
CA is particularly developed in the south of France (Midi-Pyrenées, Aquitaine) and in Ile de France. The three main crops cultivated under CA are wheat, barley and rape. The rate of the area cropped under no-ploughing has increased since 1994 for every crop (SCEES, 2001 *in* CORPEN, 2004).

Crop	Rate of the area under no ploughing in 1994	Rate of the area under no ploughing in 2001	Area under no ploughing (in ha) in 2001
Hard wheat	37.4%	44.0%	100 200
Rape	17.9%	21.9%	195 300
Soft wheat	11.5%	17.1%	734 000
Winter barley	4.9%	11.0%	154 100
Sunflower	5.6%	8.4%	42 800
Maize (grain)	2.4%	6.9%	115 600
Pea	1.7%	6.0%	15 000
Maize (feed)	1.7%	4.4%	60 300
			1 423 800

Table 1: importance of no ploughed areas at the national scale
(SCEES, 2001 *in* CORPEN, 2004)

I-1-2- Organic Farming

In France, 540 000 hectares are cropped under Organic Farming practices, which represent about 2% of the agricultural-used area (Agence Bio, 2004). France is the 25th country in the world and the 12th in the EU regarding the relative surface under organic farming practices (Saddier, study report, 2003). The main crops grown in organic farming is protein-oil crops and cereals. Fruits and vegetables sectors are the smaller ones.

I-1-3- GMO

In France, GMO is limited by the moratorium. The surfaces of the experiments on GMO are still decreasing: from 85 ha in 1999 to 7 ha in 2004.

The experiments on GMO are managed by

- INRA on poplar
- Monsanto on maize
- Biogemma on maize
- Geves on maize
- CETIOM on rape
- ARVALIS on maize
- CIRAD on coffee
- PIONNER on maize

I-2 – Potential factors inducing evolution

I-2-1- Pedo-climatic conditions

Soil water erosion is a growing issue in France. Erosion induces not only a reduction of soil fertility which results from soil losses in cultivated areas, but also environmental nuisances: floods and mudslides in housing areas or on road networks (in Alsace or the Pays de Caux for instance), or superficial water pollution (in Brittany) (Boiffin et Monnier, 1994). In the areas where erosion is an issue, CA extension is higher.

In the loamy lands of the North of France, **soils are very sensitive to crusting**. One way able to limit crusting is to keep a permanent cover on the soil.

Soil turn-over causes the **rising of the deep stones**. Giving up ploughing is a method limiting stone rising.

On the other hand, the soil constraints probably induce many farmers to alternate ploughing and reduced tillage. In fact, according to soil characteristics and in particular **humidity**, it is difficult to establish a continuous no-plough cropping system (Barbier and Chevrier, study report, 2002).

I-2-2- Economic conditions

In 1970, farmers began to reduce soil tillage because they wanted to **decrease labour time**. The objective was to seed winter wheat as soon as possible after maize.
By the beginning of the 80's, the interest for these techniques decreased due to the favourable economic conditions and because of the high costs of herbicides (Goulet, study report, 2004).

It was the **economic pressure** that really induced the extension of CA, along with the Common Agricultural Policy reform in 1992. Farmers were afraid of the drop in cereal prices and they looked to **reduce costs** in order to maintain the direct margin. Moreover, international economic conditions **(**GATT negotiations and globalization of agricultural products trading) made competition more pronounced and induced farmers to reduce costs and **improve productivity** (Goulet, study report, 2004).

At the same time, **various farming materials** were built and perfected, improving the quality of sowing and crop residue management (Barbier and Chevrier, study report, 2002). In addition, **herbicides costs decreased**, particularly *glyphosate*, which facilitated weed management. All these factors favoured CA extension.

Nevertheless, the **financial risk** during the transition period from a conventional cropping system to a conservative cropping system is important and can be dissuasive for farmers to change their methods (Barbier and Chevrier, study report, 2002).

I-2-3-Policies

Agreements can be made between farmers and the Government in order to develop actions in terms of socio-economic or environmental issues (**CTE[1] was substituted in 2003 by CAD[2] agreements**). Conservation Agriculture practices are considered in the environmental policies. Farmers are able to ask for subventions in order to encourage them to use CA practices (Barbier and Chevrier, study report, 2002).

Organic Farming was first regulated in 1980 as part of the directive for Agriculture orientation. Then, OF regulation was modified by decree in 1988 and completed in 1996 by another decree concerning foodstuff and non-processed agricultural products. In 1998, a **development scheme for OF** was proposed by Alain Riquois: the PPDAB (Multi-annual Development Scheme for Organic Farming). The objective is to allow French OF to regain a leadership in Europe, both in quality and quantity – that is to say reach 25000 farms and 1 million hectares by 2005. This scheme contains three sections of administrative actions, including a section devoted to Research, Development and Training. As part of this section, the DGER (Higher authority of Education and Research) made an inventory of the actions of Research, Development and Training in 1998. The main research institute concerned was the INRA.

By request of the minister of Agriculture, a new inventory of OF was carried out in 2003 in order redirect the PPDAB. Following Mr.Saddier's report (Saddier, study report, 2003), new measures in favour of OF were presented by the minister of Agriculture in 2004. Some of the objectives are:

- ✓ Increase of the development of training and research
- ✓ Comprehension of the economic markets
- ✓ Connection between the national and the European regulations

Concerning **GMO,** experiments and culture are carefully regulated. The authorization of scattering and marketing is only given after the complete analysis and assessment of risks in terms of public health and environment. The organisms responsible for this analysis are the CGB: (*Commission du Génie biomoléculaire:* Bio-molecular Engineering Committee) and the AFSSA (*Agence Française de sécurité sanitaire des aliments:* French Agency for health safety of food).

GMOs authorized by the guideline 2001/18/CE are the following:

- **Allowed for all uses** (import, culture, and industrial processing): 3 varieties of maize (Bt-176 from Novartis, MON 180 from Monsanto and T25 from AgrEvo) and 1 variety of tobacco (ITB-1000-0X from SEITA)
- **Allowed only for import with a view to further industrial processing:** 1 variety of rape (RR from Monsanto) and 1 variety of maize (BT-11, from Novartis)
- **Allowed from culture and marketing of seeds**: 2 varieties of chicory
- **Allowed for production and marketing of cut flowers**: 1 variety of carnation (from Florigène).

[1] CTE : Contrat Territorial d'Exploitation
[2] CAD : Contrat d'Agriculture Durable

I-2-4- Sociological conditions

Ploughing is a traditional technique and has always been a symbolic practice. Up until the seventies, it was the only way to till the soil in France. For many farmers, renouncing ploughing represents a cultural revolution for which they are not prepared. Moreover, public opinion can prevent techniques from changing: farmers who don't plough anymore are often badly considered by their neighbours (Barbier and Chevrier, study report, 2002).

Nevertheless, the farmers who have given up ploughing are often members of working groups. Associations gathering together farmers doing CA are created (APAD[3], BASE[4] and FNACS[5]). Within the group, farmers are able to exchange experiences, set up technical references and improve their practices.

II – Conditions for obtaining results on Conservation Agriculture

II-1- Partners

Confronted with the extension of Conservation Agriculture practices in France, different partners are working together in order to improve know-how and to assess the impacts of these practices. The partners contacted are the following:

- **Research institutes**:
  - ✓ INRA: Institut National de la Recherche Agronomique (Toulouse, Orléans, Montpellier, Rennes, Versailles, Grignon, Avignon, Laon-Reims-Mons, Dijon)
  - ✓ Universities (Rennes, Orléans, ISARA, ESA, ESAP)
- **Technical institutes**:
  - ✓ ITV (vine),
  - ✓ ITB (sugar beet),
  - ✓ Arvalis-Institut du végétal (cereals),
  - ✓ CETIOM (sunflower, rape…),
  - ✓ ACTA (studies on weeds in cropping systems)
- **Chambers of Agriculture*:*** There is one per department in France. They aim to assist the farmers in farming and cropping system management. The studies are carried out often in response to farmers' request.

II-2- Main experiments in France

The results presented in the report mainly come from experimental stations. Even if many studies are carried out on farms, results are rarely published and often contradictory; therefore conclusions are difficult to extrapolate. Moreover, the follow-up on farm experiments is difficult to realize. For example, measures are often sporadic. Nevertheless, on-farm studies are able to take into account a large range of cropping systems and pedo-climatic conditions.

II-2-1-Field experiments

1- Boigneville: This long term experiment (since 1970) is located in the Parisian basin. It is managed by *Arvalis-Institut du végétal*. The objective is to compare three tillage practices:

[3] APAD : Association pour la Promotion d'une Agriculture Durable
[4] BASE : Bretagne, Agriculture, Sol et Environnement
[5] FNACS : Fédération Nationale d'Agriculture de Conservation des Sols

- Conventional Tillage (CT): ploughing to 30 cm depth followed by superficial tillage (field cultivator) and sowing.
- Superficial Tillage (ST): cultivation to approximately 12 cm depth, with a rotavator, a field cultivator and sowing
- No-Tillage (NT): direct sowing

The experiment uses different cultures: continuous wheat, continuous maize (stopped) maize-wheat rotation irrigated (stopped), maize-wheat rotation not irrigated, and wheat – beet – spring barley rotation (since 1998).

2- Estrées-Mons: the experiment on conservation tillage practices was established in Northern France and was started in 1999. It is managed by *INRA Mons*. Two tillage practices are compared: conventional tillage and superficial tillage (5-6 cm).
Three cropping systems with different compaction risks are compared:

- I - Low compaction risk. The rotation was pea / winter wheat/ flax/ winter wheat. Sowing and harvesting always carried out during a dry period.
- II - Medium and III- high compaction risk: the rotation was: sugar beet/ winter wheat/ maize/ winter wheat. Cropping system II is managed to avoid sowing and harvesting in wet conditions. Cropping system III was managed to maximise light interception by sugar beet and maize (sowed and harvested during wet periods).

The objective is to evaluate the effects of cropping systems management on soil structure.

3- Kerguehennec: The experiment was started in 2000 in the south of Brittany (Morbihan). It is managed by the *Chamber of Agriculture of Morbihan.*
The experiment contains two main sub-experiments with different objectives:

The "agronomic experiment" aims to test the effects of tillage practices on soil properties and to assess the management of reduced tillage systems. Three systems are compared with different tillage practices under maize/wheat/rape/wheat rotation: conventional tillage, superficial tillage and direct drilling. Four fertilization strategies are also tested: mineral fertilization, chicken manure, bovine manure and pig manure.

The "environmental experiment" aims to measure runoff and herbicide transfers under natural or simulated rainfalls. Three tillage systems are compared under maize-wheat rotation.

4- La Cage: The experiment was started in 1997 and is managed by *INRA/INAP-G* (Grignon). It aims to perfect cropping systems economically viable and to assess their environmental and technical performances. The systems are managed according to a succession of given directives set up at the beginning of the study. The directives are kept or changed whether the targeted fixed yield is attained or not. Four cropping systems are compared.

- Intensive system: the objective is to attain maximum production possible given soil and climate conditions.
- Integrated management system aims to minimize environmental nuisances by reducing inputs. At the same time, gross margin is maintained by compensating for production decrease by limiting inputs.
- Organic farming system aims to respect specifications for organic farming practices (no chemical input)
- Permanent cover and zero tillage system started in 1999. It is managed as the integrated system but with no tillage. Two cover crops are tested: red fescue and white clover. The rotation is wheat –maize-wheat-pea. The yield objective fixed for wheat is 68 q/ha.

5- Grignon: Situated in the Parisian Basin, several experiments were established here by *INRA/INA P-G.*

(1). The first experiment was started in 1957-1958. It aimed to test three reduced tillage systems (ploughing to 25 cm, ploughing to 15 cm, and superficial tillage with a cultivator (10cm)). The test no longer exists.

(2). An experiment carried out from 1983 to 1986 in order to study the effects of cropping systems on weed dynamics. Three tillage practices were studied: conventional tillage, superficial tillage and direct drilling.

(3). An experiment conducted from 1999 to 2001 in order to analyse the relationship between wheat and fescue as a continuous cover crop.

(4). A experiment was launched in 2002 in order to study the functioning and the impacts of mixed intercropping grown in direct sowing. Ten permanent cover crops are studied in mixed stand with wheat.

6- Montlaur: this experiment, situated in the South of France, started in 1996 by *IRD-Montpellier*. It aimed to assess erosion and runoff under various management practices. The experimental design included seven treatments: flat mouldboard ploughing, raised mouldboard ploughing and superficial tillage with either mineral fertilizers or sheep manure, and no tillage with sheep manure only. The soil erodibility was assessed by field rainfall simulation. The experiment was stopped in 1998.

7- La Jaillère: this long-term experiment is located in western France and is on-going. It is managed by *Arvalis-Institut du Végétal*. It aims to assess the impact of soil management on water quality. Measurements of pesticide transfers started in 1994. The crop rotation is maize – wheat. Two soil management techniques are compared: conventional system and direct drilling including exceptional decompaction and stubble breaking.

8- Auzeville: This experiment, carried out from 1971 to 1981, is located in southern France. It is managed by *Arvalis-Institut du Végétal*. It aims to study cropping system management. Three techniques are compared: conventional tillage, superficial tillage and no-tillage. The crop rotation is maize-wheat.

9- Baziège: This long-term experiment, started in 1984, is located in southern France and is managed by *ACTA*. Two soil management practices are tested: ploughing and no ploughing. Two weed control practices are also tested: intensive weed control and minimum weed control. The rotation studied is sorghum-sunflower-winter wheat. This experiment aims to study the effects of soil tillage practices and weed control on weed development.

10- Coings: This experiment, located in the Centre of France, was carried out from 1985 to 1992 and was managed by *Arvalis-Institut du Végétal*. Two tillage practices were compared (ploughing and no ploughing) and three levels of weed control were also tested (low, conventional and high weed control). The rotation studied was rape-wheat-barley. The experiment aimed to study the impacts of soil tillage and weed control on weed dynamics.

11 – Saint Aubin la Plaine: This experiment, located in Vendée (western France), was carried out from 1970 to 1982 and was managed by *Arvalis-Institut du Végétal*. Three tillage practices were compared: conventional, superficial and no tillage. The rotation studied was maize-wheat. The experiment aimed to study cropping systems management without ploughing

12- Courseulles: This experiment, started in 1990, is situated in western France (Calvados) and is managed by *ACTA*. Two practices are tested: ploughing and superficial tillage. Between 1996 and 2000, biological analysis was carried out.

II-2-2- Main on farm studies

13- Midi Pyrenées: :A network of 20 agricultural fields was set up in 2001 in order to assess the effect of no-tillage on cropping systems and soil characteristics in relation with water erosion (13 fields divided in two plots comparing ploughed and unploughed, and 7 full fields being unploughed). Fields were studied in terms of various indicators (organic matter content, microbial biomass, stability, earthworm activity, erosion, weed infestation…) It is coordinated by the *Regional Chamber of Agriculture of Midi Pyrénées.*

14- Bretagne: A network of agricultural fields was set up in 2003. Ploughed fields and no-tilled fields are compared according to various characteristics: soil and cropping system. The objective is to integrate various cropping systems in different pedo-climatic conditions in order to have diverse results. It is coordinated by the *Chamber of Agriculture of Morbihan.*

15- Pays de Caux: this area is composed of intensively cultivated silty loam plateaus with gentle slopes. It is hardly affected by water erosion. Several studies are carried out.

(1). A working group was initiated and several sites were defined in farmers' fields in order to measure erosion and runoff. The Chamber of Agriculture of Seine Maritime, ofEure and INRA/INAPG participate in this working group.

(2). A scientific experiment was started on farm. It aims to assess several agricultural practices regarding runoff and erosion risk**.** Five different intercrop treatments were tested to compare their effects on runoff and erosion: no-till, light duty mouldboard ploughing, mustard intercrop, superficial tillage with a cultivator applied either under dry or humid conditions.

16- Châtel Gérard : An experiment was conducted from 1997 to 2000 in eastern France (Yonne). The goal was to test several crops residue management techniques in a no-tillage system for cropping rape. Five techniques of stubble breaking crossed with five sowing techniques (sowing machine) were tested. This experiment was managed by *CETIOM, Arvalis-Institut du végétal, the Chamber of Agriculture of Cote d'Or and Yonne.*

17- Centre: Two studies are conducted:

(1): An on-going experiment was started in 1999 in a field using integrated cropping systems management (superficial tillage and no herbicides). It aims to study specific richness and diversity of fauna in this innovative system.

(2): A network of 12 fields was studied between 2001 and 2004 (fields divided in two plots: 11 comparing soil with or without a permanent cover and one comparing ploughing and no ploughing). The experiment aimed to study the impact of permanent cover and no ploughing on *Carabideae.*

18- Alsace: the experiment, situated in eastern France, was managed in 2004 by the *ARAA*, the *Chamber of Agriculture of Haut Rhin* and the *Chamber of Agriculture of Bas-Rhin*. It aimed to assess the impact of reduced tillage on soil surface state and runoff and erosion.

III – Significance and impact of the results obtained on Conservation Agriculture

III-1- Carbon cycle and greenhouse gas emissions

III-1-1- Dynamics of organic matter: organic carbon production and mineralization

The results obtained showed that:
- Reduced tillage induced an increase of organic matter content in the superficial layers
- Return of organic matter and organic carbon mineralization were lower in the no-till system
- Mineral particles associated with organic matter in no-till system protected OM from mineralization
- In a vineyard with permanent grass cover, the speed of decomposition of organic matter and mineralized carbon content were higher

At Boigneville, **reduced tillage induced an increase of soil organic matter contents in the superficial layer**: it was estimated at 3,6% and 2,6% for no-tillage and superficial tillage, whereas it was 2% for conventional tillage. At the depth of 20 cm, soil organic matter content became lower in reduced tillage systems (no-tillage and superficial tillage) than in conventional tillage systems: 1,6% versus 2% (*in:* Labreuche et Bodet, 2001).

It is possible to assess the effects of tillage on the turnover of the soil organic matter, using the natural quantity of ^{13}C in the soil. C_4 plant (e.g. maize) is richer in ^{13}C compared with C_3 plants (e.g. wheat). The difference sustains during the decomposition of these two types of plant material. In conclusion, soil carbon derived from maize is distinguishable from that of wheat by its isotopic composition (Balesdent *et al*, 1990). The study, carried out on the Boigneville experiment, showed that in the no till treatment:

- ✓ **The vertical distribution of the organic carbon is modified**: it was observed that 75% of the organic carbon returned from the latter crop (maize) to the 0-30 cm layer can be found in the uppermost 5 cm. On the other hand, in the ploughed plot, a uniform vertical distribution of organic carbon returned from maize was observed.
- ✓ **The return of organic carbon from maize is lower**.
- ✓ **Organic carbon mineralization was also lower**. In fact, the amount of original soil organic matter mineralized in 17 years was doubled in the conventional tillage (0.95 kgC/m²) compared with that in no-till (0.45 kgC/m²). In no-till, the extent of mineralization was approximately the same in the top layers as in the 10-25 layers, despite differences in physical and chemical conditions.

The effect of superficial tillage was the same as that of conventional tillage but affected only the tilled layer (Balesdent *et al*, 1990).

More organic matter is located in stable aggregates in no-till than in tilled systems (Puget *et al*. 1995, 1996, 2000). **Mineral particles associated with organic matter** in aggregates **protect it from mineralization.** Conventional tillage directly affects this association, by mechanically breaking aggregates and by exposing them to rain on the bare soil surface. This “deprotection” induces organic matter release and an increase of organic matter degradation by microbial activity. The “protective capacity” offered by macroaggregates against biodegradation would increase with soil organic matter and clay content and duration of no tillage (Balesdent *et al*, 2000).

At Boigneville, a study was carried out in order to establish what level of soil structure protects soil organic matter. Soil structure was progressively destroyed and C and N mineralization were measured. Limited destruction (soil sieved at 12,5 and 2 mm) had no effect on C and N mineralization. **Increasing soil disturbance** (mesh size ranging from 250µm to 50µm) resulted in **greater carbon and nitrogen mineralization** for all treatments with the exception of the surface layer of the no-till treatment. **The most pronounced effect** was observed in the **deeper layer of the no-till treatment,** which shows an important effect of organic matter protection. On the contrary, in the conventionally tilled soils, no statistical differences in mineralization were observed when increasing the soil disturbance (Oorts *et al*, proceedings, 2004). Further studies are needed in order to understand why there was no effect of destruction in the upper layer of the no-till soil.

Some studies were carried out in the Mediterranean wine producing areas in order to assess the effect of some soil management treatments (among them grass covering) on the microbiological activity and on the organic matter decomposition (Chantelot and Renaud, proceedings, 2004). Some trends were observed: it was noticed that the percentage of microbial carbon and **mineralized carbon content tended to be higher in the systems with a continuous grass cover**. Furthermore, in these systems, the **rate of decomposition of organic matter in standard laboratory conditions was higher**. On a mass of litter initially contained in a hermetic litter-bag, the remaining mass is lower by 5% in the samples with grass cover compared with the tilled samples.

III-1-2- Carbon storage

Results obtained showed that:

- Reducing tillage induced an accumulation of carbon in topsoil and a decrease in the deeper layers
- Carbon stock was higher in no-till systems (average storage 0,2 ± 0,13 tC/ha/year)
- The Particulate Organic Matter rate increased in systems with a permanent cover

Compared to ploughing, direct drilling implies **an accumulation of total carbon in topsoil**. At Boigneville, the carbon accumulation in topsoil during 12 years of no-tillage management is estimated at 22 ‰ whereas it is only 10‰ when ploughed. On the contrary, as the former tilled layer was not fed anymore by overturning the soil, **carbon decreased in the deeper layers**. At 25 cm, the carbon content reached 6‰ whereas it was still 10‰ in the ploughed system (Guérif, 1986 *in* Guérif, 1994).

Some studies showed that the **carbon stock was higher in direct drilling than in ploughing.** The difference increased with time. (Guérif, 1994).Arrouays *et al* (2002) reported **an average storage of 0,2 ± 0,13 tC/ha/year.** The carbon content difference at the balance would be 12 tC/ha (Arrouays *et al*, 2002). At Boigneville, after 8 years, the difference in carbon stock between ploughed system and direct drilling system was about 1t/ha, whereas it was 5,2 t/ha after 28 years (carbon stock calculated for a constant mass of soil with return of crop residues). The increase of storage in relation with the reduction of tillage fluctuates between 100 and 300 kg/ha/year in function with the techniques used and the duration of implementation. Over 28 years **at Boigneville**, the carbon storage observed is similar for superficial tillage and direct drilling: it was **0,1 tC stored/ha/year** (Thevenet *et al*, 2002). It is slightly lower than the one estimated by Arrouays *et al* (2002).

Recent data acquired on **both C amounts and soil organic matter quality**:

(i) confirmed Boigneville (30 years of no tillage under cereal cropping and without cover crop) to be a relatively low C storing No Till experiment compared to others,

(ii) revealed a **significant increase by 8% of carbon stock** at La Cage in the no till plots (5 years of no tillage under cereal cropping and with permanent cover crop) compared to the plots under the productive system (Balabane *et al*., 2005).

As far as additional carbon storage was concerned, the authors highlight the hypothesis of a higher importance of the incoming flux from the cover in comparison with the physical protection due to no-till.

Concerning SOM quality, only cropping systems with a permanent cover differed from conventional systems in the distribution of total C stocks between particulate (> 50 µm) and humified (< 50 µm) organic matter. At Boigneville, POM-C%Total C was similar, about 15%, in both no till and conventional till plots, whereas in the "permanent cover and zero tillage" system at La Cage, it increased by 23% over 5 years compared to the productive system (Balabane *et al*., 2005). POM-N could constitute a more reliable indicator of the effect of different till management on soil functioning than to POM-C (Balabane *et al*., 2005).

III-1-3- Greenhouse gas emissions

- N_2O and cumulated CO_2 emissions seemed to be higher in the no-till system

A study carried out at Boigneville showed that the **CO_2 emissions were significantly different between the ploughing system and the no-till system, in half of the cases.** Depending on soil characteristics, CO_2 emissions were sometimes higher and other times lower in the conventional tillage system compared to the untilled system. Over a 12 month period, the total quantity of emitted CO2 was 3162± 453 kgC/ha for the ploughed system and 4068± 221 kgC/ha for the no-till system (Nicolardot *et* al, proceedings, 2004).

Regarding the functioning of N cycle, there is an interaction between the N2O emissions and the C cycle. Various results showed that in the soils with high organic matter content, the intensity of N_2O emissions tended to be higher (Hénault *et al*, 2001).
The observations waged at Boigneville showed that N_2O emissions were on average lower than 0.25 gN/ha/h. However**,** due to an important contrast of results, no significant difference was observed between ploughed and no-till systems. Nevertheless, **the untill system tended to emit more N_2O than the conventional system** (Nicolardot *et* al, proceedings, 2004).

III-1-4- Models for studying carbon dynamics

- The Hénin-Dupuis model takes into consideration two pools of organic carbon. It overestimates the carbon losses
- The AMG model takes into consideration three pools of organic carbon: the active fraction of the organic matter, the stable fraction of the organic matter and the crop residues
- The two parameters of the AMG model (mineralization rate and humification coefficient) decreased in no-till systems
- The AMG model simulates correctly the evolution of organic matter depending on the agricultural situations

Several models were set up in order to simulate the evolution of the carbon stock.

The **Hénin-Dupuis model** takes into consideration two pools of organic carbon: the first one corresponds to the carbon contained in the crop residues and the second one corresponds to the carbon contained in the humic organic matter (Hénin and Dupuis, 1945).

This model badly reproduces the carbon evolution because it overestimates the soil carbon losses (Thevenet *et al*, 2002). That's why it was improved.

A new model was suggested and tested by Andriulo, Mary, Guérif (Andriulo *et* al, 1999). It considers three pools of organic carbon (the organic matter pool was divided in a stable fraction and in an active fraction). The model implies two parameters: k_1, the humification coefficient which represents the efficiency of the conversion from organic residues to humic carbon and k_2, the mineralization rate of the active fraction. These parameters were adjusted in the Boigneville experiment. The obtained results are similar to the Balesdent's study: they show that **reducing soil tillage decreased the mineralization rate** in relation to the depth of tillage (k_2=0,046/year with ploughing and k_2=0,017/year with direct drilling). Furthermore, the **humification coefficient decreased in the no-till system**, as the residues decomposed at the soil surface (Wylleman, study report, 1999). The model was tested on 390 cases. It explained 60% of the observed differences. The model slightly underestimated the observations, but it is much more realistic than Henin-Dupuis's model which only explained 34% of the observed differences (Mary and Wylleman, proceedings, 2001)

The AMG model allows one to simulate correctly the evolution of the stocked organic matter depending on the agricultural situation. For instance, a simulation of the carbon stock evolution relative to the tillage depth and the level of organic return is available. Direct drilling is the practice which allows the most important storage, whatever the level of organic return. Introducing soil tillage, even if it when superficial (<5cm), would reduce the carbon saved: it reduced by 10% if the organic return is high and by 25% if the organic return is low. On the other hand, it is also possible to simulate the effect of occasional ploughing in a system usually managed by reduced tillage on the carbon stock. For instance, ploughing one year out of four in a direct drilling system induces a decrease of saving carbon by 50% in comparison with continuous direct drilling (Arrouays *et al*, 2002).

Finally, by using the kinetic model of the carbon stock evolution when changing from a ploughed system to a direct drilling system, it was possible **to simulate a variety of situations of carbon storage which correspond to different hypothesis for the extension of direct drilling practices in France**. For example, if 50% of the arable soils (19Mha) were converted to direct drilling management, the total quantity of carbon accumulated in soils would raise to 70MtC within 50 years. If one supposes that the change of the surfaces in direct drilling would be progressive and that ploughing would be done every 4 years, the additional storage would be reduced to 35MtC in 50 years (Arrouays *et al*, 2002).

III-2- Erosion and runoff risks

- Structure stability improved in the upper 3 cm in no-till systems, particularly in case of microcracking and explosion
- Permanent vegetal cover grown in no-till systems improved aggregate stability more efficiently than systems without a vegetal cover
- Young organic matter was responsible for macroaggregate (>2µ) stability
- Run-off and soil losses were linked to water-stable macroaggregation and carbon organic content
- Erosion was reduced in no-till systems
- Runoff was reduced during the crop and during the intercrop if there was a cover, whereas it increased during the intercrop in no-till systems without cover

III-2-1- Soil structure stability related to erosion and runoff risk assessment

III-2-1-1 - Relationships between soil management and structural stability

The first results obtained at Boigneville are taken from the measured rates of the stable aggregates after being treated with benzene. It was noticed that the stability was unchanged in the ploughing system and was unaltered in the deeper layers with superficial tillage management or no-tillage management (Agb= 3 or 4%). On the contrary, **the stability was improved in the upper 3 cm in no-tillage system** (Agb = 10 to 25%) (Monnier *et al*, 1976).

These results were refined using another method which permits one to evaluate the structure stability in comparison to different mechanics of desegregation: 1): explosion by heavy rain (tested by immersion), 2): microcracking depending on repeated moderate rains and desiccations (tested by humidifying), or 3): kinetic energy created by rain drops (tested by shaking) (Le Bissonnais, Le Souder, 1995). This new method characterizes the structure stability of topsoil in relation to erosion impact. The results obtained showed that **not tilling the soil improved topsoil structure stability**, particularly in case of **explosion** and **microcracking**. For example, at Boigneville, the particles "mean weight diameter" (MWD) for the immersion test was approximately 0.2mm for ploughed soils, 0.4 mm for superficially tilled soils, and 0.5 mm for untilled soils. In the case of the humidifying test, particles MWD were respectively: 1.00 mm, 1.3mm and 1.6mm. On the other hand, the shaking test gave contrasted results. Differences were insignificant at Boigneville (MWD approximately 1.4mm for the 3 tests) whereas at La Cage, in the "permanent cover and zero tillage" system, stability of topsoil is improved (MWD average is 1.9mm approximately for the "permanent cover and zero tillage" system and 1.3 mm for the "intensive" system). These differences may be explained by clay content: the clay content is higher in Boigneville soils than in the other soils. Consequently, aggregates are more cohesive at Boigneville and thus more resistant to shaking (Balabane *et al*, 2005).

On the other hand, **permanent vegetal cover grown in the no-till system** (cover crop at La Cage) **improved aggregate stability more efficiently** than a system without vegetal cover. The observation would reveal the role played by roots in soil structure (Balabane *et al*, 2005).

In the Midi Pyrénées, results did not show a systematic improvement of stability in untilled systems. Nevertheless, in 7 cases out of 9, differences were favourable to no-tillage (average increase of MWD for the 3 tests by 0.26mm). (Midi-Pyrénées, CA, study report, 2004)

III-2-1-2 – Relationships between soil organic matter, structural stability, biological activity and erosion and runoff risks

In the Midi-Pyrénées, stability tests show that **structure stability was dependent on soil properties** (especially organic matter content and clay content). Stability test on "Boulbenes" (soil with low organic matter content and low clay content) gave particles with a MWD lower than 1 on average, the test on calcareous and clayey soils (low organic matter content but clay content>25%) gave values between 1 and 2 on average, and on clayey alluvium (high clay content > 25% and high organic matter content >3%) gave values higher than 2 on average (Midi-Pyrénées CA, study report, 2004).

The study carried out at Montlaur assessed the relationship between soil erodibility, macroaggregate stability and carbon content of the surface samples. **Run-off and soil losses were linked to water-stable macroaggregation** (which prevents soil crusting) **and carbon**

organic content for the studied soil. In particular, during the first 30 minutes of rainfall, runoff and soil losses were closely correlated with topsoil initial water-stable macroaggregation for the three systems (r=0.891, r=-0.950, r=-0.900 respectively): but not with the topsoil carbon content. By the end of the rainfall, turbidity and soil losses were closely correlated with topsoil carbon content (r=-0.954 and r=-0.950 respectively), and to a lesser extent, with water stable macroaggregation (r=-0.796 and r=-0.791 respectively). The effects of agricultural practices on erodibility were therefore dependent on the effects on water stable macroaggregation and carbon content in the superficial soil layer (Barthès *et al*, 1999). Moreover, in the experiment, there is no significant effect of the inputs (mineral fertilizers or sheep manure) on runoff and soil losses.

Young organic matter was responsible for macroaggregate (>2µ) stability. A study on the Boigneville experiment showed that aggregate stability was higher for the no-till treatment than for the superficial and conventional treatments. The stable macroaggregates were richer in total carbon than the microaggregates. The macroaggregates contained the additional organic matter with a large percentage of young organic carbon. The young organic carbon was assumed to be responsible for the aggregate stability (Puget *et al*, 1995).Young C comprised 50% particulate organic matter, 20% associated with silt and 30% with clay particles (Puget *et al*, 2000).

III-2-2- Land management and risk assessment

Several experiments have been set up by Chambers of Agriculture in the concerned areas. They aim to evaluate the effects of some agricultural practices regarding run-off and erosion.

In Alsace, results showed that **untilled areas induced a decrease of run off** by 10 and a decrease of sediment exports by 2 compared with ploughed areas. Moreover, soil surface states were less deteriorated in the case of untilled systems. However, the results are mixed among the different sites because runoff closely depends on rainfall, which varies from one site to another (Armand, study report, 2004).

In Seine Maritime, the results are the following: (Seine Maritime CA *et al*, study report, 2004):

- In beet cultivation, **mustard sowed without ploughing reduced runoff** by 1.5 times in comparison with sowing after a spring ploughing.
- For a long intercrop, **mustard sowing after superficial tillage with a cultivator implied a reduction of runoff** by 5 in comparison with a field without tillage, and by 15 in comparison with a field with two successive superficial interventions and without cover crop.
- **Growing a ray grass under maize crop allowed reducing runoff by 80%** for long and weak rainfalls. Nevertheless, the ray grass efficiency might decrease when rainfall intensity increases.

These results have to be cautiously considered. The measures were often sporadic and the experimental protocols were applied with difficulty.

In the Midi-Pyrénées, results showed that no-tillage had reduced erosion risks and the effect had increased over a long duration (erosion decreased by 63% for a field using organic farming and no-tillage system for 22 years compared to a field using conventional tillage (Delaunois *et al*, study report, 2004).

The research experiment carried out in the Pays de Caux showed that in 1993-1994, in the case of mouldboard ploughing, erosion reached 182 kg sediment/ha and runoff volume was 3,2 mm. In comparison, **no-till treatment resulted in low erosion** (40 kg/ha) but **high runoff** (6,1mm). Compared to no-till, mustard intercrop significantly reduced runoff (1,5 mm) without significantly increasing erosion (82 kg/ha). The superficial tillage in humid conditions led to an increase of runoff (12,4mm) and erosion (301 kg/ha), presenting the highest risk for both runoff and erosion (Martin, 1999).

The way farming practices modify soil surface characteristics and, as a result, **runoff and erosion processes, must be considered on various scales:** on spatial scales (from field size to small-watershed level) and on time scales (yearly/ daily). Several studies were carried out in the Pays de Caux, with silty loam soils susceptible to crusting. On the field scale, a simple relation was established to link the agricultural state and the runoff risk. On the watershed level, a model was set up: STREAM (Sealing and Transfer by Runoff and Erosion related to Agricultural Management). Different information is required at different points of the watershed (slope, land use, crop cover,…) and also information concerning the simulated rainfall (amount, intensity, duration….). The model permits one to simulate the runoff module's outputs. There is no study as to date regarding the impact of no-tillage on runoff and erosion at a watershed level. However, it is possible to use STREAM in order to test several anti-erosion schemes using several CA practices and to choose the most efficient in a given context (Martin *et al*, 2004)

III-3- Water pollution

- Pesticides reactivity depended on their application period : in no-till systems pesticides transfers decreased in case of spring application and increased in case of autumn/winter application

III-3-1- Nitrate lixiviation

According to a summary of several experiments, **leaching of nitrates seems to be reduced by reduced tillage**. However, opposite effects have also been unobserved (Barriuso *et al*, 1994). No French research has been found on this subject.

III-3-2- Pesticides reactivity, runoff and pollution risks

Results obtained on the pesticides reactivity while reducing soil tillage are contradictory. Most research is American, and the extrapolation to French farming situations should to be done with caution (Barriuso *et al*, 1994).

At La Jaillère, results showed that **pesticide fluxes depend on their application period**. In the case of **spring application, *atrazine* transfers decreased by 60% in untilled systems, for similar volumes of runoff** (on average, 194 mm for the untilled fields and 229 mm for the ploughed fields over three years). From 91% to 99% of these losses occurred during the winter following the application. *Epoxiconazole* gave the same results when spread on the wheat crop during the spring. On the other hand, **during the autumn, volume of runoff after the first rainfall was globally higher in the untilled system** (13.95 mm versus 8.4 mm on average for the two campaigns). When the crop was treated during autumn, the ***DFF* concentration obtained was increased** for the two years by 2.5 and 5 in the untilled system compared with the ploughed system (Real *et al*, 2005).

At Kerguehennec, results are coherent with the ones obtained at La Jaillère. Under wheat crop **during the autumn and winter**, **runoff was higher for the untilled soil** (average

volumes of runoff over the two years: 12.85 mm for untilled system and 5.9 mm for ploughed system). ***Isoproturon*** **concentrations were higher in untilled system**: 1240.7 mg/ha on average over the two campaigns versus 136,75mg/ha.
On the other hand, for maize crop during **the spring**, **runoff was lower for the untilled system** (on average over the two campaigns: 1.4mm versus 19.9 mm for the ploughed systems). ***Sulcotrione*** **concentrations were higher in the ploughed fields** (on average for the two campaigns: 5331mg/ha versus 134.15mg/ha in no-tillage) (Real *et al*, 2005).

A thesis is on going in the south of France: it is studying the impact of the organic matter and mineral particle association (nature, localisation, association degree) on the herbicides retained in the soil. The crop studied is irrigated maize. A ploughed system is compared with an untilled system, with or without a permanent cover crop (Alletto, on-going thesis).

III-4- Biological properties and biodiversity

III-4-1- Microorganisms

- Microbial biomass did not significantly change in the entire 0-30cm layer between ploughed and no-till systems
- Microbial biomass increased in the upper layer of no tilled soils

The DMOSTRA project showed that **changes** induced by alternative cropping systems regarding **microbial biomass were more important in topsoil** than in the entire 0-30cm layer. There was an **increase of microbial biomass in the upper layer** of the systems managed without ploughing and with permanent soil cover (mulch or permanent crop cover). At La Cage, in the "permanent cover and zero tillage" system, there were 181 µg of microbial C /g of dry soil in topsoil (0-5 cm) whereas there were only 129.6 µg microbial C/g of dry soil in the productive system. . No significant impact of the cropping system was observed on the total bacteria microflora due, perhaps, to the method used which only counted cultivable bacteria. Likewise, it was coherent with the results found in the bibliography. As spatial variability within a parcel was observed, it was difficult to assess structure modifications of the bacterial communities. Regarding the **fungi biomass**, **important and rapid changes (**over 6 years)**, were observed in the "permanent cover and zero tillage" system**. As far as the entire 0-30 cm layer was concerned, there was no difference between the "permanent cover and zero tillage" and the "intensive" system (Balabane *et al*, 2005).

The experiment carried out at Courseulles gave the same results. The differences were low in the entire tilled layer. The microbial total carbon was by 2223kg/ha in the ploughed system whereas it was 2079kg/ha in the superficial tilled system (Chaussod, proceedings, 2001). I**n the topsoil, microbial biomass was higher in the superficial tilled system** than in the ploughed system (+114mg C in the microbial biomass/kg soil). On the contrary, **in the deep layer, microbial biomass was lower in the superficial tilled system** (-59mg C of microbial biomass/kg soil in comparison with ploughing). The number of microbes in reduced tillage system was nearly twice as high in topsoil as in the deeper layer. On the contrary, the distribution was homogeneous in the ploughed system (ACTA, 1999 *in* Labreuche et Bodet, 2001).

In the Midi-Pyrénées, measures of microbial biomass showed that generally, microbial biomass was higher in the untilled field (increase by 39 gmicrobialC/100g soil on average in the 0-20 cm layer). A **decreasing gradient of microbial biomass was also observed with depth** (Midi-Pyrénées CA, study report, 2004).

III-4-2- Macrofauna

- No-till systems often increased earthworm biomass and density. The anecic species became the predominant species
- Permanent cover seemed firstly to favour proliferation of slugs. Then the cover seemed to protect crop from slug consumption
- *Carabidae's* density and diversity was higher in systems with permanent cover
- Abundance, specific richness and diversity of microarthropods were higher in vineyards with natural grass cover

III-4-2-1- Earthworms

A study carried out at Boigneville, showed that **earthworm density were unexpectedly lower under reduced tillage** (6 specimens/m²) and higher under deep-ploughing (67 specimen /m²). Moreover, an analysis showed that earthworm densities were positively correlated with limestone depth. The influence of the limestone depth seemed more important than the tillage effect. The herbicide treatment, often higher in reduced tillage, was also put in consideration: some products being toxic for earthworms (Topoliantz *et al*, 2000).

In the DMOSTRA project, the results appeared different: at La Cage and Boigneville, **no-till systems** (with permanent vegetal cover at La Cage and without permanent vegetal cover at Boigneville) showed **an increase by 3- to 5-fold in earthworm biomass and in earthworm density** compared with the conventional tillage system. The biomass increase was mainly due **to large anecic species present in larger amounts in the no-till systems.** The number of species also increased under non till. At La Cage 7 different species were found in the "permanent cover and zero tillage" system whereas there were 5 in the "intensive" system. At Boigneville, 5 species were found in the no-till system versus 4 in the conventional system. (Balabane *et al*, 2005)

Similar results were obtained by Grandval : while reducing soil tillage, earthworm biomass was multiplied by 5 (Granval *et al*, 1993).

At Kerguehennec, using a test with formol followed by a correction by manual counting, measures showed that there was **no significant difference between total earthworm abundance** in ploughed fields or in untilled fields. This might be related to the fact that the experiment was managed for only 4 years. However, regarding relative abundance of earthworm communities, the results were similar with the DMOSTRA project: **the number of anecic species was higher in untilled fields** than in ploughed fields (on average 40% and 60% of anecic species in superficial tillage and no tillage versus 20% in conventional tillage). Moreover, species diversity was larger in reduced tillage: Shannon index is 1.87 and 1.91 in superficial tillage and no-tillage and 1.68 in conventional tillage (Alletto, study report, 2002).

III-4-2-2- Slugs

The study in the region Centre showed that **permanent vegetal cover favoured slug proliferation** the first year (979 slugs in a system with permanent cover, versus 204 in a system with no soil cover). After 3 years, the trend reversed: there were 126 slugs more in the

system without permanent cover. The hypothesis proposed to explain this observation was that **permanent cover protected crops from slug consumption** (Bout, study report, 2004).

III-4-2-3- Carabidae

The study carried out in the region Centre showed that **species diversity was high in integrated systems**: 74 species of *Carabidae* were found whereas only 13 species were found in a productive system in *Seine Maritime*. Seven species represented more than 81% of the whole population: *Poecilus cupreus, Platysma vulgare, Ophonus rufipes and Anchomenus dorsalis* were dominant (Rougon *et al*, 2001).

In the region Centre, the study of various fields allowed to assess the impact of vegetal cover on *Carabidae* populations. Since the installation of the cover, ***Carabidae's*** **density and diversity had quickly improved**: the number of species found on all the fields had increased from 39 to 71 and the number of individuals trapped was multiplied by 5. A similar change was observed when introducing no tillage: on the whole field, the number of *Carabidae* trapped was three times higher and 17 other species were found. Moreover, more sensitive species had substituted pioneer species: *Anchomenus dorsalis*, *Carabus auratus*, *P. rufipes* and *H. dimidiatus.* This is interesting in terms of slug regulation (Bout, study report, 2004).

III-4-3-3- Microarthropods

Soil acarina and collembola communities were studied during three years to compare the impact of agricultural practices in Mediterranean vineyards. The results show that **natural grass** and weeds controlled by post emergence herbicides **had a favourable influence on abundance, specific richness and diversity** of several taxonomic groups (Collembola, total Acarina, immatures of Oribatida), whereas tillage and weeds controlled by pre and post emergence practices had a negative influence. (Chantelot and Renaud, proceedings, 2004)

III-4-3- Macroflora

- Weed population increased more quickly
- Seeds were concentrated in topsoil and seed-stock evolution was lower in no-till systems
- Reduced tillage practices increased the abundance of multiannual species. No-till systems favoured perennial species.
- Weed species differ in accordance to their period of emergence and the longevity of the seed stock
- Soil management practices induced variations in emergence rates
- Weed control had a significant influence on weed stock composition

In the bibliography, experiments which aimed to compare the effects of soil management on weed development led to contrasting results. In fact, the cultural history of a field, the efficiency of weed control and the cultivated crop play a crucial part in the evolution of weed flora. It **is impossible to establish a direct relation between soil management practices and the evolution of the grain stock** (Debaeke, 1987). However, several long term experiments revealed some trends.

In untilled areas, weed populations increased more quickly than in ploughed areas. At Coings, after 3 consecutive years of minimal weed control, 280 foxtails/m² were observed in untilled systems compared with 80 foxtails/m² in ploughed systems (Rameau *et al*, proceedings, 1992).

In general, **reduced soil tillage changes the quality and quantity of weed communities** (Debaeke, 1994). Soil management changes induce **modifications of the vertical distribution of weeds seeds** in the soil. The study carried out at Grignon showed that 70% of the seeds were concentrated in the 0-10cm layer in the no-till system. In the ploughed system, the same layer contained only 50% of seeds. Nevertheless, after 30 years without any deep tillage, the deeper layer would still contain 30% of the seed potential (Debaeke, 1987). Modifications in the vertical distribution induced changes in the species selected depending on their characteristics:

- ✓ **Conventional systems induced development of annual species (**e.g.: *Viola ssp*. et *Veronica ssp.,* Rameau *et al*, proceedings 1992) and limited the development of perennial species. Species whose seed stock is persistent (50-60 years) are better adapted to ploughed soils.
- ✓ On the contrary, **reduced-tillage or no-till systems increased the importance of biannual or multiannual species** (*Rumex sp*.). Direct drilling allowed the growth of rhizomes in topsoil and consequently **favoured perennial species** (*Carduus sp*., *Convolvulus sp*., *Elytrigia sp*., *Rubus sp.* ..) ..) to the detriment of annual species. (Verdier *et al*, proceedings, 1990). Species which seed are small and temporary (6-10 years) are adapted to reduced tillage systems. (Debaeke, 1994)

At Grignon, main mechanisms of weeds flora development were studied for dicotyledonous flora, taking cultural practices into account. (Debaeke, 1987)

- ✓ **Soil management practices induced variations in emergence rates**. Without any tillage, the percentage of emergence per year did not exceed 1%.
- ✓ Weed species differed in accordance to their **period of emergence** (autumn/winter or spring) and **by the longevity of seed stock**. Emergences were more numerous in autumn in ploughed systems whereas they were more numerous during the spring in untilled systems.
- ✓ The **seed stock evolution was slower in untilled systems**.

The same study at Grignon led to **establish a model simulating the quantitative evolution of the weed seed stock.** The initial stock and the actual stock were linked by the evolution rate of the seed stock, depending on cultural practices and seed characteristics. The model was tested on ploughed and untilled fields. A simulation of the evolution of seed stock for several species gave coherent results with the real situations observed (Debaeke, 1987).

Weed control has an influence on weed stock composition (Dessaint *et al*, 1990). At Baziège, the results showed that the effect of weed control in relation to the effect of soil tillage practices varied in function to species characteristics (Verdier *et al*, proceedings, 1990).

- For annual species, the crucial factor was the longevity of grains. *Setaria viridiset* or *Seteria verticillata,* species whose seed stock was temporary, varied under the influence of the two above mentioned factors. In an untilled system, with efficient weed control, these species induced a decrease by 65.6% of the total seed stock. On the contrary, for *Anagallis arvensis* and *Anagallis foemina*, species whose seed stock was permanent, emergences were more numerous in ploughing. Weed controls had little effect.
- *Convolvulus arvensis*, a perennial species, is sensitive to the interaction between the two factors. This species could be controlled by ploughing along with intensive weed control.

A **typology of the problems induced by weeds in relation to soil management practices was set up**. It was a qualitative synthesis of species that survive in soil in relation to different tillage treatments (Debaeke, 1994).

III-5- Physical properties

- Porosity was lower and bulk density was higher in the soil upper layer of no-till systems.
- No tillage affected pores spaces of structure (mainly packing pores)
- Porosity reached a balance state, in which the remaining pores correspond to cracking pores and pores from biological activity
- Cracking and perforation process are crucial for soil structure regeneration
- Traficability was improved, resistance to root penetration seemed to be higher, water content tended to increase and hydraulic conductivity was reduced in no-till systems

III-5-1- Soil structure: porosity - bulk density

Total porosity varies in function of soil humidity and soil clay content (Stengel, 1976). The result has to be taken into account when comparing various treatments with different water contents.

Various results showed **a decrease of soil porosity in untilled systems** compared to the ploughed systems (Stengel, 1986 *in* Guérif, 1994; Foy, study report, 2004; Alletto, study report, 2002).

✓ At Boigneville, Stengel observed such a **decrease only in the former tilled layer** but no significant difference was observed under the depth of 28 cm. Moreover, he showed that soil porosity quickly decreased in the upper layer (drop of initial porosity by 25%) and reached **a pseudo-balance state** at the end of three years (structure porosity varying between 5 and 10%).

✓ At Mons, **porosity evolution depended on the degree of soil compaction**. When the compaction risk was low, the volume of the structure pores was maintained over 3 cropping years. On the contrary, when the compaction risk was high, the index of empty spaces decreased by 2 over 3 years. Likewise, for the two levels of compaction, the size of compacted areas tended to increase and their number tended to decrease (Foy, study report, 2004)

No-tillage affects the pores space of structure (Guérif, 1987 *in* Guérif 1994). The analysis of soil porosity revealed that the largest pores were the first ones to be affected. The percentage of macropores (>1.77 mm²) was 9.8% in conventional tillage and reached 6.7% in superficial tillage and 2.6% in direct drilling. **Packing pores** (representing more than 50% of the large macropores) **were the first ones affected by compaction** due to direct drilling (Hallaire *et al*, 2004).

The remaining pore space corresponds to the cracking pores, created by alternation of humidifying and desiccation, and **pores from biologic activity**, mainly earthworm activity (Guérif, 1994). **Soil porosity increased with earthworm biomass**: relative porosity increased by 4% in comparison with the control when earthworm biomass increased by 20g/m² (Cluzeau, 1999, *in* Alletto, study report, 2002). Earthworms not only create galleries but also create small aggregates with an important packing porosity (Hallaire *et al*, 2004). At Kerguehennec, the cracking pores were more numerous in a direct drilling system than in a ploughed system (14.5% versus 9 % in the10-20 cm layer) (Alletto, study report, 2002).

At Mons, **cracking** due to climate and **perforation** by earthworms **induced a decrease of the surface of compacted areas**. This process is crucial for the soil structure regeneration (Foy, study report, 2004).

Bulk density, inversely related to soil porosity, **was higher in untilled systems**. At Kerguehennec, the first year, bulk density was 1.41 in direct drilling in the whole layer, whereas, in ploughing, it was 1.27 in topsoil and 1.30 at 25cm. These trends are being confirmed over time (Alletto, study report, 2002).

A thesis is being carried out at Grignon on a cropping system without tillage and with permanent vegetal cover. It aims to study the mechanisms of soil structure evolution in innovative systems (biological activity and climate influences). Moreover, it aims to characterize the consequences of the evolution on water fluxes (Carof, on-going thesis).

III-5-2- Traficability

At Boigneville, **traficability was improved in the untilled system**. At water-holding capacity, considering a pressure close to the one produced by a tractor (200/300 kPa), vertical distortion was only several millimetres in the untilled system whereas it affected the whole tilled layer in the ploughed system (Guérif, 1994).

III-5-3- Soil resistance to root penetration

At Kerguehennec, after 2 years, for the ploughed system, the profile was homogeneous and the average resistance was 450 N/m². On the other hand, **resistance increased in the superficial tillage system and in the no-tillage system**: it reached 500N/m² and 525 N/m² respectively. These results should be considered with caution, because the measures are quite irregular (Alletto, study report, 2002).

III-5-4- Hydraulic conductivity

At Kerguehennec, excluding wheel tracks, ploughed systems had high conductivity (>150mm/h) whereas **it was low in untilled systems** (<10mm/h). In the superficial tilled systems, using the Beer-Khan method, conductivity was high in the upper layer (70 to 150 mm/h). Under 5 cm deep, it quickly fell to reach values close to the untilled system ones. In the wheel tracks, for systems whose hydraulic conductivity was high, the decrease was important while the soil was compacted (by 90% in the ploughed system). On the other hand, in direct drilling when there was compaction, conductivity decrease was slight (by 30%) (Alletto, study report, 2002).

Another study showed that when the hydraulic potential was -0.05 kPa, conductivity was 50 times lower under direct drilling than under ploughing (Hallaire *et al*, 2004).

III-5-5- Soil water content

The experiment at Mons showed more important water content in topsoil on untilled soil compared to ploughed soil. On the contrary, the trend reversed in the deeper layers. The study is on-going and the results are not yet published (Boizard, private comm.).

III-6-Soil Chemical properties

- N, P2O5, K2O, MgO and CaO rates increased in the upper layer of no-till systems
- N stocks didn't show significant difference between no-till and ploughed systems
- Potential mineralization and denitrification seemed to be higher in no-till systems
- The pH and CEC tended to be lower in no-till systems

III-6-1- N dynamics

The untilled fields **are enriched in total nitrogen in the upper five centimetres** by 14% at Boigneville and 27% at Grignon in comparison with ploughed fields. In the superficial tilled fields, there is also a slight enrichment: 10% at Boigneville and 14% at Grignon. Below 10 cm depth, there is no difference in the nitrogen content between ploughed and non ploughed fields (Langlet and Remy, 1976).

T**otal nitrogen stocks** in recent studies at Boigneville showed that there were **no significant differences between ploughed systems and untilled systems**. Total nitrogen content in a soil mass of 3300 t/ha is, on average, 4 t/ha for both the systems. Consequently, even if ploughing implied a temporary enrichment in the upper layer, the variation of annual balance sheet didn't exceed approximately several 10 kg/ha. (Germon *et al*, 1994)

A study carried out at Boigneville concerning organic nitrogen mineralization showed that in all trials, the quantity of N mineralized for no-tillage, superficial tillage and conventional tillage were comparable, but **potential mineralization seemed higher for no-tillage**. Nevertheless, statistical tests are to be conducted to evaluate significant differences (Laurent *et al*, proceedings, 2004).

Denitrification seemed to be higher in a no-tillage system. At Auzeville, after nitrogen fertilizing, the quantity of $N\text{-}N_2O$ produced in the untilled system reached 100g/ha/day, whereas it remained low in the ploughed system. (Germon *et al*, 1994)

Results regarding the quantity of mineral nitrogen available during the year were contradictory. The first studies at Boigneville and Grignon showed **similar quantities of mineral nitrogen available during the whole plant cycle** for the ploughed and the untilled systems (Langlet and Rémy, 1976). However, by the end of 1989 at Boigneville, a study, dealing with soil tillage mixed with crop residues management, showed that nitrates production during the autumn was higher in the ploughed system than in the untilled system. (Germon *et al*, 1994)

III-6-2- P and K dynamics

In the Midi-Pyrénées, **P_2O_5 and K_2O rates tended to be higher in the untilled soils** (on average an increase of 37 mg/kg and 0,08 g/kg). Moreover, P_2O_5 and K_2O rates were higher in the upper layer: the gap between the values found in 0-10cm and in 20-30 cm were by 44 mg/kg for P2O5 and 0,14g/kg for K2O. The irregularity of the results was extremely important; consequently they should be considered carefully (Midi-Pyrénées CA, study report, 2004).

At Boigneville and Saint Aubin, the results confirmed that the **upper 10 centimetres of the untilled soil were enriched in P_20_5 and K_2O**. On average, the increase observed over 8 years compared to the ploughed system was by +0.30‰ for P_20_5 and +0.40‰ K_2O at Boigneville and by +0.20‰ for P_20_5 and +0.70‰ for K_2O at Saint Aubin (Balland, 1982).

III-6-3- Other properties

In the Midi-Pyrénées, the annual results obtained for 8 pairs of fields showed that **MgO and CaO rates tended to be higher without ploughing** (on average increase of 0,04 g/kg and 0,07 g/kg). The **pH and CEC tended to be lower**: -0,3 for pH and -0,34 meq/100g for the CEC. Variations were observed between the upper and the deeper layer: the pH tended to decrease in the deeper layer (-0,38 on average) (Midi-Pyrénées CA, study report, 2004).

III-7- Cropping system management

- Reducing tillage increased the number of weed treatments. Rotation has to be taken into account to control weeds. There was a significant effect of weed control on weed development.
- The most efficient practice to reduce stubble in surface was to do stubble break twice with a cover crop
- In "direct drilling with permanent cover" systems, the association of two grasses was unfavourable and only leguminous were able to stop weeds. The competition between the cover crop and the culture should be important and induce a decrease of the yield
- Reducing tillage globally had no effect on yields if sowing was done in good conditions and if the soil was well-drained

III-7-1-Yields

At Boigneville, wheat yield did not show significant differences between conventional, superficial tillage and no-till systems. Some trends showed that when the soil was not well drained, the yield was higher in the ploughed system (+5 quintals) than in the direct drilling system. **Yields are closely linked to soil compaction**, **soil drainage, and the sowing machine used for maize** (Caneill *et al,* 1994)

Recent studies gave the same results: **reducing tillage globally had no effect on yields, if sowing was done in good conditions** (good structure and low humidity) and if the soil was well-drained (Viaux, 1999, Le Garrec, study report, 2003).

Soil management impact on the building of yield is variable. It is difficult to systematically classify yields in function of the soil technique used. Classification generally depends on climate and soil conditions and characteristics of the cropping system (Boiffin *et al*, 1976, Le Garrec, study report, 2003). At Boigneville, for maize, every stage of the crop cycle was affected by soil management. The untilled system was always penalized in comparison with the ploughed system (Boiffin *et al*, 1976)

III-7-2-Weed management

Reducing soil tillage induced an increase in the number of weed treatments. At Grignon, 1.5 treatments were applied on average for the ploughed system, 1.9 in superficial tillage and 2.5 in direct drilling (Debaeke, 1994).

The quality of weed control is crucial in untilled systems. This observation was confirmed at Baziège: the **effect of weed control was significant to explain the evolutions of seed stock and further weed development.** Contrarily, there was no significant effect of soil management practices (Verdier *et al*, proceedings, 1990). In the Midi-Pyrénées, the studies on weeds gave the same results. After 4 years, differences in weed infestation between ploughed systems and untilled systems remained the same. **The weed infestation rates observed were more closely related to the quality of weed control** than to the soil management practices.

Rotation may be taken into account in order to control weed development. At Baziège, if the summer crops were dominant, it prevented proliferation of winter species (e.g.: foxtail and oats) (Mamarot *et al*, proceedings, 1992).

Two experiments are being carried out in Burgundy in order to assess the efficiency of several crop management systems regarding weed infestation.

✓ The first experiment was conducted to evaluate the effects of different cropping systems, including chisel or mouldboard ploughing, on a population of herbicide-resistant blackgrass (*Alopercurus myosuroides* Huds.). In all the cropping systems, blackgrass density decreased. The introduction of spring crops into the rotation gave the best results, both from an economical and weed management point of view (Chauvel *et al*, 2001)

✓ Another experiment was initiated in order to test several systems under "**integrated weed management**". A reduced tillage system is being tested: no mouldboard ploughing or mechanical weeding. The results are favourable: infestation is correctly contained, compared to the standard system. The experiment proposes a range of management options which make it possible to reduce the reliance on herbicides for weed control. However, it should be confirmed on a more long term. The economic consequences and their acceptability by farmers will be studied (Munier-Jolain *et al*, proceedings, 2004)

III-7-3-Crop residue management

At Châtel Gérard, experiments on crop residue management before rape sowing showed that the most efficient practice to reduce stubble in surface was to **stubble break twice** with a cover crop. Stubble quantity decreased by 3 (Yonne CA, study report, 2000)

III-7-4-Machines

Experiments at Châtel Gérard on rape crops showed that Horsch Sem Exact was the most efficient sowing machine for the three years considered. It gave the best emergence rates. Huard SD (sowing machine with disks) or Vaderstaadt Rapid (rapid sowing machine) gave satisfactory results depending on the quality of previous stubble breaking (Yonne CA, study report, 2000).

III-7-5-Experimental innovative systems

III-7-5-1- Direct sowing with mixed intercropping

Several systems of direct drilling under permanent vegetal cover are being experimented in France. The goal is to perfect cropping systems in terms of economical viability and respect for the environment.

At La Cage, the experiment is on-going, the conclusions drawn to date are:

✓ The association of two grasses was unfavourable: it allowed the development of disease and parasites. Fescue associated with wheat induced diseases of wheat stalk (*take all disease of cereals*) and proliferation of worms eating into roots and stalks (frit fly).

✓ Direct drilling under permanent cover gave good results the first year: yields always exceeded the objective of yield by on average + 6 q. The cover had a positive impact on the environment during the intercrop. However, the following years, competition with the cover crop seemed to penalize the culture: yields losses varied between 40% and 90%. The loss was slightly less important with clover than with fescue but remained heavy.

Research projects would tend to establish a cover crop for only two successive years. Moreover, regular alternation of cover species would be interesting (Saulas, private communication).

A short term experiment established in Grignon studied in detail the relationship between fescue and wheat. The number of grains in the wheat associated with fescue decreased by 1000 grains/m², showing that competition between the cover crop and the culture started early. Finally, the yields were only slightly affected (~70Q/ha). Nevertheless, disease seemed to increase in the wheat cultivated with fescue: 30% of the wheat infected by

"*take all disease of cereals"* versus 20% in the wheat without fescue. Fescue fixed soil nitrogen: with fescue, the remaining nitrogen in the soil increased by 10 kgN/ha (Ghiloufi *et al*, proceedings, 2001).

At Grignon, a "direct drilling with permanent living cover crop" system allowed to study competition between the cash crops and the cover crops. The results obtained concerned wheat because maize and pea failed to emerge (Carof, study report, 2003):

- Wheat seemed to compete in terms of nitrogen, water, and light. Depending on the cover crop species (leguminous, grasses, scrophulariaceae, cruciferous), wheat biomass compounds were affected at different stages.
- Nitrogen deficiency observed for all treatments were lower with leguminous: Effects of competition appear at the end of the stage "ear emergence" whereas it appears as early as the stage "ear at 1cm" with grasses.
- Only leguminous were able to stop weeds (*Lotus curniculatus L, Medicago sativa L., Medicago lupulina L.*). *Trifolium repens L.* was the only weed species that could grow due to its similar nature with the cover crops. However, the infestation rate stayed lower than 1plant/m². Other cover crops favoured weed development with an infestation rate reaching 3plants/m².

In Southern France, an experiment is being carried out on irrigated maize under permanent cover. This system is innovative in France and the study aims to assess the cropping system management. The first year, the high competition between cover crop and maize induced an important drop of yield. The study is on-going. If the control of the cover, the sowing, fertilization and irrigation are improved, it should be possible to reduce yield losses (Deytieux, study report, 2004).

III-7-5-2- Reduced tillage in organic farming

A study has recently started aiming to collect references on reduced tillage practices in organic farming. Cash crops and crops pertaining to market gardening are being studied. Measures will be taken on experimental stations and on-farm in order to consider various cropping systems and pedo-climatic conditions (ADAR project "*Optimization of soil tillage (ploughing, reduced tillage) in organic farming"*, Gautronneau, private communication).

III-8- Socio-economic impacts

- Direct margins were globally similar in conventional and CA systems
- Reducing tillage induced a decrease of machinery costs and labour time, and often induced an increase of pesticides costs

III-8-1- Direct margins

There is a direct correlation between margin and yield. If there are no differences in yields between the systems, direct margins should be maintained (Paris *et al*, 1976). **Direct margins were globally similar in conventional and CA systems** (Jean-Robert, study report, 1999).

A survey carried out in the Cotes d'Armor showed that conservation tillage also **improved** direct margins (from 125 to 190€/ha) (Le Garrec, study report, 2003).

III-8-2- Machinery global costs

Two surveys in different French areas showed that **reducing tillage induced a decrease of machinery costs** (Barbier and Chevrier, study report, 2002; Le Garrec, study report, 2003). The reduction depended on the region, the culture cropped and the previous crop. In Indre et Loire and Cotes d'Armor, the reduction was estimated between -10% and -43%**.** The reduction corresponded to.5€/quintal in Indre-et-Loire to 1.5€/quintal in Cotes d'Armor (Le Garrec, study report, 2003).

III-8-3- Labour time

Reducing soil tillage **allows saving labour time**. The saving of time depends on the technique chosen and on the culture cropped (Rieu, proceedings, 2001). In the survey in Indre-et-Loire and Cotes d'Armor, the reduction of labour time was estimated between 50 min and 100 min/ha depending on the culture. (Le Garrec, study report, 2003). For sowing winter wheat, the reduction in time reached 15 min to 1h15 (Cottais, proceedings, 2001).

III-8-4- Pesticides costs

The results of the survey in Indre-et-Loire and Cotes d'Armor showed that conservation tillage did not have a direct correlation to the quantity, and therefore cost, of pesticides used (from -14€ to +15€/ha) (Le Garrec, study report, 2003). The results of this survey were contradictory to results from another survey in Bourgogne and Lorraine, where herbicides costs were multiplied by 2 (Gilet, study report, 2001). At Boigneville the results were the same: herbicides costs increased by 10% in superficial tillage and by 160% in direct drilling (Manichon *et al*, 1980).

IV– Conclusions and proposals

The main studies carried out in France dealt with the **different impacts of innovative cropping systems on**

- ✓ soil characteristics (physical, chemical and biological properties),
- ✓ environment (runoff and erosion, carbon storage, water pollution)
- ✓ cropping system (weed development and yields)
- ✓ farming system functioning (labour time, direct margin, costs)

The results showed that if CA practices are mastered, they have generally positive impacts on soil characteristics, cropping systems and environment.

According to different criteria of suitability, shrinkage and compactibility, soils can be ranked for their **suitability for direct drilling**. The validation of the predictive aspect of soil suitability for direct drilling based on their physical properties requires further study (Stengel *et al*, 1984).

Interest for CA practices is increasing and more and more studies are being carried out. On-going research is mainly oriented toward two directions:

- ✓ **Understanding the functioning** of the soil-plant system. Relationships between the characteristics of the cropping system are complex. Comprehension of the relations and interactions existing in the system allows the farmer to understand the reaction of the system in a practice and thus, to be able to perfect the management of the cropping system.

- ✓ **Perfecting innovative cropping systems** (integrated pest/weed management, DMC), in terms of economical viability and respect of environment, taking into account the farmers' constraints.

The main results presented come from research studies. However, some research experiments are not representative of real farming situations. In order to extrapolate the results, it is important to take into account farmers' constraints and a variety of soil and climate conditions. The results found in the groups of farms studied (Bretagne, Midi-Pyrénées, Centre) allow us to have a wider point of view of the impacts of the CA practices.

Many farmers who practice CA are often carrying out their own experiments. They often are more advanced than research institutes in setting up viable cropping systems. It is impossible to collect all the results from farmers. Nevertheless, some farmers points of view are presented by the partner 5 (association FNACS).

Following the results presented in this report, research directions can be proposed:

- ✓ **Soil water content**: how to manage it?
- ✓ **Pesticides**: effect of the mulch and mechanisms of pesticides retaining, how pesticides react in association with residues?
- ✓ **Microbial communities**: what are the changes induced by soil tillage?
- ✓ **Permanent cover and reduced tillage systems**: find directives in order to manage correctly the system, find a combination cover crop/commercial crop which allows an economically viable system.

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