Title: Soil conservation practices in organic farming: overview of French farmers' experiences and contribution to future cropping systems design

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Abstract

In organic farming, as crops production is directly depending on soil quality, farmers pay attention to preserve soil ecosystem in order to benefit from better ecological services. Today, soil conservation practices, such as ploughless soil tillage and cover cropping, have gained prominence in organic cropping systems and provide for great potentials such as maintaining or increasing soil fertility, saving labor and reducing energy costs.
This paper focuses on organic farmers who integrated or tended to integrate soil conservation practices in their cropping systems. The aims of this study are (i) to understand how these new combined practices are managed in relation to farmers' objectives and constraints and (ii) to identify difficulties encountered by farmers and how they deal with it. This work provides a reference base for designing new organic cropping systems.
Our study was based on 24 semi-structured interviews with farmers, having diverse farming systems and different levels of experience. They were located over France in various pedoclimatic situations.
From these interviews, we developed a typology based on the frequency (occasional or systematic) of use of both ploughless soil tillage and cover crop along the crop rotation. Four different strategies were observed. We found two main factors to explain the diversity of strategies: (i) farmers' objectives and (ii) capacity of adaptation facing constraints such as weed infestation, pedoclimatic conditions or equipment availability.
Understanding these factors is a key issue for designing future sustainable organic cropping systems and find suitable solutions.

1. Introduction

Organic agriculture systems are identified as an alternative to conventional food producing systems to face current economical and environmental challenges. Organic agriculture (i) is strictly regulated through the organic standards (eg: prohibition of chemical synthetic inputs) and (ii) consists in a whole-farm approach including natural resources management and aiming to achieve self-sufficiency on farm (eg: closed cycle in nutrients) (Watson et al., 2002).

Because of these characteristics, soil quality is a crucial issue for organic producers. Indeed, as crop production is directly depending on soil health, farmers pay attention to preserve soil ecosystem in order to benefit from better ecological services. Consequently, farmers are looking for more sustainable forms of management in their systems, as far as soil conservation practices are concerned. Innovative practices from conservation agriculture have gained prominence in organic cropping systems because these practices provide great potentials such as maintaining or increasing soil fertility, saving labor and reducing energy costs (Hobbs et al., 2008). Conservation agriculture is based on three agrosystem management principles: (i) non-inversion tillage to limit soil disturbance (ploughless tillage as direct drilling or chisel plow…), (ii) permanent soil surface cover (as cover cropping or mulching), (iii) diversification of rotations and intercropping (FAO, 2012). The application of these three principles correspond to several agronomic strategies from direct drilling through living mulches to reduced tillage with cover crop introduced between two main crops (Derpsch et al., 2010).

The interests of soil conservation practices are higher when these practices are fully applied together than when they are isolated (Kassam et al., 2009). As crop rotation is traditionally forming a part of organic cropping systems, the main challenges in adoption of soil conservation practices are the adoption of both cover cropping and ploughless tillage. Indeed, in organic farming, the period between two main crops is usually managed to limit weed infestation by using false seedbed technique (Bàrberi, 2002) and ploughing remains the most common soil tillage technique used to manage weeds and incorporate organic surface residues (Teasdale et al., 2007).

Currently, references on soil conservation practices are coming from conventional agriculture studies. In organic farming, few studies are leading to understand the adoption of conservation practices whereas this type of agriculture has been shown as able to improve soil fertility and provide ecosystem services (Maeder et al., 2002). These improvements are mainly due to the organic matter input and forage legume presence in rotations. Thus, both organic and conservation approaches raised greater expectations towards farm sustainability. Today, the question remains because organic research studies are mostly done on an analytical approach either on ploughless tillage (Peigné et al., 2007 ; Krauss et al., 2010) or cover cropping (Løes et al., 2011). However, organic farmers are innovating towards the integration of soil conservation practices (Gerber, 2008).

In this context, the aims of this paper are (i) to describe the diversity of agronomic strategies combining ploughless tillage and cover cropping, (ii) to understand how these combined practices are managed in relation to farmers' objectives and constraints and (iii) to identify difficulties encountered by farmers and how they deal with it. For this purpose, several French organic farmers who integrated or tended to integrate soil conservation practices in their cropping systems were interviewed. This overview of farmers 'experiences provides major keys to design new sustainable cropping system in organic farming.

2. Data and methods

The data collection was carried out in summer and autumn 2010. First, we contacted local organic advisors all around France to get a list of organic farmers who are supposing or claiming to use soil conservation practices. From this list of around hundred contacts, we selected the farmers who seemed to be the most experienced in soil conservation practices. Thus, we called 70 farmers to have an overview of their cropping systems management. Then, only farmers who integrated a high frequency of conservation tillage, cover cropping or both into their cropping systems were selected to further our expectations. The others were using ploughless tillage or cover cropping too occasionally and were not very sensitive and experienced with these thematic. Finally interviews were conducted with 24 farmers.

A semi-structured interview guide was used to cover topics such as (i) description of the farm (socio-economic, soil and climate conditions), (ii) identification and description of the cropping systems integrating soil conservation management, (iii) formalization of farmers' objectives linked with these practices, (iv) description of the difficulties encountered regarding the adoption of these innovations and how they dealt with.

The interviews lasted between 2 and 4 hours, depending on the time availability of each farmer. The information exchanged was recorded.

Furthermore, a secondary interview, shorter than the first, was made by phone one year later, on autumn 2011. The objectives of this second interview were to update farmers' experiences and to validate the analysis made after the first interview.

To represent the diversity of agronomic strategies managed by the 24 farmers, we developed a typology. This typology considers ploughless tillage and cover cropping practices. For a visual support, we graphically positioned each cropping system on two axes according to the frequencies (occasional or systematic) of cover cropping and ploughless tillage use along crop rotation. The frequency of ploughless soil tillage use was calculated by the ratio: number of main crops sowing preparations without ploughing / number of crops sowing preparation along the rotation.

The frequency of cover cropping use along the crop rotation was calculated by the ratio: period (in month) when the soil is covered between two mains crops / total period between two mains crops along the rotation.

3. Results

3.1. Global description of the sample

The 24 organic farmers met were recognized by advisors or peers as users of soil conservation practices. This number of farmers is low. Even if our method of farmers' inventory could not be exhaustive, this low number of farmers shows that soil conservation practices are today atypical managements in organic farming (regarding the number of advisors who were contacted and the total number of French organic farmers producing crops, which is estimated at around 8 000 (Agence bio, 2011)).

Farmers were located over France in various pedoclimatic situations, including four broad geographical zones: north/northeast, middle-east, southwest and west. A wide diversity of production systems, farm structure and levels of experience were also represented by this sampling. Sixteen farmers were specialized in crops production and eight were in crop-livestock mixed systems.

3.2. Description of the typology

There are (i) 13 farmers who totally stopped to use the mouldboard ploughing and 11 farmers integrating occasional ploughing into their cropping systems ; (ii) 20 farmers who were frequently integrating cover cropping between two crops into their cropping systems whereas 4 did not use cover cropping.
When we cross these two practices, four groups are pointing out. Global characteristics of each group are presented in the table 1.

3.2.1. Group 1: plough back after trying to stop mouldboard ploughing

This group is composed of two farms which are characterized by occasional ploughing (one ploughing every 4 to 8 years), and no cover cropping.

These two farmers strongly limited ploughing because they wanted to preserve soil ecosystem and reduce labor. These farmers reduced ploughing for a long time (more than 20 years). They tried to stop it totally for agronomical objectives but, after 5 to 8 years, crop production performances were reduced by huge weeds infestation. Facing that, they considered that it was necessary to plough back in order to satisfy crops production stabilization and economic profitability.

These farmers did not integrate cover crops in their cropping systems for three main reasons. Firstly, the conditions of soil and climate can be constraining for cover crop establishment. One farmer is located in South-East of France and there is a lack of soil humidity at cover crop sowing period. The other farmer is located in Middle-East of France and soil can be wet at cover crop destruction period. Secondly, cover cropping lead to an increase in labor needs. Thirdly, stubble cultivation and false seed bed technique are used to control weed infestation between the main crops period and the presence of a living cover impede these interventions.

3.2.2. Group 2: Intensive soil ploughless tillage

These two farms are characterized by intensive non inversion soil tillage and the absence of cover cropping along crop rotation.

These two farms are located in South-west of France on a clay soil where the climate is dry during summer period. The cropping systems of these farms are based on a strong presence of spring crops with a high use of inputs (irrigation and organic fertilizers).

Farmers systematically use soil conservation practices because they do not want to disrupt soil biological activity. Nevertheless, farmers frequently use deep non inversion tillage to increase soil porosity and limit perennial weeds.

Farmers don’t integrate cover cropping mainly because their systems are very sensitive to weed infestation. Consequently, the period between two crops is very important for them to manage stubble cultivation and numerous false seed-bed cultivation techniques. In addition, they argue that the dry climate limits cover crops development. Furthermore, they consider that cover crops seeds are expensive.

3.2.3. Group 3: Pragmatic soil tillage and toward cover cropping integration

This group is based on the use of occasional ploughing and the frequent use of cover cropping between two mains crops along the rotation. This group contains 9 farms in a broad diversity of pedoclimatic conditions and farming systems (Table 1).

These farmers largely reduced ploughing mainly for agronomic and labor consuming reasons. However, they use occasional ploughing to deal with delicate situations as (i) temporary meadows destruction, (ii) establishment of some spring crops (such as maize) to increase warming in heavy soil and (iii) weeds control.

These farmers, who are mainly on specialized crops production systems, integrate more and more cover cropping between two mains crops to reduce organic fertilizer inputs and enhance soils fertility. The practices are thus managed in a pragmatic way relative to these objectives. Plow is not considered to be negative for soil quality because it remains occasional and it is compensated by a strong presence of cover cropping.

3.2.4. Group 4: Towards the combination of soil conservation practices

This group of 11 farms can be defined by systematic ploughless tillage and occasional to frequent cover cropping use along the crop rotation. Farmers in this group are not experienced in soil conservation practices and the cropping systems are ongoing evolution.

These farmers want to manage the whole soil conservation practices for numerous reasons. First of all, they give a strong importance to soil preservation because they had to face some problems in the past (erosion for example). Then, they want to limit their dependence to organic matter inputs. Lastly, they are looking for new technical challenges (as integrating agroecology principles into their cropping system management) in order to be professionally satisfied. Regarding these objectives, these farmers are sure that soil conservation practices are suitable solutions.

However, these combinations of practices are quite difficult and farmers are facing many difficulties. For example, weed control or competition between the main crop and the permanent covers are the main constraints. Most of the farmers accept these difficulties and consider it as inherent consequences of learning new practices. There is no reference to adjust their judgment on these practices so they have to explore themselves these innovations. For three farmers of this group, economic performances were limited by the reduction of crop yield. Nevertheless, these farmers are persevered and exploring other technical solutions to optimize their cropping systems such as integrating new main crops or cover crops.

This group presents the strategies which are the closest to conservation agriculture management as farmers were trying to combine reduced tillage and cover cropping together. Nevertheless, within the sampled farmers, no one integrated systematically cover cropping and ploughless tillage.

4. Group determinants

4.1. Farmers' objectives

Cropping systems are the results of a compromise between farmers' objectives. We identified five intended farmers' objectives which are particularly explained the reasons of the differences management between the four groups.

First of all, all the farmers are sensitive to soil conservation. However, when soils are considered as sensitive to degradation, such as erosion, some farmers give priority to this objective. For example, farmers of the group 4 want to strongly integrate soil conservation practices in their cropping systems because these practices are viewed as relevant solutions to face these objectives.
The second objective is to gain in autonomy as far as fertilizer inputs are considered. The farmers of groups 3 and 4, mainly specialized in crops production, have the willingness to limit external dependence on organic matter. Thus, the role of cover cropping is essential in their cropping systems to provide nutrients to soil (in particular nitrogen) necessary to the development of following crops.
The third objective is the stabilization of crop performances. For example, for the farmers of group 2, ploughing is used to satisfy crop production stabilization whereas this practice is considered, by these farmers, like limiting the good performance of soils.

The fourth objective is the research of new challenges. This objective is very important for farmers of group 4. The explorations of new technical tracks enable farmers to optimize their cropping systems and revalorize their profession.

The last objective is related to the personal convictions of farmers. For example, farmers of group 4 are mostly tending to an ideal cropping system as near as possible to natural ecosystems (limiting soil disturbance, keeping soil cover, favoring facilitation between plants) (Malézieux, 2012). Ploughing was considered by these farmers as an unfavorable practice regarding the pursued agronomic goals such as soil biological activity. The willingness to integrate soil conservation practices is that, in some cases, the difficulties generated by these innovations impact negatively the economic performances.

Agronomic strategy of each group is the results of a compromise between these various objectives.

4.2. Farmers' capacity of adaptation

Globally, the farmers of each group are satisfied with the performances obtained with their respective cropping systems even if it is not always the case in the group 4 where these experiences led to limitations in crop performances. The control of the consequences of soil conservation practices is or was not always possible and adaptations are or were necessary to face the encountered difficulties.

First of all, pedoclimatic constraints can represent considerable obstacles regarding to the adoption of soil conservation practices (Rabah, 2010). In one hand, the climate can constrain cover crop success because of (i) dry conditions in summer at the sowing period or (ii) wet conditions in autumn or winter at cover crop destruction period. On the other hand, the textural properties of soils can be problematic. Ploughless tillage limits the soil porosity and can enhance soil compaction in sensitive soils. These pedoclimatic restrictions can decrease crop production.

Then, ploughless tillage generally generates more important weeds infestation (Tørresen et al., 2003). These difficulties of weed control can, in certain cases, involve weaker performances of production than with mouldboard ploughing. All the farmers were or are still confronted with these weed constraints, in particular by the perennial ones.

Lastly, plant residue management (Soane & Ball, 1998) and temporary meadows destruction (Trump, 2008) were the third main constraints regarding soil conservation tillage adoption. Difficulties in seed-bed preparation or meadow species volunteers in the new established crop could lead to a decrease of crop performances.

Facing these difficulties, farmers adapted their cropping systems differently according to their personal objectives but also according to the pedoclimatic or socio-economic constraints.

A first set of levers, involving only few modifications of the cropping systems, was set up by the farmers of groups 1 and 2, and to a lesser extent, those of group 3. It is the case of the occasional use of ploughing to destroy temporary meadows, to limit perennial weeds and to facilitate spring crops' establishment at the end of the rotation. In addition, to limit weed infestations and to favor soil porosity, other levers were mobilized as (i) intensive used of mechanical equipment deeply or superficially, and (ii) almost systematic use of mechanical weeding (even for winter cereals). These farmers thus have a strategy of adaptation based on efficiency or substitution. They seek to reduce ploughing (group 1) or to substitute it by the frequent and intensive use of non-inversion soil tillage (group 2).

Another set of levers, involving major modifications within the cropping systems and even at the farming system scale, were integrated mainly by farmers of the group 4 and few farmers of group 3. First of all, some of these farmers invested in specialized tools to destruct cover crops or prepare sowing in a living cover crop or dead mulch, such as strip-till or direct drilling. Then, other levers were used to limit weeds infestation such as suppressive crops or cultivars, or the presence of a permanent cover crop. Lastly, modifications in the cover crop management and the search for permanent cover cropping were carried out: intercropping, relay intercropping or direct seeding and strip tillage are used or explored. These new combinations of practices thus need a re-design the initial cropping systems. This is done by farmers, step by step, according to their respective available technical solutions.

5. Discussion and conclusion

This example on the appropriation and adaptation of soil conservation practices showed that organic farmers are innovating towards a better consideration of their objectives such as soil preservation, yield stabilization or organic matter autonomy. It confirms the findings of other authors about farmers' capacity to innovate and evolve their cropping systems (Chambers et al., 1989 ; Faure et al., 2010 ; Leitgeb et al., 2011). These innovations are differently integrated by farmers. Four types of agronomical strategies were identified regarding the frequency of ploughless tillage and cover cropping uses. Farmers' objectives and capacity of adaptation facing difficulties are the determinants of these four agronomic strategies. No strategy fully integrates systematically cover cropping and ploughless tillage; despite the interest of some farmers of the group 4.

Today, scientists are looking for new cropping systems able to preserve soil ecosystems and maintain or increase food production (Dore et al., 2011 ; Le Gal et al., 2011). Conservation agriculture and organic farming provide answers to these global challenges. That is the reason why it seems essential to propose and test new cropping systems based on the principles of these two types of sustainable agricultures. Integrating lessons from this farmers 'experiences study could be advantageous for future cropping systems design projects.

First, farmers' experiences give operational knowledge on the integration of the cropping methods with ploughless soil tillage or cover cropping in organic farming. This knowledge is related to the identification of (i) the difficulties encountered by the farmers and (ii) the levers which are mobilized to deal with them.

Then, the majority of farmers feel isolated regarding the adoption of these innovations. They are confronted with learning difficulties. Sharing these experiences within a dynamic group of farmers could favor the appropriation of these innovations.

Finally, the study of the four agronomic strategies shows two essential points. On the one hand, bridges exist between the different strategies. Indeed, a change in objectives or the impossibility of overcoming an obstacle can force farmers to change their strategy. For example, the farmers of group 1 moved from a period of systematic ploughless tillage, like the farmers of group 2 are currently, before returning to an occasional use because of strong weed infestations. In addition, the adoption of soil conservation practices requires global cropping systems modifications or redesign of their cropping systems as shown in the group 4. This concept of redesign comes from the framework of analysis ESR (efficiency-substitution-redesign) suggested by (Hill & MacRae, 1996) and created to describe the transition of agricultural systems towards durability. The other groups were more focused on efficiency strategies like limitation in ploughing (group 1) or substitution strategies by replacing ploughing by intensive non inversion tillage (group 2).

Table 1: Global description of the four groups

			Group 1	Group 2	Group 3	Group 4
Number of farms			2	2	9	11
Priority goals		Soil preservation	+	+	++	+++
		Yield stabilization	++	+++	++	+
		Nutrient use efficiency and autonomy	+	+	+++	+++
		Facing new challenges	o	o	o / +	++
Soil tillage management	Specific practices	Deep non inversion tillage	+	+++	+	o / +
		Superficial non inversion tillage	+	++	+	+++
		Mouldboard ploughing	+	o	+ / ++	o
		Direct drilling or strip-tillage	o	o	o	+ (test)
	Difficulties encountered	Weed competition	++	+	++	++
		No suitable equipments	+	o	+ / ++	o
		Soil compaction	+	+	+	+
		Removing perennial leys	+	+	+++	+
	Technical solutions	Competitive crops or cultivars against weeds	+	o	++	++
		Mouldboard ploughing	+	o	+ / ++	o
		False seed-bed	+	+++	+	+
		Mechanical weeding	+	+++	o / +	o / +
		Keeping soil cover	o	o	+	++
		Equipment investment	+	++	+	++ / +++
		Deep rooted cover crops use	o	o	++	+++
Cover crops management	Specific practices	Growing cover crops between two mains crops	o	o	+ / ++	+++
		Keeping permanent cover crop	o	o	o / + (test)	+ (test)
		Cover crop Intercropping	+	o	++	++
		Cover crop relay intercropping in main crop	o	o	++	++
	Difficulties encountered	Not enough humidity during sowing period	++	++	+	+
		Too much humidity during destruction period	+	++	+	+
		Cover crop removing	o	o	+++	++
		Cover crop competition	o	o	o	++
	Technical solutions	Specialized equipments (seeding combined with harrows…)	o	o	+	++
		Frost -sensitive cover crops	o	o	++	++
		Cover crop sowing date (before main crops harvest…)	o	o	++	++
		Less competitive cover crops	o	o	o	++

Degree of relevance: +++ = very high; ++ = high; + = medium; o = absence

References

Agence bio (2011). L'agriculture biologique, chiffres clés 2010, La Documentation française.

Bàrberi, P. (2002). Weed management in organic agriculture: are we addressing the right issues? Weed Research 42(3): 177-193.

Chambers, R., Pacey, A. & Thrupp, L. A. (1989). Farmer First: farmer Innovation and Agricultural Research. T. B. Press. New-York.

Derpsch, R., Friedrich, T., Kassam, K. & Hongwen, L. (2010). Current status of adoption of no-till farming in the world and some of its main benefits. Int J Agric & Biol Eng 3(1): 1-25.

Dore, T., Makowski, D., Malezieux, E., Munier-Jolain, N., Tchamitchian, M. & Tittonell, P. (2011). Facing up to the paradigm of ecological intensification in agronomy: Revisiting methods, concepts and knowledge. European Journal of Agronomy 34(4): 197-210.

FAO. (2012). Conservation agriculture. Retrieved 10 January 2012. Available at http://www.fao.org/ag/ca/index.html

Faure, G., Gasselin, P., Triomphe, B., Temple, L. & Hocdé, H. (2010). Innover avec les acteurs du monde rural: la recherche-action en partenariat. Presses agronomiques de Gembloux, Quae.

Gerber, M. (2008). Stratégies de travail du sol économes en énergie dans les systèmes de culture en agriculture biologique : détection, élaboration, évaluation multicritères a priori. Mirecourt, Inra ; Region Lorraine ; CGA Lorraine. http://www.prodinra.inra.fr/prodinra/pinra/data/2008/10/PROD2008a2b0e9ac_2008102103 4431430.pdf

Hill, S. B. & MacRae, R. J. (1996). Conceptual Framework for the Transition from Conventional to Sustainable Agriculture. Journal of Sustainable Agriculture 7(1): 81-87.

Hobbs, P. R., Sayre, K. & Gupta, R. (2008). The role of conservation agriculture in sustainable agriculture. Philosophical Transactions of the Royal Society B: Biological Sciences 363(1491): 543-555.

Kassam, A., Friedrich, T., Shaxson, F. & Pretty, J. (2009). The spread of Conservation Agriculture: justification, sustainability and uptake. International Journal of Agricultural Sustainability 7(4): 292-320.

Krauss, M., Berner, A., Burger, D., Wiemken, A., Niggli, U. & Mäder, P. (2010). Reduced tillage in temperate organic farming: Implications for crop management and forage production. Soil Use and Management 26(1): 12-20.

Le Gal, P. Y., 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 104(9): 714-728.

Leitgeb, F., Funes-Monzote, F. R., Kummer, S. & Vogl, C. R. (2011). Contribution of farmers' experiments and innovations to Cuba's agricultural innovation system. Renewable Agriculture and Food Systems 26(04): 354-367.

Løes, A. K., Henriksen, T. M., Eltun, R. & Sjursen, H. (2011). Repeated use of green-manure catch crops in organic cereal production - grain yields and nitrogen supply. Acta Agriculturae Scandinavica Section B: Soil and Plant Science 61(3): 164-175.

Maeder, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P. & Niggli, U. (2002). Soil Fertility and Biodiversity in Organic Farming. Science 296(5573): 1694-1697.

Malézieux, E. (2012). Designing cropping systems from nature. Agronomy for Sustainable Development 32(1): 15-29.

Peigné, J., Ball, B. C., Roger-Estrade, J. & David, C. (2007). Is conservation tillage suitable for organic farming? A review. Soil Use and Management 23(2): 129-144.

Rabah, L. (2010). Adoption of conservation agriculture in Europe: Lessons of the KASSA project. Land Use Policy 27(1): 4-10.

Soane, B. D. & Ball, B. C. (1998). Review of management and conduct of long-term tillage studies with special reference to a 25-yr experiment on barley in Scotland. Soil and Tillage Research 45(1–2): 17-37.

Teasdale, J. R., Coffman, C. B. & Mangum, R. W. (2007). Potential long-term benefits of no-tillage and organic cropping systems for grain production and soil improvement. Agronomy Journal 99(5): 1297-1305.

Tørresen, K. S., Skuterud, R., Tandsæther, H. J. & Hagemo, M. B. (2003). Long-term experiments with reduced tillage in spring cereals. I. Effects on weed flora, weed seedbank and grain yield. Crop Protection 22(1): 185-200.

Trump, A. (2008). Non-inversion tillage in organic arable cropping. Craven Arms, Institute of Organic Training and Advice (IOTA).

Watson, C. A., Atkinson, D., Gosling, P., Jackson, L. R. & Rayns, F. W. (2002). Managing soil fertility in organic farming systems. Soil Use and Management 18: 239-247.