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A holistic view of Maraîchage sur sol vivant. Participatory action research with a group of market gardeners in France

Amandine Faury
Master of Science in Agroecology

To Marco.
You dedicated your last words to me. It is my turn to dedicate my words to you.
This thesis does not only represent my most enriching experience as an agroecologist, but it also represents my deepest gratitude for what you have done in my life.

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ABSTRACT

A recent farmer-led movement called *Maraîchage sur Sol Vivant* (MSV) or in English, "*market gardening on living soil*" gathers market gardeners that develop agroecological cropping practices that place soil at heart of their cropping systems. In Drôme-Ardèche (France) a group of market gardeners have committed themselves to a four-year project with the aim to improve the performance of their farming systems with the practices of *Maraîchage sur Sol Vivant*. One part of this project was to co-design and co-evaluate innovative cropping practices on nine participant farms of the group, using a research methodology based on: (1) diagnosis of the initial situation on each farm, (2) co-design of innovative cropping practices, (3) collaborative creation of the co-evaluation process, (4) on-farm co-evaluation of the innovative cropping practices using simple indicators of performances, and (5) final group meeting to present and discuss the results of the on-farm co-evaluations. The aim of the participatory action research was to characterise *Maraîchage sur Sol Vivant* in regard to the participant farmers motivation, sources of inspiration, learning processes and cropping practices, and to explore the research methodology that was based on co-design and co-evaluation of innovative cropping practices. Through semi-structured interviews with the market gardeners from the group, this case study has identified farmers motivations, sources of inspirations and learning processes that shed light on farmers' engagement in *Maraîchage sur Sol Vivant.* The findings highlight five cropping practices characteristics of the nine MSV-farms: (1) reduced tillage, (2) organic matter additions and mulches, (3) green manure and cover crops, (4) plastic covers, and (5) prophylactic management, that ensure diverse functions such as (1) soil protection, (2) soil regeneration, (3) crop health, and (4) work convenience. Pre-requisites for and outcomes of the participatory action research methodology have been identified. The co-evaluation of the cropping practices has shown to increase farmers' mutual and experiential learning and their ability to implement change. Future research should include multi-sites randomized trials to (1) assess the sustainability and provide understanding of MSV-cropping practices (2) identify the pre-requisites for implementing these cropping practices, and (3) improve potential for adaptation and adoption.

Keywords: M*araîchage sur Sol Vivant*, agroecology, market gardening, cropping practices, co-design, co-evaluation, farmer-led movement, soil conservation, participatory action research.

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List of abbreviations

ADAF: *Association Drômoise d'AgroForesterie.* The organisation managing the research project in Drôme-Ardèche (France).

BPREA: *Brevet Professionnel Responsable d'Exploitation Agricole* or 'professional license for farm management' in English.

FAO: Food and Agriculture Organisation of the United Nations.

MSV: *Maraîchage sur Sol Vivant* or 'market gardening on living soil' in English.

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1. INTRODUCTION

CONTEXT: THE AGROECOLOGICAL TRANSITION

Farming and food systems created in the wake of the Green Revolution are facing sustainability challenges. Characterized by high dependency on external inputs, industrial agriculture failed to produce enough healthy food for human beings while ensuring environmental protection and a decent future for next generations. Currently, industrial agriculture is driving the loss of ecosystem services, i.e., the vital services provided by functioning ecosystems that human beings derive benefit from (Fisher et al., 2009; Sarukhán et al., 2005; Tallis & Kareiva, 2005; Zhang et al., 2007). Furthermore, agriculture also has a considerable stake in ecosystem services, being both a major producer of ecosystem dis-services and beneficiary of ecosystem services as inputs for agro-systems functioning (McIntyre et al., 2009).

Thus a shift from industrial agriculture toward an agroecological paradigm where agriculture does not work against but rather with nature, is needed (Frison, 2016). This agroecological paradigm considers: (1) protecting and increasing ecosystem services, (2) increasing adaptation to local conditions, and (3) involving human communities and stakeholders of the food and farming systems. Indeed, agroecological approaches to agriculture, as opposed to industrial agriculture, are built on ecosystem services (regulating and supporting services), replacing external inputs such as fertilisers, pesticides, or irrigation that are used in industrial systems (Gliessman, 2016). Agroecological farming systems protect and increase supporting and regulating services, which in turns, serve as major factors of production for the system (Zhang et al., 2007). Thus, agroecological farming systems are built on a set of cropping practices -i.e., agroecological practices- that rely on and protect ecosystem services (**figure 1**) (Kremen et al., 2012).

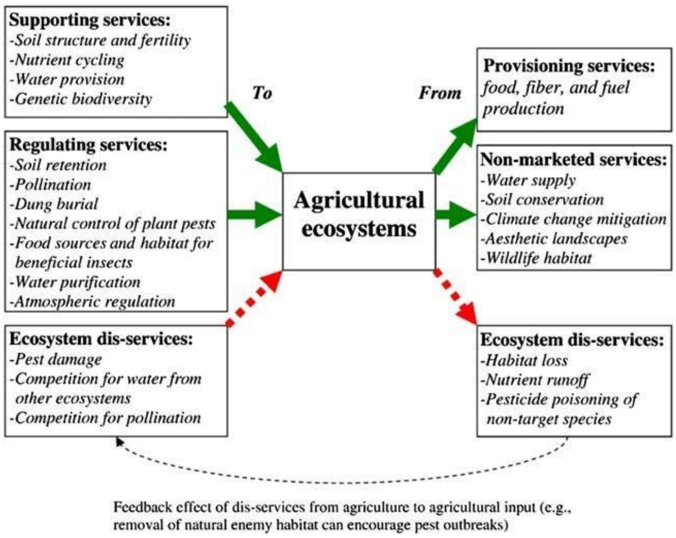


Figure 1: Ecosystem services and disservices to and from agriculture. Solid arrows indicate services, whereas dashed arrows indicate disservices (Zhang et al., 2007).

The study of agroecosystems, called agroecology, aims at understanding and redirecting agroecosystems toward sustainability (Méndez et al., 2013; Wezel et al., 2009). This transition toward agroecological practices refers to the application of ecological principles in order to design site-specific sustainable farming systems (**table 1**). Rather than technical recipes to be applied by the world's farmers, agroecological practices can take several forms -e.g., rotations, green manures, minimum tillage, agroforestry, use of natural pesticides- depending on socio-economic contexts and biophysical conditions (Nicholls et al., 2017).

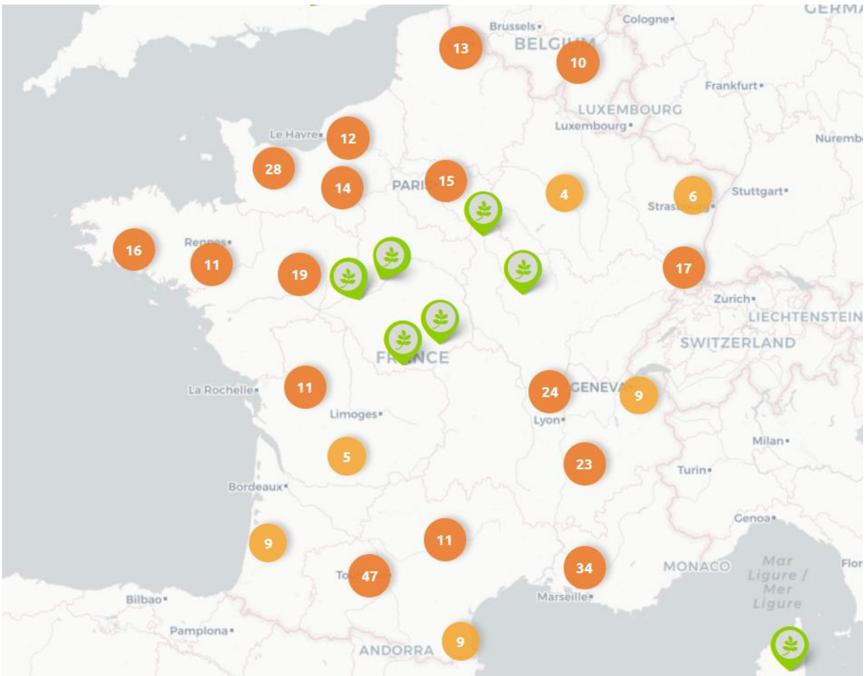
Table 1: Agroecological principles for the design of biodiverse, energy efficient, resource-conserving and resilient farming systems (Nicholls et al., 2017).

1. Enhance the recycling of biomass, with a view to optimising organic matter decomposition and nutrient cycling over time.
2. Strengthen the "immune system" of agricultural systems through enhancement of functional biodiversity — natural enemies, antagonists, etc., by creating appropriate habitats.
3. Provide the most favourable soil conditions for plant growth, particularly by managing organic matter and by enhancing soil biological activity.
4. Minimise losses of energy, water, nutrients and genetic resources by enhancing conservation and regeneration of soil and water resources and agrobiodiversity.
5. Diversify species and genetic resources in the agroecosystem over time and space at the field and landscape level.
6. Enhance beneficial biological interactions and synergies among the components of agrobiodiversity, thereby promoting key ecological processes and services.

Developing sustainable agroecosystems requires linking science with practice. Thus, a grass-root approach integrating farmer, local and scientific knowledge is needed (Frison, 2016; Méndez et al., 2017; Meynard et al., 2012; Nicholls et al., 2017). An approach to the agroecological transition, called participatory action research focuses on involving farming and food systems' stakeholders as "active participants of an iterative process that integrates research, reflection, and action" (Méndez et al., 2013). Participatory action research has been increasingly employed in agroecology to lead sustainable changes with people (Braun et al., 2006; Cuéllar-Padilla & Calle-Collado, 2011; Méndez et al., 2013; Vaarst et al., 2007). Such approaches have connected science with practical issues, creating relevant research in local contexts and opportunities for common learning (Altieri, 1999; Duru et al., 2015; Hatt et al., 2016; Méndez et al., 2017; Méndez et al., 2013; Vilsmaier et al., 2015).

A farmer-led movement: *Maraichage sur Sol Vivant*

French market gardeners show a growing interest for agroecological practices -i.e., cropping practices that rely on and protect ecosystem services. A farmer-led movement initiated in 2012, called *Maraîchage sur Sol Vivant* (MSV) or in English, "*market gardening on living soil*" gathers market gardeners engaged in the agroecological transition in France (**figure 2**). The term *Maraîchage sur Sol Vivant* also encompasses a set of cropping practices in market gardening that "place soil at heart of the cropping system, by ensuring shelter and food to the soil macro and micro fauna" (my translation) (MSV-Normandie). *Maraîchage sur Sol Vivant* combines the conservation agriculture approach in field crops -based on crop diversification, permanent organic covers, and reduced tillage- with philosophies and methods inspired from bio-intensive organic farming, permaculture, and natural agriculture (**see §2.1**).



<u>**Figure 2**: Map of the farms in *Maraîchage sur Sol Vivant* in France in 2020 (Vivant, 2020). Colour codes (orange, red) show the density of farms in each area. Green shows individual farms.</u>

Although conservation agriculture has been widely studied in field crops (Norris & Congreves, 2018; Phatak, 1992), application of its principles to vegetable production and market gardening has been poorly documented (Barbier, 2020). As highlighted by Wezel & Silva, “each production system represents a distinct group of management practices”, and the study of these diverse systems allow to deepen our understanding of agroecological practices (Wezel & Silva, 2017). Since vegetable cropping systems currently use intensive management practices, they represent one of the greatest concerns regarding their impacts on ecosystem services. This coupled with the importance of vegetable intake for the human diet creates a clear necessity for developing and studying agroecological vegetable cropping systems (Norris & Congreves, 2018; Phatak, 1992).

The absence of scientific literature on *Maraîchage sur Sol Vivant* highlights a knowledge gap with regards to farmers motivation, sources of inspiration, learning processes and cropping practices in this movement. It is a recent farmer-led movement, and available knowledge derive from these farmers who are constantly innovating (MSV-Normandie, 2017; MSV, 2017). Introducing farmers’ knowledge that result from local adaptations of agroecological principles into the scientific sphere could increase our understanding of agroecological systems. On the other hand, there has been an increasing number of market gardeners that are becoming interested in the practices of *Maraîchage sur Sol Vivant* and are confronted by the lack of technical and scientific references to guide them. Consequently, as embedded in the national farmer-led movement, several farmers groups recently emerged in diverse regions of France around a common interest for cropping practices in *Maraîchage sur Sol Vivant* with the aim of pooling their knowledge together through farmers exchanges. Acknowledging this farmers knowledge and linking it with theory in a participatory action research would provide understanding of MSV-cropping practices and insights of the motivations behind these farmers willingness to engage in an agroecological transition.

Guiding market gardeners in the design and evaluation of innovative cropping practices

The increasing number of farmers groups involved in *Maraîchage sur Sol Vivant* increases the need to develop methodologies for guiding them in their transition. Along with participatory approaches, systems (re)design are greatly recommended for guiding the agroecological transition (Meynard et al., 2012). The agroecological transition can be defined as a complex process of social and technical co-evolution shifting from industrial to alternative systems that involves changes in values, skills, knowledge and practices (Blesh & Wolf, 2014; Nicholls et al., 2017). The transition period has been conceptualized as three stages: (1) increased input efficiency, (2) input substitution, and (3) system redesign (Meynard et al., 2012). As pointed out by Meynard et al., "approaches centred on improving the efficiency of inputs or substituting one input for another will not be enough to resolve all the issues [that agriculture is facing]" (Meynard et al., 2012), highlighting the need to "move forward in the design and evaluation methods of innovative farming systems" (Meynard & Girardin, 1991).

Some studies have focused on farmer's field school as a way to increase farmers knowledge exchange and learning of agroecological practices (Braun et al., 2006; Vaarst et al., 2007), or on developing guidelines to (re)design agroecological cropping systems in pair -i.e., farmer and extension service- (Aubertot et al., 2018) or with a group of farmers (Reau, R. C., M et al., 2018). However, participatory design and evaluation of innovative cropping practices -i.e., cropping practices that are new in the context they appear- have not been studied, *a fortiori* in market gardening. In response to this research gap, the present participatory action research will develop a co-design and co-evaluation methodology generalizable to farmers groups engaged in the agroecological transition.

A group of market gardeners engaged in *Maraîchage sur Sol Vivant*

In Drôme-Ardèche (France), a group of market gardeners engaged in *Maraîchage sur Sol Vivant*, committed to a four-year project with the aim to improve the performances of their farming systems in *Maraîchage sur Sol Vivant*. While the farming systems of the group members were heterogeneous, the market gardeners gathered around the same objectives: (1) to decrease negative impacts of soil management on soil quality, (2) to increase yields by improving soil fertility (3) to decrease needs for irrigation, (4) to improve work management and reduce work difficulties (ADAF, 2019a; ADAF, 2019b).

The four-year project was managed by a local organisation named Association Drômoise d'AgroForesterie (ADAF) following an iterative process of (1) evaluation, (2) reflection, (3) experimentation, (4) evaluation, (5) dialogue, (6) (re)design and (7) diffusion. The present participatory action research occurred during the first year of the project, from November 2019 to November 2020.

Research questions and objectives

Since no scientific study has focused on *Maraîchage sur Sol Vivant* so far (MSV-Normandie, 2017; MSV, 2017), this study is an attempt to provide an holistic view of *Maraîchage sur Sol Vivant* through the case study of a group of market gardeners located in Drôme-Ardèche (France). In regard to the research gap in participatory design and evaluation of cropping systems, this participatory action research aims at co-designing and co-evaluating innovative cropping practices in *Maraîchage sur Sol Vivant* with the group of farmers and developing a co-design and co-evaluation methodology generalizable to farmers groups engaged in the agroecological transition.

Considering these gaps of knowledge, the present participatory action research aims to answer the following research questions through the case study of a group of market gardeners engaged in *Maraîchage sur Sol Vivant* in Drôme-Ardèche (France):

1. What characterizes *Maraîchage sur Sol Vivant* with regards to farmers motivation, sources of inspiration, learning processes and cropping practices?
2. What characterizes a research methodology based on co-design and co-evaluation of innovative cropping practices?

2. The case of *Maraîchage sur Sol Vivant*

The lack of scientific literature and the living grassroots nature of *Maraîchage sur Sol Vivant* creates a difficult setting for a typical literature review on the subject. Since there is a time gap between the emergence of new agricultural system and the stabilization of key words in the scientific literature to define it, no scientific paper could be found by researching '*Maraîchage sur Sol Vivant'* or 'market gardening on living soil'. Therefore, a rough picture of the sources of inspiration and cropping practices of *Maraîchage sur Sol Vivant* was drawn from both grey literature gathering farmers knowledge through web articles, agricultural magazine, farmers trainings, farmers gatherings; and from scientific studies that relate, at least partially, to cropping practices in *Maraîchage sur Sol Vivant,* defined under the terms 'conservation agriculture for vegetable production', 'reduced tillage', 'cover crops', 'no-till', 'reduced tillage', and 'mulches' (Donatelli et al., 2007; Fourrié et al., 2013; Hoyt et al., 1994; Morse, 1999; Sarrantonio, 1992; Vedie & Buffard, 2013; Vollmer et al., 2010).

2.1 Sources of inspiration

While farmers involved in *Maraîchage sur Sol Vivant* have developed their own set of cropping practices, they have been inspired by existing methods, movements, and philosophies such as conservation agriculture, bio-intensive organic farming, permaculture, and natural agriculture. These sources of inspiration are presented in this section.

2.1.1 Conservation agriculture

Such as conservation agriculture, *Maraîchage sur Sol Vivant* aims at creating resilient and productive farming systems, following three guiding principles: (1) crop diversification, (2) permanent soil organic cover and (3) reduced tillage (FAO, 2017; Hobbs, 2007; Scopel et al., 2013). Conservation agriculture has been defined by the Food and Agriculture Organisation of the United Nations (FAO) as a promising sustainable production method that "enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production" (FAO, 2017). Thus, conservation agriculture has been promoted as a production method that "reduces production costs, soil erosion and soil fertility degradation under both tropical and temperate conditions" (Scopel et al., 2013).

Each of the three guiding principles of conservation agriculture, as embedded in agroecological principles, aims at enhancing supporting and regulating ecosystem services. The principles of conservation agriculture and their related ecological principles are presented in **figure 3.**

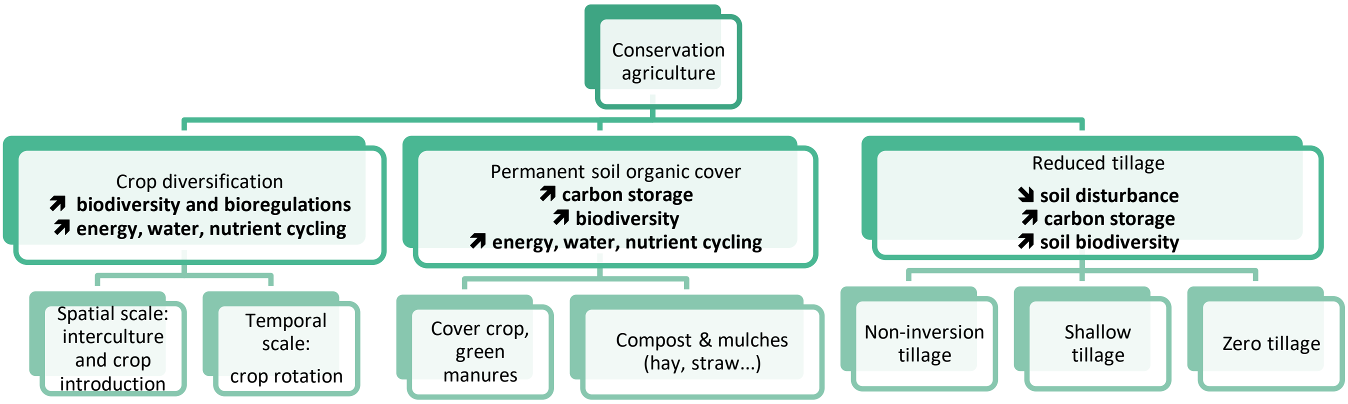


Figure 3: Diversity of practices in conservation agriculture based on three guiding principles, underlying ecological principles (in bold) adapted from Jones et al. (2005) and Lahmar (2010).

Conservation agriculture and its impacts on agroecosystems have been widely studied (Casagrande et al., 2016; Derpsch, 2003; Hobbs, 2007; Knowler & Bradshaw, 2007; Lahmar, 2010; Peigne et al., 2018; Peigné et al., 2007; Pittelkow et al., 2015; Ryan & Peigné, 2017; Van den Putte et al., 2010). Several reviews have gathered evidence of the benefits of conservation agriculture on ecosystem services (Hobbs, 2007; Holland, 2004; Jones et al., 2006; Lahmar, 2010; Palm et al., 2014; Scopel et al., 2013).

While relying on the same agroecological principles, *Maraîchage sur Sol Vivant* differs to conservation agriculture because it specifically concerns vegetable production and market gardening. *Maraîchage sur Sol Vivant* has not been studied yet, whereas most conservation agriculture research and development projects have been focusing on field crops such as cereals and oleo proteaginous (Norris & Congreves, 2018; Phatak, 1992). Vegetable cropping systems are characterized by complex rotations with a high variety of crops, demanding high planning and intensive management. Market gardening requires high levels of fertilisation, high hand-labour and low mechanisation because of the relatively small fields. These specificities represent opportunities for developing alternative soil management practices (Barbier, 2020; Norris & Congreves, 2018; Sarrantonio, 1992).

Even though, in field crops, conservation agriculture is often not combined with organic agriculture because of the high reliance on herbicides (Casagrande et al., 2016; Scopel et al., 2013), the relatively small size of fields in vegetable production allows the use of alternative weed control strategies such as manual weeding or application of high amount of crop residues at the soil surface, thus increasing the potential for adoption in organic agriculture. As highlighted by Sarrantonio in a study on cover crops for vegetable production, the high diversity of crops cultivated in vegetable production is an opportunity for developing cropping practices based on the two other principles of conservation agriculture -i.e., reduced tillage and permanent soil cover- (Sarrantonio, 1992). Soil covers are more commonly used in vegetable cropping systems as part of the weed management, especially organic mulches, and plastic covers. On the other hand, vegetable crops have higher market value compared to field crops, which represents an opportunity to invest time and energy for improving management and productivity of these systems (Barbier, 2020; Sarrantonio, 1992).

2.1.2 Bio-intensive organic farming

Bio-intensive organic farming is a method of market gardening on small surface areas, from which emerged the term 'microfarms' that refers to small commercial market gardens. 'Microfarms' have been studied by Morel & Léger who identified several characteristics: "cultivated acreage smaller than official recommendations for market gardening; community-oriented marketing through short supply chains; wide diversity of plants cultivated; and low level of mechanisation and investment" (Morel & Léger, 2016; Morel et al., 2017). This farming system is especially attractive to young farmers coming from a non-agricultural background, usually with limited access to cultivated land and agricultural equipment, and with ecological and social aspirations. While representing an important trend in the number of newly installed farmers in France, these farming systems are relatively recent and understudied (AgrobioBasseNormandie, 2015; Le Cam, 2019; Morel & Léger, 2016; Morel et al., 2017). Practices in bio-intensive organic farming have been inspired from the Parisians market gardens of the 19th century. These market gardens produced high quality vegetables all-yearlong for the whole Parisian population on very small, productive market gardens, using intensive engineering and management, and high amounts of horse manure (Moreau & Daverne, 1846). Philosophy and practices of bio-intensive organic farming -i.e., producing high quality food on small and productive market gardens all-yearlong- have been adapted to other contexts and spread by Fortier in Canada (Fortier & Bilodeau, 2014), Coleman and Jeavons in the USA (Coleman, 2019; Jeavons, 2001), Hervé Gruyer & Hervé Gruyer in France (Hervé-Gruyer & Hervé-Gruyer, 2015) and to some extent, by the network of farmers in *Maraîchage sur Sol Vivant*.

2.1.3 Permaculture

Maraîchage sur Sol Vivant, such as bio-intensive organic farming, has been inspired by permaculture. Funded by Bill Mollison and David Holmgren by the end of the 1970's in Australia, permaculture provides tools to holistically design productive and resilient farming and food system - and more globally, the entire society- according to three ethics: (1) care of Earth, (2) care of people, (3) distribute good surplus to our needs (Holmgren, 2002; Mollison, 1988). From these ethics derived twelve principles inspired by processes, structure and patterns of nature in order to guide the design and management of sustainable farming systems, as described by Holmgren (Holmgren, 2002). Krebs & Bach (2018) reviewed scientific evidences of the application of these principles to re-design agroecological farming systems, and their findings can be summarized in **table 2** (Krebs & Bach, 2018).

Table 2: Summary of the twelve permaculture principles (Holmgren, 2002) with corresponding approach (bottom-up or top-down), relation (design process, management, agroecosystem structure), and examples with scientific evidence (Krebs & Bach, 2018)

Principle	Approach	Relation	Examples with Evidence
I. Observe and Interact	bottom-up	Design process, management	Adaptive management
II. Catch and Store Energy	bottom-up	Agroecosystem structure	Organic mulch application Rainwater harvesting measures Woody elements in agriculture
III. Obtain a Yield	bottom-up	Design process, management	Emergy evaluation Ecosystem services concept
IV. Apply Self-Regulation and Accept Feedback	bottom-up	Agroecosystem structure	Enhancement of regulating ecosystem services Natural habitats in agricultural landscapes Wildflower strips
V. Use and Value Renewable Resources and Services	bottom-up	Agroecosystem structure	Legumes and animal manure as nutrient source Mycorrhizal fungi
VI. Produce no Waste	bottom-up	Agroecosystem structure	Animal manure Human excreta Waste products as animal feed
VII. Design from Patterns to Details	top-down	Agroecosystem structure, Design process	Natural ecosystem mimicry Use of grazing animals in cold and dry climates Structurally complex agroforests in tropical climates
VIII. Integrate Rather than Segregate	top-down	Agroecosystem structure	Integration of livestock in corn cropping Cereals and canola used for forage and grain harvest Integration of fish in rice cropping Polyculture (crops)
IX. Use Small and Slow Solutions	top-down	Agroecosystem structure	Inverse productivity-size relationship Agroforestry systems
X. Use and Value Diversity	top-down	Agroecosystem structure	Plant species diversity Pollinator diversity Habitat diversity Diversified farming systems
XI. Use Edges and Value the Marginal	top-down	Agroecosystem structure	High field border density Field margins Edges with forests
XII. Creatively Use and Respond to Change	top-down	Design process, management	Decision-making under uncertainty Increase ecological resilience Directed natural succession

When applied to market gardening, permaculture generally takes the form of aesthetics, productive and resilient farming systems characterized by reduced tillage, permanent soil organic covers, crop diversification and association, and low dependency to resources, as attested by the example of *'La Ferme du Bec Hellouin*' (Hervé-Gruyer & Hervé-Gruyer, 2015). Above all, permaculture is a philosophy and a lifestyle based on ethics. Market gardeners in *Maraîchage sur Sol Vivant* often align with permaculture's philosophy and values, making it an inspiration source for both their lifestyles and farming systems (Trives, 2020).

2.1.4 Natural agriculture

Another source of inspiration for *Maraîchage sur Sol Vivant* is the natural way of farming developed by Masanobu Fukuoka in Japan in the 1980's (Fukuoka, 1985; Fukuoka, 1989). Inspired from natural ecosystems and opposed to modern agriculture, this agriculture method and green philosophy promotes the least disturbance of agroecosystems by avoiding the use of pesticides, fertilisers, and tillage, thus reducing cultivation operations to the minimum (Fukuoka, 1985; Fukuoka, 1989). This inspiration from natural ecosystems along with the desire to reduce cultivation operations to the minimum are shared characteristics with cropping systems developed in *Maraîchage sur Sol Vivant*. **Appendix 1** presents the similarities between *Maraîchage sur Sol Vivant* and its sources of inspiration.

2.2 Cropping practices

2.2.1 Soil coverage

In MSV-cropping systems, soils are covered to improve soil health and weed control. Benefits of soil organic covers have been proved in vegetable cropping systems (Masiunas, 1998; Morse, 1999; Norris & Congreves, 2018; Price & Norsworthy, 2013; Vedie & Buffard, 2013). The types of organic cover used are diverse and can be divided in three categories : (1) dry covers such as straw or chipped wood, (2) wet covers of fresh material such as grass or alfalfa, (3) living mulches such as cover crops or green manures laid down eventually under a black plastic cover -also called silage tarpaulins- prior to plantation or seedling (Barbier, 2020). Several studies have shown that growing periods, destruction time and methods are determining features for growing cover crops (Donatelli et al., 2007; Morse, 1999; Price & Norsworthy, 2013; Sarrantonio, 1992; Vedie & Buffard, 2013; Vollmer et al., 2010). Similarly, soil temperature, C:N ratio of the organic cover, and nutrient levels required for the following crop were shown to be important leverage points when using permanent organic covers (Donatelli et al., 2007; Morse, 1999; Price & Norsworthy, 2013; Sarrantonio, 1992; Vedie & Buffard, 2013; Vollmer et al., 2010).

2.2.2 Integrated weed management

Weed management strategies developed in MSV-cropping systems generally rely on a prophylactic approach using (1) soil organic cover, (2) plastic covers, (3) cover crops or longer crop rotation. Permanent soil organic covers (living mulch, dry or wet cover) decrease the amount of light reaching the soil and thus, impede weed germination (Barbier, 2020). Cover crops or longer crop rotation including meadows can also be part of the weeding strategy by competing with weeds and decreasing weed grain stocks (Le Cam, 2019; Masiunas, 1998; Morse, 1999; Price & Norsworthy, 2013). A meta-analysis on the effects of cover crops on vegetable cropping systems showed that integrating cover crops significantly decreases weed pressure and increase soil total nitrogen (Norris & Congreves, 2018). However, Smith & Mortensen found that perennial weeds were challenging in cropping systems where soil mechanical disturbance is reduced to the minimum due to a shift in weed communities (Smith & Mortensen, 2017). Price & Norsworthy raised the need to "identify appropriate high-residue cover crop choices and integrated weed management practice for use in vegetable cropping systems" (Price & Norsworthy, 2013).

2.2.3 Reduced tillage

In MSV-cropping systems, tillage is reduced to the minimum in order to protect the soils and increase soil biodiversity and biological activity. Reduced tillage has shown to enhance soil organism's abundance, soil biodiversity and biological activity because of the preservation of soil organisms' habitats and nutritive sources (Bouthier et al., 2014). Several studies have found that reduced tillage and no-till combined with organic matter addition increased soil organic matter (Holland, 2004; Thomazini et al., 2015). The mechanisms underpinning the effects of soil tillage on agroecosystems are shown in **figure 4**.

Permanent seedbeds can be set-up to avoid soil structure degradation (Le Cam, 2019). Reduced tillage can decrease fuel consumption, investments in machinery and greenhouse gas emissions (Barbier, 2020). However, in vegetable cropping systems harrow tillage is widespread and tillage operations are frequent due to the intensive nature of such systems (Le Cam, 2019). Thus, reduced tillage is especially challenging in vegetable cropping systems because of (1) a lack of available equipment for direct seeding and planting in mulches (2) an increase of weeds - especially biennial and perennial - that are otherwise controlled by tillage, (3) lower soil temperature because of a lack of soil warming provided by tillage, resulting in precocity losses of spring crops (Barbier, 2020; Hoyt et al., 1994; Morse, 1999).

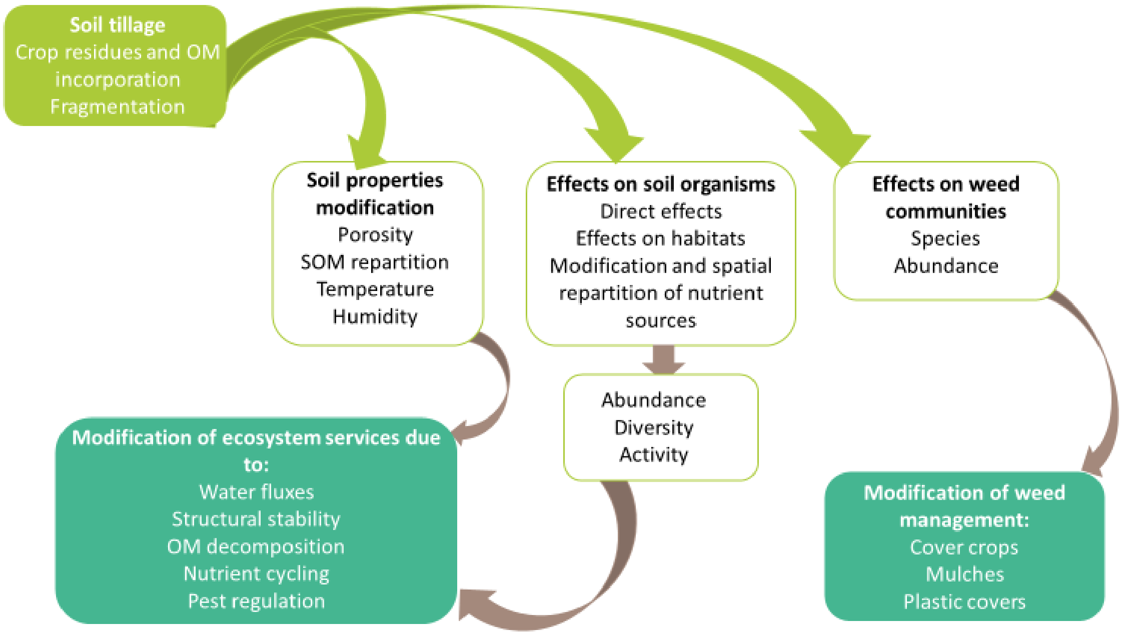


Figure 4: Conceptual diagram of the effects of soil tillage on soil properties, soil organisms and weed communities and their subsequent effects on ecosystem services and weed management, inspired from Bouthier (Bouthier et al., 2014). Legend: OM: organic matter, SOM: soil organic matter.

2.2.4 Organic matter additions

In MSV-cropping systems, organic matter additions target soil regeneration, i.e., the creation of new soils and revitalization of soil health by enhancing soil organic matter, soil organic carbon, soil biodiversity and biological activity. Indeed, in vegetable cropping systems, soil organic matter and biological activity must be high in order to retain water and nutrients and mineralize enough nutrients for growing vegetables. Parisian's market gardeners of the 19th century were aware of the high needs of vegetables and applied high amounts of manure to take extra care of their soils (Moreau & Daverne, 1846). As experienced by a farmer in *Maraîchage sur Sol Vivant* "the vegetable yields used to be excellent when we cultivated in meadows with soil organic matter rates of 5%, but when we cultivated in meadows with soil organic matter rates ranging from 8 to 10%, the upper yields limits were removed. For us, it was clear that we had to increase soil organic matter to dispense the use of soil tillage and get the best production as fast as possible" (my translation) (Barbier, 2020). For soil regeneration, it has been preconized to use chipped wood or ramial chipped wood, with high C:N ratio -and with a low degradation rate - to increase soil organic matter and biological activity within a few years (Barbier, 2020). Positive effects of ramial chipped wood applications on soil organic matter, biological activity, soil structure, porosity, moisture and crop yields have been found in several studies (Barthes et al., 2010; Caron & Lemieux, 1999). In *Maraîchage sur Sol Vivant,* ramial chipped wood are applied at high rates of 100t/ha or even higher to regenerate soils prior to vegetable cultivation (Barbier, 2020; *Formation maraîchage sur sol vivant*, 2020). According to a farmer in *Maraîchage sur Sol Vivant*, an addition of 100t/ha of ramial chipped wood with a high C:N ratio and an iso-humic coefficient of 50% can increase soil organic matter by 1% after only one year (Barbier, 2020).

3. Methodology

3.1 A participatory action-oriented research

According to Méndez et al., “while researchers are aware of their own professional needs and pressing theoretical questions within their academic fields, these priorities do not often align with needs of farmers and other social actors”. Echoing from this pitfall, the present research arises from a farmers engagement in the agroecological transition through an iterative process that includes evaluation, reflection, experimentation, evaluation, dialogue, (re)design and diffusion, in collaboration with a local organisation ADAF (ADAF, 2019b). This research fits into an agroecological participatory action research approach in the way that it is characterized by (1) the involvement and empowerment of farmers, (2) its action-oriented objective, that is to re-direct site-specific farming systems toward sustainability, (3) the consideration of the whole crop system, and (4) the development of strategies to achieve long term benefits, particularly building soil fertility (Méndez et al., 2017; Méndez et al., 2013). In this case, farmers’ involvement and ownership over the project can be defined as interactive, so that the development of the research analysis and process were done jointly with the participants (Cuéllar-Padilla & Calle-Collado, 2011).

3.2 Methodological framework

The co-design and co-evaluation methodology presented in this section was inspired by soft system methodology, that addresses complex systems and aims at taking action, following an iterative process that fits the iterative approach followed by ADAF (Checkland, 1999; Checkland & Poulter, 2006; Checkland, 1989; Smyth & Checkland, 1976); and by existing guidelines for designing cropping systems (Aubertot et al., 2018; Reau, R. et al., 2018). Drawing from these methodologies, the present research started by (1) a diagnosis of the initial situation in each farm, followed by (2) a co-design of innovative practices, (3) a collaborative creation of the co-evaluation process on the farms, (4) an on-farm co-evaluation of the innovative cropping practices using simple indicators of performances, and (5) a final group meeting. The overall co-design and co-evaluation methodological framework followed in this research is summarized in **figure 5**.

3.2.1 Step 1: Diagnosis of the initial situation

Prior to the diagnosis, soil samples were taken from each plot dedicated to the study and were sent for lab analysis to Célesta Lab and KinseyAg. Alongside, a visual soil assessment was carried out for identifying main soil characteristics using the method developed by Shepherd (Shepherd, 2008). The first farm visits occurred in December and January, in order to diagnose the initial situation in each farm. The visits included (1) a participatory observation, in which the researcher worked side-by-side with the farmer in the farm, (2) a shared lunch with the farmer, to establish trust among the farmer and the researcher (3) a semi-structured interview with the farmer following the interview guide presented in **appendix 2**. The data collected during the first visit identified (1) the issues encountered in the development of cropping practices and systems in *Maraîchage sur Sol Vivant* and (2) the levers of actions mobilizable to co-design agroecological cropping practices.

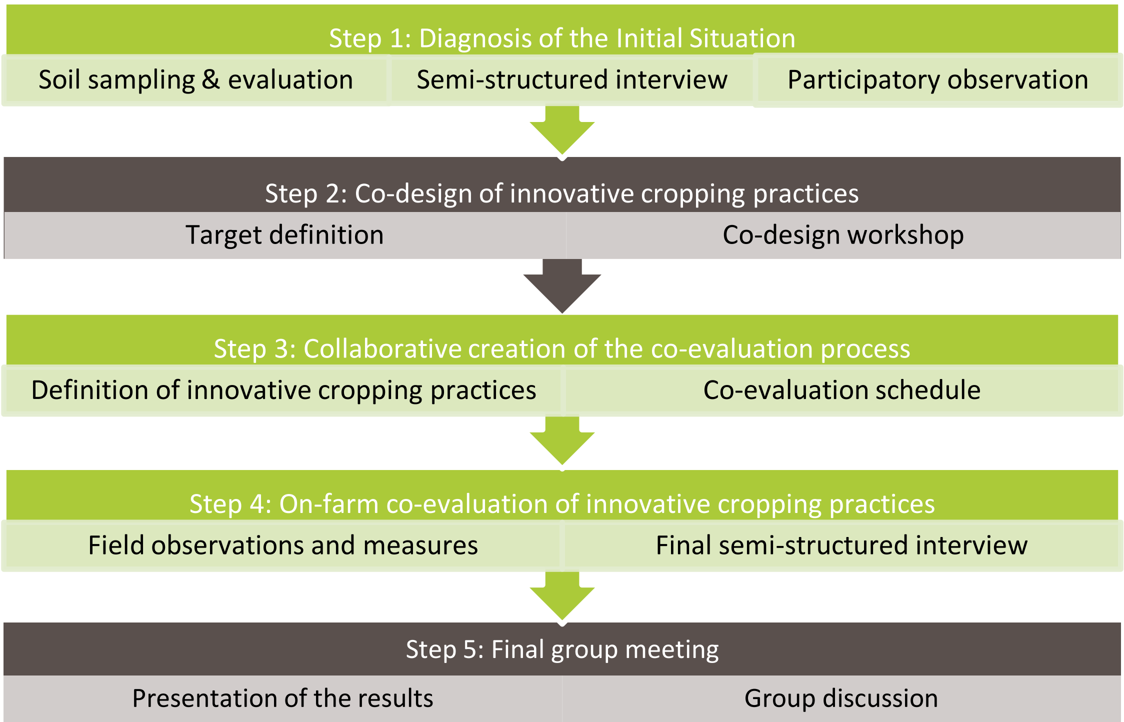


Figure 5: Process of the co-design and co-evaluation of innovative cropping practices followed along the research. In green the activities conducted in pair (researcher with the farmer), in brown the activities conducted in group (all the farmers with the researcher).

3.2.2 Step 2: Co-design of innovative cropping practices

Drawing on the issues and levers identified during *step 1: diagnosis of the initial situation*, the targets of the co-design workshop -i.e., context, objectives, constraints- were defined. A group meeting was held on 21st January 2020 and was attended by the nine participants farmers, seven local farmers outside the project, two members of ADAF, one trainer-advisor in *Maraîchage sur Sol Vivant* and the researcher, in order to collect innovative ideas and develop innovative cropping practices for each case studied. The meeting was facilitated by the researcher and started by an explanation of the workshop process and participants roles. It was followed, for each of the nine cases by (1) a presentation of the current cropping practices characterizing the chosen cropping system, (2) a definition of the target of the cropping practices to be (re)designed, (3) a collective knowledge exchange on the topics previously defined, (4) a brainstorming on technical solutions to achieve the objectives. The facilitator guide developed for the co-design workshop is presented in **appendix 3**.

3.2.3 Step 3: Collaborative creation of the co-evaluation process

Second farm visits were conducted in March to define with each farmer (1) the innovative cropping practices to be implemented on the cropping system, and (2) the co-evaluation schedule of the cropping practices performances during the growing season. The innovative cropping practices were defined using (1) the results of the soil analysis, (2) the technical solutions raised in the co-design workshop (*step 2: co-design of innovative cropping practices*). Simple indicators of performances and protocols for data collection were developed prior to the farm visit and discussed with the farmer in order to reach a common agreement on the co-evaluation schedule. The visits lasted between one and three hours in each farm and were conducted by phone-call in four of the nine farms because of the covid-19 pandemic. The facilitator guide developed for the visit is presented in **appendix 4**. An experimental device sheet was developed prior to the visit as a tool and memo for the collaborative creation of the co-evaluation process. The experimental device presented for each experiment, (1) the objectives, (2) the research questions, (3) the hypothesis, (4) descriptions of the 'usual' and 'test' modalities, and (5) the co-evaluation schedule, as discussed with the farmers during the visit. The experimental device sheet was sent to all farmers as a memo and summary of the visit (**appendix 5**).

3.2.4 Step 4: On-farm co-evaluation of innovative cropping practices

The co-designed cropping practices were implemented on the farms in spring 2020. The cropping practices were tested on a chosen crop, on a seedbed or a plot named 'test'. To enable comparisons, the usual cropping practices of the farmer on the chosen crop were implemented on another -adjacent- plot named 'usual'. As an example, if the farmer tested no-till on tomato - 'test' modality-, the farmer also cultivated tomato with soil tillage – 'usual' modality- as he/she usually does. The experiment was meant to be a decision support to orient changes in the participants cropping and farming systems.

Since the data was collected through on-farm evaluation, the data needed to be contextualized prior to drawing conclusions. To enable contextualization of the findings, data on the study site included (1) soil characteristics from the results of the soil analysis and from the visual soil assessment (*step 1: Diagnosis of the initial situation)*, (2) history of the study sites -i.e., previous crop, fertilisation, soil tillage, weed pressure- (*step 1: Diagnosis of the initial situation)*, (3) the experimental device -i.e., purpose and objectives of the test, modalities- defined with the farmer during *step 3: Collaborative creation of the co-evaluation process*, (4) cultivation operations -i.e., soil, weed and pest management- recorded by the farmers during *step 4: on-farm co-evaluation of innovative cropping practices*, for both modalities in a crop logbook.

A set of agri-environmental and socioeconomic indicators were defined to evaluate, in collaboration with the farmers, the performances of the co-designed innovative cropping practices in each farm during the growing season, from April to November 2020. Simple indicators were chosen according to (1) the literature review on *Maraîchage sur Sol Vivant* and (2) the farmers' needs identified along the research. As suggested by Bockstaller et al., the indicators were chosen according to their objectives and end-users, so that they were meant to enable (1) farmers' decisions to orient changes in their cropping systems, (2) multi-criteria assessments of the performances of the vegetable cropping systems (Bockstaller et al., 2008). The indicators were constructed to be as explicit and transparent as possible and the results of the indicators were discussed with the farmers by the end of the experiment (*step 5: final group meeting*). The indicators were calculated for both the 'usual' and the 'test' modalities. The set of indicators and the calculation methods are presented in **appendix 6**.

Data to calculate the indicators was collected participatively by: (1) the farmers, following simple protocols in their crop logbook prefilled prior to the co-evaluation (**appendix 7**), (2) the researcher through direct observations and measures on the field following simple protocols (**appendix 8**), (3) both the farmer and the researcher during the final semi-structured interview that occurred between 15th September and 2nd October, and lasted between 1 and 2 hours. The objectives of the final semi-structured interviews were to (1) collect the data from the crop logbook, (2) interpret and discuss the preliminary results of the innovative cropping practices with the farmer, (2) evaluate the outcomes of the research on the participants -i.e., learning, involvement, benefits, and limits of the methodology. The interview guide developed for the final semi-structured interview is presented in **appendix 9**. All the data was then combined in an excel data base prefilled with calculations forms to calculate each indicator.

3.2.5 Step 5: Final group meeting

A final one-day group meeting was held at the end of the project, on 12th October 2020, and attended by seven of the nine participants to the research, seven other local farmers, three members of ADAF, and the researcher. The objectives of the group meeting were (1) to compare farming and cropping systems characteristics among the participants farms, (2) to present and discuss the preliminary results of the innovative cropping practices, (3) to discuss modification and diffusion of the cropping practices tested, (4) to discuss the perspectives of the group and of the research project. The facilitator guide developed for the final group meeting is presented in **appendix 10**.

3.3 Study site

The study site is situated in Drôme-Ardèche, in the Rhône-Alpes region, France (**figure 6**).

Figure 6: Location of the study site in France.

Located along the *Rhône* river, 200 km to the Mediterranean, on the western alpine limits, the climate in Drôme-Ardèche is Mediterranean altered by continental and oceanic influences, evolving with altitude. The climate is characterized by strong sunlight, temperate winters, and dry summers, with strong wind coming from the north in the valley. With the context of climate change, temperatures are raising in the region, and drought periods last longer -up to four months. The landscape varies from valleys along the *Rhône* and the *Drôme* rivers, to mountainous areas on the western side of Ardèche -part of the *Central* massif- and on the eastern side of Drôme -part of the *Vercors* massif- with hilly areas on the northern parts of Drôme. Agriculture is a dominant activity in the region and is characterized by cereals, oleo-proteaginous crops, and fruits in the plains; viticulture along the valleys; polyculture in mountainous areas; olive trees, aromatic and medicinal plants in southern areas; and vegetable production. The soils in the region are alluvial soils along the rivers and eroded soils in mountainous areas. Bedrocks are mostly calcareous, which results in basic soils.

3.4 Participants farms selection

As in any multiple-case study, the farms selection did not follow a sampling logic but rather a replication logic (Yin, 2017). Therefore, the nine farms were part of the MSV-farmer group in Drôme-Ardèche and were not meant to be representatives of farms in *Maraîchage sur Sol Vivant*, but rather to be of theoretical relevance. Therefore, the multiple-case study enabled to (1) show a variety of systems in *Maraîchage sur Sol Vivant,* and (2) understand the mechanisms underpinning these systems. Indeed, as emphasized by Graneheim & Lundman: “choosing participants with various experiences increases the possibility of shedding light on the research question from a variety of aspects” (Graneheim & Lundman, 2004). The characteristics of the nine MSV-farms that participated in the research are presented in **§4.1**.

As suggested by Barreteau et al. (2010), a first contact with the participants was organized at the beginning of the research to investigate farmers' willingness for participating in the project as well as their needs and expectations regarding the research project. A consent form summarizing (1) the research questions and objectives, (2) the project managers and partners, (3) the farms selection, (4) the research process, (5) the levels of involvement expected from the participants, (6) information on data utilization and protection, (7) information on participants rights was signed by the participants after this first contact and prior to data collection (**appendix 11**). Throughout this thesis, the participants were identified by fictitious names to keep their anonymity (**§4.1**).

3.5 Characterization of *Maraîchage sur Sol Vivant*

3.5.1 Data collection

Data to characterize *Maraîchage sur Sol Vivant* was collected during *step 1, diagnosis of the initial situation* through semi-structured interviews. The semi-structured interviews occurred in December and January. They lasted between 2 and 4 hours and were audio-recorded. The interviews were structured according to an interview guide (**appendix 2**) and organized as follow: (1) general information about the farm (history, surface, commercialization, pedoclimatic conditions etc.), (2) transition to *Maraîchage sur Sol Vivant* (inspiration and learning sources, reasons for converting, expected and experienced benefits and challenges), (3) agronomic aspects (soil and pest management, crop rotations, irrigation, general characteristics of the cropping systems etc…), (4) economic aspects (incomes, costs, brut margin), (5) social aspects (workload, work satisfaction, values, visions, missions). Data from the semi-structured interviews were complemented with participatory observation during *step 1 diagnosis of the initial situation* and direct observations during visits throughout the entire project. Data collected by observations were recorded in a logbook.

3.5.2 Data analysis

The cases were first described in farm sheets using the following structure: (1) general information about the farm, (2) values, vision, mission of the farmer, (3) transition to *Maraîchage sur Sol Vivant* (inspiration sources, expectations, transition steps, stage in the transition, observed outcomes, ongoing projects), (4) cropping practices (soil and pest management, tillage, cropping system description, equipment), (5) economic performances (commercialization modes, gross margin, autonomy, investments) (6) social performances (workload for each activity, number of holidays), (7) comparative vision of the farm using a set of 7 indicators shown in a spider web, in comparison to the means of the indicators from the group. This farm description -i.e., the farm sheet- was used for communication with farmers among the group and outside the group, as well as for future market gardeners in *Maraîchage sur Sol Vivant*. An example of a farm sheet is presented in **appendix 12**.

After describing the cases in the farm sheets, data was analysed using qualitative content analysis (Graneheim & Lundman, 2004). The interviews were transcribed, read several times, and meaningful parts of the text -i.e., meaning units- were highlighted, in light of the research sub-questions (**appendix 13**) in order to find promising patterns or concepts -i.e., pattern matching logic- (Yin, 2017):

- What are farmers motivations for converting to *Maraîchage sur Sol Vivant*?

- What has inspired *Maraîchage sur Sol Vivant*?
- From which learning processes have resulted on-farm implementations of *Maraîchage sur Sol Vivant*?
- What characterizes the cropping practices in *Maraîchage sur Sol Vivant* with regards to soil, weed, and pest management?
- What explains similarities and differences in cropping practices among the farms?
- What are the benefits and limits of the cropping practices in *Maraîchage sur Sol Vivant*?

Meaning units were then categorized both in a deductive way -i.e., categories emerged from the literature review and the interview guide- and in an inductive way -i.e., categories emerged from the transcripts. Categories were defined considering the whole context, so that they could capture the essence of the meaning units. The categories were then arranged into themes. The structure of the data analysis including the themes and the categories is presented in **appendix 14.**

For each theme, data from the nine cases were described and compared using a cross-cases synthesis, a suitable analytical technique used in multiple-cases studies which aims at retaining the holistic feature of the individual cases while comparing and synthesizing within-cases patterns across the cases (Yin, 2017). Finally, the synthetized patterns were compared to the literature for each theme, and linked with existing theories (Saldaña, 2015). Credibility, dependability, and transferability of the findings were ensured by: (1) carefully selecting meaning units so that their essence could be captured in the categories; (2) selecting categories so that they cover all relevant data; (3) reporting representative quotations from the transcripts to illustrate differences and similarities among different themes; (4) writing analytic memos and taking notes in a log-book in order to reflect on the data analysis process (Saldaña, 2015); (5) clearly describing the study context -e.g., participants selection, farming systems- to ensure transferability of the findings (Graneheim & Lundman, 2004).

3.6 Characterization of the research methodology

3.6.1 Data collection

Data on the co-design and co-evaluation methodology developed and followed in this participatory action research was collected continuously during the research project. Observations were recorded in a logbook shortly after contacting the participants (phone call, visit) with the aim of identifying the participants points of view on the research process. The logbook was also used by the researcher to track, reflect, and learn during the research process. The logbook was filled weekly and structured as follows: (1) what has been done, (2) what has been learn, (3) problems, modifications, ideas, questions on the research process, (4) what should be done next.

Data from both semi-structured interviews (*step 1: diagnosis of the initial situation* and *step 4: on-farm co-evaluation of innovative cropping practices*) was collected through notes and audio records to identify (1) farmers' expectations on the research project, and (2) outcomes of the project from the participants points of view. Specifically, data on the co-design workshop (*step 2: co-design of innovative cropping practices*) was collected through: (1) notes taken along the workshop, (2) a survey questionnaire intended for the workshop participants. The questionnaire was structured as follow: (1) satisfaction about the workshop format, (2) expectations regarding the workshop, (3) learning outcomes, and (4) suggestions for improving future co-design workshops (**appendix 15**).

3.6.2 Data analysis

Data from the logbooks, the semi-structured interviews and the survey questionnaire were synthetized, combined, and scrutinized in light of the third research question 'What characterizes a research methodology based on co-design and co-evaluation of innovative cropping practices?' and of the sub-questions formulated in the case study protocol (**appendix 13**):

- What are the steps of the co-design and co-evaluation methodology?
- What was the participants points of view on the co-design and co-evaluation methodology?
- What characterizes the exchanges and mutual learning between the actors?
- What characterizes participants involvement?
- What are the benefits and limits of the co-design and co-evaluation methodology?
- What are the pre-requisites to co-design and co-evaluate innovative cropping systems?

The analysis aimed at finding promising patterns or concepts -i.e., pattern matching logic- and provide methodological guidelines for future co-design and co-evaluation studies (Yin, 2017)

4. Characteristics of *Maraîchage sur Sol Vivant*

4.1 Cases description

The main characteristics of the nine farms are presented in **table 3.** Detailed farming and cropping systems characteristics are presented in farm sheets (**appendix 12**) included in a technical leaflet (to be published in 2021).

The cultivated acreages for market gardening in the nine farms that participated in the study range from 3000m² to 20ha, with five farms cultivating less than 1ha, two farms cultivating between 1ha and 3ha, and two farms cultivating more than 3ha. Human working power varies between 1.2 and 11 workers per farm -i.e., human working unit or full-time equivalent-, with an average 3.3 workers per farm. All of the farms surface area except Alex's farm are below the recommended 1.5ha per human working unit for market gardening, as defined by French official agricultural development agencies (GRAB/FRAB, 2009). All farms were created quite recently -i.e., less than 15 years ago- and three of them were created less than three years ago. All farms combine market gardening with other farming activities such as animal production -e.g., laying hens, sheep breeding-, fruit, and berries production. Four farms associate vegetable and fruit production on the plot -i.e., market garden-orchard-, where vegetables are cultivated in between the rows of fruit trees. All farms practice organic farming however one farm does not have the certification.

Three of the farmers are from an agricultural background-i.e., they have been raised in a farm-whereas the others are from a non-agricultural background. For instance, Emile has settled on the family farm, as he explained: "I have always been into it [agriculture] and I have always wanted, since childhood, to become a farmer and president of a cooperative like my father" (all quotations for interviews are literal translation from French). Ten of the farmers have previously studied or worked in different fields. They have reconverted into market gardening for diverse reasons. Danielle said: "I was a chef, and I've found a lack of choice on the market stalls and I said to myself: it would be more fun to grow things like that, so I could choose my ingredients through the seed catalogs instead". When he finished his PhD in organic chemistry, Maurice decided to pass a professional license in farm management in organic market gardening -BPREA in French- to align with his values as he expressed: "[The thesis] was too complicated, so much headlock for such a small thing, so insignificant, I was asking myself lots of questions on the meaning, like many people, and then I've heard about permaculture that could produce crops without smashing the soil, so after the thesis I wanted to do market gardening". Six of these farmers have had to pass a professional license in farm management in organic market gardening prior to settling their farms.

Table 3: Characteristics of the nine MSV-farms.

Farmers names	Total acreage	Cultivated acreage in market gardening	HWU	Other activities on the farm	AB	Year of installation	Farmer's background	Studies	Previous experience in market gardening	Land access	Commercialization modes	Transformation	Mechanization level
Alex	20ha	20ha	11	Laying hens	X	1984 (family farm)	Agricultural background	Horticulture, agronomy, and vegetal production	Work on the family farm (horticulture, vegetables), several internships during his studies	Family farm	Direct selling on the farm, markets, half-wholesale, Restaurants		High
Charles	4,3ha	2ha	3	Fruit production (MGO), laying hens, plants production, lacto-fermentation	X	2007	Reconversion	Engineer in agronomy	1-year work in a farm Internship (6 months) in Japan	Purchased	Baskets (CSA), organic store, restaurants	X	Low + AT
Claude & Thomas	5,3ha	5000m²	2,5	Fruit production	X	2018	Reconversion	BPREA (Thomas)	3-years work in a collective farm (Claude) / 1-year volunteering in farms (Thomas)	Collective farm, career lease	Organic producers store, market, organic shop, basket (CSA)		Non-mechanized
Danielle	1ha	4000m²	1,2	Fruit and aromatic production (MGO), plant production, catering	X	2008	Reconversion	BPREA	None (gardening only)	Rented	Market (plants), Catering (direct selling)	X	Non-mechanized
Emile	34,8ha	3,5ha	4,5	Fruit Production (MGO), cereals and fodder	X	2014	Agricultural background	Fruit production & horticulture	Family farm (orchard, horticulture, vegetable)	Family farm	Half-wholesale, organic producers store, baskets (CSA)		High
Jean	6ha	1ha	2,75	Walnut production, laying hens, vegetable seed production	X	2007	Reconversion	BPREA	6 months internship in a farm	Collective project, family farm	Organic store, markets, organic producers store		Low
Léa & Marc	4,7ha	7000m²	2	Berry production	X	2009	Reconversion	Bachelor in natural resources and environment, certificate of specialization in organic farming, BPREA (Léa), / Forestry bachelor (Marc)	1-year work and internship in farms / none	Purchased	Organic producers store, baskets (CSA), restaurants	X	Low + AT
Maurice	1ha	3800m²	1,5	Sheep breeding	(X)	2018	Reconversion	PhD in organic chemistry BPREA	Internship (<6 months) in a farm	Collective project	Market, camping shop		Non-mechanized
Marie & Anthony	3ha	3000m²	1,5	Fruit production (MGO), berries, laying hens	X	2019	Reconversion	Engineer in agronomy (Marie) / Journalism, BPREA (Anthony)	1-year volunteering in farms	Purchased	Direct selling on the farm, baskets (CSA), organic store		Non-mechanized

Legend: HWU: Human Working Unit, MGO: Market Garden Orchard, AB: Organic agriculture (X) organic agriculture without label, CSA: Community supported agriculture, AT: Animal traction

Except two farmers who have settled on their family's farm, most farmers had little experience in market gardening before starting -i.e., less than 3 years-, as Claude explained: "I messed up a lot and I had to learn the job little by little by correcting my mess". Charles said: "I actually trained in market gardening for only a year and half, which was well insufficient (…). There are many things I had not seen, there are some vegetables (…) that I planted but did not harvested. (…) I did not know the varieties they were growing. The schedule, vaguely (…). Oh yeah, here I wasted time, by adding two or three years of training, I think I would have earned here on my expenses. Because the experience you are making on your own farm, it is at your own expenses".

Three farms have been created on purchased land previously not cultivated in market gardening. One of the farms has been settled on a rented plot, and three farms were created as part of collective projects. All farms products are sold through short supply chains, although some products are sold through semi wholesale in the two largest farms. All farms sell their products through direct sale, on the farm, through vegetable baskets such as CSA -i.e., Community Supported Agriculture-, or in the markets. On three farms, products are sold in an organic store, and in four farms they are sold in an organic producer store. Two market gardeners sell their products to local restaurants. Three market gardeners sell value added products: two market gardeners sell fermented products, and one market gardener cooks her products and sells these dishes through catering.

Overall, the farm characteristics are heterogenous among the participant farmers in terms of (1) farm size, and (2) mechanisation levels. However, most farmers have settled quite recently and come from a non-agricultural background -i.e., reconversion. All farms are cultivated in organic farming and combine vegetable production with other productions. These results align with a recent study that reported that 30% of the new farms in France were established by young farmers with no-agricultural background. According to this study, these young farmers were attracted by organic agriculture (63% of them) and short supply chains (58%), showing that the characteristics of the farms studied are representative of the trend in farms creation in France (JeunesAgriculteurs, 2013). According to Morel's definition, all farms except Alex's farm are microfarms, that is to say, "commercial soil-based market gardens cultivating organic vegetables with less than 1.5 ha per farmer in rural France" (Morel et al., 2017). Consistent with the microfarms defined by Morel, most of the studied farms were created by farmers with no agricultural background, they are not necessarily mechanized, and they produce a wide diversity of vegetables, mostly sold through short supply chains (Morel et al., 2017).

4.2 Transition to *Maraichage sur Sol Vivant*

4.2.1 Motivations for conversion to *Maraichage sur Sol Vivant*

The reasons mentioned by the farmers for converting to *Maraîchage sur Sol Vivant* can be gathered in four analytic categories (1) soil health, (2) crop health, (3) work convenience, and (4) farmers' values. Occurrences of the categories of motivations for conversion to *Maraîchage sur Sol Vivant* are presented in **figure 7**, along with relevant quotations from the farmers interviewed.

Soil health

Five of the farmers mentioned soil health as a reason for converting to *Maraîchage sur Sol Vivant* (**figure 7**). Indeed, some farmers have observed soil degradation on their fields and wanted to remediate it. As highlighted by the adoption of the EU Thematic Strategy for Soil Protection by the European Commission on 22 September 2006, soil degradation processes are increasing among European countries through erosion, organic matter decline, compaction, salinisation, landslides, contamination, sealing and biodiversity decline (Montanarella, 2007). The severity of land degradation is thus a factor for converting to cropping practices that aim at enhancing soil protection. In conservation agriculture for instance, awareness and concerns for soil erosion are factors for adoption (Knowler & Bradshaw, 2007).

One farmer converted to *Maraîchage sur Sol Vivant* because he considered *Maraîchage sur Sol Vivant* as an extension of the approach in organic agriculture. Even though organic agriculture is defined by sets of regulations -e.g. the AB regulations- where soil management is poorly addressed, the philosophy and principles carried out by the organic pioneers like Howards emphasized the improvements of soil fertility and the re-use of wastes to close nutrients loops in organic agriculture (Howard & ClE, 1950).

Crop health

Two farmers quoted 'crop health' as a motivation for converting to *Maraîchage sur Sol Vivant* (**figure 7**). This motivation relies on the fact that soil health must enhance crop health. This is consistent with soil health definition: "soil health has been defined as the capacity of soil to function as a vital living system to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health" (Larkin, 2015), so that soil management practices promoting soil health such as *Maraîchage sur Sol Vivant* can potentially benefit to crop health as well.

Work convenience

Three farmers quoted 'work convenience' as a reason for converting to *Maraîchage sur Sol Vivant* (**figure 7**). Work convenience is defined here as a beneficial outcome of a practice on work efficiency and farmer's work management, so that it decreases work difficulties -physical and mental- and workload.

According to a study of work difficulties on 24 farms in organic and diversified market gardening in France, workload was considered as unacceptable for 84% of the farmers interviewed (Richir, 2013). Difficulties in diversified organic farms are due to complex cropping systems and high personal involvement, resulting in mental pressures (Dupré et al., 2017; Richir, 2013). Thus, potential for work convenience is an important factor for adoption of cropping practices in *Maraîchage sur Sol Vivant.*

"There is a kind of common sense to do that. And that is true, you take a step toward Nature, she takes two toward you, that is so true. You do a little and finally everything gets easier. One must always go in the direction of Nature." Alex

"(…) That meant a lot to us, obviously, young people with our ideals, our wishes to rethink agriculture… I was having the experience of ploughing 20ha fields with my big tractor of 200 CV when suddenly, I yearned to put a bit more of my hands into the soil, to have something [a farm] smaller, well cared for." Claude & Thomas

"I never liked tilling the soil, I always had the sensation of making the tsunami to everyone!" Danielle

"This is what seems the most logical, the most natural way to grow the crop." Maurice

"This was not our objective; this was our sensitivity [to the environment]." Léa & Marc

"And above all, in our state of mind (…) we are guests on Earth (…). It is making the land better than what it was before your crop. We really want to improve everything we have, try to respect soil life, animals… Soil is not just a support for the crops." Marie & Anthony

"It is also by love to all we have read in agronomy books, we were pleased to read 'your soil must be alive, your soil must be healthy so that the plants are healthy as well'." Claude & Thomas

"[In my previous farm], we had too much of a slope to pass the tractors and cultivators, so we tried techniques that allowed us to reduce soil tillage because of the large slope making it so slow to dry out (…). Which would have made us work very late in the season. We would have been pissed off all the time, it was very complicated. So, we tried to not till the soil to avoid these constraints which are actually only mechanicals and topographic constraints." Claude & Thomas

"Agriculture is the law of the right time, it has to be the right time to prepare the soil, it has to be the right time to hoe, it has to be the right time to plant, all the time it has to be the right moment. So, it revealed to be more efficient [to stop hoeing with animal traction and] to work manually, what is potentially more time-consuming, but if it is done at the right time, you don't have to do it again." Charles

"We have noticed that our soils were compacted once we passed the tractor and we asked ourselves what we do, and how do we do?" Léa & Marc

"In my [first] ten years of practice [in market gardening], I was seeing few earthworms, and I felt that my soil was becoming more and more inert." Jean

"I arrived to Maraîchage sur Sol Vivant through the question of weeds and soil tiredness in my greenhouses, particularly with nematodes, and also outside with viruses." Emile

"For me it goes further [than organic agriculture], there is organic agriculture and making it on a living soil, and I really believe in that. That is the continuity of organic agriculture. Because you can be organic and have destroyed soils with water stagnation, it does not grow, you must always put fertilizers and everything." Alex

Figure 7: Farmers' motivations for converting to *Maraîchage sur Sol Vivant:* occurrences of the analytic categories and quotations from the semi-structured interviews.

Farmers' values

Most of the reasons mentioned by the farmers for converting to *Maraîchage sur Sol Vivant* can be embedded in the analytic category 'farmers values', i.e., personal ways of thinking influencing their vision and behaviour. The farmers interviewed cited common values linked to strong social and ecological considerations: 'reduce impacts on the environment', 'autonomy', 'respect and care of human beings', 'respect and care of biodiversity', 'aesthetics', 'viability', 'considerations for future generations', 'participating to the development of organic and ecological agriculture', 'producing healthy products', 'feeding local consumers' etc (**figure 7**). It appears from the semi-structured interviews that farmers' values guided the design and the management of their cropping systems. These results are aligned with the findings from Casagrande, who concluded that motivations for adopting conservation agriculture among organic farmers depend on farmers' values and environmental concerns (Casagrande et al., 2016). Similarly, Blesh & Wolf (2014) pointed out that reasons and motives for converting to agroecological practices lie in psychological factors at the farmers' level -farmers' experiences and values- (Blesh & Wolf, 2014).

4.2.2 Inspiration sources

When developing cropping systems in *Maraîchage sur Sol Vivant,* farmers have been inspired by existing influences and methods in agriculture, gathered in seven analytic categories: (1) biointensive organic farming, (2) organic agriculture, (3) agroforestry, (4) biodynamic, (5) natural agriculture, (6) permaculture, and (7) conservation agriculture (**figure 8**).

The most frequently mentioned influence is permaculture (**§ 2.1.3**) Similarities between permaculture and *Maraîchage sur Sol Vivant* lie on application of ecological principles and inspiration from natural ecosystems for farming systems design, as well as on common ecological and social ethics (Mollison, 1988). Three farmers have also emphasized that adaptation of permaculture was required for implementation in commercial market gardening (**figure 8**). So far, permaculture has been mostly used to design projects that target autonomy and family gardens rather than commercial gardens. Thus, the permaculture approach was adapted to professional market gardeners, addressing aspects such as commercialization, productivity, profitability, work convenience.

Biointensive organic farming has been mentioned by four farmers as an inspiration source for developing their cropping systems in *Maraîchage sur Sol Vivant*. These farmers especially mentioned books such as the "practical guide of market gardening in Paris" (Moreau & Daverne, 1846), books written by Fortier (Fortier & Bilodeau, 2014), Coleman (Coleman, 2019), referring to biointensive organic farming (**§ 2.1.2**). Conservation agriculture, agroforestry, biodynamic, organic agriculture, and natural agriculture are also extended influences that have inspired the farmers for developing their cropping systems in *Maraîchage sur Sol Vivant*. All these methods, such as *Maraîchage sur Sol Vivant,* rely on agroecological principles. **Appendix 1** summarizes the similarities of *Maraîchage sur Sol Vivant* with its sources of inspiration.

"We had noticed that we had compacted soils when we pass the tractor, and we thought what we do, how do we do what, so we had this entrance of the biodynamic." Léa & Marc

"We also did a training in permaculture and there was always this idea to regenerate the soil. And *Maraîchage sur Sol Vivant* for me, it is 200% into that." Marie & Anthony

"Living soil, permaculture, all of this was starting to emerge in 2004 when I did my training. It was something that meant a lot to me, and that seemed to me completely non-adapted for market gardening, for commercialization, so more than a garden, I couldn't see, it seemed impossible." Jean

"By seeing people who grew in the permaculture way, who grew things, from here it just needed a kind of professional way to do that." Maurice

"For me there are two main biases: permaculture and reduced tillage in field crops and their practice of green manures." Danielle

"I've read the book of the Parisians market gardeners, who explained [to grow on a small and well cared space], and that inspired me. Ok, take a small plot but work on it the best way you can, 'delicately'. This approach, I like it very much, and I think that is a lot about personality, but I feel I can spend time, cultivate my garden well, take care of all that, and that feels good to the head, to feel I'm able to take care of my garden without being overwhelmed, without running all the time." Claude & Thomas

Figure 8: Farmers' inspirations sources: occurrences of the analytic categories and quotations from the semi-structured interviews.

4.2.3 Learning processes

When inquired how they have learned *Maraîchage sur Sol Vivant,* farmers mentioned various learning processes, gathered in seven analytic categories: (1) books, (2) trainings, (3) network, (4) inspiring figures, (5) YouTube videos, (6) seminars and conferences, (7) on-farm experiences -i.e., the iterative cycle farmers learn from when testing innovative cropping practices on the farm- (**figure 9**).

Interestingly, most educational resources mentioned by the farmers interviewed were not linked to agricultural schools or agricultural institutions. Indeed, knowledge is spread between the market gardeners through (1) books written by farmers themselves, (2) trainings, usually offered by farmers or former farmers, (3) networks, when farmers visit others farms or discuss with other farmers, (4) through inspiring figures -i.e., well-known innovative farmers-, (5) YouTube videos, usually shot on pilot farms, (6) seminar and conferences, sometimes organized by farmers, (7) on-farm experiences led by the farmers through iterative cycles of tests and observations, usually inspired by other farmers' cropping practices. Thus, innovative cropping practices and systems in *Maraîchage sur Sol Vivant* are co-created by farmers, as outcomes of social learning among MSV-farmers in France, i.e., the learning process fostered by social interactions in a group by both learning and teaching (Bandura, 1977).

It must be emphasized that *Maraîchage sur Sol Vivant* results from local adaptations of agroecological principles, requiring on-farm experiences for their implementation, thus creating specific knowledge through experiential learning. Experiential learning as described by Kolb, is s a learning cycle in which the learner goes through four steps: (1) concrete experience, (2) reflective observation, (3) abstract contextualisation, (4) active experimentation (Kolb & Kolb, 2018). Indeed, as emphasized by Blesh & Wolf, "farmers need to develop innovative practices adapted to their local context, which often entails going through a lengthy process of trial and error." (Blesh & Wolf, 2014). These results suggest that, unlike most conventional cropping practices learned from agriculture institutions for instance, *Maraîchage sur Sol Vivant* is a farmer-led movement that requires active involvement from the farmers -through reading, networking, training etc- in order to learn MSV-cropping practices. These results align with the findings from Scopel et al., who concluded that learning ecological principles and inter-related cropping practices were challenging pre-requisites for farmers converting to conservation agriculture (Scopel et al., 2013).

On the other hand, it appears that in most of the learning processes that emerged from the semi-structured interviews, support provided by other MSV-farmers seemed to be a cornerstone of the transition (**figure 9**). The network of market gardeners involved in *Maraîchage sur Sol Vivant* acts as a catalyst for discussion, reflection, and adaptation among the farmers. Based on mutual support, social learning improves the sense of belonging to a group as well as commitment, thus catalysing agroecological transitions (Blesh & Wolf, 2014; Duru et al., 2015). Similarly, in a study aiming to understanding the agroecological transition on a set of cereal producers and rotational grazers in the Mississippi river Basin, Blesh et al., found that farmers learned through interactions with different people, because, unlike in industrial agriculture, there is "no recipe" in agroecologically managed cropping systems (Blesh & Wolf, 2014). Moreover, other studies have emphasized the importance of seeing the success in the neighbour -i.e., 'seeing is believing'- and feeling supported for farmers engaged in the agroecological transition (Braun et al., 2006; Cross & Ampt, 2017; Méndez et al., 2017).

"In Auroville (India), 50 years ago it was a desert due to deforestation (…), and today when you go to Auroville, (…) it is a heaven, a jungle, and they made it in 50 years. And we have visited quite a lot of farms that were a bit in permaculture, agroecology etc. and it was beautiful, and when I was going there, I was thinking 'this is what I want to have' (…)." Marie & Anthony

"He is gardening without any soil tillage. He built seedbeds (…) in which he cultivates without any soil tillage for the last ten years by bringing organic matter always on the top (…). So, there is a small corner where carrots were harvested and he puts a tomato plant here, next to it he will plant three plants of alfalfa. Green manures and vegetables grow next to each other in a kind of organized clutter." Charles

"That was a guy who worked with the MGRAPA (Brazil) (…) there are areas where they stopped ploughing to avoid this catastrophe, erosion, so they experimented many things." Claude & Thomas

"And we are in contact with Charles who had the same kind of philosophy, so we made some parallels, we've seen him changing many things, every time we visited him, he told us 'I'm doing that, I'm doing permanent seedbeds etc' and every time we discussed it, and back home we read" Léa & Marc

"I thought: if there are some who have 1ha in market gardening and who reached to do what I wanted to do at the beginning, I have to go back to that, and I stop tiring myself with animal traction and with soils I feel more and more fragile." Jean

"(…) And the big boom it is the trainings at ADAF, the first time Pierre Besse came I had tears in my eyes. You feel suddenly less alone (…)" Danielle

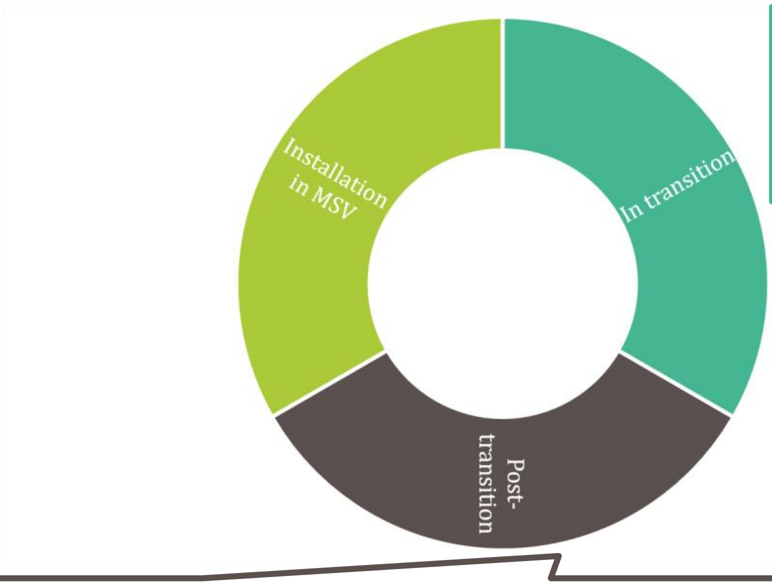
"And after there is Pierre Besse, he was an important character, so I watched him in video, I've seen him during trainings twice I think, and that are people who made me feel confident." Charles

Figure 9: Learning processes toward *Maraîchage sur Sol Vivant*: occurrences of the analytic categories and quotations from the semi-structured interviews.

All resources mentioned by the farmers have also been sources of inspiration, showing that inspiration is an important driver of learning among the farmers interviewed. Most farmers have been inspired by the visions of farms they have visited through networking, or by inspiring figures in *Maraîchage sur Sol Vivant* (**figure 9**). While being inspired by different approaches and farming systems, it must be emphasized that farmers in *Maraîchage sur Sol Vivant* adapted inspiring techniques for their own conditions -e.g., soil, climate, topography, socio-economic constraints, farm's organisation, farmer's values, visions, and preferences etc. Indeed, adaptation has been pointed out by Nicholls et al., as a pre-requisite for implementing agroecological principles, also defined as "no recipe farming" (Nicholls et al., 2017).

4.2.4 State in the transition and transition patterns

In the group we can distinguish farmers (1) who have settled their farm directly in *Maraîchage sur Sol Vivant,* (2) in transition toward *Maraîchage sur Sol Vivant*, and (3) who have been through a transition toward *Maraîchage sur Sol Vivant* (**figure 10**).



"We have the plot below that has 3.5% of organic matter, so this one, I think it will probably be the first one to be in no-till. And the others will probably switch [to no-till] slower." Léa

"I did one year with a tractor, two years with a motocultor, and one year with animal traction [before stopping soil tillage]." Danielle

"In 2018, we had 50% of the farm conducted in *Maraîchage sur Sol Vivant*, in 2019 we had 80% and now we'll be at 100%." Jean

"As long as a technique has not been proven by five or six years of practice, you don't know if it is valid or not." Charles

"For instance, I added the hay only on the long-cycle periods vegetables, so squashes. Since the beginning, the squashes were grown on mulch, I think I was too closed off with animal traction to accept the fact that hay [mulches] could gain ground on my garden…" Charles

Figure 10: States in the transition toward *Maraîchage sur Sol Vivant*: occurrences of the analytic categories and quotations from the semi-structured interviews.

Here we define the transition as a process through which farmers shift from managing organic cropping systems without major considerations on soil health to systems organized around soil health protection and relying on agroecological principles. The transition occurred mainly through a step-by-step process (**figure 10**). The step-by-step process to shift toward cropping practices in *Maraîchage sur Sol Vivant* allows the farmer to become more familiar and confident with the approach, to master new cropping practices and adapt work management on the farm. The transition period is also considered as a testing period since farmers usually start by trying innovative cropping practices on a small part of the farm prior to larger adoption. In agreement with Catalogna et al., the transition period allows farmers to adjust and adapt innovative cropping practices to their farming systems, and thus, to limit risks undertaken by changing practices on the farm (Catalogna et al., 2018).

The transition process affects and is affected by farmers psychological and cognitive factors such as mental barriers or ways of thinking (**figure 10**). As pointed out by Blesh & Wolf in a study on a community of practice, "transitioning to new management systems also involves internal, cognitive changes—such as thinking differently about the farm and farming." (Blesh & Wolf, 2014).

4.2.5 Synthesis

The main features of the transition toward *Maraîchage sur Sol Vivant*, as described by the interviewees are presented in **figure 11**.

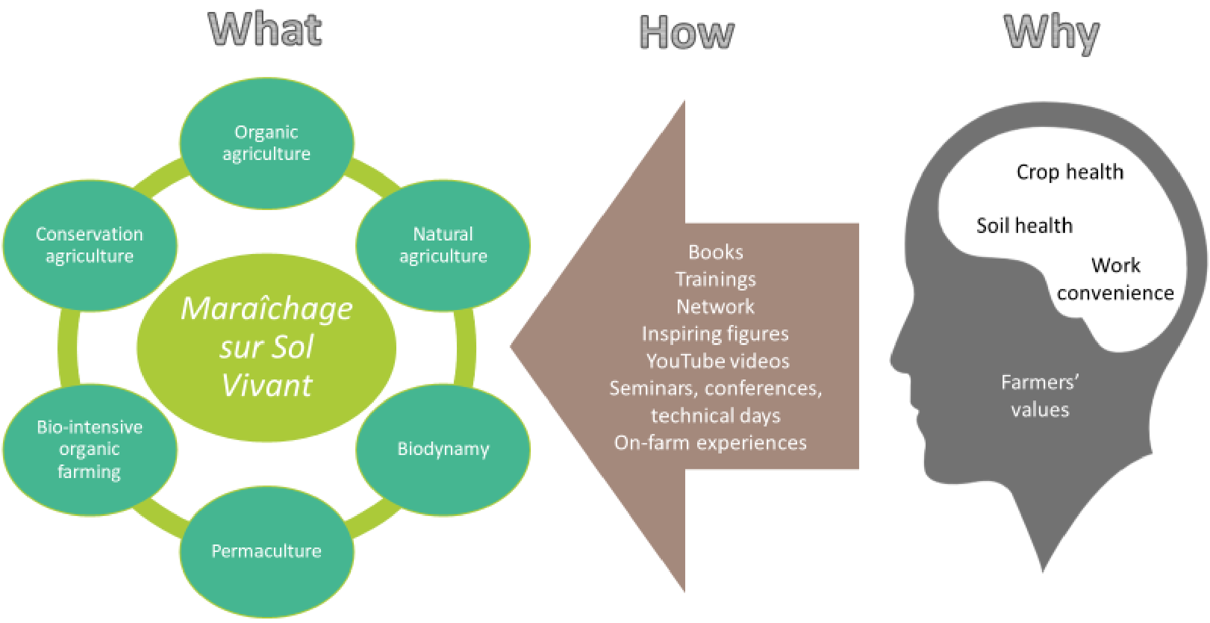


Figure 11: Conceptual diagram of the transition toward *Maraîchage sur Sol Vivant,* as described by the interviewees.

Looking at the way the interviewees engaged in the transition, it appears that the group of market gardeners shares essential characteristics of a 'community of practices' (COP) in the way that: (1) the marker gardeners share similar objectives regarding their cropping systems -i.e., to increase soil health, crop health, work convenience- and their values are aligned, (2) they create and share knowledge through social and experiential learning, thus creating a common culture based on similar objectives, aligned values, common knowledge and inspiration sources, (3) their cropping systems are designed thanks to farmer's exchanges, mutual support and local adaptation of agroecological principles, (4) they actively participate in the transition process (Blesh & Wolf, 2014; Cross & Ampt, 2017). The transition toward *Maraîchage sur Sol Vivant* can be qualified as bottom-up, so that the changes require active involvement from the farmers in contrast to top-down transitions catalysed by external factors -e.g., policy incentives. These findings are confirmed by Blesh's definition of agroecology: "agroecological practices are being cultivated by resourceful people who selectively draw on support from local and non-local actors, and who are blending current scientific and ecological knowledge with historical and experiential knowledge from working farms" (Blesh & Wolf, 2014).

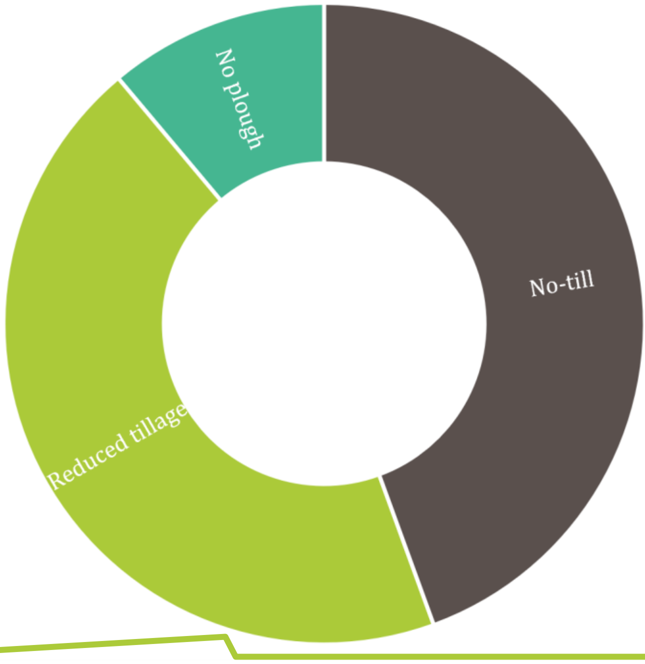
4.3 CROPPING PRACTICES IN *MARAÎCHAGE SUR SOL VIVANT*

Cropping practices in the nine MSV-farms that participated in this study were very diverse. The analysis of the semi-structured interviews shows that the MSV-cropping systems in the participants' farms were designed and managed using a combination of 19 cropping practices for soil, weed and pest management, thoughtfully chosen to fit local constraints -e.g., soil, climate, crop, available equipment- and farmers objectives (**figure 12**). This section links experiential knowledge developed by the farmers on cropping practices in *Maraîchage sur Sol Vivant* with scientific knowledge. Characteristics of the cropping practices in *Maraîchage sur Sol Vivant* are highlighted using practical examples of cropping strategies implemented on the nine MSV-farms in Drôme-Ardèche within their benefits and challenges, as expressed by the farmers during the semi-structured interviews.

Figure 12: Cropping practices in *Maraîchage sur Sol Vivant*: occurrences of the cropping practices implemented on the nine MSV-farms in Drôme-Ardèche.

4.3.1 Reduced tillage and no-till

Soil tillage practices were various in the nine MSV-farms in Drôme-Ardèche (**figure 13**). Four farms practice no-till, i.e., soils are not or barely tilled for soil preparation and weed management. Four farms practice reduced tillage, i.e., tillage operations and intensity are reduced to a minimum, with the aim of decreasing negative impacts of soil tillage. One farm practices no plough, i.e., conventional tillage without ploughing.



"Today, I consider that we are 100% in *Maraîchage sur Sol Vivant* with zero soil tillage, and globally we still rely on soil bio structuration, so on soil life." Claude & Thomas

"Since I'm in organic farming, I don't use or barely use the plough, (…) so, I'm in superficial [or reduced] tillage, it's not necessarily better, but basically it is grinding and one or two dethatching, and (…) I put the organic fertiliser and then, I pass the rotative harrow." Emile

"We will make permanent seedbeds with the aim of not tilling them anymore." Léa & Marc

"I do green manure, and since long time already, I realised that soil tillage realised by the green manure is sufficient in itself. In some cases, after growing green phacelia, crimson clover, the soil is in the same state than after using the best tools." Charles

"We don't have to worry about which tool will till the soil for soil preparation or which suite of tools will suit the soil. And the tools they are the hands, it is precision agriculture, it does not cost as much as a satellite! So that we work with what we see, here the question is what to put on the soil, and we work with wood, straw, hay, leaves (…)" Maurice

Figure 13: Soil tillage practices in the nine MSV-farms in Drôme-Ardèche: occurrences of the analytic categories and quotations from the semi-structured interviews.

The semi-structured interviews showed a shift in the way market gardeners think and manage their cropping systems in reduced tillage and no-till compared to conventional tillage. In conventional tillage, the soil is tilled for soil preparation prior to sowing or planting, in order to bury crop residues and create -macro-porosity. Soil tillage is also used for weed management, using for instance, a cover-crop or a de-thatcher prior to plantation or seedling, or hoeing during the cropping season. The novelty in reduced tillage is that soil preparation and weed management are ensured through different cropping practices that replace soil tillage (**figure 4, § 2.2.3**). Soil preparation is ensured through biological structuration, creating porosity otherwise provided by soil tillage. Weeding provided by soil tillage is replaced by prophylactic weed control techniques such as (1) cover crops and green manures

(**§ 4.3.2**), (2) mulches (**§ 4.3.3**), and (3) plastic covers (**§ 4.3.4**). The farmers identified several benefits and challenges in the implementation of reduced tillage and no-till on their farms (**figure 14**).

"Now, the soil tillage is scheduled in August and September, when I till the soil in the best conditions. In August, it's hot, dry, there is no problem, there is no risk to make a plough pan or whatever. And, since I grow a green manure in between, I don't care about the finishing state of the soil, this is very fast, sometime in one pass of ridging hoods and one pass of cultivator it's done, the soil is ready enough to grow a green manure." Charles

"If the field is clean, I would rather use the direct seeding machine, that would destroy less the soil than if I take the cultivator that goes down to 30cm and that breaks everything." Alex

"Our biggest mistake, is to till the green manure at the beginning of the season and to break all the work that was done by earthworms, by soil life during winter." Léa & Marc

"[Before reducing tillage], on the three periods of soil tillage in the year, I needed a minimum of fifteen days for each soil tillage period to do all these passes. If you totalize on the year, it is around twenty passes of machines on a period of 2 months put together, when the soil will be bare and tilled. So that was a problem because it means some time, but it is time working on the tractor so it is not that much, but it is above all a mental charge, that is to say, that you have all these plots you need to prepare in spring, it's tough to find windows [for soil tillage] each time, (...) so on the 6 passes you do, there is one that is not done during the right conditions, that's almost sure." Charles

Benefits

- Soil structure
- Soil protection
- Soil biodiversity
- Soil fertility
- Work convenience

Challenges

- Weed control
- Soil warming
- Context-dependant

"The new problems [since I stopped tilling] I have are bindweed, thistle, quackgrass and that keeps me busier than usually." Jean

"(...) There is another problem, the perennial weeds. (...) It happened to me to not till a plot for 2 years, so at the end, it is horrible, there is quackgrass and bindweed everywhere, that's hell! So, I must come back to soil tillage in periods when I can let weeds die, so rather in summer before growing a green manure." Charles

"On some crops, it is still challenging to grow things that should grow fast such as lettuces, radishes, spinaches, spring crops." Jean

"I categorized my vegetables in two categories to make it easier: those with vigorous rooting systems, that grow well in untilled soils, and those who need a softer soil." Charles

"(...) There are some [farmers] who don't till their soil at all since they have settled, and there are some like me who, it is not to find an excuse, but I think my soil constraints make it complicated to stop all soil tillage." Charles

"Sometimes I have no choice because when we do mechanical harvests like potatoes or carrots, (...) we're stuck because we scratch our soil everywhere (...)" Alex

"For us it is a bit different because we are on a small acreage, we cultivate 5000m², it is very small. It is what allows us to work without mechanisation, entirely manually because when we say no soil tillage, we work entirely by hand (...)" Claude & Thomas

Figure 14: Benefits and challenges of reduced tillage and no-till observed by the MSV-farmers, and quotations from the semi-structured interviews.

Weed control appeared to be challenging for the farmers practicing reduced tillage due to a shift from annual to perennial weed communities (**figure 14**). As explained by Smith & Mortensen, the level of disturbance of a cropping system, characterized by its frequency and intensity, selects functional traits of weed communities (Smith & Mortensen, 2017). Therefore, a shift in weed communities led to a shift in weeding strategies in reduced tillage.

Losses of crop precocity due to slower soil warming were also reported by farmers who are practicing reduced tillage (**figure 14**). The lack of mechanical macroporosity that traps air and the soil coverage that protect the soil from sun radiations result in lower soil warming in reduced tillage and no-till. However, soil warming is necessary to enhance biological activity and mineralization in spring and maintain crop growth (Wilcox & Pfeiffer, 1990). Crop precocity is critical in market gardening for (1) satisfying the consumer demand in spring, and (2) increasing crop successions, so that more crops can be cultivated on the same surface area each year. Losses of crop precocity have been reported in other studies on no-till vegetable cropping systems (Morse, 1999), thus stressing the need to develop practical solutions for market gardeners in reduced tillage and no-till. For instance, the farmers interviewed used dark mulches (**§ 4.3.3**) or plastic covers to increase soil warming (**§ 4.3.4**). Further technical solutions could be developed, based on soil covers that increase soil warming or on selection of varieties that require lower soil temperatures.

The farmers interviewed highlighted the benefits of reduced tillage and no-till on soil quality (**figure 14**). For instance, the farmers interviewed explained that when soil tillage is less frequent, it can be done on good soil and during good climate conditions, thus reducing the negative impacts of soil tillage on soil structure -e.g., compaction. These arguments are supported by several studies that reported positive effects of no-till and reduced tillage on: (1) soil structure, (2) soil protection -e.g., from sun degradation, erosion-, (3) soil biodiversity, and (4) soil fertility (Holland, 2004; Soane et al., 2012; Thomazini et al., 2015).

Farmers have also observed the benefits of no-till and reduced tillage on work convenience such as improved work management due to less tillage operations. For example, some farmers raised the benefit of being able to work in the field longer due to better water infiltration in soils managed in no-till and reduced tillage. These observations were supported by Thomazini et al., who reported higher water holding capacity in organic no-till vegetables systems including cover crops compared to systems in conventional tillage (Holland, 2004; Thomazini et al., 2015).

Overall, it appeared from the semi-structured interviews that the effects of no-till and reduced tillage depend on diverse factors such as soil type, climate, and crops. For instance, some farmers reported better production in reduced tillage cropping systems, depending on the crop rooting systems and requirements. Looking at the characteristics of the four farms in no-till, three of them are not mechanized. Moreover, the farm with the largest surface area and highest mechanisation level practices tillage with higher intensity. These results suggest that no-till can dispense mechanisation in the farms, and that reduced tillage is more adapted to small farms where manual work is feasible.

4.3.2 Cover crops and green manures

The terms 'green manure' and 'cover crop' were used by the farmers to refer to the cultivation of a non-commercial crop in between commercial crops with the aim of not harvesting or returning the harvest to the soil. The semi-structured interviews showed that all farms except one cultivate green manures and cover crops when possible, i.e., when soils are not cultivated for a sufficient period. Choices of cover crop species among the MSV-farmers interviewed depend on (1) seeds availability, (2) the period, (3) termination methods, (4) targeted goals and benefits expected by the farmer.

The farmers identified several benefits and challenges when growing cover crops and green manures (**figure 15**). Farmers reported benefits of cover crops on soil quality resulting from (1) the soil protection against soil degradation such as erosion, and (2) the positive effects of the cover crop residues on soil fertility. These observed benefits of cover crops on soil fertility can be explained by (1) the rhizosphere activity of the cover crop that enhances soil biodiversity and biological activity, (2) the cover crop residues that increase soil organic matter, and enhance nutrient cycling (Carnavalet, 2015; Norris & Congreves, 2018).

It appeared from the semi-structured interviews that cover crops and green manures were also cultivated as a prophylactic weed management strategy. Indeed, cover crops compete with the spontaneous vegetation and decrease the weed seeds stocks, thus resulting in lower weeding requirement on the following crop.

The farmers also reported practical challenges with cover crop termination (**figure 15**). They practiced diverse termination methods such as (1) frost, (2) grinding, (3) rolling with a roller, (4) dethatching or any other tilling method, (5) a combination of frost, grinding or rolling with plastic covers occultations (6) grazing. These termination methods appeared to be highly context dependent -e.g., crop species, climate-. The optimal termination period seemed to be particularly critical to avoid crop regrowth. In many cases, the farmers estimated that the cover crop was likely to grow back, so that grinding, or rolling was combined with occultation with plastic covers. Even though specific rollers -i.e., roller crimpers- have been developed to ensure cover crop termination, they were not affordable for the market gardeners. These results suggest that experiments are needed to determine adequate termination methods and periods for diverse cover crops in market gardening.

On the nine farms, cover crops were sowed (1) *on the fly*, with or without rolling after seedling; (2) with seeders with or without mechanical soil preparation -e.g., with direct seeders-; (3) during hoeing in the previous crop -i.e., intercropping. Cover crop management differed on the farms, from few to many cultural operations -e.g., irrigations, fertilisations-, depending on local conditions and on farmer's objectives. Indeed, some farmers aimed at maximizing cover crops benefits by rapidly setting-up a dense and uniform cover crop. These results suggest that cover crops cultivation is knowledge-intensive and requires good understanding of species cycle and physiology. In agreement with Morse's recommendations, cover crop cultivation must be embedded in an integrative weed management on the whole crop system (Morse, 1999).

"This is important, not to keep bare soil on the seedbeds, and ideally, to use green manures to cover them, and when we can't because it's too late or because we will sow soon after, we use a woven plastic cover. Either we grow a green manure, either we use a plastic cover during winter." Claude & Thomas

"By growing cover crops, that enriches [the soil], that diversifies, we feel we have soils in evolution (…)" Alex

"I like growing sunflower in my cover crops because sunflowers last longer in the season. With sorghum, from 20th October, the leaves start to die, and the light reaches the soil whereas the sunflower stays. Sunflowers have very flat leaves so that the light does not reach the soil." Alex

Benefits

- Soil protection
- Soil biodiversity & fertility
- Weed control

Challenges

- Termination methods
- Context-dependant

"I destruct the green manure in spring, by grinding and dethatching." Emile

"We arrive to the right stage, beginning of April, this is phacelia blooming so you grind it, and it does not grow back, and that comes to a period, in April, it's the big blow [starts of the growing season resulting in high workload for market gardeners], and that would coordinate with phacelia and mustard blooming." Alex

"When [the green manure] is high, putting a plastic cover on it is horrible. We tried last year on a meadow, we had to roll on the plastic cover to lay the grass underneath." Jean

"Because, when a phacelia is implanted in summer, it is at the maximum of its growth at the beginning of winter, so winter will already harm it a lot, and then you just have to put a plastic cover quickly to finish to kill it." Charles

"We harvested everything, we sowed [the green manure], then around middle of May, we made it grazed by the sheep for two days." Maurice

"I'm using a big mix [of seeds], there are cereals, legumes, flowers, old seeds, anything (…). Depending on the season, I don't have sprinkling irrigation so I sow before a rainfall and after I let it grow, so that the plants managing well with these constraints would grow, or if it starts raining a lot, the mix will be more diversified, for me it is very linked to the rainfalls." Danielle

"It depends on the season, if I can sow [green manures] during summer it is forage sorghum (…) and in winter I grow oats or rye, with vetch, phacelia, forage radish, clover." Emile

"Today, I think I sow my green manure too late, because I don't know well the things yet, but I think that once your crop is clean with hoeing (…) quickly you can sow a cover crop in your crop, for all crops that are not harvested mechanically: cabbage, bean, chicory, cardoon. I do it at the end of the summer and that works really well!" Alex

Figure 15: Benefits and challenges of cover crops and green manures observed by the MSV-farmers, and quotations from the semi-structured interviews.

4.3.3 Mulches and organic amendments

All MSV-farmers in the study used to bring organic material to the soil such as straw, hay, green manure residues, manures, compost, ramial chipped wood, chipped wood, or organic fertilizers. Organic materials were either brought on the soil surface through mulches or integrated into the soil using tillage tools. It appeared that the choice of organic matter depends on: (1) access to organic matter, (2) available equipment, (3) soil properties, (4) crop needs, (5) farmers' objectives. Organic materials used by the market gardeners were mostly locally produced and affordable. Thus, finding organic material appeared to be one of the first stages in starting cropping systems in *Maraîchage sur Sol Vivant*. Practical solutions were found by the farmers, such as collaboration with neighbouring tree surgeons to deliver pruning wastes for free. Other farmers used the manure produced on the farm by animal production activities. Hay and straw were either bought from neighbouring farmers or produced on the farm by mowing the grass in other fields or in the foot passes. Access to organic matter of good quality such as material free of weed seeds or detritus was challenging (**figure 16**). Choice of organic matter seemed to depend on available equipment as well. For instance, access to equipment that enables plantation on thick mulches, spreaders, and mowers were decisive to implement organic amendments on the farm. On the other hand, mechanisation, and especially mechanical weeding appeared to constraint mulching. Indeed, the farmers reported that the presence of a litter or mulch on the soil surface was impeding mechanical weeding such as hoeing because the litter impeded the tools. Sowing was also challenging in presence of a mulch, so that direct seeding appeared to be possible only on a compost mulch. Because direct seeders were not available to the market gardeners, hay and straw mulches were removed manually prior to seedling. The overall benefits and challenges of mulches and organic amendments identified by the farmers are presented in **figure 16**.

First, the farmers highlighted the benefits of mulches on soil protection against sun light, wind, and water degradations such as soil erosion. These observations were confirmed by several studies that reported reduction of soil losses between 50 and 90% in presence of a mulch (Edwards et al., 2000; Scopel et al., 2005). Improved soil fertility was observed by the farmers and explained by better conditions -light, temperature, humidity- under the mulch that enhance soil biological activity. Indeed, soil buffering appeared to be an important feature of the mulch for the market gardeners who observed better growth in summer and later growth in spring. Soil buffering is less suitable in spring because soils need to dry out and warm up to support growth of spring crops. Aware of this phenomenon, the market gardeners have developed strategies such as using green waste compost mulches to enhance soil dry out and warm-up. However, because green waste compost dries out and warms-up faster, its use appeared to be challenging in terms of water management. Therefore, it can be concluded from the semi-structured interviews that the type of organic material for mulching must be thoughtfully planned to suit the crop and the growing period.

"[The compost mulch] preserves the soil from sunlight and that always maintains a certain humidity, which makes that, for instance here we can observe earthworms active all year long. (…) And we realised that, when filling a little bit more in compost mulch, that was preserving a little bit more the soil underneath, it kept it more humid, and the vegetables implanted well in the compost before rooting in the soil." Claude & Thomas

"Generally, what I have observed and that is really beneficial with hay, vegetables have a regular growth all summer, the hay protects the soil from extremes temperatures, from sun, so I have a more temperate soil (…). There is no yellowing of the leaves, no fading of the green, the green is sustained." Charles

"Looking at soil structure, there is nothing to do, but it is ten years of organic matter additions, so that it changes everything (…) The rapidity to digest things is phenomenal so I'll have to find organic materials" Danielle

"My crop fertilisation, it is the organic material from the previous year, generally, with the spring green manure, that is still rapidly available. But it is not thought in terms of direct fertilisation. (…) I have the organic matter from the mulch of the previous year that is the main crop pantry. [So, it is] straw or hay, and then, underneath I put things that are rapid [to mineralize] so the crushed green manure, on the top I put dregs of beer, (…) the mowed grass from the foot passes or from the end of the plot. (…) What matters is that it flows all the time, so that there are always things to eat for soil life, and so for the plants." Danielle

"Normally we don't need [to do manual weeding], (…) I think [this year] I have done manual weeding only in the eggplants because I think we had not mulched enough. (…) If they are well mulched, there is no problem. (…) Sometimes we are a little stingy and you see it immediately, sometimes when your plant is not very high, you don't dare to not smother it (…) and you can be sure that after, everything grows back." Léa & Marc

Benefits

- Soil protection
- Soil fertility
- Crop growth
- Weed control

Challenges

- Soil warming
- Water management
- Organic matter quality & access
- Available equipment
- Fertilisation

"You have to be careful with hay, for instance that keeps humidity in summer and when it gets warm and humid, there is rot (…). In winter it is excluded. I have tried only once to grow on hay [mulches] in winter, too many issues with fungi, especially on lettuces. Anyway, that keeps the cold for too long and we need a soil that warms up very quickly for summer crops." Charles

"When working with mulches, it is necessary to water much more when you water. You need to fraction more, (…) when you water, it is not 20mm because it does not go through [the mulch], you have to put 50mm so that it goes through the mulch. (…) When you put only 20mm (…) only the top gets a little wet and that evaporates or otherwise the mulch stays humid, but the soil is not." Emile

"So, what is not easy is to have the right organic material, not too dirty, that goes well to mulch the crops, so straw without thistles (…). So last year I had a wheat straw that was not really clean, so it resown some weeds, especially thistle." Emile

"With the leak hole punching machine, it drills the seedbed under the hay mulch in six minutes when, by hand, I used to take one hour (…). I can plant salads (…), bunch onion, fennel; that are some of the densest crops (…). I can generalise hay to almost all crops, so the time saving will be huge because hoeing disappears almost completely." Charles

"The constraint is mechanisation. I know that with mechanisation, I would never work with 20cm of hay for instance. So, it excludes almost directly everything like total soil coverage." Alex

"There are these stories of nitrogen hunger that can happen but there are way shorter, way less pronounced than with straw, and that is because hay is a complete food. (…) Systematically we bring the hay at least 15 days or 3 weeks before [planting] the vegetable, so that the microorganisms started to degrade the hay. If there is a nitrogen hunger there are no vegetables to suffer the consequences of it, and when we bring the plant, hay digestion has already started (…), and I never see nitrogen hunger episodes anymore." Charles

Figure 16: Benefits and challenges of mulches and organic amendments observed by the MSV-farmers, and quotations from the semi-structured interviews.

In some cases, the farmers reported additions of large amounts of organic materials in the soils as a soil regeneration strategy to increase soil organic matter content, enhance soil biodiversity and biological activity. The soil regeneration strategy consisted of an addition of large amounts of carbonaceous organic material with high humification potential such as crushed wood. As reported by Barbier, an addition of 100t/ha of chipped wood with an iso-humic potential of 0.5 can potentially increase the soil organic matter content of 1% in only one year (Barbier, 2020). As highted in a technical article on the use of ramial chipped wood for soil regeneration, organic materials have different functions: "compost is used to feed soil life and bring nutrients to the plants while ramial chipped wood can rebuild and maintain soil structure, long term fertility and soil stability (…) the organic material contributes to trophic chains without any loss" (Caron & Lemieux, 1999), so choice of organic material to be added should depend on the soil and crop needs as well as on the organic material characteristics. Even though scientific studies have shown the positive effects of organic matter additions on humification, nutrient cycling, soil structure, and water-holding capacity (Caron & Lemieux, 1999; Mannering & Meyer, 1963), future research should study the effects of several modalities of additions of large amounts of organic materials -i.e., different organic material types, addition methods and periods, etc.- in diverse pedoclimatic conditions. Furthermore, the MSV-farmers faced challenges in the fertilisation strategy that rely on biological activity for nutrient cycling. For instance, nitrogen immobilizations were observed by the farmers on crops cultivated shortly after additions of organics materials with high C:N ratios. Therefore, the market gardeners combined organic materials that is slow to decompose and mineralize -e.g., straw, crushed wood- with organic material that decomposes and mineralizes faster -e.g., fresh green manure, chicken manure.

The semi-structured interviewed showed that mulches were also integrated in a prophylactic weed management strategy by the MSV-farmers. The farmers reported positive effects of the mulch on weed germination, depending on the mulch characteristics -e.g., material, thickness- and on the soil weed communities -e.g., species, abundance- as confirmed by several studies on the topic (Masiunas, 1998; Vollmer et al., 2010).

Benefits of mulches on work convenience were also identified by the farmers who reported reduction in weeding requirements in mulched cropping systems (**figure 16**). However, workload reduction due to less weeding were reported to be (counter)balanced by workload due to organic material addition or mulching. For instance, Charles reported difficulties in the plantation on thick mulches, so that a leak hole punching machine was adapted to make holes in the mulch to ease the plantation. Future studies should be conducted to assess workloads and work convenience in mulched cropping systems and practical solutions should be developed.

Embracing the complexity of the mulches, organic amendments, and fertilisation in *Maraîchage sur Sol Vivant*, the semi-structured interviews highlighted that these cropping practices are very context-dependant. This raises the need to increase understanding of soil functioning in *Maraîchage sur Sol Vivant*, and conduct systems experiments to guide the farmers in their choices.

4.3.4 Plastic covers

Plastic covers were used on all the participants farms expect one. Two types of plastic covers were most widely used by the MSV-farmers: (1) black plastic covers and (2) woven plastic covers. Black plastic covers are waterproof so that they occult sunlight and impede water and air exchanges. Woven plastic covers are made of woven plastic covers so that they occult most sunlight and allow water and air exchanges. To a lesser extent, other plastic covers were used: (1) thin and permeable plastic covers, (2) biodegradable plastic covers made of bioplastic, (3) biodegradable plastic covers made of hemp. Benefits and limits of plastic covers identified by the farmers are presented in **figure 17**.

Plastic covers were used in between the crops or during crop cultivation. Plastic covers were used for soil preparation prior to plantation or seedling. Indeed, light occultation avoids all plants germination -especially with black plastic covers- and kill all plants that could have grown, even the perennials, depending on the occultation period and length. Therefore, plastic covers appeared to be an effective and convenient technique for prophylactic weed management prior to cultivation, thus replacing weed management that could be otherwise done by soil tillage (**figure 17**). Occultation periods were adjusted by the farmers depending on (1) the weed type, (2) the weed coverage, and (3) the season. Indeed, perennial weeds require longer occultation periods -i.e., up to several months- to decay compared to annual weeds -i.e., few days. It appeared from the semi-structured interviews that the occultation periods were shorter in spring and summer compared to autumn and winter. Occultation periods in winter generally lasted from the harvest of the last summer crop until sowing of the first spring crop. The MSV-farmers also used plastic covers during crop cultivation, so that crops were planted directly on the plastic cover after making holes. This technique appeared to be convenient to avoid weeding in the transplanted crops, as shown by Rajablariani et al., who found a reduction of 84-98% of the weed biomass on vegetables cultivated on plastic mulches compared to bare soil (Rajablariani et al., 2012).

The MSV-farmers highlighted that plastic covers were also used to cover the soil, thus replacing cover crops functions such as soil coverage and weed management, when growing a green manure was impossible -e.g., because of the season, or because the period was too short. By avoiding the light reaching the soil and by keeping the soil moist, increased soil biological activity was observed by the farmers under the plastic cover. Thus, it appeared that the farmers placed the waterproof black plastic covers on a moist soil to increase biological activity and keep the soil moist until removal. Overall, plastic covers seemed to be one of the very few solutions that enabled direct seeding without soil tillage (**figure 17**).

The interviewees observed better soil warming when using plastic covers, resulting in improved crop growth and precocity (**figure 17**). These findings were confirmed by several studies on the effects of plastic mulches on vegetable crops that reported increases in soil temperature up to 3 to 6°C higher than in bare soil, depending on the colour of the plastic mulch (Streck et al., 1995; Subrahmaniyan & Zhou, 2008).

However, it appeared that the use of plastic covers was challenging in windy places because the plastic covers could be blown away and damage the crops. Overall, it appeared from the semi-structured interviews that the use of plastic covers questioned the farmers regarding the sustainability of MSV-cropping systems, especially on plastic consumption and dependency on fossil fuels (**figure 17**). Some farmers hypothesised that the plastic consumption due to the use of plastic covers could counterbalance the fossil fuel consumption saved by reduced tillage. Thus, future research should study the effects of MSV-cropping systems on fossil fuels consumption and greenhouse gases emissions, and affordable solutions based on biodegradable covers should be developed.

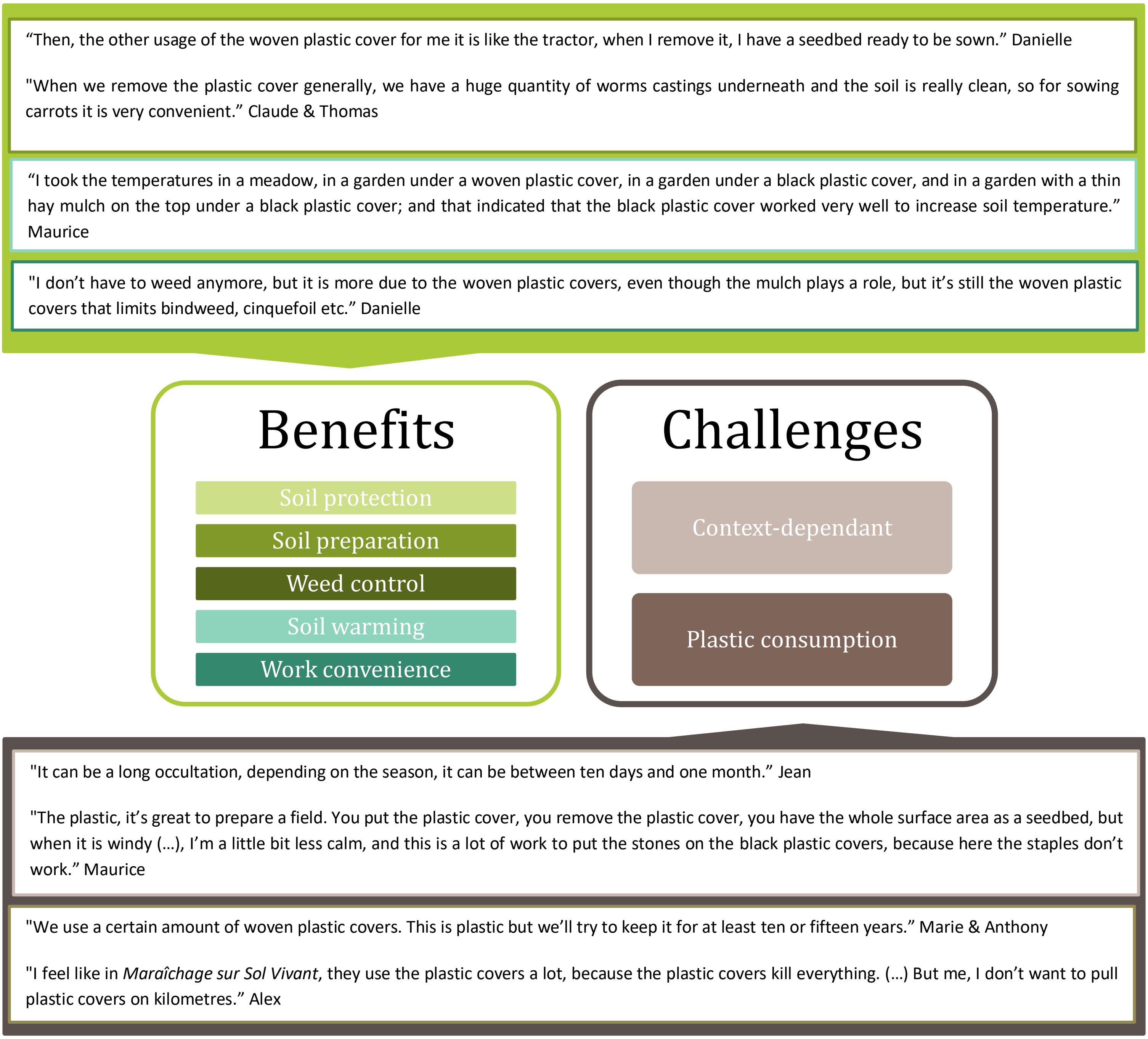


Figure 17: Benefits and challenges of plastic covers observed by the MSV-farmers, and quotations from the semi-structured interviews.

4.3.5 Prophylactic management

Weed management

In the participants farms, weed management was mostly maintained preventively, using cover crops (**§4.3.2**), mulches (**§4.3.3**), plastic covers (**§4.3.4**), and rotations**.** As a result, mechanical weeding was reduced or even stopped in some cases. In the cases of Alex and Emile, mechanical weeding was practiced instead of mulching because (1) a thick mulch would have impeded the use of available equipment such as hoe or harvesters, (2) the high surface area would have required huge amounts of organic matter to be mulched, and (3) mulching would have been too time-consuming in absence of adequate equipment.

In most cases, the prophylactic weed management was completed with manual weeding, especially done on bare soils, in the holes of the plastic covers, or when the mulches were too thin. Claude explained: "I weed the seedlings by hand. Since we usually alternate transplanted crops with sowed crops, we usually seed a garden after an occultation period, so that weed germination is not that high”. Since manual weeding is time-consuming and laborious, farmers have developed innovative prophylactic strategies that combine several weed control practices. For instance, Claude & Thomas used thick compost mulches, plastic covers, and wooden formwork for their seedbeds; and grew a permanent cover crop in the foot passes to limit manual weeding to the minimum.

PEST MANAGEMENT

Similarly to weed management, pest management was also preventative and integrated into the cropping system using a combination of practices. Charles explained the underlying approach of the prophylactic pest management: "I assume that the work needs to be done beforehand: the plants should not get sick. This is not a normal state to be sick, so it is necessary to find the conditions that make the vegetable healthy”. This approach was confirmed by Chaboussou who highlighted that pest problems are “linked to the disturbance in the nutritional balances of crop plants and destruction of life in the soil” (Chaboussou, 2004).

The high crop diversity along with the small plot characteristics of market gardening appeared to decrease risks of crop damages due to pest proliferation. Indeed, the crop diversity in all farms was typically high, with between 50 and 1000 varieties cultivated. This diversity of production can be explained by (1) the commercialization through short supply chains, that requires a high diversity of products to satisfy the consumer demand and by (2) the farmers ideals -i.e., their vision of the ideal farm- where aesthetics and diversity are cornerstones. However, it must be emphasized that in the MSV-farms*,* crop rotations were used to a lesser extent than in field crops. Due to the diversity and complexity of cropping systems in market gardening, the crop successions were rather thought in terms of space optimization and crop needs, as explained by Maurice: "There is no crop rotation like we consider it, I mean to turn the crops to avoid problems and everything. I don’t consider that, I consider only the harvest ease, the mulching ease, the soil state, the period”. MSV-farmers gave more importance to the alternance of mulches types and plastic covers to ensure soil and weed management than to the alternance of crop types for pest management.

For pest management, the MSV-farmers used mechanical protection such as basing to remove the insects from the plants, and nets to protect cruciferous crops from fleas. Beneficial organisms were protected by preserving and creating habitats such as tree rows, grass strips, insects’ hotels, and relay plants. Charles explained: “Hazel is one of the autochthon plants that host the highest diversity of beneficial insects. There is tansy, there is althea, I realised there are very late blooming. Tansy will rather attract Diptera, while the althea will rather attract melliferous insects. They share the fact that they have late blooming, but they host different communities”. In some cases, beneficial organisms were introduced -i.e., biological control- when their natural abundance was considered as not sufficient -e.g., *Bacillus thuringensis* against carrot and leak flies. Biological activity and crop health were also enhanced by spreading or spraying stimulating substances -e.g., comfrey, nettle- that help the plants to react against pests. Danielle said: "I don’t really spray anymore, but in my mulches, I always put a little bit of horsetail, nettle, comfrey, basalt. For me it is their [the plants] first aid kit. They have their pantry and their first aid kit, including for the plants I sell to gardeners”. Curative organic treatments such as copper, sulphur, anti-slug, black soap, and essential oils were also sprayed when the farmers considered that the other strategies were not effective.

MSV-farmers also raised challenges with management of pests such as voles and slugs that increase in presence of a mulch that provides them with shelter and food. This was confirmed by Scopel who concluded that "the conservation agriculture systems with tillage reduction and crop residue retention on the soil surface favour the proliferation of slugs, snails and mice" (Scopel et al., 2013). Research and development on these topics should thus be required to understand the biological cycles and ecological niches of these species and find practical solutions.

4.3.6 Synthesis

Five main cropping practices have been identified as characteristics of the MSV-farms in Drôme-Ardèche: (1) reduced tillage, (2) mulches and organic amendments, (3) cover crops and green manures, (4) plastic covers, and (5) prophylactic management. This combination of practices targets (1) soil protection, (2) soil regeneration, (3) crop health, and (4) work convenience (**figure 18**). Benefits of MSV-cropping practices on soil quality (soil structure, soil biodiversity, soil fertility) have been raised by MSV-farmers. Several studies have already showed and explained the benefits of reduced tillage, cover crops, organic matter additions and mulches on soil quality (Caron & Lemieux, 1999; Holland, 2004; Mannering & Meyer, 1963; Scopel et al., 2005; Thomazini et al., 2015). However, it appeared that more research is needed to understand the effects of the soil regeneration strategy in *Maraîchage sur Sol Vivant* and subsequent effects on crop health. In practice, efforts should be made by development agencies and extension services to guide farmers in fertilisation strategies based on additions of organic materials. By providing the farmers' points of view, this study showed the benefits of MSV-cropping practices on work convenience as well. These benefits, and work convenience particularly, appeared to be decisive factors for the MSV-farmers. These findings highlight the need to pay more attention to work convenience when evaluating and developing innovative cropping practices.

The interviewees identified several challenges related to these cropping practices such as: (1) reduced soil warming, (2) weed control (especially perennials), (3) green manure termination, (4) water management, (5) fertilisation, (6) access to adapted equipment, (7) access to organic materials of good quality, (8) plastic consumption, and (9) proliferation of slugs and voles. These challenges represent areas of improvement for research and extension services.

Overall, the analysis of the cropping practices in the nine MSV-farms in Drôme-Ardèche has revealed a wide diversity of cropping practices among the farms, showing that *Maraîchage sur Sol Vivant* has a high potential for adaptation to local constraints -pedoclimatic, socioeconomic. It appeared that cropping systems in *Maraîchage sur Sol Vivant* are designed and managed following agroecological principles that, when applied to different conditions, lead to diverse on-farm adaptations and innovations, as highlighted by Nicholls: "Agroecology does not promote technical recipes but rather above principles, which when applied in a particular region take different technological forms depending on the local socioeconomic needs of farmers and their biophysical circumstances" (Nicholls et al., 2017).

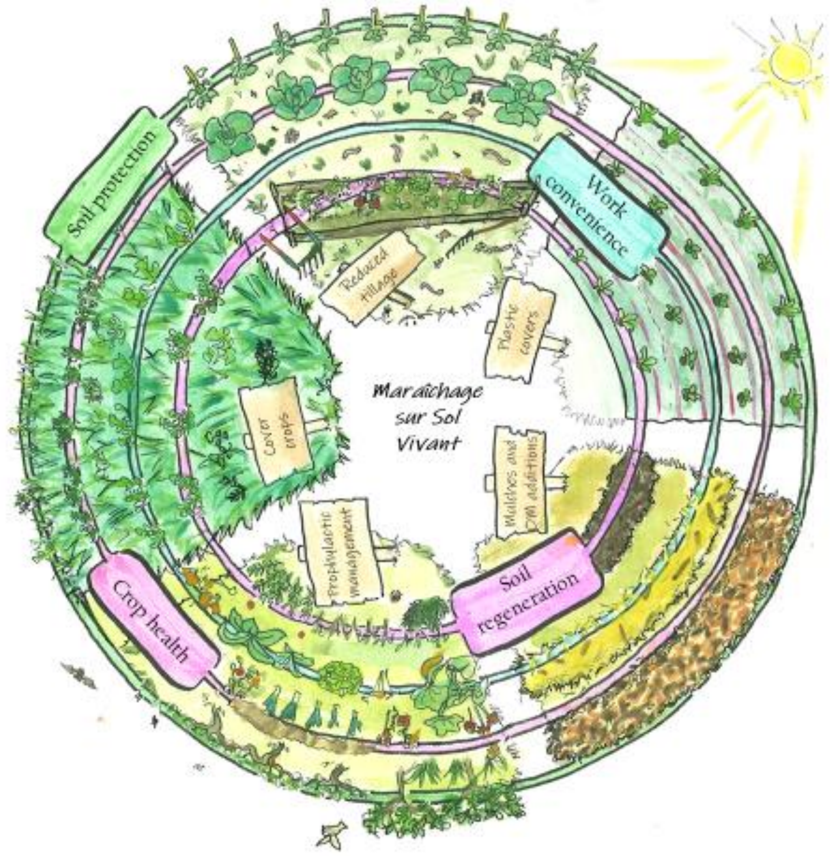


Figure 18: Conceptual representation of the cropping practices in *Maraîchage sur Sol Vivant* and their targeted functions. *Illustration published with permission of the artist © Yulian Dobrev*

4.4 Synthesis of the characteristics of *Maraîchage sur Sol Vivant* among the MSV-farmers in Drôme-Ardèche

The study of the nine MSV-farms in Drôme-Ardèche revealed differences in terms of farm size and mechanisation levels, as well as similarities among the farms. Most farmers settled quite recently and came from a non-agricultural background -i.e., reconversion. The farms were practicing organic farming and combined vegetable production with other productions. Products were diverse and mostly sold through short supply chains.

The participant farmers shared similar objectives that motivate them to actively participate in the transition process toward *Maraîchage sur Sol Vivant*: to increase soil health, crop health, work convenience- and to align with values around strong social and environmental considerations. The study shows that the MSV-farmers create and share knowledge on *Maraîchage sur Sol Vivant* through social and experiential learning. Their cropping systems were designed and managed thanks to farmers exchanges, mutual support, and local adaptation of agroecological principles.

The multiple-case study identified five cropping practices characteristics of the MSV-farms in Drôme-Ardèche: (1) reduced tillage, (2) organic matter additions and mulches, (3) green manure and cover crops, (4) plastic covers, and (5) prophylactic management that are combined to ensure diverse functions such as (1) soil protection, (2) soil regeneration, (3) crop health, and (4) work convenience. Indeed, soil is at heart of the cropping systems in *Maraîchage sur Sol Vivant,* as explained by Maurice*:* "Here we talk about putting down organic material, to not touch the soil, so not to mineralize more than what happens naturally, so the advantage is that each action we take inherently improves the soil".

5. Characteristics of the co-design and co-evaluation methodology among MSV-farmers in Drôme-Ardèche

5.1 Answering farmers needs

It appeared from the first semi-structured interviews that the relevance of the research project for the MSV-farmers was the main reason for them to participate in the project. Specifically, the participants expressed their needs for (1) having an external point of view on their cropping and farming systems, (2) being supported and accompanied in their innovations, (3) acquiring agronomic knowledge, and (4) technical knowledge for managing cropping systems in *Maraîchage sur Sol Vivant.* During the first semi-structured interviews (s*tep 1: diagnosis of the initial situation*), most participants mentioned issues related to the knowledge gaps in *Maraîchage sur Sol Vivant* such as "a lack of validated cropping systems" (Alex). The participants expected thus to "fill a gap of knowledge and help people to start in *Maraîchage sur Sol Vivant*" (Marie & Anthony) by participating in this participatory action research. Indeed, situated between theory and practice, between fundamental and applied research, participatory action research is at confluence between a need for research -from the researcher- and a need for change -from the participants and users- (Liu, 1997; Richer, 2011). The originality of this case lies in the fact that the participants had identified needs to both increase knowledge and solve the problems faced in practice, so that interests on the research where shared by the actors of the research, as recommended by Méndez for participatory action research (Méndez et al., 2013).

The fact that the research project was articulated around the cases -the farms-, considering their own objectives, needs, and constraints was particularly adapted to benefit the participants and steer participation, as expressed by Claude: "We need answers that correspond to our realities (…). I was agreeably surprised that you contacted me saying, I have soil analysis to do (…). It started well, by something concrete and directly useful for us, and I have to admit that this counted a lot in the fact that we did not doubt of our implication in this project". The particularity of participatory action research is that it connects problems with site-specific solutions, notably by acknowledging the local context. As highlighted by Méndez, the development of context specific strategies enabled by participatory action research are more likely to be sustainably adopted (Méndez et al., 2013).

5.2 The practical framework

During the final semi-structured interviews, all participants highlighted the convenience of the participatory action research for them due to (1) the schedule, (2) the flexibility of the methodology, (3) the level of organisation and rigour of the project, (4) the transparency and clarity of the process.

The schedule of the activities has shown to be adapted to the market gardeners' schedule. Indeed, time-consuming activities were avoided during work peaks (spring, summer). Schedule and timing of the activities appeared to be essential in this participatory action research, where high involvement was required from already overloaded participants. For instance, some farmers pointed out that the results of the soil analysis arrived too late (beginning of march) to adapt their cropping practices (especially in terms of fertilisation). It must be highlighted here that the participants were especially interested by the soil aspect of the project and expressed in the final semi-structured interviews that they would have liked to spend more time on understanding their soils -e.g., using the soil analysis- and finding ways to adapt their cropping practices.

Furthermore, most activities occurred on the participants farms -except the co-design workshop and the final group meeting-, and the visits were planned with flexibility to ensure farmers availability. As emphasized by Richer, action-research is a global approach rather than a method, because it does not involve scheduling rigid actions (Richer, 2011).

Organisation, rigour, transparency, and clarity were ensured all along the research. For instance, the co-evaluation protocols to achieve the on-farm co-evaluation of innovative cropping practices (*step 4*) were integrated in crop logbooks provided to the farmers, and the crop logbooks were pre-filled prior to data collection. Prior to the on-farm co-evaluation, experimental devices were co-developed with the participants, and the evaluation protocols (**appendix 7** and **8**) were discussed during *step 3: collaborative creation of the co-evaluation process.* Generally, all steps of the research were clarified and discussed with the farmers at the beginning of the research and along the research. This approach as embedded in participatory action research, shows an intentional design to (1) share the leadership with the participants, (2) maintain trust and transparency, (3) increase participants accessibility to the results (Méndez et al., 2013). Overall, organisation, rigour, flexibility, and adaptability of the research project were pointed out as pre-requisites to ensure convenience of the research for the participants. The convenience of the research project seemed to be crucial to ensure participants' active involvement (**§ 5.6**).

5.3 The co-design workshop

The co-design workshop was structured around the individual cases -the nine farms that participated in the project. For each case, (1) the current practices to be redesigned were presented; (2) the target of the cropping practices to be (re)designed was defined within its context, objectives, and constraints; (3) a collective knowledge exchange occurred between the farmers, followed by (4) a brainstorming on technical solutions and innovations (**§ 3.2.2** and **appendix 3**). Steps (1) and (2) were necessary to establish a diagnosis and target the co-design, as stressed by Deytieux et al.,: "irrespective of the design method used, an initial evaluation of cropping system sustainability is a key first step, identifying the strengths and weaknesses of existing systems before attempting to design new ones". Step (3) facilitated the relevance of the solutions resulting from the brainstorming, as recommended by Reau (Reau, R. et al., 2018). Farmers satisfaction on the workshop was assessed through a survey questionnaire filled at the end of the workshop (**figure 19**).

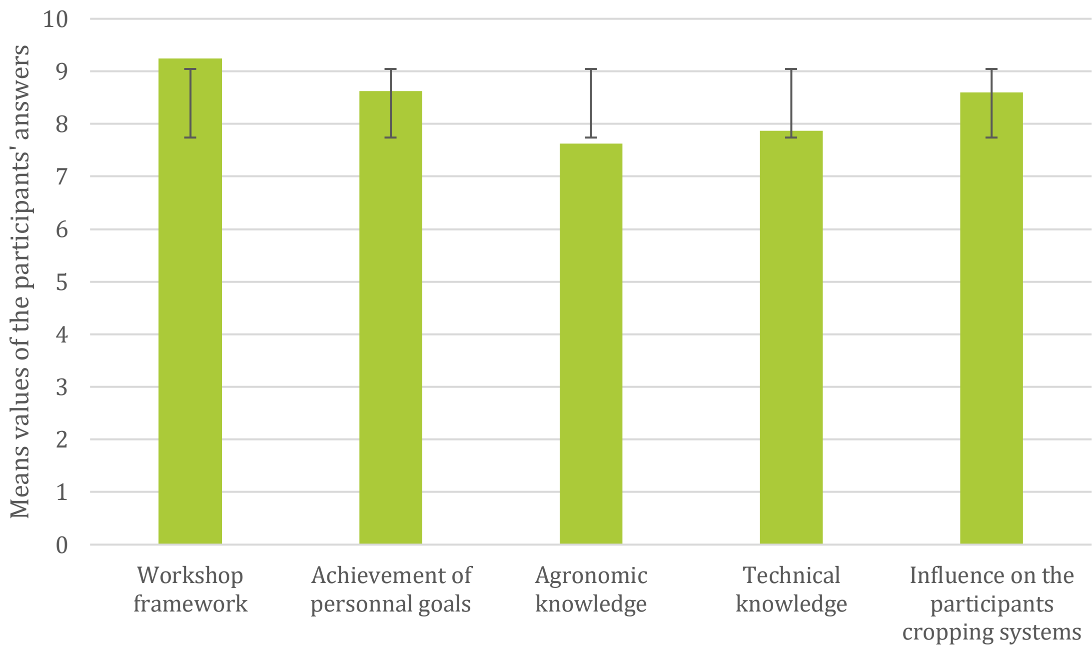


Figure 19: Farmers satisfaction on the co-design workshop from the survey questionnaire (**appendix 15**). The questionnaire was filled by the sixteen participants in the workshop. Participants were asked to grade from 1 'not at all' to 10 'absolutely' their satisfaction for each theme.

It appeared from the survey questionnaire that the workshop framework fitted the farmers needs for knowledge sharing and technical improvements. The participants set goals such as: 'sharing experiences with others', 'gain knowledge and skills to settle a farm in *Maraîchage sur Sol Vivant*', 'get ideas of cropping practices to experiment on my farm', 'improving my cropping systems in *Maraîchage sur Sol Vivant*', 'discuss technical options for diverse crops', 'understand the key points of cropping systems in *Maraîchage sur Sol Vivant* to achieve my transition', 'reflect on different cropping systems'.

However, some participants emphasized a lack of concrete solutions emerging from the workshop, as expressed by Claude during the final semi-structured interviews: "Between us [market gardeners], technical advises are a little bit going around in circles". This can be due to a 'fixation' phenomenon, i.e., the effect of 'going around in circles' when looking for innovative solutions. As also reported by Reau, this phenomenon may occur in co-design workshop settings, and restrict creativity and innovation in the solutions found by the participants (Reau, R. et al., 2018). This limit raises the need for more collaboration with R&D institutes and extension services, and especially with (1) technical advisors in agroecological practices in market gardening for providing advises to the farmers, (2) an experienced facilitator that fosters enriching and relevant dialogue among the farmers (**§ 5.7**). Indeed, the workshop participants considered that the presence of the trainer/advisor was fruitful due to his external perspective, his knowledge and skills on the topic. Drawing from the participants feedbacks on the workshop, it appeared that farmers are more receptive to external trainers/advisors with (1) experiences in similar farming situations -e.g., farm size, means of production, climate, soil, vision of agriculture-, (2) expertise, (3) agronomic and (4) technical knowledge.

Dynamism was pointed out by the participants as an important feature of the workshops. All farmers participated actively throughout the workshop. Proactivity is an important feature of experiential and social learning (Lieblein et al., 2012). Feedback from the workshop participants show that farmers had gained both agronomic and technical knowledge from the workshop and that it influenced concretely the way they planned to manage their cropping systems.

However, the workshop has shown to have little impact on the final design of the innovative cropping practices on the farms. It seems that the participants had already reflected on the targeted cropping practices for the co-design when preparing the workshop with the researcher during s*tep 1: diagnosis of the initial situation*. It also appeared that the workshop participants expected small technical solutions and mutual learning rather than a whole system (re)conception, suggesting that a simpler knowledge exchange on targeted topics involving (1) experienced farmers who have innovated on the targeted topic, and (2) expert with knowledge on the targeted topic, would have been more adapted to the participants needs. These findings also suggest that all participants were not ready to implement simultaneous changes in their farming systems, as recommended by Meynard et al. for systems redesign (Meynard et al., 2012). On the other hand, it does appear that due to the diversity and complexity of the cases, (1) a specific co-design workshop should have been organized for each topic or each case, (2) the co-design workshops should have included different participants, carefully chosen to master each specific topic for the co-design, (3) the facilitator should have been able to spot and remediate the 'fixation' phenomena, and (4) the cases and the targets should have been better selected to fit the co-design workshop.

Interestingly, I observed that the MSV-farmers implemented innovative cropping practices inspired from the co-design workshop on cropping systems not targeted during the workshop. This shows the potential of this type of workshop for fostering farmers' learning and innovations. These observations are in agreement with Meynard et al. who pointed out that reflexive interactive designs aim not only at improving a cropping system but also at creating a cycle of innovation and improvements (Meynard et al., 2012).

5.4 On-farm co-evaluation of innovative cropping practices

The cropping practices co-designed (s*tep 2: co-design of innovative cropping practices)* were implemented in spring 2020 on the participants farms and tested on a chosen crop, on a seedbed or a plot named 'test'. To enable comparisons, the usual cropping practices of the farmer on the chosen crop were implemented on another -adjacent- plot named 'usual'. The co-evaluation of the innovative cropping practices occurred during the growing season, from April to November, depending on the crops. Participants were asked to record all cultural operations, as well as observations, yields, and crop health in a crop logbook, according to simple protocols (**appendix 7**). The indicators were then analysed empirically by comparing each modality - 'test' and 'usual'- and interpreted in light of the specific objectives of the test, as settled with the farmer during s*tep 3: Collaborative creation of the co-evaluation process ().* The results of the co-evaluation (*step 4: on-farm co-evaluation of innovative cropping practices)* are presented in **appendix 16** as an embedded unit in this study, and include for each case, the characteristics of the test (study site, experimental device, cropping system description) and the performances of each cropping practice tested. The results were used to (1) answer the participant's questions that arose out of their shift toward *Maraîchage sur Sol Vivant*, and to (2) orient changes in the studied cropping and farming systems, as suggested in participatory action research (Méndez et al., 2013).

At the end of the study, all farmers agreed that the co-evaluation method was adapted and convenient for them because: (1) the crop logbook was well prepared so that they knew what to record and how to record it, (2) their task in the co-evaluation was not too constraining because it concerned only one crop and one plot, (3) the experimental device was defined with the farmer with flexibility.

However, the participants have shown criticism regarding the robustness and validity of the results of the on-farm co-evaluations. Conditions and constraints due to on-farm experimentation have been pointed out as limiting factors for robust and rigorous experimentations, as highlighted by Alex: "We have less time than in an experimental farm, there is heterogeneity in the irrigation, it is not really an experimental protocol because normally there are blocs with repetitions, and we are limited". The farmers also raised the issue of the study length, arguing that one year was too short to evaluate changes in cropping practices, particularly changes on soil quality. Indeed, during a transition, several changes occur in the farming system, so that measuring indicators of performances is especially relevant on the long term to evaluate and guide the changes at different levels. Unlike in an experimental design, on-farm evaluations do not provide enough modalities, repetitions, accuracy of the measures, and suitable testing period to be of good validity and robustness. As explained in a review on methods to assess the sustainability of cropping systems, lack of validity is characteristic of single site studies, because of the very specific pedoclimatic and socio-economic conditions of the study site (Deytieux et al., 2016). Exploring the performances of each cropping practices on a wide range of production situations would have resulted in higher validity of the results.

However, the on-farm co-evaluation approach held in this study was relevant in the sense that it was tailored to the farmers' needs, and because empirical knowledge developed from farmers innovations are essential to the agroecological transition when they are adapted to the production situations (Le Cam, 2019). As described by Husson et al., in a study on an approach to participatory design of innovative cropping systems, cropping systems evaluation can be done in two successive loops: a first loop consists in evaluating the performances of the cropping systems in the farming situation using simple indicators, while a second loop based on randomized trials can increase understanding of the processes in innovative cropping systems (Husson et al., 2015). A second loop evaluation would thus be required in the project to (1) provide scientific references on the performances of innovative cropping practices, (2) identify the pre-requisites for implementing the cropping practices and to, (3) improve potential for adaptation and adoption among a wider range of farmers.

On the other hand, the shared evaluation between the farmer and the researcher appeared to be motivating for the farmers, since most participants highlighted that they appreciated the researcher visits in terms of frequency, length, purpose, and discussions; and that they felt accompanied and supported in the co-evaluation. Charles said: "The visits were nice and regular. I would have been less willing to participate if I would have had to carry everything on my own".

Some farmers especially enjoyed becoming farmers-researchers, and showed dedication in the evaluation process, as explained by Marie & Anthony: "We communicate on this, we spotlight the fact that we are farmers but that we also do tests in an approach of research and improvement, and that valorises the farm and our work". Interestingly, most farmers initiated other tests and experiments on their farm by themselves, using tools that were introduced to them through the research -e.g., observation, notes in the crop logbook, construction of experimental device-, as stated by Marie & Anthony: "We will try to be more rigorous and sometimes to compare different methods". Charles explained: “We have done a lot of experimentation [in the past] but without protocols and rigor. It helps to do it well”.

Above all, these results show that experiential learning and increased ability to implement changes resulted from the co-evaluation process, which merges the findings of Pret on a similar study, who concluded that on-farm experimentations were source of learning among farmers rather than robust research deliverables due to all inherent constraints of on-farm experimentations on small surface area (Pret, 2018b).Overall, drawing on these findings, research and development agencies should collaborate more with innovative farmers to (1) develop evaluation protocols for their innovation, (2) analyse the results, (3) compare the results, and (4) communicate on the results. Results of cropping practices evaluations along with description of the study sites should be made available to establish databases and compare performances of diverse cropping systems in diverse productions situations, and further guide the farmers in the transition.

5.5 Exchanges and mutual learning

Exchanges and mutual learning -i.e., learning from others- were identified as main benefits of the research for the participants. Linkages between the farmers provided (1) during the group meetings (*step 2: co-design of innovative cropping practices* and *step 5: final group meeting*), and (2) by the researcher through the frequent on-farm visits were appreciated by the participants and considered as ‘open-minding’. A strong feeling of being a part of a group emerged from the participants along the research, as explained by Marie & Anthony: “We always think *Maraîchage sur Sol Vivant*, I am on several Facebook groups, I always try to get information, to learn (…)”. The emulation and stimulation brought by a group of farmers sharing the same objective -to improve their soil- seemed to increase farmers’ motivations to learn and implement changes on their farming systems, as expressed by Maurice: “The stimulation, to know that someone tried this like this, and that he or she had these issues, or these results, and their analysis also, it is very interesting”. These findings highlight that learning and capacity building are key components of participatory approaches.

It appeared from both the participants and the researcher point of view that interactions with the researcher resulted in mutual learning because of the frequent on-farm visits resulting in enriching discussions on diverse topics -e.g., technics, agronomy, society, ecology. Indeed, mutual learning is characteristic of participatory action research in which the researcher teaches the research approach to the participants and brings knowledge to understand relationships in the variables of the project, while the participants provide knowledge accumulated from their experience on the field and relevant insights for data collection (Liu, 1997). It seems that the trust established early in the study, and notably during the participatory observation, initiated a human centred research that was beneficial to both the participants and the researcher, as expressed by Maurice: “I like the way you come to measure, it is like a laboratory for you (…), for me there is the presence of someone touching the soil as well, I mean it is way better than a simple spoken collaboration”. These characteristics made the collaboration particularly appreciated by both the researcher and the participants as articulated by Danielle: “It was unusual compared to all studies I have participated to, because of the organisation, and because of the human side and the collective aspects of the study: it was enriching”.

However, according to the farmers, exchanges should be accentuated through the project by increasing the frequency of gatherings and on-farm visits with the farmers group. The participants also suggested to increase linkages with (1) research and development, (2) extension services, and (3) different types of approaches to market gardening, as expressed by Claude: “For me, we need people who come from the production world, who don’t come from organic agriculture”. Inspiration and adaptation are important features in agricultural innovations, thus raising the need to bridge disciplines and approaches to develop innovative agroecological cropping systems. Indeed, the whole concept of the farmers group is based on farmers exchanges facilitated through meetings, farms visits, etc. However, due to the Covid-19 pandemic, these gatherings could not have been scheduled. In the future, a wider diversity of exchanges -e.g., training, farm visit, exchanges with extension services, interactions within the farmer group, group discussion of the results- should be facilitated to catalyse learning processes among farmers from a group. According to Husson et al., the learning processes at work in innovative farmers groups result from (1) the real-life situation, (2) linkages between cropping systems performances and actions taken by the farmers, (3) the diversity of knowledge of the participants, (4) linkages between theory and practice, explaining and justifying the innovative practices, (5) the organisation of the project, with successive steps having diverse implications (Husson et al., 2015).

During the final semi-structured interviews, all participants agreed that the project had made them reflect on their cropping and farming systems, which shows the relevance of the iterative process of research, reflection and action, characteristic of participatory action research, in agreement with Méndez et al. (Méndez et al., 2017). However, most farmers admitted that the outcomes of the whole project were difficult to evaluate after only one year. When the final semi-structured interviews occurred (*step 4: on-farm co-evaluation of innovative cropping practices*), the results of the co-evaluation had not been analysed nor presented to the participants. The preliminary findings were presented during the final group meeting (*step 5: final group meeting*), on October 12th. A technical leaflet will be used to disseminate the output of the research project for the farmers group, and for other market gardeners interested by *Maraîchage sur Sol Vivant*. Jean hypothesized that the learning outcomes of the cropping practices co-evaluation would be especially beneficial to the market gardeners who did not participate in the study, suggesting that agricultural innovations appear in pilot farms and then disseminate to other farms. This phenomenon of innovation and dissemination has similar characteristics of ‘farmer innovation circles’, that Cross & Ampt define as the informal networks and mechanisms used by farmers for the development of innovative systems (Cross & Ampt, 2017). Drawing from the DATE model, learning outcomes of the approach could be further extended to external farmers by (1) evaluating the cropping practices in broader contexts, through randomized trials on multiple pilot farms, (2) evaluating conditions for adoptions (Husson et al., 2015).

5.6 Involvement

I observed active involvement from the participants along the research process. For instance, the research was initially designed for seven farms from the farmer group, but two other farms from the group contacted the organisation on their own initiative to participate in the research. During the soil sampling and soil visual assessment (*step 1: diagnosis of the initial situation*), most participants manifested their interest in the field, and participated on their own to the visual soil assessment with me. All farmers participated in the co-design workshop. When participation to an activity of the research process was not possible, such as for Danielle and Maurice who could not fully participate in the on-farm co-evaluation, farmers seemed to experience frustration, as expressed by Danielle: "My only deception is that I could not conduct the trial (…)”. Moreover, all participants expressed high interest in reading the research thesis and the technical leaflet, showing a common feeling of involvement among the participants. Participants displayed commitment to seek improvements, as shown by their initiative to set-up other trials on cropping practices in *Maraîchage sur Sol Vivant* on their farms. Overall, participants involvement seemed to be a pre-requisite to the success of this participatory action research. Indeed, since this research was human centred, most of the data was collected thanks to the participants whose involvement drove their willingness to spend time and energy providing data. I have also noticed that involvement could result in mental pressure for farmers who feel already busy with farming, commercializing, which is especially the case in market gardening. My task as a researcher lied thus in fostering participants involvement while making sure they did not feel mental pressure from the research project, as highlighted by Marie & Anthony: "[The researcher] knew how to put a little bit of pressure on but in a very pleasant way, we never felt like a black sheep, but we felt like we had to be serious".

Overall, participants involvement was stimulated during the participatory action research by (1) frequent on-farm visits, (2) frequent contacts with the farmers, (3) a clear definition of the participants roles at each stage of the research, (4) encouraging farmers' feedback along the research process, (5) adapting the research design for the participants, (6) building confidence with the participants and establishing mutual trust between the participants, and (7) researcher involvement. These features fit Barreteau's recommendations to avoid participants rejections and disappointments in participatory action research, such as to (1) clarify and express the process well ahead of any event and let it open for modification, (2) be flexible, so that the researcher and the participants can rethink and renew the process at different stages of the research, (3) include assessment of participants satisfaction and expectations at each interactive stage or event (Barreteau et al., 2010). Drawing from the final semi-structured interviews, it appeared that in practice, these characteristics of the research were well received by the participants.

Depending on the participatory action research, involvement can also be fostered through participants remuneration, which was not the case in this study because of a lack of funding. Since the study was designed to suit farmers' needs, services were provided to the participants alongside the research such as soil analysis, interpretation of soil analysis, answers to technical questions, etc. In light of the different classification of participation in participatory action research presented by Cuéllar-Padilla & Calle-Collado, it seems that the level of participation in this study can be characterized as interactive, so that the development of the research analysis and process were done jointly with the participants (Cuéllar-Padilla & Calle-Collado, 2011). This level of participation along with supported participation and self-mobilization were promoted by Cuéllar-Padilla & Calle-Collado for participatory action research in agroecology, while participation through material incentives was discouraged because it would "establish inequal exchanges, and discourage interaction between people and research teams" (Cuéllar-Padilla & Calle-Collado, 2011). Even though I agree that higher ownership from the participants encourages initiatives and concrete changes, I argue that future participatory action research should provide a financial compensation (when possible) when research work is provided by the participants. I hypothesized that higher recognition of farmers' role in developing agroecological cropping systems would catalyse farmers innovations.

5.7 My role as a researcher/facilitator

My task as a researcher was to combine two different and interrelated activities: (1) the research activities, and (2) the group facilitation, i.e., the 'case development'. Research activities mainly included (1) research design, (2) data collection, (3) data analysis, (4) academic reading and writing. These activities required high rigour to ensure validity, -i.e., to identify appropriate data collection methods and show when and how the research findings can be generalized (Yin, 2017)-, and relevance of the research, so that the findings answer identified knowledge gaps and practical needs. Facilitation activities articulated around (1) organising group activities, meetings -e.g., schedule, agenda, notes, reports, guiding discussions-, (2) connecting farmers within the group, and with external resources -e.g., contact persons, tools, literature-, (3) guiding the farmers in their transition. These activities required high communication skills, adaptation, and open-mindedness in order to establish trust and collaboration with the group of farmers. These findings were supported by several studies that have described the facilitator role and documented its importance for (1) accompanying the reflection, (2) guiding the process of the activities, (3) fostering trust, exchange, and conviviality (Aubertot et al., 2018; Bayot et al., 2008; Pret, 2018b; Vaarst et al., 2007).

The combination of the two roles was challenging for me because I had to (re)define my role and the purpose of the data collected at each stage of the process. The reflections on this twofold role were recorded weekly in a logbook. As pointed out by Richer, "action research, in addition to resolve dysfunctions, develops the researcher reflexivity which is a component of professionalism" (Richer, 2011). My learning experience as a researcher/facilitator was profound and diverse, and included learning on: (1) *Maraîchage sur Sol Vivant*, (2) cropping and farming systems in market gardening, (3) group dynamics, (4) dynamics of changes, (5) farmers' learning, and (6) research and development in agroecology, all essential to me as an agroecologist.

My role as a researcher/facilitator was well received by the participants. The collaboration grew organically depending on the farmers' needs and personalities. The trust required in both participatory action research and farmer groups (Aubertot et al., 2018; Bayot et al., 2008; Pret, 2018b; Vaarst et al., 2007) was gradually established with farmers while spending time discussing and going in the field together.

It must be emphasized that, as embedded in a participatory action research, combining group facilitation with research appeared to be especially relevant and adapted to both ensure participation and accompany changes on the ground. Indeed, this shift of the researcher role towards facilitation has been reported in several participatory action research (Cuéllar-Padilla & Calle-Collado, 2011; Méndez et al., 2017; Pret, 2018a). As explained by Richer in action research, the researcher steps back along the research process, so that space is made for participants ownership and capacity building (Richer, 2011).

5.8 Implications for further research and practice

Practical suggestions can be drawn from this study to guide future research and practice on co-design and co-evaluation of innovative cropping practices in farmers groups. It appeared from the characteristics of the co-design and co-evaluation methodology presented in this study that future workshops to design innovative cropping practices within a group of farmers should be articulated around interrelated activities that include: (1) understanding the case and the target of the co-design, (2) knowledge sharing, (3) individual reflection, (4) restitution through group discussions. Emphasis should be put on precisely defining the targets of the workshop within their context, so that they are understood by all participants. In co-design workshops, the facilitator tasks are essential and should include: (1) to clearly explain the process and the participants role, (2) to guide the participants toward the discussion, ensuring focus is kept on the case, (3) to direct the workshop and keep the schedule, and (4) to send reports to the participants. The facilitator profile, such as the group dynamics create the condition for success in these types of workshops.

The importance of the workshop preparation was stressed in this study, showing that co-design workshops should be structured around individual cases carefully selected to fit the co-design pre-requisites, so that the participants are willing to implement simultaneous changes in their cropping and farming systems. Moreover, relevant information should be collected on the cases beforehand to (1) identify the context and the problem areas, and thus ensure the relevance of the process for each case, (2) identify the most promising and adapted systems among the group of farmers to direct the discussions. All relevant data collected on the case -e.g., pictures, economic data, soil analysis- should be presented to the participants during the workshop or prior to the workshop. Care should be taken when preparing the workshop schedule so that enough time is dedicated for each case and for each activity. Depending on the target of the co-design and on the aim of the project in which it is embedded, co-design workshops could take longer than described in this study and could be scheduled frequently along a period. Follow-up from the structure organising the workshop is required in order to accompany the participants in implementing the changes in the cropping or farming systems. The follow-up can range from simple contacts with the participants such as phone calls, to meetings, diagnosis, and evaluation of the changes. As explained by Meynard et al., improvements in the cropping practices are more likely to occur when the "design initiate a process of continuous improvement based on iterative process" (Meynard et al., 2012). It must also be highlighted that participants selection is likely to impact the outcomes of co-design workshops and should be adapted to the objectives of the co-design workshop. Participants can include: (1) farmers from the group, (2) farmers external to the group with different perspectives, (3) experts, trainers or advisors, and any extension agent carefully chosen to answer the farmer's needs, (4) a facilitator, and (5) other stakeholders susceptible of raising relevant points or sharing relevant knowledge. Having more participants would increase potentials for bridging experiences and knowledge, and thus, to use both local and scientific knowledge for the design.

Participatory evaluations of on-farm innovations have been poorly documented. Drawing from the results of this one-year co-evaluation of innovative cropping practices, several suggestions can be developed for future research and practice. The process and the methods of the co-evaluation should be adapted to the participants to ensure data collection, so that they fit the participants schedule, availability, and degree of involvement. The time and resources required from the participants for the evaluation should be reduced to the minimum. Protocols for the evaluation should be as simple as possible so that they can be applied in any situation. Emphasise should be put on choosing the adequate mean for recording farmers observations and measures, and if necessary, diverse means should be suggested to fit each participants preference. For instance, data can be recorded by the farmers in crop logbooks, smartphones, or pre-filled sheets. Depending on the objectives -and constraints- of the on-farm evaluation, the evaluation length and the study sites should be defined with the aim of increasing farmers' learning and ability to take decisions for their future cropping and farming systems. The results of the on-farm evaluations should be analysed and presented to the participants, during meetings and through technical leaflets for example. Simple indicators of success should be chosen to ease the analysis and interpretation of the results. Particularly, care should be taken when constructing the indicators, choosing reference values and aggregation methods to keep the transparency and the action-oriented feature of the indicators. Results should be discussed among the farmer group, with the researcher and an extension agent to open perspectives for further improvements. This group discussion enables to assess the outcomes of the actions taken and understand the processes underpinning the results.

The diffusion of the results of the co-evaluation was not addressed in this study but should be part of the overall framework in order to increase the scope of the co-design and co-evaluation. However, care should be taken when generalizing the findings of on-farm evaluations due to site-specific factors that impact the results. Second loops of evaluation based on multi-sites randomized trials are suitable to increase the validity of the cropping practices co-evaluations to a broader range of situations. Moreover, factors of adoption of innovative cropping practices should be identified to improve their potentials for wider diffusion (Husson et al., 2015).

Above all, a main take away from this study is that adaptation of the research to the participants needs and to the broader context are pre-requisites in participatory action research. This ensures relevance of the findings for both the users and researchers. Participants active involvement is a pre-requisite in co-design and co-evaluation studies, and must be targeted in the research design, and stimulated by the researcher who shifts toward a facilitator role. Indeed, this research has shown to increase mutual and experiential learning and farmer’s ability to implement changes. Overall, even though the overall methodology to co-design and co-evaluate innovative cropping practices among a group of farmers presented in this study has been shown to work well in practice, it must be reminded that future project will have specific features, and thus their design and management should be carefully adapted to the participants and to the context.

Conclusion

This is the first study that has focused on *Maraîchage sur Sol Vivant*. The study has given a holistic view of this farmer-led movement that gathers French market gardeners who place soil at heart of their cropping systems. This case study has identified farmers motivations, sources of inspirations and learning processes that shed light on farmers' engagement in *Maraîchage sur Sol Vivant.* The market gardeners shared similar objectives regarding their cropping systems -i.e., to increase soil health, crop health, work convenience- and their values were aligned around strong social and environmental considerations. They engaged in the agroecological transition through a bottom-up approach, so that the design and management of their cropping systems resulted from farmers exchanges and mutual support. They create and share knowledge through social and experiential learning, thus creating a common culture based on similar objectives, aligned values, common knowledge and inspiration sources. Thus, their cropping systems were based on local innovations and adaptations of agroecological principles. The findings highlighted five cropping practices characteristics of the cropping systems on the nine MSV-farms in Drôme-Ardèche: (1) reduced tillage, (2) organic matter additions and mulches, (3) green manure, (4) plastic covers, and (5) prophylactic management. The combination of these cropping practices targets diverse functions such as (1) soil protection, (2) soil regeneration, (3) crop health, and (4) work convenience. The market gardeners faced challenges in the implementation of the MSV-cropping practices such as: (1) reduced soil warming, (2) weed control, (3) green manure termination, (4) water management, (5) fertilisation, (6) access to adapted equipment, (7) access to organic materials of good quality, (8) plastic consumption, and (9) proliferation of slugs and voles. Therefore, future research should assess the sustainability of MSV-cropping systems and provide better understanding of the mechanisms at work in *Maraîchage sur Sol Vivant*.

The participatory action research methodology based on co-design and co-evaluation of cropping practices has answered farmers' needs, allowing for shared interest in the research between both science and practice. Drawing from the participants point of view, the convenience of the methodology was a pre-requisite for their participation due to (1) the schedule, (2) the flexibility, and (3) the level of organisation, as well as (4) the transparency and clarity of the process. Overall, participants active involvement has shown to be crucial for the success of this research project, and thus must be targeted in future participatory action research and stimulated by the researcher who shifts toward a facilitator role. The results of the-co-evaluation of the innovative cropping practices has shown to increase farmers' mutual and experiential learning and their ability to implement changes. This process initiated and fed a cycle of innovations through an iterative process of research, reflection, and action, that characterizes participatory action research (Méndez et al., 2013). Unlike in an experimental design, the results of the on-farm evaluations were not of good validity and robustness for research due to the inherent constraints of on-farm experimentation and single site studies. However, it revealed that there is a need to conduct scientific experiments on cropping systems and practices in *Maraîchage sur Sol Vivant*. Like the DATE approach (Husson et al., 2015), co-design and co-evaluation methodologies should be followed by multi-sites randomized-trials in order to (1) provide scientific references on the performances of innovative cropping practices, (2) identify the pre-requisites for implementing the cropping practices, and (3) improve potential for adaptation and adoption among a wider range of farmers. Efforts should be made by extension agencies to up-scale *Maraîchage sur Sol Vivant* and accompany farmers in the agroecological transition by (1) facilitating farmers access to adequate resources such as organic materials and agricultural equipment, (2) catalysing exchanges among farmers, and (3) increasing linkages between science and practice. Overall, the diversity of cropping practices implemented on the farms showed that, as embedded in an agroecological paradigm, *Maraîchage sur Sol Vivant* is knowledge intensive and has high potential for adaptation to local constraints. It implies that instead of applying cropping techniques as recipes, (future) market gardeners in *Maraîchage sur Sol Vivant* should combine and adapt cropping practices according to their own objectives and context.

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APPENDIX 1: SIMILARITIES BETWEEN *MARAÎCHAGE SUR SOL VIVANT* AND ITS INSPIRATION SOURCES.

Legend: marks indicate characteristics that are at least partially shared between Maraîchage sur Sol Vivant and its inspiration sources.

	Conservation agriculture	**Bio-intensive organic farming**	**Permaculture**	**Natural agriculture**	**Maraîchage sur Sol Vivant**
Reduced tillage	x		x	x	x
Permanent seedbeds		x			x
Avoidance of mineral fertilisers and pesticides		x	x	x	x
Permanent soil organic cover (cover crops, mulches)	x	x	x	x	x
Crop diversity	x	x	x	x	x
Short supply chains		x	x	x	x
Low mechanisation		x	x	x	x
Low investment		x	x	x	x
Small surface area		x			x
Low dependency to external resources			x	x	x
Inspiration from natural ecosystems	x		x	x	x
Labour-intensive		x			x

APPENDIX 2: INTERVIEW GUIDE (*STEP 1: DIAGNOSIS OF THE INITIAL SITUATION*)

General information

- Surname, name:
- Address:
- E-mail address:
- Phone number:
- Year of installation:
- Legal status:
- Agricultural surface area:
- Cultivated surface area:
- Surface area rented:
- Surface area in property:
- Number of human work unit:
- Labels:
- Productions and activities:
- Commercialization modes (in % of production):
- Climate (describe climate specificities):
- Soil (describe soil specificities):
- Farm's history (describe the former use of the farm and major past events):
- Farmer's history (education, experiences, origins…):

Transition to *Maraîchage sur Sol Vivant*

- How did you get to know *Maraîchage sur Sol Vivant*, how did you learn and develop these cropping practices?
- What have been your main failures and successes when adopting cropping practices in *Maraîchage sur Sol Vivant*?
- What changes induced by the implementation of cropping practices in *Maraîchage sur Sol Vivant* (on equipment, work management, pests, etc.) on your farm have you observed?
- What are the main outcomes and challenges you expected when adopting cropping practices in *Maraîchage sur Sol Vivant*?
- What effects of cropping practices in *Maraîchage sur Sol Vivant* have you experienced on your farm (outcomes, challenges)?
- What questions are you asking yourself with regards to the evolution of your cropping practices in *Maraîchage sur Sol Vivant?*
- What synergies and tensions have you observed between cropping practices in *Maraîchage sur Sol Vivant* and existing practices on your farm (organic agriculture, animal traction…)?

Agronomy

- Describe one or two cropping systems that are representatives of your farm. Describe the crop rotation, tillage (type, depth), seedling method, soil management, weed management, green manures, cover crops (species, destruction modes) etc when possible.
- Describe your irrigation system (source, crops, modes)
- How much of your plants and seeds are produced on the farm (in %)?
- Greenhouses (number and surface area)
- Describe the equipment and tools you use for market gardening
- What type of organic matter do you use on the farm, how much each year, where do they come from and how much do they cost?
- How many varieties are cultivated on the farm? According to what criteria did you choose them?
- Which crops are the most sensitive to pests? How do you deal with them (pest management)?

- What are the main weed species present in the farm? How do you deal with them (weed management)?

Economy

- What are the benefits, subsidies, operation costs, fix expenses, staff expenses, gross margin of the farm in 2019?
- Do you think your farm is economically viable and robust?

Social

- What is your workload in average (in season, off season)? Detail for administrative activities, weeding, other production activities, commercialization, and harvest (in % of the total workload).
- How many holidays do you have each year?
- How many days do you spend in training each year?
- What tasks or activities do you like the best and the least in your job and why?
- How satisfied do you feel about your job?
- Are you accompanied by extension services?
- What are the values you align with and put in practice in your work?
- How do you envision your ideal farm? What would your farm look like in your dream?
- What are the objectives you are trying to achieve with your activity on the farm?

Cropping practices design

- What objectives should be achieved by the new cropping system?
- What are the specificities and constraints to which the cropping practices should be adapted for?
- On which plot and crop would you like to set up and test new cropping practices this year?
- What was the initial cropping system in this plot/for this crop?
- What do you think about this research project? What are your expectations?

APPENDIX 3: FACILITATOR GUIDE (*STEP 2: CO-DESIGN OF INNOVATIVE CROPPING PRACTICES*)

Purpose of the workshop: To gather the market gardeners that participate to the research in order to co-design innovative cropping practices adapted to each farm.

Objectives of the workshop:

1. To share technical and agronomic knowledge on cropping practices in *Maraîchage sur Sol Vivant*
2. To start a collective reflection on the cropping systems in *Maraîchage sur Sol Vivant*
3. To gather ideas and technical solutions from the group of farmers for each case

Process of the workshop:

1. **Explanation of the process and roles**. Remind how the workshop fits within the research project, explain the rules and the process of the workshop (10 min).

Facilitator role:

-Explanation of the workshop: We will work on a concrete situation specific to each farmer. Each farmer will alternately take the central position while the others will reflect and use their knowledge and experiences to help the farmer in central position. For each situation, I will present the current cropping practices characterizing the farm and the objectives and constraints for the development of the new cropping practices. A time will be dedicated for you to share your knowledge and experiences related to the topic. It is also the opportunity for you to ask specific (agronomic, techniquel) questions to the trainer/adviser. Finally, 5 min will be dedicated to reflecting individually and writing technical solutions on a note. We will then explain these solutions and past them on the poster dedicated to the farm.

-Explanation of the attitudes and modes of expression: kindness, active listening, non-judgement, empathy, decentration. The farmers are the first to contribute to the discussion, followed by the trainer/adviser. The facilitator makes sure that the group explores ambitious and innovative solutions without sticking to the current situation nor on the feasibility of the solutions. Avoid lengthy monologues, or detailed descriptions of the current cropping practices.

Participants role:

Your task as a participant is to bring your knowledge and experience to inspire and help others to re-think their cropping practices without dictating cropping practices. You are invited to take part to the discussion at ANY TIME, and you should not hesitate to question the farmer in central position for a better understanding of the situation. Please, stay focus on the situation of the farmer in central position. No censorship or self-censure. Do not hesitate to get off the beaten tracks. Avoid judgement. The farmer in central position should show active listening with the propositions and he or she is invited to take notes of the suggestions that have been made.

Trainer/adviser role:

The trainer/adviser will act as any other participant during the workshop, but after the farmers have already expressed their opinions and suggestions. It is very important to facilitate reflection, discussion and knowledge sharing from the farmers themselves. The trainer/adviser is in charge of answering specific questions raised by the farmers.

2. **Brief presentation of the current cropping practices characterizing the farming system** (PPT presented by the facilitator, with diagram and photos) 5 min
3. **Definition of the target of the new cropping practices to be designed and clarification of the objectives** (PPT presented by the facilitator, with objectives and constraints) 5 min
    - Why had the objectives not been reached with the current cropping practices?
    - What were the problems encountered?
4. **Knowledge sharing on the topic** 10 min
    - What are the pre-requisites for the new cropping practices to reach the objectives?
    - Has someone already experienced a similar situation? How did he/she overcome the challenge? The facilitator can invite some farmers to share their experience.
5. **Brainstorming** on technical solutions and innovations to achieve the objectives. 5 min individual reflection, 10 min collective restitution. Brief synthesis of the solutions suggested.
    - Individual reflection question: 'What cropping practices could help reaching the objectives?'
    - Restitution: 'What are the links between the cropping practices suggested and the objectives?'

Appendix 4: Facilitator guide (*Step 3: Collaborative creation of the co-evaluation process*)

Purpose of the visit: To be ready for the growing season and for the on-farm co-evaluation

Objectives:

1. To interpret the results of the soil analysis with the farmer
2. To define the cropping practices to be implemented on the chosen crop/plot.
3. To define and schedule the on-farm co-evaluation

Process (3h) :

1. Discuss the results of the soil analysis (30-45min): explain different values, their meaning, interpretation regarding soil functioning and cropping practices, answer the farmer's questions.
2. Discuss the cropping practices (30-45min): 'after reflecting on what has been said at the workshop, what did you came back with and why?'
    a. Seeding date/time
    b. Density, spacing
    c. Seedbed dimensions, number of rows
    d. Varieties
    e. Fertilisation
    f. Cover crop
    g. Plastic covers
    h. Mulch (material, time of application, depth)
    i. Crop health management (phytosanitary treatments and prophylaxis)
    j. Weeding management
    k. Harvest (scheduled time, harvest method)
3. Discuss the experimental device (1h):
    a. Would you like to test different modalities? Define the cropping practices for each modality tested
    b. What would be the 'usual' modality? Define the cropping practices for the 'usual' modality
    c. Present the table of indicators of performances: 'what do you think about it?', "do you think it feasible to collect this data?'?
    d. Define the schedule to be followed by the farmer and by the organisation for the on-farm co-evaluation
    e. Explain the evaluation protocols and how to use the crop logbook
4. Synthesis of the next steps (10min)

Appendix 5: Example of an experimental device sheet

Crop: onion

Objectives:

- To identify the advantages and limits of two mulches (compost and hay) compared to bare soil.

Question:

- Which mulch is the most adapted?
- What are the advantages and limits of each mulch type compared to bare soil?

Hypothesis:

- Onions would grow better on hay.
- Higher workload for onions plantation on hay
- Better quality of the onions on hay
- Lower weeding requirements on hay
- The compost that has been applied late in the season could create nitrogen immobilization and impact crop growth

Experimental device:

- 1 seedbed with hay mulch ($75m^2$)
- 1 seedbed with compost mulch ($75m^2$)
- 1 seedbed without mulch (bare soil) ($75m^2$)

Schedule of the next visits:

- Organic matter decomposition evaluation (tea-bags removal) between 20th and 30th of July
- Sugar content evaluation (brix) during the harvest (from August)
- Final interview in September

Memo:

- Crop health evaluation (notebook)
- To note on the notebook any intervention on the crop, the date, and the working time.
- To weight the harvests separately for each modality
- Do not hesitate to take pictures or note any other information

Appendix 6: Set of indicators and calculation methods (*step 4: on-farm co-evaluation of innovative cropping practices*)

Set of indicators

The co-designed innovative cropping practices in *Maraîchage sur Sol* Vivant –'test' modality- and the usual practices -'usual' modality'- were implemented and evaluated during the growing season by both the participants and the researcher (from April to November 2020; *step 4: on-farm co-evaluation of innovative cropping practices*), using a set of agri-environmental and socioeconomic indicators (**table 1**), discussed with the farmer prior to data collection *(step 3: collaborative creation of the co-evaluation process*). The data was collected using simple protocols (**appendix 7 and 8**) that allow quantitative estimation of empirical observations.

Table 1: Set of agri-environmental and socioeconomic indicators calculated for the evaluation of the performances of the innovative agroecological practices.

Criteria	Indicator	Measure unit	Data collection method
Agronomic performances			
Crop production	Crop yield	Kg product/100m²	Crop logbook (farmer)
	Product quality	% sellable products	
	Sugar content	% brix	Measure (researcher)
Crop health	Crop health	Farmer's estimation of crop health (weeds, diseases, pests; /10)	Assessed with the farmer during the final semi-structured interview
Environmental performances			
Pesticide usage	Treatment frequency index	Number of doses of pesticide applied	Crop logbook (farmer)
Nitrogen	Residual nitrogen	Kg $N0_3^-$-NH_4^+/ha	Measure (researcher)
Soil quality	Humus balance	t humus/ha	Crop logbook (farmer)
	organic matter decomposition		Measure (researcher)
Economic performances			
Crop profitability	Income from crop sales	€/100m²	Assessed with the farmer during the final semi-structured interview
	Operation costs	€/100m²	
	Gross margin	€/100m²	
Social performances			
Social aspects at the farm level	Workload	Number of working hours for crop management (soil preparation, weeding, harvest) in hours/100m²	Assessed with the farmer during the final semi-structured interview
	Work convenience	Farmer's estimation of work convenience (/10)	
	Integration in the farming system	Farmer's estimation of work feasibility (/10)	

The visual soil assessment score (Shepherd, 2008) carried out during *step 1: diagnosis of the initial situation* was not included in the indicators of performances because the indicator is not sensitive to the changes induced by the cropping practices after only one year. Water consumption did not figure as an indicator of performances because irrigation can significantly change from one seedbed to another.

Indicators calculations

Crop yield

$$Crop\ yields\ (kg/100m^2) = \frac{\sum harvested\ products\ (kg)}{Plot\ surface\ area\ including\ foot\ passes\ (m^2)} \times 100$$

Product quality

Farmers used their own criteria to determine whether their products were sellable or not.

$$Product\ quality\ (\%) = \frac{\sum sellable\ products\ (kg)}{\sum harvested\ products\ (kg)} \times 100$$

Sugar content

Sugar contents of the products were measured by the researcher on the product -root, fruit, leaf- using a refractometer to test the quality of fruits and vegetables (Harrill, 1998). The refractometer is a device that measures light refraction in a solid or liquid depending on the content of this solid or liquid. Thus, the refractometer expresses the dry matter content and indicates the sugar content in % Brix - sugar content is higher with higher dry matter content. This measure enables evaluation of product quality, photosynthesis activity or plant health (Andersen, 2007).

Five ripe vegetables were harvested by the end of the morning on each modality –'test' and 'usual'- from which a juice was extracted and measured with the refractometer (Harrill, 1998; Production, 2020). The sugar content mean was then calculated on the five products.

Crop health

Crop health -weeds, diseases, pests- were estimated by the farmer and the researcher in the final semi-structured interviews by ranking the average crop health from the growing season on a scale from 1 to 10, 10 being the best performance -i.e., very healthy crop. To support the estimation, farmers were encouraged to observe and note in their crop logbooks the crop health state -at least before weeding or before spraying- using a simplified protocol (**appendix 7**). The researcher also assessed the crop health state during its visits, using the same protocol.

Treatment frequency index

All treatments applied to the study crop were recorded by the farmers in their crop logbooks - nature, rate, application date. Subsequently, treatment frequency indexes were calculated for all pesticides -i.e., pesticide usage. Higher indexes show more intensive use of pesticides.

$$Treatment\ frequency\ index = \frac{\sum doses\ of\ pesticides\ applied\ on\ the\ crop}{\sum standard\ doses\ of\ the\ pesticides}$$

Residual nitrogen

Residual nitrogen was measured at the end of the growing season (between 15th September and 2nd October). Soil samples were taken at 20 cm depth and sent to a laboratory for NO_3^- and NH_4^+ analysis. Residual nitrogen was expressed in kg N/ha, as a sum of NO_3^- and NH_4^+.

Humus balance

Humus balances were calculated based on (1) the amount of fertilisers and organic material (organic amendments, crop residues, cover crop) applied to the soil during the season, (2) their iso-humic coefficient -K1-, and (3) the quantity of humus mineralized in the soil, that results from the humus mineralization coefficient, the weight of fine soil and soil organic matter content in soils, as indicated in the soil analysis results. A positive balance indicates practices that accumulate soil humus -building soil fertility-, while a negative balance indicates depleting practices -unsustainable for soil fertility.

$$Humus\ balance\ (t/ha) = \sum OM\ applied\ to\ the\ soil\ during\ the\ season\ (t/ha) \times K1 - weight\ of\ fine\ soil\ (t/ha) \times SOM\ (\%) \times\ K2$$

ORGANIC MATTER DECOMPOSITION

The indicator 'organic matter decomposition' was calculated using the teabag index method (Keuskamp et al., 2013) that measures decay rates of dead plant material using tea-bags (green tea and rooibos) as standard plant litter in plastic mesh bags buried into the soils for three months. Weight losses indicate stabilization rate -from the green tea that is easy to decompose- and initial decay rate of organic matter -from the rooibos that has a slower decay rate. Given these two parameters, the decomposition rate can be calculated, using a calculation sheet[1]. The decomposition rate depends on (1) environmental conditions (humidity, temperature, pH, nutrients contents), (2) chemical properties of the organic matter, and (3) abundance and diversity of decomposers. Thus, it can provide insights on the effects of cultivation operations on soil functioning (Keuskamp et al., 2013). Five tea bags of each type were marked, weighted, and buried at 8 cm depth by the end of April 2020 in each plot. The buried places were marked using bamboo sticks. After three months, the tea bags were dried for 48h at 70°C and weighted, and the calculation sheet was filled.

INCOME FROM CROP SALES

The income from the crop sales was calculated as follows:

$$Income\ from\ crop\ sales\ (€/100m^2) = yields\ of\ sellable\ products\ (kg/100m^2) \times selling\ price\ (€/kg)$$

OPERATION COSTS

All operation costs -e.g., seeds, plants, fertilisers, organic material, pesticides, irrigation water- were listed and estimated with the farmer during the last semi-structured interviews (*step 4: co-evaluation of innovative cropping practices*), using bills when necessary. Costs of machinery -e.g., tillage- was assessed using a national referential for calculating production costs in agriculture (France, 2018). Costs of water were calculated according to a cost of 0.07€/m^3. Labour costs were estimated according to the national cost of a minimum wage per hour (11.42€/hour)[2].

[1] For more information, see: http://www.teatime4science.org/method/stepwise-protocol/
[2] https://www.expert-comptable-tpe.fr/articles/cout-salaire-smic-charges-patronales/

$$Crop\ expenses\ (€/100m^2) = \sum costs\ of\ inputs\ (€/100m^2) + \sum costs\ of\ machinery\ (€/100m^2) + \sum costs\ of\ labour\ (€/100m^2)$$

Gross margin

The gross margin was calculated as follows:

$$Gross\ margin\ (€/100m^2) = Income\ from\ crop\ sales\ (€/100m^2) - crop\ expenses\ (€/100m^2)$$

The gross margin provides insights on the commercial benefits made on the crop and indicates the profitability of the cropping practices.

Workload

The farmers recorded the workload associated with each cultivation operation on each plot in the crop logbook. Workloads were recorded for (1) soil preparation -e.g., tillage, organic matter additions-, (2) seedling/planting, (3) weeding, (4) harvests, and (5) other activities -e.g., treatments. The total workload on each modality was thus calculated as follows:

$$Workload\ (\text{hours}/100\text{m}^2) = \sum worktimes\ due\ to\ each\ cultural\ intervention\ on\ the\ crop\ \ (hours) \times \frac{plot\ surface\ area\ including\ foot\ passes\ (m^2)}{100}$$

Work convenience

Work convenience is defined here as the beneficial outcome of cropping practices on work efficiency and farmer's work management, so that it decreases physical and mental work difficulties -e.g., painful postures, manual handling of loads, repetitive work, pressure, stress- and workload. It was evaluated by the farmer during the final semi-structured interviews (*step 4: co-evaluation of innovative cropping practices)* on a scale ranging from 1 to 10, 10 being the best performance -i.e., very convenient.

Integration in the farming system

The indicator 'integration in the farming system' referred to: (1) complexity in cropping practices implementation, (2) overlapping working peak with other farming activities, (3) availability of technical resources and materials, (4) the broader integration of the cropping practices in the existing farming system. Integration of the cropping practices in the farming system was estimated by the farmer during the final semi-structured interviews (*step 4: co-evaluation of innovative cropping practices*), on a scale ranging from 1 to 10, 10 the best score -i.e., cropping practices are very well integrated in the farming system. For both work convenience and integration in the farming system, farmers were asked to explain how they experienced the innovative cropping system.

The agri-environmental and socioeconomic performances of the cropping practices were discussed with the farmers during the final semi-structured interviews, and during the final group meeting (*step 5: final group meeting*). Notes and audio recordings were taken during the semi-structured interviews.

The overall timeline of the indicator's evaluation is presented in **figure 1**.

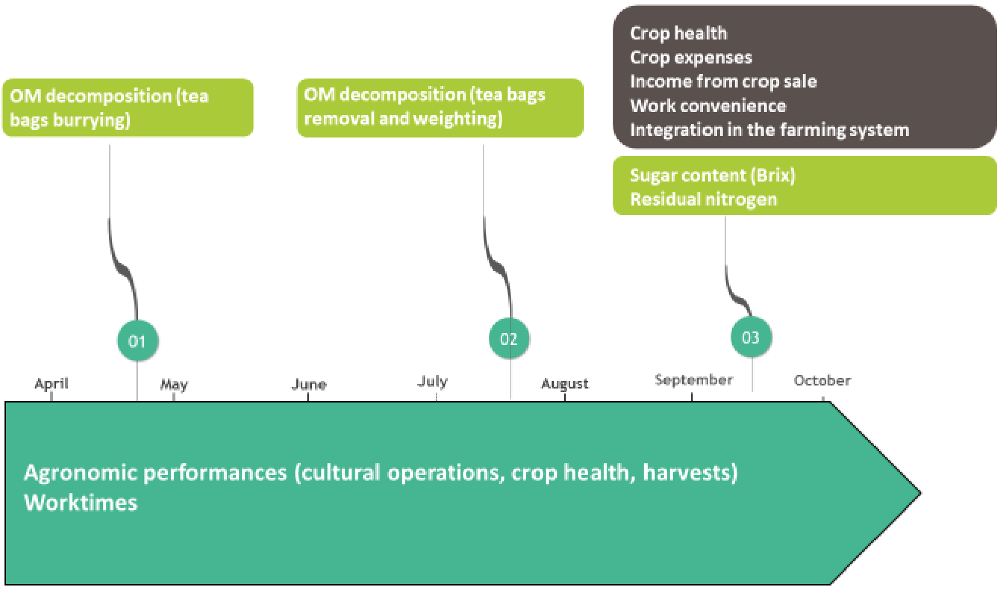


Figure 1: Timeline of the indicator's evaluation. Blue indicates data collected by the farmers in a crop logbook, green indicates data collected by the researcher by on-field measures, brown indicates data recorded during the final semi-structured interviews.

DATA ANALYSIS

The analysis of the indicators, as an embedded unit of analysis in the multiple case study, were meant to be a decision support to orient changes in the studied cropping and farming systems, as suggested in the participatory action research methodology (Méndez et al., 2013). Analysis of this sub-unit, unlike in an experimental design does not provide enough modalities, repetitions, accuracy of the measures, and suitable testing period to be of good validity and robustness. Thus, the data was analysed in an empirical way to enable a systemic study of the complex and innovative cropping systems. The indicators of the performances were compared in each case, for each modality - 'test' and 'usual'- and interpreted in light of the specific objectives of the test, as settled with the farmer during *Step 3: Collaborative creation of the co-evaluation process.*

APPENDIX 7: CO-EVALUATION PROTOCOL- FARMER VERSION (*STEP 4: ON-FARM CO-EVALUATION OF INNOVATIVE CROPPING PRACTICES*)

Cultivation operations

Protocol: note all cultivation operations carried on the crop on both modalities ('test' and 'usual' modalities) in details, as well as the date and the workload for each cultivation operation (see example).

List of cultivation operations to be recorded:

- Green manure management: note the seedling, the termination, and any other cultivation operation on the green manure.
- Occultation (plastic covers): note the date of occultation and the date of plastic cover removal
- Seedling: note the sowing date, the sowing rate and the variety sowed.
- Tillage: note each tillage operation, the type of tool used, and the soil depth tilled.
- Organic matter applications and fertilisation: note the applications of organic matter and fertilisers: type of organic material, quantity, mulch thickness.
- Pest management: note each addition beneficial organisms, crop health stimulating substance and treatments (herbicide, insecticide, fungicide). Specify the product used, the rate, and the surface area sprayed.
- Weeding: note weeding operations and the tool used.
- **Note the workload for each intervention**

Important: do not forget to note any differences between the 'usual' plot and the 'test' modalities! Please feel free to jot down any other helpful observations or questions you would like to discuss in the crop logbook.

Example:

Modality	Date	Cultivation operation	Details on the cultivation operation	Workload	Observations
Test	25/01	Occultation with plastic cover		30 min	Presence of weeds
Test	28/03	Plastic cover removal		30 min	Absence of weeds
Control	01/04	Cover-crop	2 passes (15 cm)	1h	Presence of weeds
Test and control	01/04	Input of organic fertiliser 'biovit'	10-1-1, 100kg/ha, incorporated with cover crop on the control plot	20min	

Production

<u>Protocol:</u> weight the harvests in each modality separately. Please note also the weights of the harvests considered as unsellable.

<u>Example:</u>

	'test' modality		*'control' modality*		*Observations*
Date	***Total weight of the harvest***	***Weight of unsellable products***	***Total weight of the harvest***	***Weight of unsellable products***	
22/07	*10kg*	*500g*	*12kg*	*400g*	Unsellable tomatoes had mildiou

Cover crop production

<u>Protocol:</u> Prior to cover crop termination, browse the whole plot and estimate the cover crop height:

Cover crop height	**Estimated production**
Ankle	1t DM/ha
Knee	3t DM/ha
Hip	5t DM/ha
Shoulders	10 t DM/ha

<u>Example:</u>

	'test' modality		*'control' modality*		*Observations*
Date	***Cover crop height***	***Estimated production (t DM/ha)***	***Cover crop height***	***Estimated production (t DM/ha)***	
05/05	*Hip*	*5t DM/ha*	*Hip*	*5t DM/ha*	*The cover crop is homogeneous and was blooming*

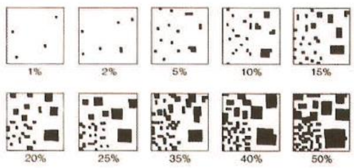
Crop health

Protocol: Observations are carried out prior to any weed or pest management operation; and if attacks, diseases, or weed germination are observed. For each observation, browse the plot and note the average health status separately for insect pests, diseases, and weed coverage. For each species, assess the severity of the symptoms and the weed coverage by estimating the percentage of plants affected or soil covered by weeds using the evaluation scale below. Do not hesitate to take pictures.

Evaluation scale:

Class of symptoms or weed coverage (in % of plants affected or soil covered by weeds):

- A: 0
- B: <1%
- C: 1-10%
- D: 10-20%
- E: 20-50%
- F: >50%



Pests/diseases/weeds repartition:

- Hom: Homogeneous
- Hét-G: Heterogeneous by gradient
- Hét-S: Heterogeneous by spots

Example:

Modality	***Date***	**Class of symptoms or weed coverage (A-F) per specie**	**Pests/diseases/weeds repartition *(Hom/Hét-G/Hét-S)***	***Observations***
Test and control	*05/05*	*C mildiou*	*Hét-T* *Hét-G*	See picture sent on 05/05

Appendix 8: Co-evaluation protocol- researcher version (*Step 4: On-farm co-evaluation of innovative cropping practices*)

Sugar content

Principle: the refractometer is a measuring device that determines the light refractive index from a solid or liquid matrix (example for water = 1.33 for air = 1). This index can be observed when light beam is deviating and depends on the nature of the environment in which it is propagated. The beam angle deviation depends on the concentration of soluble dry matter in the medium, the higher the concentration of soluble dry matter, the greater the refraction. A 25% brix means that there are 25 grams of soluble content (sugar) and 75 grams of water in 100 grams of solution. The sugar level (% BRIX) is used to evaluate photosynthetic functioning, plant health, fruit or vegetable quality. It can also provide indications relative to crop resistance to pests and stress.

Material:

- Knife
- Garlic press
- Refractometer
- Pipette
- Squeeze bottle of distilled water
- Protocol and evaluation sheet

Protocol**:** The measure should be done at the end of the morning if possible. Sample 5 products (fruit, leaf, or root, depending on the crop). Extract the juice from the leaves, fruits, or roots with a garlic press. Place one to two drops of the liquid on the refractometer. Wait one minute (until the liquid temperature is equal to that of the device) read the sugar level on the refractometer (expressed in brix). Note the date of the measure, the date of harvest of the products, the type of product tested, the modality, the cloud coverage, the brix rate, and the sharpness of the line.

Organic matter degradation

Material:

- 10 Lipton Green tea bags (EAN 87 10908 90359 5)
- 10 Rooibos tea-bag (EAN 87 22700 18843 8).
- An indelible black marker
- A scale
- A shovel
- 20 sticks

Protocol:

1. Mark the tea bags on the white side of the label with a permanent black marker.
2. Measure the weight of the tea bag. Take a scale with at least two digits (0.01). Three digits is better.
3. Bury both teabags in separate, 8 cm-deep holes, conservation agriculture 15cm apart. Keep the labels visible above the soil.
4. Mark the burial site with a stick.
5. Write down the date, shading of the soil (1-5, from none to completely), impact by humans (1-5, no impact to completely impacted), vegetation type and other experimental conditions of the site.
6. Recover the tea bags after approximately 90 days.
7. Remove adhering soil particles and dry the tea bags in a stove for 48h at 70°C (not warmer!).
8. Take the tea out of the bag, be careful not to lose any material.
9. Weigh the tea (0.01 or .001 g).

APPENDIX 9: INTERVIEW GUIDE (*STEP 4: ON-FARM CO-EVALUATION OF INNOVATIVE CROPPING PRACTICES*)

Purpose of the visit: to collect the last data from the co-evaluation and get farmers feedbacks on the research.

Objectives of the visit:

1. To collect all missing data for the farm sheets
2. To check the farm sheet with the farmer
3. To collect the data from the crop logbook
4. To collect (and check) all other data on the co-evaluation (socioeconomic data)
5. To draw first conclusions with the farmer on the co-evaluation
6. To evaluate the outcomes of the research on the participants (learning, involvement, benefits and limits of the methodology)

Material:

- Laptop with updated data base
- Smartphone (voice recording and camera)
- Updated and printed farm sheet
- List of missing data for the farm sheets
- Field material

Process:

1. Data collection on the field (2h)
    - Brix
    - Slake test
    - Visual Soil Assessment
    - Soil samples for residual Nitrogen
2. Ask missing data on farm sheets and check with the farmer (30min)
3. Collect data on the cropping practices evaluation (from the crop logbook + by asking the farmers) (30min)
    - Crop protection (dose, surface area, name of the product)
    - Fertilisation (fertilisation values, name of the product)
    - Water (irrigation flow, duration and frequency of irrigation, number of drips and sprinklers)
    - Crop profitability (product price, operation costs: seeds and plants, fertilisation, tillage passes, crop protection, small material, others)
    - Work convenience: ask the farmer to estimate the convenience of the cropping practices tested (1: inconvenient, 10: very convenient). Ask the farmer to explain. To evaluate work convenience, please consider following features: painful postures, manual manutention of weights, mechanical vibrations, usage of dangerous products, exposition to extreme weather conditions, noise, repetitive work.
    - Integration in the farming system: ask the farmer to estimate the integration of the cropping practices tested in the farming system (1: unfeasible, 10: very feasible). Ask the farmer to explain. To evaluate, please consider following features: cropping practices complexity, peak of work, availability and access to necessary resources and material, integration of the cropping practices in the whole farming system.
4. Discuss the results and start drawing conclusions with the farmer: "What conclusions can be drawn regarding agronomic performances, environmental performances and socioeconomic performances?",

“Would you implement these cropping practices again in the future? And why? » « Would you change anything on your cropping practices in the future?” (30min)

5. Evaluate the outcomes of the research on the participant (learning, involvement, benefits and limits of the methodology): “What did you think about the research project?”, “What were the benefits and limits of the research methodology?”, “Did the project change anything on your cropping practices? If yes, please explain”, “Did the project had any effect on anything else? If yes, please explain”, “What have you learned during the project? Do you remember something striking from the research project?”, “If the project was to be renewed, would you change something? What? And why?” (30min)

APPENDIX 10: FACILITATOR GUIDE (*STEP 5: FINAL GROUP MEETING*)

Purpose of the meeting: to present and discuss the preliminary findings of the on-farm co-evaluations

Objectives of the meeting:

1. To present the different farm studied (comparative visions of the farms)
2. To present the preliminary results of the cropping practices co-designed and co-evaluated on the farms
3. To discuss the perspectives regarding the cropping practices: modification, diffusion
4. To discuss the perspectives of the farmer group and of the research project

Process:

1. Coffee, tea (9h-9h30)
2. Presentation of the schedule, the farm sheets, the comparative study of the farms and the earthworms study (9h30-10h45)
3. 10h45-11h Coffee break
4. Presentation and discussion of the results of the cropping practices co-designed and co-evaluated on the farms (11h-12h30)
5. Lunch break (12h30-14h)
6. Presentation and discussion of the results of the cropping practices co-designed and co-evaluated on the farms (14h-16h)
7. 16h-16h15 Coffee break
8. 16h15-17h30 Presentation and discussion of the perspectives of the farmer group and of the research project
9. Give the farm sheets to the farmers

APPENDIX 11: CONSENT FORM

Information and participation to the research "Co-design and co-evaluation of cropping practices in *Maraîchage sur Sol Vivant*"

This document is to inform you about the research process and your participation to the research "Co-design and co-evaluation of cropping systems in *Maraîchage sur Sol Vivant*" that will be conducted this year until the end of October 2020 for the validation of the Master of Science in Agroecology (NMBU) of Amandine Faury.

Research questions and objectives
The objectives of the research are the following:

- To study cropping systems and innovative cropping practices in *Maraîchage sur Sol Vivant*
- To co-design cropping systems and innovative practices in *Maraîchage sur Sol Vivant*
- To evaluate cropping systems and innovative practices in *Maraîchage sur Sol Vivant* on a 'test' plot in each farm

This research will aim to answer these questions:

- What characterizes cropping systems and practices in *Maraîchage sur Sol Vivant?*
- What are the performances of innovative practices in *Maraîchage sur Sol Vivant?*
- How to co-design and co-evaluate cropping systems in *Maraîchage sur Sol Vivant?*

Research project, responsible and collaborators

The *Association Drômoise d'AgroForesterie* (ADAF) is responsible of the project. Amandine Faury, master student in agroecology (NMBU, Norway) is in charge of conducting the research. The project is developed in collaboration with researchers in agroecology from NMBU, SupAgro and ENSAT.

Participant selection

You have been selected to participate to this research because of your commitment into the GIEE MSV animated by ADAF, of your motivation regarding cropping practices in MSV, and because of your interest for the research project that has been designed with the hope to meet your expectations. The heterogeneity of your farming systems and practices in MSV as well as your locations are also assets for this research.

Your contact information and information regarding your farms have been get from ADAF via ASVIDA meetings, questionnaires, and farm visits.

Research process: activities to be noted in your agenda

- **Soil sampling (from 9th December to 17th December):** Soil samples will be taken on the studied plot for analysis of soil physical, biological and chemical properties (realised in laboratories KinseyAg in the USA and Celesta Lab in France). Data on the studied plot will be collected (previous crop, yields, next crop, history of last amendments, and if available, analysis of last organic material brought to the field), and visual soil assessment. These analyses will allow us to adapt your cropping systems and practices to your soil.

- **Participative work on the farm and interviews (from 17th December to 17th January):** In the morning, we will work together on the farm. The afternoon will be dedicated to the interview. The interview will last around three hours. I will ask questions on your cropping and farming systems and on your vision of *Maraîchage sur Sol Vivant.* With the data collected, I will make farm sheets and write a technical leaflet that will be used for discussion with the group and with other farmers in France.
- **Workshop "knowledge sharing, brainstorming on technical solutions to co-design innovative cropping practices" 21th January, during the training in MSV with François Mulet (20th-21th January):** you are invited to a co-design workshop to reflect with the farmers and François Mulet on the new cropping systems and cropping practices to implement and evaluate in 2020 in each farm. A time will be dedicated for discussion and brainstorming (techniques, tools, feedbacks on experiences…) on each of your situation. Your presence during this workshop is essential to initiate the co-evaluation in 2020.
- **Visit on your farm "collaborative creation of the co-evaluation process" (approximately 2h in February):** thanks to the soil analysis results, we will define together the new cropping practices to implement and the co-evaluation schedule.
- **On-farm co-evaluation:** In spring and summer, we will evaluate the performances of the tested cropping practices according to the schedule defined together in February. I will come several times on the farms during the growing season to measure indicators on the studied plot.
- **Final interview:** We will discuss the results of the on-farm co-evaluation and reflect on the research project.
- **Final meeting (autumn):** I will present the preliminary results of the research. A time will be dedicated to group discussions.

During the research, data will be collected through notes, questionnaires, photos, observations, and the interviews will be audio recorded so that I can keep track of our exchanges.

What does your participation involve?

Your participation to this research requires your presence at each of these activities (thanks for contacting me in case of impediment). Your participation is voluntary and independent of your involvement in the GIEE (you can decide to not participate to the research while being member of the GIEE). You can decide whenever you want to withdraw your participation to the research project without giving any reason. In this case, all data collected on you will be anonymized.

How will your data be used?

Your data will be saved in a data base and will be used to write my master's thesis and perhaps a scientific paper. I will also use your data to write a technical leaflet "MSV-farms" as well as for other events and activities organised by ADAF (GIEE meetings for instance). Your data could also be used in the case of a longer-term study, in this case you will be informed. Please let me know if you do not want your surname, name, location, and photos to be disclosed in these documents or if you have any other question or comments. All other personal information will be kept confidential.

Your rights:

As a research participant, you can:

- Access all data that was collected on you and ask for a copy
- Ask us to delete your data
- Ask us to correct collected data if they are not correct or complete

Contacts

You can contact me on ……….. or by email: amandine.faury@adaf26.org

Consent

I (participant's name and surname) give my consent to participate to the research "Co-design and co-evaluation of cropping practices in Maraîchage sur Sol Vivant" managed by ADAF for the master's thesis in agroecology of Amandine Faury.

☐ I acknowledge having been informed of the objectives of the research and how the data collected will be used.
I give my consent to participate in the research:
☐ I authorize the collection of data in the above-mentioned framework until the end of the research project (end of fall 2020)
☐ "I authorize the publication of my personal information (last name, first name, location, photos)
☐ "I authorize my information to be kept in the ADAF databases after the end of the project (for further studies)

Surname, name Date Signature

Appendix 12: Example of a farm sheet

Claude

« L'arrêt du travail du sol n'est possible qu'avec le mulch»

Informations generales

SAU : ha

Surface cultivée en maraîchage :

Installation :

Statut juridique :

Statut d'accès à la terre :

Fermage

Label : AB

Activités principales :

Maraîchage, arboriculture (installation)

Altitude : de 470 à 550m

Climat : Très exposée au vent du Nord. Ensoleillement important en été. Gelées tardives jusqu'à début avril.

Pluviométrie : ? mm

Température max : 40,3°C

Sols : argilocalcaires à forte rétention d'eau et à réchauffement lent.

Le maraicher

Auparavant entrepreneur en gestion de conflits, Claude s'est tourné vers le maraichage par son attrait par la complexité du métier de maraîcher, et pour le challenge à la fois au niveau agronomique et de la stratégie d'entreprise. Il a été maraîcher pendant 3 ans sur une ferme collective à la ferme de la Berthe dans la chartreuse. Issu d'un milieu agricole, il n'a pas de formation en agriculteur.

Historique de la ferme

En réponse à un appel à projet, Claude s'est installé sur une ancienne parcelle de luzerne, cultivée depuis 20 ans en grandes cultures (blé/luzerne) avec peu de restitution de MO.

Sources d'inspiration

Claude est autodidacte. Il s'est d'abord initié aux pratiques de MSV, en particulier la culture sur couche de compost à la ferme de la berthe où particulièrement adaptée aux contraintes mécaniques et topographiques (pente importante, rééssuyage lent). Il a été particulièrement influencé par un collègue qui a ramené la technique de culture sur mulch de compost du Brésil. Le mulch de compost permet de préserver le sol, conserver l'humidité et favoriser l'enracinement des légumes. Ils ont ensuite perfectionné la technique avec des bardages en bois le long des planches pour éviter l'enherbement. Il s'est beaucoup inspiré de lectures (J.M Fortier, guide pratique de la culture maraîchère de paris, Coleman, G.Domenec)

Ce qu'il recherche avec le MSV

- Améliorer la gestion du travail (gain en temps, flexibilité et confort)
- Améliorer la vie des sols, la fertilité
- Augmenter la production

Claude

Agronomie

Gestion de la fertilite

- Compost de déchets verts
- Fumier de chèvre
- Tourteaux de ricin ou kerrazote (minéralisation lente)
- Guanor (minéralisation rapide)

Gestion de l'enherbement

- Occultation bâche tissée
- Bardage des planches
- Enherbement des passe-pieds en graminées et trèfles
- Désherbage manuel et au toutilo

Gestion des maladies et ravageurs

- Filet (mouche du chou et de la carotte et protection contre le vent)
- Bassinage (3x/jour sous tunnels pour augmenter l'hydrométrie et favoriser les auxiliaires)
- Hôtels à insectes sous tunnels
- Traitement au soufre (oïdium)
- Traitement au cuivre (mildiou et cladosporiose sur tomates)
- Traitement au savon noir et HE d'orange douce (pucerons noirs)
- Bandes collantes (mouche du terreau)

Travail du sol

- Microculteur (incorporation des résidus d'engrais verts)

Irrigation

- Goutte à goutte systématique
- Aspersion sous serre

Varietes cultivees

Environ 70 choisies pour leur goût, vigueur, santé et productivité.

Engrais vert

Utilisation d'engrais verts (pois/trotical) en interculture

Son installation en MSV

A son installation, Claude a mis en place des planches permanentes de 0,75 x 25m bardées et recouvertes de 10 cm de compost de déchets verts, sans aucun travail du sol. Il a constaté que, malgré un temps de mise en place de 1 à 2h par planche (coût d'environ 60€), la culture sur mulch de compost permet de gagner en temps et en confort. L'enherbement est très faible du fait du stock semencier quasiment inexistant dans le compost, et le non-travail du sol est facilité. De plus la culture sur compost convient à toutes les cultures. Le sol est devenu meuble, riche en éléments nutritifs, et retient bien l'humidité. La population de vers de terre a été multipliée par deux depuis son installation grâce au non-travail du sol, à l'ajout de compost, et à la tonte des passe-pieds.

Oignons et laitues sur toile tissée (janvier)

Vue aérienne de la ferme avant plantation du verger

Turricules, témoins de l'activité des vers de terre (janvier)

Claude

Vue aerienne de la ferme

Perspectives

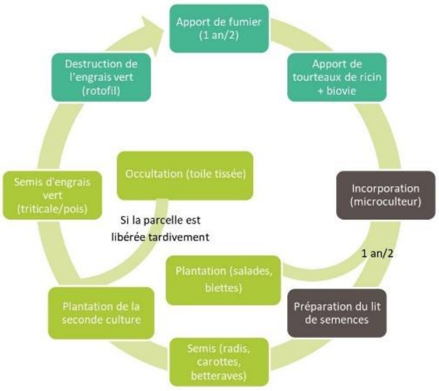
-s'associer avec Thibaut et former un GAEC.

-initier un projet collectif.

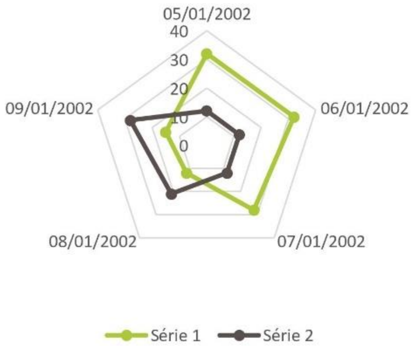
-développer les cultures extensives (pommes de terre, courges) avec des technique différentes.

-création de l'activité arboriculture (plantation de pêchers, figuiers, vigne ,pommier, poirier en 2020)

Systeme de culture



Vision comparative de la ferme



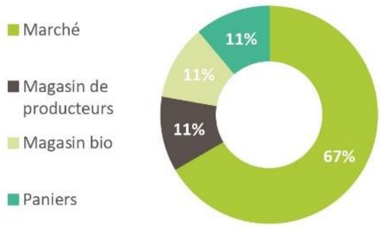
Plantation du verger (Janvier 2020)

Serre (Novembre 2019)

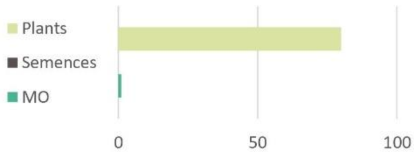
Claude

Socio-economie

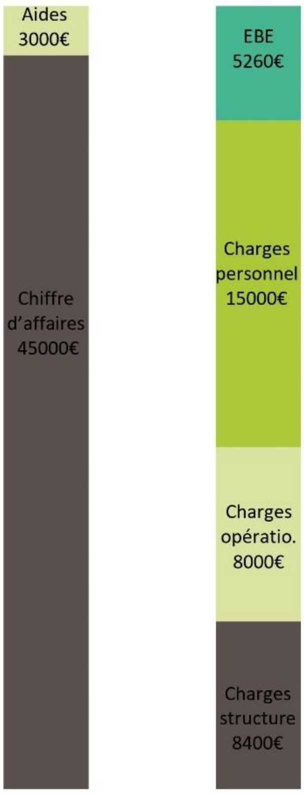
Commercialisation de mi-avril a novembre



Autonomie



Resultats economiques



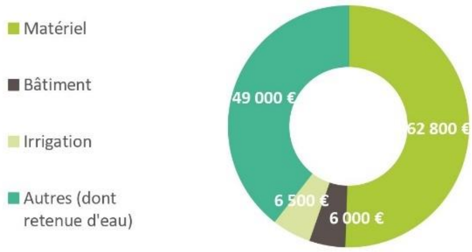
Equipements

- Microculteur (incorporation des EV)
- Semoir X
- Mélangeuse à mesclun X
- Epandeur de compost autoconstruit
- Toutilo
- Rotofil
- Tracteur Lamborghini 60CV
- Semtout
- Chariot à récolte

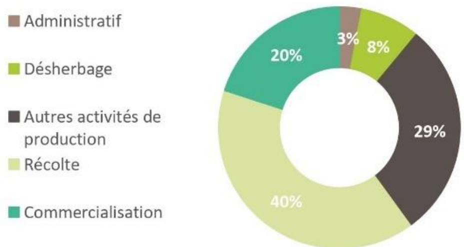

Mélangeuse à mesclun


Chariot à

Investissements



Repartition du temps de travail



- 30h/semaine en saison (mars-novembre)
- 8h/semaine en basse saison (décembre-février)
- **Temps passé en formation :** 0 jours/an
- **Nombre de jours de vacances :** 162/an
- **Niveau de satisfaction au travail :** ?/

Appendix 13: Case-study protocol

<table>
<tr><th>Gap of knowledge</th><th>Research questions</th><th colspan="2">Sub-research questions</th><th>Data collection method</th><th>Data analysis method</th></tr>
<tr><td rowspan="6">Characteristics of Maraîchage sur Sol Vivant: farmers motivation, sources of inspiration, learning processes and cropping practices</td><td rowspan="6">What characterizes Maraîchage sur Sol Vivant with regards to farmers motivation, sources of inspiration, learning processes and cropping practices?</td><td colspan="2">What are farmers motivations for converting to Maraîchage sur Sol Vivant?</td><td rowspan="6">Semi-structured interview, direct & participatory observations (logbook)</td><td rowspan="6">(1) case description, (2) qualitative content analysis, (3) pattern matching, (4) cross-case synthesis</td></tr>
<tr><td colspan="2">What has inspired Maraîchage sur Sol Vivant?</td></tr>
<tr><td colspan="2">From which learning processes have resulted on-farm implementations of Maraîchage sur Sol Vivant?</td></tr>
<tr><td colspan="2">What characterizes the cropping practices in Maraîchage sur Sol Vivant with regards to soil, weed, and pest management?</td></tr>
<tr><td colspan="2">What explains similarities and differences in cropping practices among the farms?</td></tr>
<tr><td colspan="2">What are the benefits and limits of the cropping practices in Maraîchage sur Sol Vivant?</td></tr>
<tr><td rowspan="2">Methodologies for co-design and co-evaluation of innovative cropping practices</td><td rowspan="2">What characterizes a research methodology based on co-design and co-evaluation of innovative cropping practices?</td><td rowspan="2">What are the results of the innovative practices co-evaluation?</td><td>What are the agri-environmental and socioeconomic performances of the innovative cropping practices in Maraîchage sur Sol Vivant co-evaluated on the farms?</td><td rowspan="2">Direct observations and measures from both the farmers (crop logbook) and the researcher, final semi-structured interviews</td><td rowspan="2">(1) empirical analysis: comparison of indicators of performances between the usual and the innovative cropping practices and (2) cross-cases synthesis</td></tr>
<tr><td>What conclusions can be drawn from the cropping practices co-evaluation with regards to practical improvements and broader adoption at the farm level?</td></tr>
</table>

		What are the steps of the co-design and co-evaluation methodology?	Direct and participatory observations (logbook), survey, initial and final semi-structured interviews	(1) pattern matching, (2) explanation building
		What was the participants points of view on the co-design and co-evaluation methodology?		
		What characterizes the exchanges and mutual learning between the actors?		
		What characterizes participants involvement?		
		What are the benefits and limits of the co-design and co-evaluation methodology?		
		What are the pre-requisites to co-design and co-evaluate innovative cropping systems?		

The embedded unit of analysis is shown in green. Detailed material and methods of this sub research question are presented in ***appendix 6*** *and the results in* ***appendix 16****.*

APPENDIX 14: STRUCTURE OF THE DATA ANALYSIS OF THE SEMI-STRUCTURED INTERVIEWS: TABLE OF THEMES AND CATEGORIES.

Themes	Categories	Number of farms/farmers	Farmers concerned
Cultivated acreage	Low (<1ha)	5	Maurice, Léa & Marc, Marie & Anthony, Danielle, Claude & Thomas
	Medium (1ha-3ha)	2	Charles, Jean
	High (>3ha)	2	Alex, Emile
AB	Label	8	Alex, Claude & Thomas, Charles, Danielle, Emile, Jean, Léa & Marc
	No label	1	Maurice
Year of installation	Recent (after 2017)	3	Claude & Thomas, Marie & Anthony, Maurice
	Elder (before 2017)	6	Alex, Charles, Danielle, Emile, Jean, Léa & Marc
Farmer's background	Reconversion	10	Claude & Thomas, Charles, Danielle, Jean, Léa & Marc, Marie & Anthony, Maurice
	Agricultural background	2	Alex, Emile
Farmer's studies	Studies in fields differing from agriculture	8	Claude & Thomas, Léa & Marc, Maurice, Anthony, Jean Danielle
	Studies in agriculture	4	Emile Alex Charles Marie
	BPREA	6	Léa, Thomas, Danielle, Maurice, Jean, AP
Farmer's previous experience in market gardening	Less than three years	10	Charles, Danielle, Jean, Léa & Marc, Marie & Anthony, Maurice, Claude & Thomas

	More than three years	2	Alex, Emile
Land access	Family farm	2	Alex, Emile
	Purchased	3	Charles, Léa & Marc, Marie & Anthony
	Rented	1	Danielle
	Collective project	3	Claude & TB, Jean, Maurice
Commercialization modes	Organic store	3	Charles, Marie & Anthony, Jean
	Organic producer store	4	Emile, Léa & M, Claude & Thomas, Jean
	Direct sales (CSA, markets, on farm)	9	Alex, Claude & Thomas, Charles, Danielle, Emile, Jean, Léa & Marc, Marie & Anthony, Maurice
	Local restaurant	3	Charles, Léa & M, Alex
	Half-wholesale	2	Alex, Emile
	Catering	1	Danielle
Products sold	Row products	All	
	Transformed products	2	Léa & M, Charles
Mechanization level	Non-mechanized	4	Claude & Thomas, Danielle, Marie & Anthony, Maurice
	Low	3	Charles, Jean, Léa & Marc

	High	2	Emile, Alex
Animal traction		2	Jean, Léa & Marc
Other production on the farm	Animal production	4	Maurice, Charles, Alex, Marie & Anthony
	Fruit and berries production	6	Charles, Emile, Léa & M, Claude & Thomas, Marie & Anthony, Danielle
	Market garden orchard	4	Charles, Emile, Marie & Anthony, Danielle
Crop diversity	High	all	
Motivations for conversion	Soil health	5	Alex, Claude, Emile, Jean, Léa & Marc
	Crop health	2	Claude, Emile
	Work convenience	3	Charles, Claude, Jean
	Values	6	Alex, Claude, Danielle, Léa & Marc, Marie & Anthony, Maurice
Transition	Installation in MSV	3	Claude, Marie & Anthony, Maurice
	The transition has been done through a step-by-step process	3	Danielle, Charles, Jean
	Farm currently in transition through a step-by-step process	3	Alex, Emile, Léa & Marc
Learning processes	Books	5	Alex, Charles, Claude, Danielle, Léa & Marc
	Trainings	7	Alex, Charles, Danielle, Emile, Léa & Marc, Jean, Marie & Anthony
	Network (market gardeners)	6	Alex, Charles, Emile, Léa & Marc, Jean, Maurice

	Inspiring figures	4	Charles, Danielle, Jean, Marie & Anthony
	Youtube videos	7	Alex, Charles, Danielle, Emile, Jean, Marie & Anthony, Maurice
	Seminars, conferences	2	Charles, Emile
	On-farm experiences: tests and observations	3	Charles, Claude & Thomas, Marie & Anthony
Inspiration sources	Biointensive organic farming	4	Alex, Charles, Claude & Thomas, Léa & Marc
	Organic agriculture	1	Alex
	Agroforestry	2	Alex, Emile
	Biodynamy	1	Léa & Marc
	Natural agriculture	1	Léa & Marc
	Permaculture	5	Alex, Danielle, Léa & Marc, Jean, Maurice
	Conservation agriculture	2	Alex, Danielle
Cropping practices	Soil Tillage	5	Alex, Charles, Emile, Léa & Marc, Marie & Anthony
	Cover crop and green manures	8	Alex, Charles, Claude & Thomas, Danielle, Emile, Jean, Léa & Marc, Maurice
	Relay cropping	3	Alex, Charles, Danielle
	Mulch	8	Charles, Claude & Thomas, Danielle, Emile, Jean, Léa & Marc, Marie & Anthony, Maurice

	Organic matter addition	9	Alex, Charles, Claude & Thomas, Danielle, Emile, Jean, Léa & Marc, Marie & Anthony, Maurice
	Fertilisation and biological activity stimulating substances	6	Alex, Claude & Thomas, Emile, Jean, Léa & Marc, Marie & Anthony
	Long crop rotation with annual or perennial cover crops	4	Charles, Claude & Thomas, Danielle, Emile
	High density	3	Charles, Claude & Thomas, Danielle
	Plantation on plastic covers	6	Claude & Thomas, Danielle, Emile, Jean, Léa & Marc, Marie & Anthony
	Occultation in between the crops (plastic covers)	8	Charles, Claude & Thomas, Danielle, Emile, Jean, Léa & Marc, Marie & Anthony, Maurice
	Mechanical weeding (hoeing)	2	Alex, Emile
	Manual weeding	9	Alex, Charles, Claude & Thomas, Danielle, Emile, Jean, Léa & Marc, Marie & Anthony, Maurice
	Crop rotation	6	Charles, Claude & Thomas, Danielle, Emile, Léa & Marc, Maurice
	Crop associations	1	Danielle
	Beneficial organisms protection	9	Alex, Charles, Claude & Thomas, Danielle, Emile, Jean, Léa & Marc, Marie & Anthony, Maurice
	Nets	7	Alex, Charles, Claude & Thomas, Jean, Léa & Marc, Marie & Anthony, Maurice
	Health stimulating substances	3	Danielle, Léa & Marc, Maurice
	Bio-regulating organisms inputs	2	Claude & Thomas, Emile,
	Organic treatments	9	Alex, Charles, Claude & Thomas, Danielle, Emile, Jean, Léa & Marc, Marie & Anthony, Maurice

APPENDIX 15: SURVEY QUESTIONNAIRE (*STEP 2: CO-DESIGN OF INNOVATIVE CROPPING PRACTICES*)

Satisfaction questionnaire for the workshop "knowledge sharing, brainstorming on technical solutions to co-design innovative cropping practices"

Surname, Name of the participant:

Did you like the workshop framework? (0 "not at all", 10 "absolutely")

0 1 2 3 4 5 6 7 8 9 10

Comments:

What objectives did you set yourself for this workshop?

Did you achieve them? (0 "not at all", 10 "absolutely")

0 1 2 3 4 5 6 7 8 9 10

Comments:

Have you developed agronomic knowledge during this workshop? (0 "not at all", 10 "absolutely")

0 1 2 3 4 5 6 7 8 9 10

Comments:

Have you developed technical knowledge during this workshop? (0 "not at all", 10 "absolutely")

0 1 2 3 4 5 6 7 8 9 10

Comments:

Did this workshop influence the way you envision one or more of your cropping practices? (0 "not at all", 10 "absolutely")

0 1 2 3 4 5 6 7 8 9 10

Comments:

What did you like the most during this workshop?

What would you change to improve this type of workshop?

APPENDIX 16: RESULTS OF THE CO-EVALUATION OF INNOVATIVE CROPPING PRACTICES IN SEVEN MSV-FARMS IN DRÔME-ARDÈCHE

This section presents an exploratory work realised on seven of the MSV-farms in Drôm-Ardèche that were not meant to be representative of farming systems in *Maraîchage sur Sol Vivant*. Thus, these data must be contextualized prior to drawing conclusions. For this reason, cropping systems descriptions inform the reader of the domain of validity of the results. For each case, the study site and the experimental device used for the experiment are presented, as well as the indicators of performances calculated on the cropping systems.

It must be reminded here the purpose of the co-evaluation. The innovative practices in *Maraîchage sur Sol Vivant* have been tested in-situ in small plots by the market gardeners in order to (1) test and adapt innovative practices prior to larger adoption in the farm, (2) answer some of the farmers' questions that arises from their shift in cropping practices in *Maraîchage sur Sol Vivant*. Thus, this section aims at presenting the performances of seven innovative cropping systems in *Maraîchage sur Sol Vivant* as the results of the co-design and co-evaluation that occurred with the group of MSV-farmers in Drôme-Ardèche.

5.2.1 GROWING GREEN BEANS ON COVER CROP RESIDUES IN NO-TILL

5.2.1.1 STUDY SITE (ALEX'S FARM)

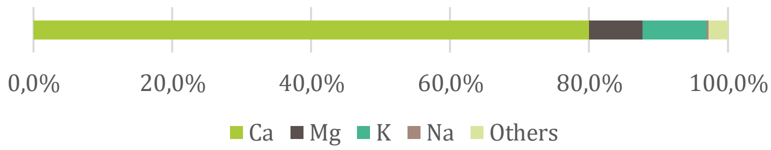
Alex's farm has a cultivated acreage of 20ha in vegetable production where 11 human working units are employed. The farm is characterized by a large surface area with a high mechanisation level. The farm's characteristics are presented in **table 3** (**§ 4.1**). No plough is practiced, and green manures (rye, vetch, fava bean, sorghum, mustard, phacelia) are cultivated during winter and in relay cropping -seedling during hoeing of the previous crop. Green manures are terminated using soil tillage methods -grinding and dethatching- prior to seedling or transplanting. Weeding is mostly ensured with manual and mechanical weeding -prior to crop cultivation, pyroweeding, hoeing-; and preventively with green manure cultivation. Fertilisation is based on manure (cattle, pig), chipped wood, green manure residues, and organic fertilisers.

Alex is currently in a transition process to *Maraîchage sur Sol Vivant,* with the aim of (1) reducing soil tillage, and (2) cultivating green manure in order to improve soil health and work convenience. A technical lockage in the transition is situated in the tension that exists between the high mechanisation level of the farm and cultivation methods on cover crop residues. Indeed, mechanical weeding -hoeing- is impeded by the presence of cover crop residues and conversely, mechanical weeding impedes cultivation on mulches.

Soil properties of the studied plot are presented in **table 1**.

Table 1: Soil properties in the studied plot (Alex's farm). The visual soil assessment (VSA) was carried out in the field in December 2019.

Bulk density (T/m^3)	1.35
Texture	Sandy
pH	8.6
%MO	2.3% including 1.3% of bounded organic matter
C/N of the MO	8.2

Microbial biomass (mg/kg)	258 High
Mineralization rate of humus (%)	4.7 Very high
Mineralization rate of soil nitrogen (%)	2.4 High
C.E.C (M.E)	12.88
Bases saturation on the CEC	
VSA score (/32)	22 Moderate

5.2.1.2 Experimental device

The purpose of the test was to implement and adapt techniques of direct seeding of large seeds crops in no-till, on cover crop residues. The objective was to compare the cultivation of green beans directly sowed on cover crop residues without any soil tillage -i.e., the innovative practice, named 'test'-, with green beans cultivated on bare and tilled soil -i.e., the usual practice, named 'usual'. Particularly, the test aimed at evaluating the effects of crop residues on seedling and weed management -pyroweeding, hoeing, manual weeding. The studied plot was made of two adjacent seedbeds of 90m² - 'usual' and 'test' modalities. Sorghum was previously cultivated on the plot as a summer green manure, followed by (1) fava bean as a winter green manure on the 'usual' modality and, by (2) phacelia and mustard as a green manure on the 'test' modality. The soil has not been ploughed for four years and was usually tilled with cultivators and hoeing in both modalities. The plot has been previously fertilised with organic fertilisers, and weed pressure was considered high with ryegrass, speedwell, and chickweed.

The cropping practices implemented and evaluated on the studied plot are presented in **table 2**.

Table 2: Cropping practices implemented on the 'test' and the 'usual' seedbeds of green beans.

Practice	'test'	'usual'
Green manure termination	Grinding (phacelia and mustard) x2	Grinding (fava bean)
Soil tillage	None	Cultivator
Fertilisation	Feather meal (625kg/ha)	
Seedling of green beans	After cover crop residues removal	
Mulch	Cover crop residues	None
Mechanical weeding	Hoeing (x2)	
Crop protection	None	
Irrigation	Sprinkling irrigation	

5.2.1.3 Results of performances of the cropping systems

The results of performances of the cropping systems are presented in **table 3**.

Table 3: Agri-environmental and socioeconomic indicators of the cropping practices on green beans. 'test' corresponds to no-till cultivation on cover crop residues, 'usual' corresponds to cultivation with soil tillage on bare soil. Bold letters show the best performance in between the tested modalities (no statistical test has been carried out).

	Indicator	Test	Usual
Agronomic performances	Yield (kg/100m²)	**17,8**	16,9
	Product quality (% of sellable products)	100	100
	Sugar content (Brix)	4,4	**4,6**
	Global crop health assessment score (/10)	5	**9**
Environmental performances	Residual N (kg NO_3^--NH_4^+/ha)	**20**	29
	Humus balance (t/ha)	**-2**	-2,3
Economic performances	Gross margin (€/100m²)	**-22.1**	-13.5
	Operation costs (€/100m²)	**146,4**	132
	Crop sales (€/100m²)	**124,4**	118,5
Social performances	Total workload (h/100m²)	3h26	**2h03**
	Work convenience (/10)	5	**10**
	Integration in the farming system (/10)	5	**10**

Green beans yields were higher in the test 'modality' compared to the 'usual' modality. However, harvests were null in one of the two line of green beans on the 'usual' seedbed. This can be due to external factors, therefore, no effect of the cropping practices on the crop yield can be concluded. No effect of the cropping practices can be concluded on product quality and sugar content neither.

Crop health was better in the 'usual' modality than in the 'test' modality because of weed coverage. Indeed, the green manure (phacelia and mustard) cultivated before the green beans did not grow rapidly enough to compete with weeds. It reached only 50cm high prior to termination. Moreover, mustard from the green manure regrew in the following crop. Indeed, the green manure was grinded at the end of phacelia blooming (25th May), but mustard was not blooming yet, so that it regenerated. The farmer also noticed that, prior to seedling, fleabane was growing on the 'test' seedbed, so that seedling conditions were not optimal -weeding should have been done prior to seedling. This highlights the flexibility required when managing cropping systems in *Maraîchage sur Sol Vivant*: if the technical lever -e.g., the green manure- is not sufficient to ensure a function -weed control-, the farmer needs to adapt the cropping systems to the constraints. This also highlights the need to design cropping systems where each function is ensured through different practices, so that the systems are more resilient and can adapt to new constraints.

Residual nitrogen was higher in the 'usual' modality. This can be explained by higher nitrogen inputs in the 'usual' modality because of (1) higher soil mineralization due to soil tillage, and (2) higher nitrogen inputs from fava bean residues than phacelia/mustard residues. It indicates higher potential of water contamination through run-off or leaching, especially if the soil is left bare over winter. Humus balances were negative in both modalities, so that both cropping systems have depleted soil humus because of low organic matter inputs. Indeed, fertilisation with feather meal does not increase soil humus, and the green manures cultivated -phacelia/mustard in the 'test' modality as well as the fava bean in the 'usual' modality- did not produce enough biomass -green manure production was estimated to be between 4 and 3t/ha respectively- to compensate losses due to soil mineralization. The humus balance was higher in the 'test' because the green manure produced more, and the residues of phacelia/mustard have higher humification potential -i.e., iso-humic coefficient K1.

Social performances were higher in the 'usual' modality because seedling and hoeing were easier on bare soil than on residues with the farmer's available equipment. The lower performance of the 'test' modality on work convenience was due to the mustard regrowth.

It can be concluded from this test that green manure management must be improved prior to broader adoption of direct seeding on cover crop residues by (1) delaying the cover crop termination, so it can produce more biomass and have more effects on weed control, (2) changing green manure species composition -e.g., to increase biomass production and soil coverage, to fit the termination period-, (3) changing green manure termination methods so that regrowth is impeded -e.g., by combining grinding with occultation, by choosing frost sensitive crops, by changing termination period. Moreover, an adequate material should be designed to facilitate seedling and hoeing on cover crop residues.

5.2.2 Growing onions on green waste compost or hay mulches

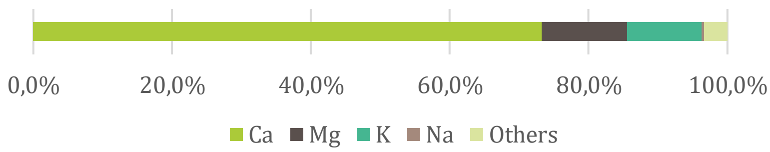
5.2.2.1 Study site (Charles's farm)

Charles's farm has a cultivated acreage of 2ha in vegetable production where 3 human working units are employed. The farm is characterized by a medium surface area with a low mechanisation level, combined with animal traction. The farm's characteristics are presented in **table 3**, **§ 4.1**. Soil tillage is reduced to ridging hoods and cultivators. Green manures are cultivated in between the commercial crops (phacelia, rye, vetch), and on half of the cultivated acreage (clover, alfalfa) -i.e., long crop rotation including annual or perennial cover crops. Green manures termination is ensured through rolling under the hay mulch, combined with occultation with black plastic covers -between two and four weeks. Weeding is mostly ensured preventively using (1) thick mulches of hay, (2) occultation with plastic covers, (3) long crop rotations including annual and perennial cover crops; and using (5) hoeing in animal traction, and (6) manual weeding. Fertilisation is based on manures (cattle, sheep, poultry), fresh grass (alfalfa or clover), green manure residues, and hay.

Set up in 2007, the farm has been through a step-by-step transition toward *Maraîchage sur Sol Vivant,* by (1) reducing soil tillage -from 8 passes per plot to 4 passes per plot-, (2) improving cultivation on hay mulches, and generalizing it to all transplanted crops using a leek hole punching machine that enables planting directly into thick mulches, (3) replacing almost all hoeing with animal traction by prophylactic weed control and manual weeding, (4) improving green manure cultivation -mostly phacelia before seedlings and rye with vetch before transplanting. Work convenience has been highly improved through the transition. Charles is currently looking for ways to reduce cultivation on bare soil and soil tillage.

Soil properties of the studied plot are presented in **table 4.**

Table 4: Soil properties in the studied plot (Charles). The visual soil assessment (VSA) (Shepherd, 2008) was carried out in the field in December 2019.

Bulk density (T/m^3)	1.45
Texture	Sandy clay loam
pH	8
%MO	4.7% including 3.3% of bounded organic matter
C/N of the MO	9.8
Microbial biomass (mg/kg)	456 Very high
Mineralization rate of humus (%)	3.2 Satisfying, a little bit low
Mineralization rate of Nitrogen (%)	2.3 Satisfying, a little bit low
C.E.C (M.E)	14.92
Bases saturation on the CEC	
VSA score (/32)	26 Good

5.2.2.2 Experimental device

The purpose of the test was to increase the use of mulches on the farm. The objective was to determine the advantages and pitfalls of green waste compost mulches -named ‘compost’- and hay mulches -named ‘hay’- compared to bare soil -named ‘bare soil’- for the cultivation of onions. Particularly, the test aimed at evaluating the effects of these two mulches types on work convenience and productivity. The studied plot was made of three adjacent seedbeds of 75m² (‘bare soil’, ‘compost’ and ‘hay’ modalities). Green beans were previously cultivated on the plot, followed by phacelia as a winter green manure. The soil has not been ploughed for twelve years and was usually tilled with ridging hoods and cultivators. The plot has been previously fertilised with composted chicken manure and green manures, and weed pressure was considered medium with quackgrass and purslane.

The cropping practices implemented and evaluated on the studied plot are presented in **table 5**.

<u>**Table 5**: Cropping practices implemented on the ‘compost’, ‘hay’ and ‘bare soil’ seedbeds of onions.</u>

Practice	‘compost’	‘hay’	‘usual’
Fertilisation	Chicken manure (2.4t/ha) Limestone powder (1.3t/ha)		
Green manure termination	Black plastic cover		
Mulch	Compost (180t/ha) added after plantation	Hay (50t/ha) added one month before plantation	

Onion plantation	Manually (using a manual homemade tool to make holes) 2 varieties	With the leak hole punching machine 2 varieties	Manually (using a manual homemade tool to make holes), after removal of the green manure residues 2 varieties
Weeding	Manual weeding	Manual weeding	Manual weeding + hoeing with animal traction
Pest management	None		
Irrigation	Sprinkling irrigation		

5.2.2.3 Results of performances of the cropping systems

The results of performances of the cropping systems are presented in **table 6**.

Table 6: Agri-environmental and socioeconomic indicators of the cropping practices on onions. 'compost' corresponds cultivation on a compost mulch, 'hay' corresponds to cultivation on a hay mulch, 'usual' corresponds to cultivation on bare soil. Bold letters show the best performance in between the tested modalities (no statistical test has been carried out).

	Indicator	'compost'	'hay'	'usual'
Agronomic performances	Yield (kg/100m²)	315.3	**346.7**	277.3
	Product quality (% of sellable products)	97.3	**100**	96.2
	Sugar content (Brix)	**3.8**	3.1	3.7
	Global crop health assessment score (/10)	7	7	7
Environmental performances	Residual N (kg NO_3^--NH_4^+/ha)	68	75	**44**
	Humus balance (t/ha)	**146.8**	6.7	-0.8
Economic performances	Gross margin (€/100m²)	296.2	**432.4**	225.6
	Operation costs (€/100m²)	562.5	538.2	**521.1**
	Crop sales (€/100m²)	858.7	**970.7**	746.7
Social performances	Total workload (h/100m²)	38h20min	**32h55min**	37h5min
	Work convenience (/10)	7.25	**7.75**	5.75
	Integration in the farming system (/10)	5	**10**	**10**

Onions yields and crop quality -% of sellable products and calibre- were higher in the 'hay' modality, followed by the 'compost' modality, compared to the 'usual' modality. This can be explained by an observed better growth recovery after onions transplantation on the hay mulch. The thick hay mulch may have buffered soil temperature and humidity during summer, thus increasing onions growth during summer. Conversely, the thin and dark compost mulch may have increased soil warm-up and dry out. Higher crop yields under the hay mulch can also be due to better nutritive inputs from hay compared to compost and bare soil. Indeed, hay has a low C:N ratio -around 25- so that it is easily mineralizable (Carnavalet, 2015). However, compost is mainly composed of stable organic material so that it is not easily mineralizable. This can be confirmed by higher residual nitrogen found in the 'hay' modality, followed by the 'compost' modality compared to the 'usual' modality. Sugar content was higher in the 'compost' and 'usual' modalities compared to the 'hay' modality. The type of mulch did not impact crop health.

Higher residual nitrogen found in the 'hay' and 'compost' modalities show higher potential for water contamination through nitrogen leaching and runoff. Water contamination risks are reduced when the soils are kept covered -mulch or cover crop- because soil coverage reduces runoff and increases infiltration. Thus, a cover crop should be cultivated after the onions, so that soil residual nitrogen would be reused for crop growth instead of contaminating waters. Humus balances were positive in both 'compost' and 'hay' modalities and negative in the 'usual' modality. These differences show that cultivation on bare soil is depleting soil humus on the long term -for instance here, losses were estimated to be of 1.8t/ha/year in bare soil-, while cultivation on mulches increases soil humus and builds soil fertility on the long term. This is especially the case with green waste compost, that has a high iso-humic coefficient (K1) -i.e., 0.82-, so that 82% of green waste compost added to the soil turns into stable soil organic matter -i.e., soil humus (Carnavalet, 2015). Compost additions are thus a good strategy to increase soil organic matter.

Gross margins were higher in the 'hay' modality due to higher yields and higher crop sales. Operation costs were higher in the 'compost' modality followed by the 'hay' modality, compared to the 'usual' modality. These differences were partially due to the cost of organic material additions in the mulched modalities. Even though mulching with compost appeared more profitable because the price of compost was lower than hay (25€/t and 165€/t respectively), this was counterbalanced with higher labour expenses in the 'compost' modality. Compost application was almost five times more time-consuming than hay application. Indeed, the seedbed width corresponded to a hay ball width, so that unrolling the hay ball on the seedbed was convenient and fast. However, large amounts of compost (180t/ha) were spread manually because in the absence of adequate equipment -e.g., spreaders. Cultivation on bare soil was more laborious than on hay mulch because more remedial weeding was necessary - hoeing with animal traction and manual weeding. Indeed, weeding workload was estimated to be 34 times higher on the 'usual' modality compared the 'compost' and 'hay' modalities. This difference in terms of weeding requirements has drastically impacted work convenience. Indeed, Charles estimated that it was more convenient to spend time on mulching and planting than on weeding along the season. However, the absence of adequate equipment for spreading the compost reduced work convenience on the 'compost' modality. The 'compost' modality was thus estimated to be the least integrated in the farming system because of (1) a lack of spreader, (2) a lack of trust on the product quality -plastic can be found in the green waste compost-, (3) a lack of technical knowledge for cultivation on compost mulches. For instance, Charles highlighted that compost mulches influence water management, so that different irrigation strategies need to be learnt and adapted to the farming system.

It can be concluded from the test that onions cultivation on hay mulch resulted in better agri-environmental and socioeconomic performances. The compost mulch was not suitable for onions cultivation, but Charles was reflecting on ways to combine the use of compost with hay on the farm. Indeed, compost offers the benefit of increasing soil warm-up and dry-out, so that it is more adapted to winter and spring crops. Direct seedling is also possible on compost mulch, so that more soils can be covered on the farm. Therefore, cultivation on compost mulches should be adapted to different types of crops.

5.2.3 Adapting cultivation techniques to improve productivity of indoor tomatoes

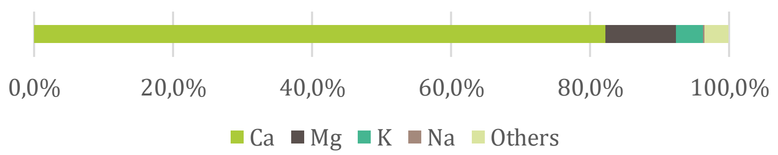
5.2.3.1 Study site (Claude & Thomas's farm)

Claude & Thomas's farm has a cultivated acreage of 5000m² in vegetable production where 2.5 human working units are employed. The farm is characterized by a small surface area without mechanisation. The farm's characteristics are presented in **table 3**, **§ 4.1**. Vegetables are cultivated on seedbeds made of wooden formworks filled with 10 cm of green waste compost. Weeding is mostly ensured preventively, using (1) black plastic covers and woven plastic covers, (2) green manures during winter (triticale and fodder peas); and with (3) manual weeding. Green manure destruction is ensured by grinding. The green manure residues are incorporated in the first 5 cm of the compost mulch with a drill. Fertilisation is based on compost and green manure residues, combined with manure and organic fertilisers.

Claude & Thomas have set-up their farm in 2018, directly in *Maraîchage sur Sol Vivant,* by making permanent seedbeds with 10cm of green waste compost in no-till, using green manures, and developing prophylactic weed and pest management strategies. Claude & Thomas are reflecting on ways to improve their fertilisation strategy in order to increase crop health and vegetable productivity -quantity and quality. Claude & Thomas are especially concerned by welfare, so they are constantly improving work convenience on the farm.

Soil properties of the studied plot are presented in **table 7**.

<u>**Table 7**: Soil properties in the studied plot (Claude & Thomas). The visual soil assessment (VSA) (Shepherd, 2008) was carried out in the field in December 2019.</u>

Bulk density (T/m³)	1.5
Texture	Sandy clay loam
pH	8.4
%MO	15.7% including 8.8% of bounded organic matter
C/N of the MO	13.3
Microbial biomass (mg/kg)	1290 Very high
Mineralization rate of humus (%)	2.1 Satisfying, a little bit low
Mineralization rate of Nitrogen (%)	1.0 Low
C.E.C (M.E)	46.97
Bases saturation on the CEC	
VSA score (/32) 0-10cm 10-20cm	 20.5 Moderate 14 Moderate

5.2.3.2 Experimental device

The purpose of the test was to improve the nitrogen fertilisation strategy in order to improve crop health and productivity. The objective was to test additions of beet vinasse during cultivation through fertigation at the nitrogen most demanding phenological stage of tomato, by measuring N leachates and using a phenological grid of the nitrogen demand of tomato. The nitrogen fertilisation strategy was combined with tomato thinning to improve productivity. The studied plot was an indoor seedbed of round tomato. Only one modality was tested -named 'test'- because beet vinasse was added through fertigation, and it was not feasible to change the irrigation system on an 'usual' seedbed.

The seedbed was previously cultivated with green beans, then with triticale and fodder peas as a green manure in winter. The previous crops were fertilised with green waste compost, cattle manure and with a combination of organic fertilisers characterized by both quick and fast mineralization rates. The weed pressure was considered low.

The cropping practices implemented and evaluated on the studied plot are presented in **table 8**.

<u>**Table 8**: Cropping practices implemented on the 'test' seedbed of indoor tomatoes.</u>

Practice	'test'
Green manure termination	Grinding and incorporation of green manure (triticale and fodder peas), 2 weeks before transplantation
Fertilisation	Green manure residues Compost mulch (added in 2018) Organic fertilisers: 1,7t/ha (10-2-2), 1,7t/ha (10-1-1), 0,9t/ha (53% K2O, 45% SO3), 17L of beet vinasse (3-0-6) in ferti-irrigation distributed from mid-July to October
Occultation	Black plastic cover, 2 weeks before transplantation and during cultivation
Other cultivation operations	Staking, pruning, leaves removal, thinning, etc.…
Crop protection	Cuivrol 3kg/ha for *Phytophthora infestans* (x2) Dipel (*Bacillus thuringiensis*) 0.7kg/ha for caterpillars (x2) Basing 2min/days when temperature is higher than 30°C indoor (x3) P19 net in spring
Irrigation	Drip irrigation + basing

5.2.3.3 Results of performances of the cropping systems

The results of performances of the cropping systems are presented in **table 9**.

<u>**Table 9**: Agri-environmental and socioeconomic indicators of the cropping practices on tomatoes. 'test' corresponds to cultivation with beet vinasse additions (no statistical test has been carried out).</u>

	Indicator	Test
Agronomic performances	Yield (kg/100m²)	2400
	Product quality (% of sellable products)	92
	Sugar content (Brix)	4

	Global crop health assessment score (/10)	7
Environmental performances	Residual N (kg NO_3^--NH_4^+/ha)	91
	Humus balance (t/ha)	-7.6t
Economic performances	Gross margin (€/100m²)	5632.9
	Operation costs (€/100m²)	1381
	Crop sales (€/100m²)	7013.9
Social performances	Total workload (h/100m²)	168,33h
	Work convenience (/10)	5
	Integration in the farming system (/10)	7

Crop yield was very high, and twice higher than the previous year -Claude & Thomas recorded yields of 1.1t/100m². This could be due to (1) better nitrogen fertilisation, thanks to beet vinasse addition, (2) more adapted crop management -leaves removal, thinning- implemented this year, (3) external factors -e.g., climate, soil, farmer skills. By looking at the soil analysis, it appears that the soil is very fertile -high soil organic matter, high CEC, high microbial biomass-, thus improving crop growth and crop health. Crop health was considered as good during the growing season. Treatment frequency index was equal to 2 doses of pesticides. Indeed, organic treatments were sprayed for crop protection against mildew and caterpillars.

Residual nitrogen was high so that it could potentially pollute waters. However, the soil samples were taken prior to nitrogen analysis at the end of September, so tomatoes were still growing. Thus, the nitrogen was more likely to be used for tomato nutrition rather than lost. The humus balance was negative because of high humus mineralization due to high soil organic matter content (15.7%). Organic matter additions realised on the tomatoes were not sufficient to compensate humus mineralization. By looking at the high soil organic matter content, it appears that increasing soil humus was not necessary. However, green waste compost or other organic material should be added in the future to maintain soil fertility.

The gross margin was very high with 5632.9€/100m², due to high crop sales. Operation costs were also quite high, due to the labour costs. Indeed, it appears that this cropping system was very intensive in terms of labour and productivity per square meters. Even though no 'usual' modality could have been tested for drawing comparison, it can be assumed that the workload was high due to the intensive nature of indoor tomato cultivation, and that it was not impacted by the tested cropping practices. Work convenience was considered as medium because of repetitive work -frequent harvests, pruning, and staking-, and difficult working conditions -heat in the greenhouse, inconvenient postures. The cropping system was well integrated in the broader farming system, even though nursery management was considered complex according to Claude & Thomas who produce their own plants. The market gardeners pointed out technical challenges with indoor tomato such as (1) ensuring precocity, (2) reaching high yields, (3) having a regular and good production until late in the season, that should be considered for improving their future cropping systems.

It can be concluded from the test that the fertilisation strategy with beet vinasse, combined with leaf removal and thinning increased drastically indoor tomato yields. Furthermore, Claude & Thomas were testing different fertilisation strategies on different crop, using a tester for residual nitrogen and phenological grids that indicate nitrogen demanding phenological stages for diverse crops. However, to answer Claude & Thomas questions on the effects of their cropping practices on crop quality, different tests should be carried out such as (1) gustatory tests, (2) nutritional content analysis, on different modalities -diverse fertilisation strategies-, and on different varieties. Fertilisation tests and effects on crop yields -quantity, quality- should be carried out on more crops in the farm to find suitable fertilisation strategies for each crop. Finally, the high agri-environmental and socioeconomic performances show that the studied cropping system can be considered as bio-intensive, because of (1) high yields on a small surface area, (2) high workload per square meter, (3) high gross margins and (4) high technicity in the management -fertilisation, crop protection.

5.2.4 Growing broccolis on cover crop residues in no-till

5.2.4.1 Study site (Emile's farm)

Emile's farm has a cultivated acreage of 3.5ha in vegetable production where 4.5 human working units are employed on cereal, vegetable, and fruit productions. The farm is characterized by a large surface area with a high mechanisation level. The farm's characteristics are presented in **table 3, § 4.1**.

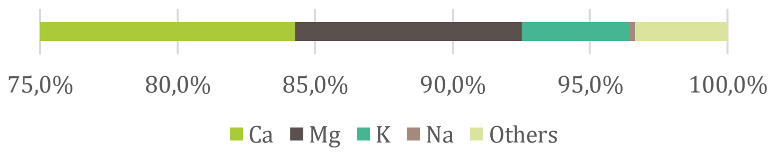
Tillage is reduced to dethatching and rotative harrowing. Green manures are cultivated in between the commercial crops (sorghum, oats, vetch, rye, vetch, phacelia, forage radish, clover). Green manure termination is ensured through dethatching, or rolling combined with occultation with woven plastic covers. Weeding is mostly ensured preventively with (1) woven plastic covers, (2) mulches (green manures residues, chipped wood and ramial chipped wood); and using (3) mechanical, and (4) manual weeding. Fertilisation is based on chipped wood, ramial chipped wood, green waste manure residues, green waste compost, and organic fertilisers.

Set up in 2014 on the family farm, the farm was first converted to organic farming, and is currently going through a transition process to *Maraîchage sur Sol Vivant,* by (1) bringing large amounts of carbonaceous organic materials (chipped wood, ramial chipped wood) for soil regeneration, (2) settling permanent seedbeds on the regenerated plots to cultivate without soil tillage and to enable plastic covers ballasting, (3) improving green manure management -seedling, termination, productivity. Emile is re-designing the whole farming system to regenerate the soils and introducing cropping systems in *Maraîchage sur Sol Vivant.*

Soil properties of the studied plot are presented in **table 10**.

Table 10: Soil properties in the studied plot (Emile). The visual soil assessment (VSA) (Shepherd, 2008) was carried out in the field in December 2019.

Bulk density (T/m^3)	1.4
Texture	Clay loam
pH	8.8
%MO	3% including 2.4% of bounded organic matter
C/N of the MO	8.4
Microbial biomass (mg/kg)	450 High

Mineralization rate of humus (%)	2.8 High
Mineralization rate of Nitrogen (%)	1.5 Satisfying
C.E.C (M.E)	22.62
Bases saturation on the CEC	
VSA score (/32)	26 Good

5.2.4.2 Experimental device

The purpose of the test was to evaluate a set of cropping practices in *Maraîchage sur Sol Vivant*: cultivation on a regenerated soil -i.e., large amounts of organic matter were added in 2018-, no-till, green manure cultivation; prior to larger adoption in the farm. The objective was to compare the cultivation of broccolis in *Maraîchage sur Sol Vivant* -named 'test'-, with a conventional set of cropping practices -named 'usual'. Particularly, the test aimed at evaluating the effects of *Maraîchage sur Sol Vivant* cropping practices on work convenience and products quality. The studied plot was made of two 51m² seedbeds situated in two different plots (100m away). Because of the nature of the test, requiring plots with different soil management -soil regeneration on one hand, soil tillage on the other hand-, the two studied plots had different historical management. On the 'test' modality, the plot was a several years old meadow -constituted of alfalfa and other species-, untilled for more than nine years. Ramial chipped wood was brought at a rate of 100t/ha in 2018. The plot was then occulted and cultivated directly with pumpkins, followed by tomatoes, without any other organic matter input. A green manure (oat, vetch, phacelia, forage radish and clover) was cultivated prior to broccoli cultivation. The weed pressure was considered as high with ryegrass, speedwell, and chickweed. On the 'usual' modality, the plot was a former apple orchard, where the trees were removed, and the soil was tilled prior to cultivation.

The cropping practices implemented and evaluated on the studied plots are presented in **table 11**.

Table 11: Cropping practices implemented on the 'test' and the 'usual' seedbeds of broccolis.

Practice	'test'	'usual'
Soil tillage	None	Plough, rotative harrow, ridging hoods
Fertilisation	50kg/ha (25%Mg, 50%S) 400kg/ha (5-3-8)	
Green manure termination	Rolling of the green manure and occultation with a woven plastic cover for 2 ½ months	None

Occultation	After GM termination, with a woven plastic cover	Prior to plantation, with a woven plastic cover
Mulch	Green manure residues	Bare soil
Crop protection	Anti-slug	
Irrigation	Sprinkling irrigation	

5.2.4.3 Results of performances of the cropping systems

The results of performances of the cropping systems are presented in **table 12**.

Table 12: Agri-environmental and socioeconomic indicators of the cropping practices on broccolis. 'test' corresponds to cultivation on cover crop residues in no-till, 'usual' corresponds to cultivation with soil tillage, on bare soil. Bold letters show the best performance in between the tested modalities (no statistical test has been carried out to).

	Indicator	Test	Usual
Agronomic performances	Yield (kg/100m²)	16.7	**25.9**
	Product quality (% of sellable products)	79.8	**93.4**
	Sugar content (Brix)	3.8	3.8
	Global crop health assessment score (/10)	3.5	**7.5**
Environmental performances	Residual N (kg NO_3^--NH_4^+/ha)	39	34
	Humus balance (t/ha)	**-0.8**	-2.4
Economic performances	Gross margin (€/100m²)	-23.4	**14.3**
	Operation costs (€/100m²)	**75.3**	76.6
	Crop sales (€/100m²)	49.9	**90.9**
Social performances	Total workload (h/100m²)	4h05min	4h05min
	Work convenience (/10)	8	**9**
	Integration in the farming system (/10)	8	8

Crop yield were higher in the 'usual' modality compared to the 'test' modality due to flea beetles and thumbtacks attacks that occurred in the 'test' modality. Indeed, crop health was estimated to be higher in the 'usual' modality for this reason. Since the two studied seedbeds were located on two different plots (100m away), no conclusion can be drawn on the effect of the cropping practice on pest damages. No difference in sugar content was measured in both modalities.

Residual nitrogen was higher in the test modality, probably due to higher stocks of soil nitrogen because of the green manure residues and of the inputs of chipped wood and ramial chipped wood in 2018 for soil regeneration. Since the broccolis were still growing during soil sampling prior to nitrogen analysis, the nitrogen was more likely to be used for broccoli nutrition rather than lost. Humus balances were negative in both modalities, showing that organic matter inputs were not sufficient to compensate mineralization. The humus balance was higher in the 'test' modality due to the inputs of green manure residues. However, inputs from the green manure residues must be combined with other organic matter additions to maintain or keep on building soil fertility.

The gross margin was higher in the 'usual' modality due to higher crop sales. Operation costs were however slightly higher in the 'test' modality due to the cost of soil tillage. Work convenience was considered high in both modalities because no weeding was needed thanks to the use of woven plastic covers during cultivation. However, because of the wind constraint, it was more difficult to stretch the plastic covers in the 'test' modality compared to the 'usual' modality where permanent seedbeds were created for plastic cover ballasting. Moreover, the soil was harder in the 'test' modality, so that planting was more difficult. Both modalities were well integrated in the broader farming system. The 'usual' modality appeared to be more adapted for plastic covers ballasting, whereas the 'test' modality was more adapted to increase crop successions. According to the farmer, another crop could be planted directly after the broccoli harvest in the 'test' modality, whereas in the 'usual' modality soil tillage would be necessary prior to plantation.

No effect of the tested cropping practices on broccoli productivity can be concluded from the test because of the attack of flea beetles and thumbtacks. The use of woven plastic covers on permanent seedbeds increased work convenience because of plastic cover ballasting. Emile concluded that he would create permanent seedbeds in most plots. He was also reflecting on wags to adapt the cropping practices to his local constraints -i.e., wind-, and decrease dependency on plastic. He was considering growing a green manure until May, that would be terminated by rolling and occultation, and subsequently planting broccolis and cabbages in the green manure residues in august. Re-scheduling the plantation of broccolis and cabbages later in August would improve work convenience by decreasing the work peak that occurs in July.

5.2.5 Growing potatoes in no-till under organic mulches

5.2.5.1 Study site (Jean's farm)

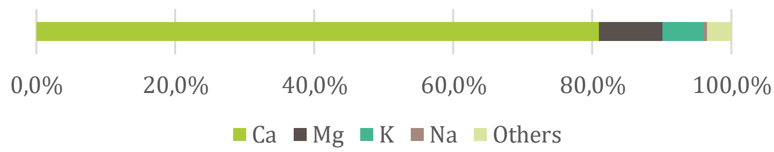
Jean's farm has a cultivated acreage of 1ha in vegetable production where 2.75 human working units are employed on vegetable, vegetable seeds, walnut, and laying hens productions. The farm is characterized by a medium surface area with a low mechanisation level combined with animal traction. The farm's characteristics are presented in **table 3, § 4.1.**

No-till is practiced on most of the surface area, except on potatoes. Green manures are cultivated during winter (rye, vetch). Green manure termination is ensured through rolling, combined with occultation using black plastic covers. Weeding is mostly ensured preventively with mulches (hay, compost, chipped wood, green manure residues), plastic covers, and with manual weeding. Fertilisation is based on green waste compost, chipped wood, poultry manure, hay, straw, green manure residues and organic fertilisers.

Set up in 2007, the farm converted to *Maraîchage sur Sol Vivant* because of concerns for soil degradation and work difficulties due to animal traction. The steps of the transition have been (1) reducing tillage frequency in animal traction, (2) regenerating soils by adding large amounts of carbonaceous material (chipped wood, green waste compost), (3) reducing the tilled surface area -by 50% the first year and 80% the second year. Jean was looking for removing all soil tillage in the farming system.

Soil properties of the studied plot are presented in **table 13**.

Table 13: Soil properties in the studied plot (Jean). The visual soil assessment (VSA) (Shepherd, 2008) was carried out in the field in December 2019.

Bulk density (T/m^3)	1.35
Texture	Sandy
pH	8.8
%MO	1.8% including 1.3% of bounded organic matter
C/N of the MO	7.9
Microbial biomass (mg/kg)	428 Very high
Mineralization rate of humus (%)	4.4 Very high
Mineralization rate of Nitrogen (%)	2.3 High
C.E.C (M.E)	13.14
Bases saturation on the CEC	
VSA score (/32)	22.5 Good

5.2.5.2 Experimental device

The purpose of the test was to cultivate potatoes in no-till, the only crop cultivated with soil tillage on the farm. The objective of the test was to evaluate potato cultivation in no-till, on a soil regenerated with large inputs of organic material -named 'test'-, and especially the effects of these cropping practices on work convenience and product quality. The studied plot was made of two adjacent seedbeds of 400m². Since the farmer wanted to stop tilling in all fields this year, it was impossible to cultivate potatoes as usual -with soil tillage- for comparison. Thus, a comparison was partially made thanks to farmer's records and estimation of the performances of the potatoes cultivated the previous year -named 'former'.

Potatoes were previously cultivated on the 'test' modality, followed by sorghum as a summer green manure. The previous potatoes were fertilised with organic fertilisers. Chipped wood and green waste compost were added to the soil surface layer at a rate of 100t/ha in 2019 on the sorghum. The plot was then occulted with black plastic covers. The weed pressure was considered high with bindweed and quackgrass.

The cropping practices implemented and evaluated on the studied plot are presented in **table 14**.

Table 14: Cropping practices implemented on the 'test' plot of potatoes.

Practice	'test'	'former'
Soil tillage	None	Herse étrille Hoeing x2

		Ridgers x2
Fertilisation	2.5t/ha castor oil cake 1t/ha (10-1-1) 100kg/ha (30% K, 10% Mg, 42,5% S) 175t/ha green waste compost 47tDM/ha of fresh alfalfa 3L/ha Bore in leaf spraying	2.5t/ha castor oil cake 1t/ha (10-1-1) 100kg/ha (30% K, 10% Mg, 42,5% S)
Green manure termination	Occultation with black plastic cover (between 1 month and 1 and ½ month)	NA
Plantation	Manually 2 series 1 seedbed/serie	Mechanically
Mulch	Green waste compost and fresh alfalfa	None
Crop protection	0.05L/ha Spinosad 0.5kg/ha Cuivrol	NA
Harvest	Manually, then, with a potato harvester	Mechanically: potato harvester
Irrigation	Sprinkling irrigation	

5.2.5.3 Results of performances of the cropping systems

The results of performances of the cropping systems are presented in **table 15**.

Table 15: Agri-environmental and socioeconomic indicators of the cropping practices on potatoes. 'test' corresponds to cultivation in no-till, under green waste compost and alfalfa residues, 'former' corresponds to cultivation with soil tillage, on bare soil. The 'former' modality was not tested. Data were collected thanks to farmer's records and observations from the previous year. Bold letters show the best performance in between the modalities (no statistical test has been carried out to).

	Indicator	Test	Former
Agronomic performances	Yield (kg/100m²)	**431.25**	250
	Product quality (% of sellable products)	70	**92.5**
	Sugar content (Brix)	3.1	NA
	Global crop health assessment score (/10)	5	8
Environmental performances	Residual N (kg NO_3^--NH_4^+/ha)	36	NA
	Humus balance (t/ha)	**167.2**	0.4
Economic performances	Gross margin (€/100m²)	**576.9**	501.5
	Operation costs (€/100m²)	285.6	**76.6**
	Crop sales (€/100m²)	**862.5**	578.1
Social performances	Total workload (h/100m²)	11h18min	**3h**
	Work convenience (/10)	5	**8**

	Integration in the farming system (/10)	3	**8**

Crop yield was higher in the 'test' modality, due to higher planting density enabled by no-till. However, product quality -% of sellable products- was higher in the 'former' modality. Indeed, 30% of the harvest was considered unsellable because of (1) green potatoes -due to exposition to sunlight-, (2) quackgrass that had grew in the potatoes, and (3) diseases -*Rhizoctonia solani.* Since the potatoes were not planted in the soil but under a mulch, and because biological activity in the soil is very high, the organic matter decomposition was too fast so that some potatoes were exposed to sunlight during their growing period, resulting in potato greening. That was also noticed by the farmer who added alfalfa in June and green waste compost at the end of July, shortly before the harvest because he had observed potatoes exposed to sunlight. *Rhizoctonia solani* may have been inoculated the previous year since potato were cultivated on the same plot. The disease might also be fostered by late growth, resulting from slow soil warming in no-till and mulched cropping systems. Thus, it can be concluded that reduced quality was probably due to no-till and the short crop rotation. Crop health was estimated to be lower in the 'test' modality due to external factors -climate, irrigation, seed. Thus, two organic treatments were applied at low rate for mildew and Colorado beetle with a total treatment frequency index of 0.7.

The humus balance was positive with an increase of 167.2t of humus per ha due to large organic matter inputs (green waste compost, green manure residues, alfalfa, organic fertilisers). The addition of green waste compost especially increases soil humus because of its high iso-humic coefficient -K1.

Gross margin was higher in the 'test' modality compared to the 'former' modality, due to higher crop sales. However, operation costs are almost four times higher in the 'test' modality because of the cost of organic matter -estimated to be of 121€/100m²-, largely added in the 'test' modality, and because of higher costs relative to labour.

Social performances were better in the 'former' modality compared to the 'test' modality. Workload was between three and four times higher in no-till because of (1) organic matter addition, (2) manual harvest. Indeed, organic matter additions were time consuming, were repeated several times during the growing season. Harvests had to be done manually so that it was more difficult and required more labour. Moreover, Jean reported that the potato lines were not easy to identify, thus complicating the harvest. Jean had to use a potato harvester at the end of the harvest in order to remove all potatoes. Work convenience was lower in the 'test' modality because of more difficult plantation and harvest, and because of higher labour requirements. The 'test' modality was not well integrated in the broader farming system because the potato harvester destroyed the seedbeds, and because repetitive organic matter additions for mulching increased the workload peak.

It can be concluded from the test that, even if potato cultivation in no-till under organic mulches was more profitable, the increased workload and inconvenience for the farmer impeded adoption of no-till on potato. According to the farmer, it would be more convenient to grow spring potatoes in no-till under organic mulches, so on smaller plots. Indeed, since the growing cycle is shorter for spring potato than for conservation potato, less organic matter would be required, and costs due to organic matter application would be decreased. Moreover, harvests are more frequent for spring potatoes, so that the surface area to be harvested would be reduced as well as needs for labour.

Environmental performances of the tested cropping practices were high, especially in terms of humification. Jean observed better soil life in the plot compared to the previous years. He was however questioning the sustainability of the tested cropping practices in terms of carbon emissions resulting from mechanical organic matter inputs. This raises perspectives for future research on the environmental impacts of soil regeneration strategies on soil fertility and carbon dynamics - sequestration and emissions.

5.2.6 Growing potatoes in no-till under a straw mulch

5.2.6.1 Study site (Marie & Anthony's farm)

Marie & Anthony's farm has a cultivated acreage of 3000m² in vegetable production where 1.5 human working units are employed on vegetable production. Recently settled on the farm (2019), Marie & Anthony are developing fruit, berries and laying hens productions. The farm is characterized by a small cultivated surface area without mechanisation. The farm's characteristics are presented in **table 3, § 4.1**.

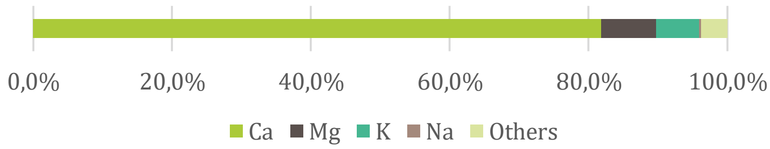
In 2019, Marie & Anthony started to cultivate 500m² of vegetables on woven plastic covers after having removed the trees from the former orchard. In 2020, they split the total cultivated surface area in four cultivated blocs: (1) the soil was tilled (superficial plough and rotative harrow) and permanent seedbeds were created, (2) the soil was left uncultivated and large amounts of crushed wood were spread on the soil surface layer -i.e., soil regeneration strategy-, (3) the soil was cultivated directly on woven plastic covers without soil tillage, (4) the soil was left uncultivated -i.e., spontaneous vegetation.

Work is done manually without mechanisation. Except in the bloc 1, crops are cultivated in no-till. Green manures have not been cultivated yet. Weeding is mostly ensured preventively with (1) mulches (fresh grass, straw), (2) plastic covers (woven plastic covers, hemp canvas, black plastic covers), and with (3) manual weeding. Fertilisation is based on poultry and horse manures, chipped wood, straw, fresh grass, and organic fertilisers. Future cropping practices will be designed to (1) avoid soil tillage as much as possible, (2) make the best use of diverse mulches, (3) regenerate soils, and (4) increase biodiversity.

Soil properties of the studied plot are presented in **table 16**.

Table 16: Soil properties in the studied plot (Marie & Anthony). The visual soil assessment (VSA) (Shepherd, 2008) was carried out in the field in December 2019.

Bulk density (T/m^3)	1.35
Texture	Sandy
pH	8.2
%MO	4.9% including 3.6% of bounded organic matter
C/N of the MO	10.4
Microbial biomass (mg/kg)	616 Very high

<table>
<tr><td>Mineralization rate of humus (%)</td><td>2.8 High</td></tr>
<tr><td>Mineralization rate of Nitrogen (%)</td><td>2 Satisfying, a little bit high</td></tr>
<tr><td>C.E.C (M.E)</td><td>17.31</td></tr>
<tr><td>Bases saturation on the CEC</td><td>
</td></tr>
<tr><td>VSA score (/32)</td><td>28.5 Good</td></tr>
</table>

5.2.6.2 Experimental device

The purpose of the test was to determine an adapted set of cropping practices for growing potatoes in no-till. The objective was to compare the performances of three methods of potato cultivation: (1) potatoes planted on a tilled and ridged seedbed -named ‘tillage’-, (2) potatoes dropped on the top of a mowed meadow and covered with a straw mulch -named ‘straw’-, (3) potatoes planted in the soil and covered with a straw mulch -named ‘andine’.

The ‘tillage’ modality was cultivated in the bloc 1, so the plot was ploughed, tilled with a rotative harrow and seedbeds were created. The plot was previously cultivated with pumpkins and fertilised with organic fertilisers. The weed pressure was considered high with quackgrass, mauve, and purslane. The ‘straw’ and ‘andine’ modalities were cultivated in the bloc 3, so without any soil tillage prior to cultivation. The plot was previously covered with spontaneous vegetation and untilled for probably more than 10 years.

The cropping practices implemented and evaluated on the studied plot are presented in **table 17**.

Table 17: Cropping practices implemented on the ‘straw’, ‘andine’, and ‘tillage’ plots of potatoes.

Practice	‘straw’	‘andine’	‘tillage’
Soil tillage	None		Plough and rotative harrow
Fertilisation	5t/ha (orga 3 3% N, 2% P, 3% K, 3% Mg) 700kg/ha ashes		
Plantation	Manually dropped on the soil surface	Manually planted in the soil (5cm deep)	Manually planted in the soil after making a furrow and a mound
Mulch	50t/ha straw 30t/ha straw (ridging)		None
Ridging	Mulch (straw)		Manually
Crop protection	None		
Irrigation	Sprinkling irrigation		

5.2.6.3 Results of performances of the cropping systems

The results of performances of the cropping systems are presented in **table 18**.

<u>**Table 18**: Agri-environmental and socioeconomic indicators of the cropping practices on potatoes. 'straw' corresponds to potatoes cultivated in no-till, under a straw mulch, 'andine' corresponds to potatoes planted in the soil without tillage, under a straw mulch, 'tillage' corresponds to potatoes cultivated with soil tillage, on bare soil. Bold letters show the best performance in between the modalities (no statistical test has been carried out to).</u>

	Indicator	Straw	Andine	Tillage
Agronomic performances	Yield (kg/100m²)	28.1	89.1	**592**
	Product quality (% of sellable products)	**95.6**	70.2	83.2
	Sugar content (Brix)	**4.4**	NA	3.8
	Global crop health assessment score (/10)	7	7	**8**
Environmental performances	Residual N (kg NO_3^--NH_4^+/ha)	**18**	**18**	64
	Humus balance (t/ha)	**10.4**	**10.4**	-1.6
Economic performances	Gross margin (€/100m²)	-238.5	-327.8	**1274.2**
	Operation costs (€/100m²)	**327.5**	534.7	356
	Crop sales (€/100m²)	89	208.9	**1630**
Social performances	Total workload (h/100m²)	**21h36min**	39h21min	28h20min
	Work convenience (/10)	**8**	6	7
	Integration in the farming system (/10)	**8**	6	6.5

Crop yields were higher in the 'tillage' modality, followed by the 'andine' and 'straw' modalities. The high difference in yields can be explained by (1) a softer soil in the 'tillage' modality compared to the other modalities -the soil was very compacted in the 'straw' and 'andine' modalities, so that it was nearly impossible to plant a spade more than 5 cm deep in the soil, (2) increased soil warm-up in the 'tillage' modality, that resulted in faster potato germination -15 days before the other modalities-, (3) higher nutrient availability in the 'tillage' modality because of previous fertilisation and higher mineralization, (4) the straw mulches in the 'straw' and 'andine' modalities were too thick so that water from rainfalls did not pass through the mulches. Product quality was higher in the 'straw' modality, followed by the 'tillage' and 'andine' modalities. Indeed, potatoes in the 'andine' modality were damaged during the harvest. Surprisingly, green potatoes were higher in the 'tillage' modality because of high wind erosion on the bare and sandy soil. However, no green potatoes were found on the 'straw' modality, testifying that the mulch was thick enough to not let the sunlight go through. Sugar content was higher in the 'straw' modality compared to the 'tillage' modality. Crop health was lower in the 'straw' and 'andine' modalities, due to wireworms and voles' damages, that proliferate in meadows and cropping systems in no-till.

Residual nitrogen was higher in the 'tillage' modality probably due to higher mineralization. Thus, the soil should not be left bare after cultivation -mulch, cover crop- to avoid nitrogen leaching and runoff, and subsequent water contamination. Humus balances were positive in the 'straw' and 'andine' modalities (+10.4t/ha), so the tested cropping practices enhanced soil humus. However, the humus balance was negative in the 'tillage' modality because organic matter inputs (organic fertiliser) were not sufficient to compensate humus mineralization.

Gross margin was drastically higher in the 'tillage' modality because of higher crop sales. In the 'straw' and 'andine' modalities, crop sales did not cover operation costs. Operation costs were lower in the 'straw' modality followed by the 'tillage' and 'andine' modalities. These differences were mainly due to differences in labour expenses. Indeed, workload followed the same trend than operation costs. 'Andine' was the most time-consuming cropping system because of a long and difficult harvest -manual harvest on a compacted soil. The 'tillage' modality required more labour than the 'straw' modality because of (1) soil tillage -soil preparation, ridging-, (2) harvest methods -it was easier to harvest potatoes on the soil surface than digging in the soil-, (3) higher yields, resulting in longer harvest. Work convenience was higher in the 'straw' modality because organic matter applications and harvests were convenient for Marie & Anthony. Work convenience was lower in the 'andine' modality because the harvest was difficult. The 'straw' modality was more integrated in the broader farming system, followed by the 'tillage' and the 'andine' modalities. Indeed, soil compaction made plantation and harvest difficult with available tools on the farm. Since the farm was non-mechanized, tillage tools and tractors had to be borrowed from neighboring farmers so that the 'tillage' modality was not integrated in this farming system.

It can be concluded from the test that cultivating potato in no-till under a straw mulch has high potential for building soil fertility and for work convenience. However, agronomic performances were very poor due to the soil conditions -compacted meadow, slow warm-up- in the 'straw' and 'andine' modalities, resulting in low crop growth in no-till. The test should be repeated on adjacent seedbeds with similar management historic and on softer soils. Moreover, future cropping systems in no-till should target faster soil warming by using a dark mulch and/or plastic covers. Marie & Anthony concluded that (1) the straw mulch should be thinner to let the water from the rainfall go through the mulch, and (2) more organic matter should be brought during the growing season if necessary. In tillage cropping systems, a cover crop should be cultivated to avoid N leaching and run-off, and more organic matter should be added to the soil. Importantly, the soil should be covered to avoid soil erosion on these sandy soils highly sensitive to wind erosion.

5.2.7 Growing carrots directly sowed on a compost mulch

5.2.7.1 Study site (Léa & Marc's farm)

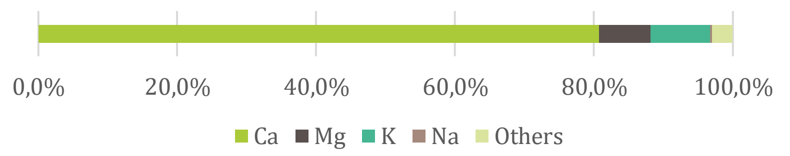
Léa & Marc's farm has a cultivated acreage of 7000m² in vegetable production where 2 human working units are employed on vegetable and berry production. The farm is characterized by a small surface area with a low mechanisation level combined with animal traction. The farm's characteristics are presented in **table 3, § 4.1.**

Tillage is reduced to cultivator, cover crop, and ridging hoods. Green manures are cultivated in winter (oat, vetch). Green manure termination is ensured by soil tillage using a cover crop. Weeding is mostly ensured preventively using (1) mulches (hay, straw), (2) woven plastic covers, and with (3) mechanical weeding -spring tine harrow-, and (4) manual weeding.

Set up in 2009, the farm is converting to *Maraîchage sur Sol Vivant* through a step-by-step process. Soil coverage was first increased using mulches and cultivating green manure. In 2020, permanent seedbeds were created with the aim of not tilling them anymore. Léa & Marc were re-thinking their crop rotations, combining cultivation on woven plastic covers, additions of diverse organic matter, green manure cultivation, green manure grinding, and occultation with plastic covers.

Soil properties of the studied plot are presented in **table 19**.

Table 19: Soil properties in the studied plot (Léa & Marc). The visual soil assessment (VSA) (Shepherd, 2008) was carried out in the field in December 019.

Bulk density (T/m^3)	1.35
Texture	Sandy
pH	8.5
%MO	3% including 2.1% of bounded organic matter
C/N of the MO	9.1
Microbial biomass (mg/kg)	389 Very high
Mineralization rate of humus (%)	3.9 Very high
Mineralization rate of Nitrogen (%)	2.6 High
C.E.C (M.E)	15.67
Bases saturation on the CEC	
VSA score (/32)	22 Moderate

5.2.7.2 Experimental device

The purpose of the test was to introduce direct seedings of small seeds crops on the farm, using a compost mulch. The objective of the test was to compare the cultivation of carrots (1) sowed on bare soil -named 'usual'-, and (2) sowed on a green waste compost mulch -named 'test'. Particularly, the test aimed at assessing the impacts of the compost mulch on weed coverage, weeding, and productivity. The studied plot was made of a seedbed of $32m^2$, divided in two parts. The seedbed was previously cultivated with green beans, and reduced tillage was practiced (cultivator, ridging hoods). The permanent seedbeds were made in 2020 and occulted with woven plastic covers prior to carrot cultivation. Two varieties of carrots were sowed on both modalities. Weed pressure was considered high with stellate and purslane.

The cropping practices implemented and evaluated on the studied plot are presented in **table 20**.

Table 20: Cropping practices implemented on the 'test' and the 'bare soil' seedbeds of carrots.

Practice	'test'	'usual'
Soil tillage	Formation of the permanent seedbeds (cross-krill)	
Fertilisation	500kg/ha (25%Mg, 50%S)	

	115t/ha of green waste compost	
Occultation	Woven plastic covers for 15 days	
Mulch	Green waste compost (3cm)	Bare soil
Seedling	With manual seedlers (2x)	
Pest management	None	
Irrigation	Micro-sprinkling irrigation until end of July, then drip irrigation	
Weeding	Manual weeding (x2)	

5.2.7.3 Results of performances of the cropping systems

The results of performances of the cropping systems are presented in **table 21**.

Table 21: Agri-environmental and socioeconomic indicators of the cropping practices on carrots. 'test' corresponds to carrots sowed on a green waste compost mulch, 'usual' corresponds to carrots sowed on bare soil. Bold letters show the best performance in between the modalities (no statistical test has been carried out to).

	Indicator	Test	Usual
Agronomic performances	Yield (kg/100m²)	**646.7**	482.2
	Product quality (% of sellable products)	91.4	**95.4**
	Sugar content (Brix)	**7.05**	6.95
	Global crop health assessment score (/10)	7	**10**
Environmental performances	Residual N (kg NO_3^--NH_4^+/ha)	**26**	28
	Humus balance (t/ha)	**92.9**	-3.2
Economic performances	Gross margin (€/100m²)	**73.4**	-2773
	Operation costs (€/100m²)	**1343.1**	3880.4
	Crop sales (€/100m²)	**1416.5**	1107.5
Social performances	Total workload (h/100m²)	**23h41**	35h58
	Work convenience (/10)	**9**	6
	Integration in the farming system (/10)	7	**8**

Crop yield was higher in the 'test' modality due to bigger carrots. However, the product quality was lower due to vole damage and broken carrots. Crop health was lower in the 'test' modality for this reason. Carrot germination was lower in the 'test' modality, so the seedbed had to be resowed.

Residual nitrogen levels were similar in both modalities. Risks of water contamination by nitrates can be considered low since the carrots were still growing during soil sampling for residual nitrogen analysis. The residual nitrogen would be used for crop nutrition rather than lost through leaching or runoff. The humus balance was negative in the 'usual' modality, showing that organic matter additions were not sufficient to balance soil humus mineralization. Humus balance was higher in the 'test' modality due to green waste compost additions, with high humification potential -K1.

Workload was lower in the ‘test’ modality due to four times less weeding. The reduced weed coverage resulted from the occultation effect of green waste compost, impeding some weed germinations. Soil preparation was more time-consuming in the ‘test’ modality because of compost additions but this effect was counterbalanced by less time spent on weeding. Because of less weeding, the ‘test’ modality was estimated to be more convenient. However, the ‘test’ modality was less integrated in the farming system because of a lack of availability of green waste compost of good quality -the compost was not well sieved, and plastic was found in it. Moreover, Léa & Marc were looking for more autonomy on the farm, so that they reflected on ways to make compost from local materials. Compost application would have been more effective if they would have a spreader on the farm. Léa & Marc were also reflecting on adapting the technique of direct seeding on green waste composts to different crops.

Norwegian University
of Life Sciences

Postboks 5003
NO-1432 Ås, Norway
+47 67 23 00 00
www.nmbu.no