UNIVERSITÉ DE RENNES 1

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

THESE DE DOCTORAT DE

L'UNIVERSITE DE RENNES 1

ECOLE DOCTORALE N° 600
Ecole doctorale Ecologie, Géosciences, Agronomie et Alimentation
Spécialité : « *Ecologie - Evolution* »

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

GRADUIERTENSCHULE FORST- UND AGRARWISSENSCHAFTEN
Agricultural Sciences
International PhD Programme for Agricultural Sciences in Göttingen

Par

Morgane HERVE

Caring for the life below-ground:

An interdisciplinary inquiry on the values of soil biota and biodiversity among European farmers

Thèse présentée et soutenue à Paimpont, le 12 mars 2021
Unités de recherche : UMR 6553 ECOBIO, UMR 6211 CREM (Université de Rennes 1) ; Center of Biodiversity and Sustainable Land Use (Georg-August-Universität Göttingen)

Rapporteurs avant soutenance :

Dr. Luca Montanarella — Scientific project manager, European Commission/Joint Research Center
Dr. Tobias Plieninger — Professor, Georg-August-Universität Göttingen
Adélie Pomade — Maître de conférences HDR, Université de Bretagne Occidentale

Composition du Jury :

Président :	Dr Julie Ingram	Professor, University of Gloucestershire
Examinateurs :	Dr. Luca Montanarella	Scientific project manager, European Commission/Joint Research Center
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Dir. de thèse :	Annegret Nicolai	Chercheuse indépendante HDR
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Invité(s)
Isabelle Feix — Experte nationale sols, ADEME

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Publications and communications

Scientific publications

Publications related to the PhD thesis:

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M.E.T Hervé, M. Renault, E. Plaas, M. Potthoff, R. Schuette, D. Cluzeau, G. Pérès, A. Nicolai (2021). How does soil biota matter in soil management in Europe? Exploring temporal dynamics and situation dependence in the valuation processes. *International Journal of Agricultural Sustainability*. *Doi:* 10.1080/14735903.2021.1964260.

M.E.T. Hervé, M. Renault, E. Plaas, M. Potthoff, G. Pérès, D. Cluzeau, A. Nicolai ***(submitted)*** Applying the Valuating Milieu framework to investigate soil biota and soil biodiversity valuations by farmers in two European regions. *Land Use Policy* (LUP-S-20-00731).

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M.E.T. Hervé, P. Boudes, C. Cieslik, D. Montembault, V. Jung, F. Burel, D. Cluzeau, S. Winter, A. Nicolai (2018). Landscape complexity perception and representation in a viticultural designation of the Loire Valley (France): a cultural ecosystem service? *Renewable Agriculture and Food Systems*, 35(1), 77–89. Doi:10.1017/S1742170518000273

Oral communication and posters

Talks

M.E.T. Hervé*, C. Agasse, E. Plaas, R. Schuette, M. Renault, M. Potthoff, D. Cluzeau, G. Pérès, A. Nicolai (2019). Integration of values plurality in the implementation of soil management strategies by European farmers. *Soil Biota driven Ecosystem Services in European Agriculture conference*, 22-23 October 2019, Braunschweig, Germany.

M.E.T. Hervé*, M. Renault, E. Plaas, H. Bergmann, T. Runge, M. Potthoff, D. Cluzeau, A. Nicolai (2018). Plural values associated with soil biodiversity among farmers in Europe. In *SFE², International Conference on Ecological Sciences*, 22-25 October 2018, Rennes, France.

M.E.T. Hervé*, M. Renault, E. Plaas, H. Bergmann, T. Runge, M. Potthoff, D. Cluzeau, A. Nicolai (2018). Plural values associated with soil biodiversity among farmers in Europe. In *ISEE, 15th Congress of the International Society for Ecological Economics*, 10-12 September 2018, Puebla, Mexico.

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Posters

M.E.T. Hervé*, M. Renault, D. Cluzeau, M. Potthoff, R. Schuette, E. Plaas, A. Nicolai (2019). Implementing the valuating milieu framework to investigate soils and soil biota values in Europe. *Soil Biota driven Ecosystem Services in European Agriculture conference*, 22-23 October 2019, Braunschweig, Germany.

M.E.T. Hervé*, M. Renault, D. Cluzeau, M. Potthoff, R. Schuette, E. Plaas, A. Nicolai (2019). Soils and soil biota values for European farmers: investigating the existence of geographical variations using the valuating milieu approach. In *49th Annual Meeting of the Ecological Society of Germany, Austria and Switzerland*, 9-13 September 2019, Münster, Germany.

M.E.T. Hervé*, A. Nicolai, M. Renault, H. Bergmann, T. Runge, D. Cluzeau, M. Potthoff, G. Pérès, E. Plaas (2018). National specific production systems may induce different perceptions of management impacts on soil biodiversity functions: comparison of five European countries. In *SFE², International Conference on Ecological Sciences*, 22-25 October 2018, Rennes, France.

E. Plaas*, A. Nicolai, M.E.T. Hervé, M. Guernion, K. Hoeffner, S. Winter, D. Cluzeau and H. Bergmann (2018). Effects on inter row soil cultivation in French vineyards – benefits for earthworms and economic implications. In *SFE², International Conference on Ecological Sciences*, 22-25 October 2018, Rennes, France.

E. Plaas*, A. Nicolai, M.E.T. Hervé, M. Guernion, K. Hoeffner, S. Winter, D. Cluzeau and H. Bergmann (2018). Effects on inter row soil cultivation in French vineyards – benefits for earthworms and economic implications. In *XIth International Symposium on Earthworm Ecology (ISEE)*, 24-29 June 2018, Shanghai, China.

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Foreword

This thesis project has emerged in Autumn 2016, with the aim to develop a collaboration between the disciplines of economy and ecology within the SoilMan program. The objective was to complement the econometric approaches introduced in the project proposal by offering another point of view on soils and soil biota values while conjugating the perspectives of various disciplines.

Both the shape and the content of this thesis reflect this attempt. I built my framework on the basis of a philosophical epistemology, applied investigation methods that were developed in Humanities, inquiried farmers on their agronomic practices in order to define the values of an object that is usually tackled by biological and ecological sciences. While incommensurably – and the word is chosen on purpose – rich, this travel has also been a story of compromises and creativity, because it is a kind of challenge to conjugate different ways of thinking, working and writing. In the following manuscripts, some readers, especially from Humanities, may feel less comfortable with the construction of the chapters written as scientific papers. For other readers, especially from ecological sciences, the addition of a theoretical framework apart could look surprising. In any case, the readers may thus not be surprised to find in the single papers some elements that have been more extensively presented in the theoretical sections. The choice here has been to assemble the writing possibilities offered by the different disciplines that looked the most useful to present my work.

Table of content

Introduction

Soils, an under-ground ecosystem with a myriad of functions

Soils correspond to a thin layer at the surface of the globe, at the basis of most terrestrial ecosystems (Whalen and Sampedro, 2010) and situated at the interface between the atmosphere the lithosphere, the hydrosphere (Ritz and van der Putten, 2012) and the biosphere. Hillel (2008) proposes to define soils as "*the naturally occurring fragmented, porous, and relatively loose assemblage of mineral particles and organic matter that covers the surfaces of our planet's terrestrial domains*".

In a nutshell, the formation of soils [1]

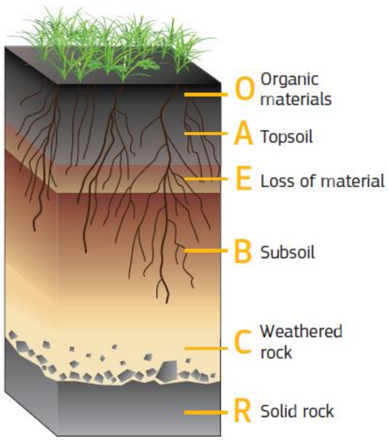
The formation of soils is a very long process initiated by weathering, a physical and chemical alteration and transformation of rocks influenced by local climatic conditions, and occurs at a time scale far greater than a single human life. Six main factors drive the long and ongoing formation of soils and influence their characteristics (Hillel, 2008): (i) the nature of the parent material, *i.e.*, the bedrock, and (ii) the local climatic conditions. The two set the conditions for the third factor, (iii) the local biotic communities. (iv) The local topography also influences the conditions in which soils are formed (*e.g.*, by driving water flows). (v) Time is also a crucial dimension of soil formation. Finally, (vi) human beings and their activities may also have a huge influence on soils ongoing formation.

In physical terms, rocks exposed at the surface of Earth are submitted to daily and seasonal variations of temperature and water content (wetting, drying), whose state can itself change (freezing). All these events induce repeated and variable physical pressures within the rock: extension, retraction, cracks… that ultimately fragment it into smaller fractions. Besides, plethora of chemical reactions change the composition of the minerals initially present in this rock. Organisms (*e.g.*, plants, animals, microorganisms…) progressively colonize the fragmented, weathered rock system. Plants that grow on the degraded material further enhance

[1] The following paragraphs owe a lot of their content to the very pedagogic synthesis written by Hillel (2008), with a few added references. Hillel (2008) is more explicitly cited when a direct quotation is placed in the text.

its fragmentation since their roots penetrate the cracks and increase physical pressures. Their death brings organic material that accumulates. Other organisms that have colonized the system participate to the degradation of this organic material and their own death adds organic material to the system. Further, long-term transformations lead to the creation of a unique soil ecosystem through a "*profile development*" (Coleman et al., 2018), where "*the formation of clay and accumulation of organic material*" is followed by a "*translocation of matter*" and a real "*differentiation of horizons*" (Hillel, 2008). These horizons are superposed horizontal soil layers, progressively and more or less differentiated, with different abiotic and biotic properties (Fig. 1).

A) Hypothetical soil profile and horizons short descriptors
(drawing from Lovell Johns Ltd in Orgiazzi et al., 2016)



O: accumulation of organic material; low mineral content)

A: mixture of organic and mineral material; high organic content; core of biological activities; requires hundreds of years to recover when damaged

E: optional horizon related to material flushed deeper by percolating water

B: mostly a mineral layer that can still be colonized by some soil organisms and plants roots

C: weathered rocks from the bedrock

R: solid bedrock, that may be the parent material of the above soil

B) Example of a soil
(picture from E. Micheli in Orgiazzi et al., 2016)

Figure 1 | Hypothetical stratified organization of a mineral soil in horizons (A) and example of a real soil (B).

The different particles that form soils are highly diversified in size, composition, relative proportions and distribution; this results in soils that are themselves incredibly diversified across the globe (Ritz and van der Putten, 2012) and in Europe as well (Virto et al., 2015).

Soils diversity can be observed at such a very fine scale that even two neighbouring soils can by highly different. For those who have to work with and to manage them, like farmers, it requires to diagnose their soils in order to know how they function as well as to adapt their practices according to their specificities. Knowledge about soil functioning can be obtained through learning-by-doing. Soil analysis is another tool available to farmers, and even compulsory within the European Union (EU), to obtain more information *e.g.*, on soil texture, structure, composition (nutrients, organic matter), chemical properties (*e.g.*, pH) and organisms.

Some soil properties and their influence on soil functioning

Functions are processes that "*regulate the flux of energy and matter through the environment (e.g., primary productivity, nutrient cycling, and decomposition)*" (Laureto et al., 2015). Soil ecosystems for instance realize crucial functions that may support and determine many other and above-ground ecosystems and that may be particularly important for Humanity's sake, *e.g.*, the regulation of water cycle, the decomposition of organic material, carbon and nutrient cycling, carbon sequestration, soil biota sustaining (including phytophagous or pathogen organisms that may jeopardize cultivated plants), diseases suppression, or primary production (Comerford et al., 2013; Hillel, 2008; Schulte et al., 2014; Techen and Helming, 2017). Soil functions are driven by soil chemical, physical and biological properties. The next paragraphs briefly introduce and define a few of them that will appear further in the thesis. Yet, the reader must be aware that this is only a partial overview and that other soil properties are crucial *e.g.*, pH, cation exchange capacity or bulk density…

Solid fraction and texture of soils

The theoretical composition of a soil in an optimum state would be: 45% of solid material, 5% of organic matter, and 50% of pores, equally filled with water or air (Kalev and Toor, 2018). The nature and the relative organisation of these fractions are among the main drivers of soil functioning (Ritz and van der Putten, 2012). Soil solid fraction can be characterized by the nature (*e.g.*, the mineral composition) and the size (ranging from pieces observable with the naked eye to very small elements that can be seen with a microscope only) of its particles. Thus, soil texture refers to the distribution of different size classes of soil particles. Usually, three main textural fractions are identified (their respective size-ranges may slightly differ between typologies): sand (particles ranging from 63 to 2000 micrometers. FAO, 2006), silt (particles ranging from 2 to 63 micrometers, FAO, 2006) and clay (particles smaller than 2 micrometers, FAO, 2006). Materials larger than 2mm (gravel, stones, cobbles, boulders) are not considered as soil material *per se* (Soil Survey Staff, 2014) even though they also influence soil functioning. Hillel (2008) compared sand and silt to a kind of soil skeleton, since they remain relatively inert, while clay would represent soil flesh, since it is the one that absorb water and solutes, shows a high plasticity and may have different behaviors in different conditions. Thus, soil texture is one of the drivers of soil functions. For instance, Wiesmeier et al. (2019) noticed that soil texture could be a promising indicator to evaluate organic carbon storage, that participates to the function of carbon sequestration. **Water regulation is also influenced by**

soil texture. For instance, in India, Patle et al. (2019) emphaiszed the role of sand for water infiltration in cultivated soils, which may benefit to crop growth. As such, texture is particularly important to consider in farming activities. An indeed, soils' texture was initially an agricultural descriptor of soils, used to evaluate the degree of easiness to work on them (*e.g.*, to till them) (Coleman et al., 2018).

<u>Soil organic matter</u>

Soil organic matter (OM) represents another crucial component of soils and research has investigated its potential roles on several soil functions. For instance, in terms of biomass production, Garratt et al. (2018) observed higher yields in cereal crops when soil OM content increases. Yuan and Theng (2012)'s review emphasized, among others, the role of OM together with clay in soil structuration and in nutrient cycling. Another function of soils related to OM is carbon storage, seen as a possible way to mitigate climate change in the context of global warming (Minasny et al., 2017). As such, OM participates to condition the suitability of soil ecosystem for plant growth. However, conclusions drawn from the scientific literature are far from complete nor clear and still submitted to discussion. For instance, OM is often perceived as enhancing water retention in soils, thereby supporting plants growth. This has been challenged by Minasny and McBratney (2018) who showed that such retained water may not necessarily be available for plants. **Still, OM is seen to be of great importance for agricultural activities and its depletion - organic carbon content is low to very low in 45% of European mineral soil (Berge et al., 2017) - has been recognized as a huge issue in Europe (Montanarella, 2007).**

<u>A huge diversity of organisms</u>

Overall, below-ground organisms have been much less inventoried and identified than above-ground ones and for long, mostly soil macrofauna received attention (Barrios, 2007). It is now acknowledged that soil ecosystems contain the most tremendous diversity of organisms on Earth, actually far beyond any above-ground ecosystem (Ritz and van der Putten, 2012). Numerous taxa are considered as being soil organisms, from bacteria, earthworms, some insects to vertebrates like moles (FAO et al., 2020; Fig. 2). For Wurst et al. (2012) the combination of soil heterogeneity (in chemical, physical and spatial terms) and organisms' adaptation to such a complex environment may explain the huge diversity of soil biota. Swift et al. (1979) differentiated between microfauna, mesofauna, macroafauna and megafauna according to the size of soil organisms (Fig. 2). Some groups count thousands of species of which only a small fraction is currently known. Soil organisms are not only diversified: their density is also incredibly high. One single gram of soil can contain up to 200m of fungal hyphae, a billion of bacteria cells and several thousand of various and different taxa (FAO, 2020). Most of these organisms are concentrated within the first 20 cm of soil, even though occasionally soil biological activity has been recorded until 2-3m of depth (Hillel, 2008). Finally, soil organisms represent a major component of biomass on Earth (Bar-On et al., 2018).

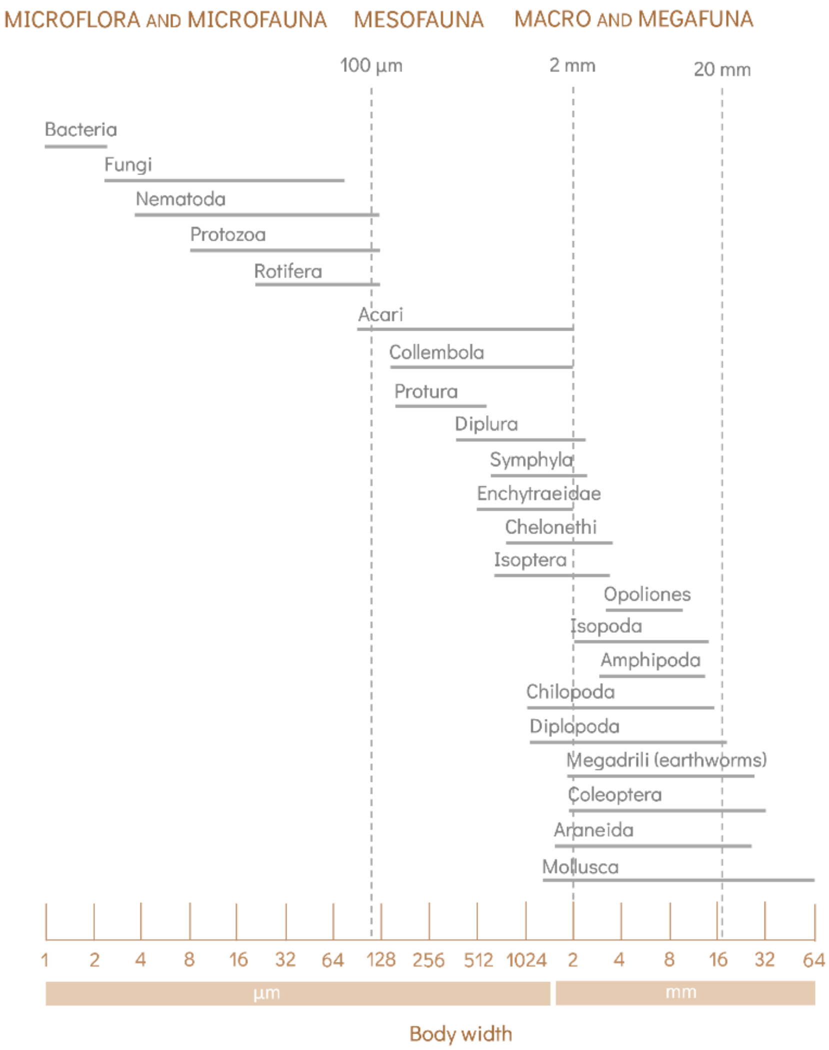


Figure 2 | Classification of soil organisms according to the width of their body (modified from Swift et al., 1979).

If soil organisms are affected by soil chemical and physical characteristics, they can also modify them in return (Kladivko, 2001; Wurst et al., 2012). As such, they are involved in the realisation of various soil functions like waste organic matter processing, carbon flux, nutrient and water cycle regulation, water filtering, soil structuration, trophic interactions, biomass production (European Commission, 2010; Wurst et al., 2012). Different organisms may participate to the realisation of different functions. Thus, soil organisms can be grouped according to the role they play in soils, *i.e.*, into different functional groups. For instance, one classification distinguishes between (i) chemical engineers (particularly involved in the degradation of OM); (ii) biological regulators (that play a key role in soil trophic chains) and (iii) ecosystem engineers (*e.g.*, earthworm, ants or termites) that have a particular effect on soil structuration and restructuration thereby modifying the habitat conditions for other soil organisms (Bottinelli et al., 2015; European Commission, 2010).

Soil biodiversity is defined as "*the variety of life belowground, from genes and species to the communities they form, as well as the ecological complexes to which they contribute and to which they belong, from soil micro-habitats to landscapes*" (FAO et al., 2020). Over the last decades, research has increasingly investigated the roles of soils organisms and biotic communities in the realisation and sustaining of soils functions (Bardgett and van der Putten, 2014; Wagg et al., 2014; Wurst et al., 2012; Tab. 1). Taxonomic biodiversity may play a role in the realisation of soil functions, *e.g.*, Gould et al. (2016) observed that plant taxonomic diversity and species identity could be relevant to consider in order to understand soils structuration in aggregates. Barrios (2007) reported possible species richness thresholds below which soil functioning could not be ensured. Besides, if the concept of soil biodiversity certainly encompasses taxonomic diversity among soil organisms, it also covers their "*genetic, phenotypic (expressed), functional, structural or trophic diversity*" (FAO et al., 2020). In general, functional diversity has a singular and crucial influence on the realisation of ecosystems functions (Díaz et al., 2006; Kardol et al., 2016), probably even more than species diversity (Tilman, 1997). In soils, for instance, microbial functional diversity has a key role in soils nutrients cycling (Trivedi et al., 2019). As such, for Wurst et al. (2012) "*the composition of the community, the traits of key species or groups and their relative abundance and complementarities*" drive soil functioning and associated processes. Overall, even though the link between soil biodiversity and ecosystems functions is still not fully understood (Bünemann et al., 2018), preserving soil biota and its diversity may be important to maintain soil functioning. For long, research on soils has been dominated by disciplines that focused on physicochemical processes and parameters, *e.g.*, on the transformation of bedrocks into soils or on the organic and mineral composition of soils, while the role of soil biodiversity remained poorly integrated (Wall et al., 2010). The conception of soils as a real habitat is more recent (Lavelle, 2012), but has encountered noticeable knowledge improvements over the last decades, even though much still remains to be studied.

Table 1 | Links between soil biota, soil functions and ecosystem services produced by the BiodivERsA SoilMan consortium. For most processes and functions, the interaction and competition between organism groups is also relevant. (Useful for illustrative purposes, but not exhaustive).

Organism	Process	Function	Service / disservice	Quantification	Farmers benefit	Societal / overall benefit	Farmers drawback	Societal / overall drawback	References
Earthworm	Feeding	Decomposition	Organic waste removal	CO_2 release; Litter disappearance, Litter weight loss, Nutrient release from litter	Less crop residue management efforts	Less efforts / and costs via land use products for organic waste removal	None	Less money and job opportunities in waste removal related value chains	Lubbers *et al.* 2013 Huang *et al.* 2020
		Trophic interaction / control on fungi / bacteria / nematodes	Pathogen repression, reduction of toxins, pathogen dispersal		Less efforts in plant protection, high quality crops, higher product prices	Less pollution of arable environments, soils and ground water	Less control over pathogen loads Possible pathogen spread by earthworms	Reduced demand and sales for products in crop protection industries	Oldenburg *et al.* 2008 Monard *et al.* 2010
		Seed predation	Weed control, Seed loss	Weed germination	Protection of crops from weeds	Less herbicide used	Less control over weed loads Possible feeding on cultivated seeds		Eisenhauer *et al.* 2010 Forey *et al.* 2011 Clause *et al.* 2015
	Burrowing	Soil structuring	Provision of bio-(macro)pores	Infiltration rate	Less water erosion, higher water holding capacity, better aeration	Less overall soil degradation	Burrows may allow fertilizers to pass through to deeper soil layers	None	Ernst *et al.* 2009 Capowiez *et al.* 2015 Piron *et al.* 2017
	Burrowing/ casting	Soil aggregation	Erosion control	Aggregate sizes and stability	Less soil loss from erosion	Less secondary constraint from erosion (soil refill)	None		Le Bayon *et al.* 2001 Le Bayon *et al.* 2002
	Burrowing/ feeding/ casting	Bioturbation	Soil fertilization by mixing organics and minerals	Soil transport	More effective use of soil nutrients (less fertilization)	Overall increase of soil fertility		Reduced demand and sales for chemical fertilizers	Van Groenigen *et al.* 2014 Van Groenigen *et al.* 2019
Mites/ Collembola	Casting	Soil structuring/ aggregation	Erosion control	Aggregate sizes and stability	Less water erosion, better aeration of soil	Less overall soil degradation	Surface runoff increases	None	Siddiky *et al.* 2012 Maaß *et al.* 2015
	Feeding on litter	Decomposition	Organic waste removal	CO_2 release, litter disappearance, litter weight loss, nutrient release from litter	Less residue management efforts	Less efforts and costs via land use products for organic waste removal	None	Less money and job opportunities in waste removal related value chains	Kaneda *et al.* 2008 Scheunemann *et al.* 2015
	Feeding on bacteria	Trophic interaction/ fungi/ bacteria control	Pathogen repression, Reduction of toxins	Soil respiration	Less efforts in plant protection, high quality crops, Higher product prices	Less pollution of arable environments, soils, and ground water	Less control over pathogen loads	Reduced demand and sales for products in crop protection industries	Sabatini *et al.* 2001 Broza *et al.* 2001
	Feeding on nematodes	Control on nematodes	Pathogen repression						Read *et al.* 2006 Kaneda *et al.* 2008
Slugs and Snails	Feeding	Decomposition (33% of total soil biota activity), but also reduce plant growth for some species	Organic waste removal, but also decrease of plant production in some species	CO_2 release, litter disappearance, litter weight loss, nutrient release from litter, but also plant attacks and growth reductions in some species	Less residue management efforts	Less efforts / and costs via land use products for organic waste removal	Holistic approach difficult to understand (direct effects less visible), change in production system (socially difficult to accept)	Less money and job opportunities in waste removal related value chains	Wolters and Ekschmitt 1997, Mason 1970a, b

	Burrowing/ feeding/ casting	Trophic interaction/ activating microflora/ bioturbation	Increasing decomposition/ mineralization	Microbial activity increase, mineral increase	More effective use of soil nutrients (less fertilization)	Less pollution of arable environments, soils, and ground water	None	Reduced demand and sales for fertilizers	Edwards 1974
	Burrowing	Soil structuring	Provision of bio-(macro)pores	Infiltration rate	Less water erosion, higher water holding capacity, better aeration of soil	Decreased erosion and drought risk	Burrows may allow fertilizers to pass through to deeper soil layers	None	Wolters and Ekschmitt 1997, Mason 1970a, b
	Prey, host, transporter	Trophic interactions/ dispersions	Food web/ pest control	Relationships in food chains	Less efforts in plant protection, high quality crops, higher product prices	Less pesticide production (leading to less pollution, less human health issues, increase in biodiversity like birds)	Holistic approach difficult to understand (direct effects less visible)	Reduced demand and sales for products in crop protection industries	Nyffeler and Symondson 2001, Rowley *et al.* 1987, Fusser *et al.* 2016, Türke *et al.* 2012
Enchytraeids	Feeding on litter	Decomposition, nutrient release, enhancing microbial activity	Organic waste removal, plant nutrition	litter disappearance, litter weight loss, nutrient release / Nmin, Ntot	Less crop residue management efforts, soil fertility	Less efforts / and costs via land use products for organic waste removal, less pollution by fertilizers	need to coordinate nutrient release from decomposition and plant nutrient demands *(e.g.,* by catch crops)	Less money and job opportunities in waste removal related value chains, reduced demand and sales for fertilizers	Graefe and Schmelz 1999 Gajda *et al.* 2017
	Burrowing	Soil structuring, formation of micropores	water infiltration and water storage; facilitation of root growth	infiltration rate; pore size distribution	less water erosion, higher water holding capacity, better root penetration	reduced loss of fertile soil by erosion	None	None	Didden 1990 Marinissen & Didden 1997
	Casting	Soil aggregation (formation of microaggregates)	erosion control, reduced risk of slaking	aggregate sizes, aggregate stability	less water erosion, higher water holding capacity	reduced loss of fertile soil by erosion			Langmaack *et al.* 2001; Marinissen & Didden 1997)
		Bioturbation	Increasing organic matter, formation of organo-mineral complexes	soil organic matter content; organic matter stability/ turn-over rate	enhancing soil fertility	reducing CO2-release		Reduced demand and sales for fertilizers	Schrader *et al.* 1997
Soil microbial biomass	mineralisation	Nutrient release	Plant nutrition	SIR, CFE	Soil fertility	less pollution by fertilizers	Need to coordinate nutrient release from decomposition and plant nutrient demands *(e.g.,* by catch crops)	reduced demand and sales for fertelizers	Wardle 1992
	Secretion	Soil aggregation/soil structuring	Erosion control/provision of pores	Aggregate sizes and stability	Less water erosion, better aeration of soil	Less overall soil degradation	Surface runoff increases	None	Abiven et al 2007 Pérès *et al.* 2013
Arbuscular mycorrhizal fungi	Branching of hyphae	Soil aggregation/soil structuring	Erosion control/provision of pores	Aggregate sizes and stability	Less water erosion, better aeration of soil	Less overall soil degradation	Surface runoff increases	None	Abiven et al 2007 Siddiky *et al.* 2012

Structure of soils

Soil structure refers to the "*the arrangement or organization of soil particles*" and is driven by the nature of the solid particles, the presence of OM and the action of various organisms, and sometimes from human activities (Hillel, 2008). Three structure classes are usually identified (Hillel, 2008):

- Single grained: soil particles are unattached to each other.
- Aggregated structure: some soil particles are attached to each other, forming aggregates of various sizes, shapes and stabilities. **This type of structure is prefered in agriculture, for it facilitates plants growth, roots settlement, water and air infiltration.**
- Massive structure: soil particles are very close and attached to each other, forming a sort of soil block that is hardly separable.

A major parameter of soil structure is porosity, *i.e.*, the proportion and distribution of spaces between solid particles. Porosity influences the easiness for organisms to move in the soil, allows or constraints interactions between them, by facilitating or hampering their contact and conditions the availability of resources for them, *e.g.*, the presence of water for plants roots. Thus, porosity appears to be a key soil property for functions like habitat for organisms, biomass production, water storage or soil stability and support (Rabot et al., 2018). Contrary to soil texture, soil structure can change with climate variations (*e.g.*, an important rainy event), biological activity (*e.g.*, bioturbation of earthworm) or **soil management** (*e.g.*, the weight of huge machineries can compact soils).

Soils under anthropogenic pressures

Despite the crucial roles of soil functions, and indirectly of soil biota, for human activities (Wall et al., 2005), soil degradations due to anthropogenic activities have been reported worldwide since the early 90's (*e.g.,* Oldeman, 1992). Erosion (by wind and water), floods and landslides, peat soils degradation, loss of carbon, compaction, salinization and sodification, contamination, acidification, loss of fertility, desertification, loss of biodiversity (both below and aboveground), spread of soil borne diseases and sealing are as many issues that have been recorded (Jones et al., 2012; Virto et al., 2015). A costs evaluation of land degradation in the EU25 led to a partial amount that went up to €38 billion per year, and yet, the costs of biodiversity loss, sealing, compaction and hindered soil functions could not even be estimated (Montanarella, 2007). Moreover, because soils are not renewable at the scale of several human generations, their degradation is all the most problematic (Powlson et al., 2011) *e.g.*,damages on soil biota may require some time before organisms recover and communities restore. Numerous threats on soils have been recorded at global scale, and among the many different causes that have been identified are land uses changes and intensification in agricultural land (FAO and ITPS, 2015). In 2018, agricultural land represented 36.85% of the total land area in the world (FAO, 2020). Thus, a transition towards more sustainable agricultural systems allowing to reduce of the negative impacts of farming activities may represent an emergency (Foley et al., 2011), to ensure ecosystems preservation but also food security.

Soil biota and their functions at stake in agricultural activities

Challenges associated with modern agriculture are numerous and its indisputable improvements in terms of food production quantity have been highly counterbalanced by its environmental consequences worldwide (Foley et al., 2005). The recorded negative impacts of agriculture activities on the environment are generated by both the extension of cultivated areas, at the expanse of natural ecosystems, and the intensification of management, to increase productivity (*e.g.*, through irrigation, fertilization, pest control and mechanization) (Foley et al., 2011). Besides, agricultural activities are incredibly dependent upon soil functioning allowed bt soil biodiversity (Lavelle, 1996). Ensuring the sustainability (see Box 1) of agricultural production thus requires to implement and to promote practices that preserve both soil agroecosystems and their functions (Plaas et al., 2019).

Box 1: On the concept of sustainability

The concept of sustainability refers to the "*use of the environment and resources to meet the needs of the present without compromising the ability of future generations to meet their needs*" (WCED, 1987). It has been initially developed to highlight the need to mitigate damages made on ecosystems and their functioning, upon which human activities depend.

In agriculture, the concept of sustainability actually covers various significations and is far from having received a consensual, unified definition (Garud et al., 2010; Garud and Gehman, 2012; Tittonell, 2014). For Geels (2010) if sustainability consists in "*a normative goal*", it is still likely to be debated on the basis of "*deep-seated values and beliefs*". Becker (1997) roots the debates on sustainability into discussions on the values of nature, and in particular into the opposition between intrinsic and instrumental values. Kates et al. (2005) The objective of a sustainable use of soils should be "to provide multiple functions for the well-being of humans and for the environment" according to Blum (2005). For Hillel (2008), applying the concept of sustainability on soils, considered as a resource, amounts to preserve their quality and their production potential by avoiding any kind of degradation on them.

In crop cultures for instance, soil management covers a great variety of activities such as soil tillage, irrigation, fertilization, crop rotations design (number, species and varieties of crops, inclusion of harvested or grazed grasslands) or the use of cover and green crops. Soil management is likely to modify soils chemical, physical and biological properties while it seeks to favor the realization of the production function (food, fiber and fuel), sometimes at the expense of the other soil functions (Schulte et al., 2014). On the other hand, some specific practices like crop rotation, manuring and composting and minimum tillage are promising management practices to limit soils degradation (Barão et al., 2019). Sometimes, the combination of different management practices rather than a focus on one single practice better explains the effects observed on soils (Roger-Estrade et al., 2010). Finally, the effects of management are also soil-dependent. Overall, an inadequate agricultural management may deeply modify the overall functioning of soil ecosystems (Nielsen et al., 2011). One of the identified reasons is that soil organisms and biotic communities are strongly affected by practices that are used in the fields (Dawson and Smith, 2007; Domínguez et al., 2018; Pelosi et al., 2014). The next paragraphs introduce a few management practices in crop culture and briefly illustrate some of recorded effects on soil biota.

Land uses intensity and crop rotations

Land intensification can be described in terms of land uses, along a gradient ranging from natural ecosystems, permanent grasslands to crops systems that more or less diversified (*i.e.*, variable length of crop rotations) and that may include temporary grasslands, or not (Ponge et al., 2013). Intensification may also be conceived in terms of management intensity (*e.g.*, quantity of inputs or frequency of implementation of a practice). Intensification of farming systems and management practices is seen to be responsible for a huge loss of soil biodiversity in Europe (Bottinelli et al., 2015; Tsiafouli et al., 2015) which may ultimately damage soil ecosystems self-regulation and functions (Thiele-Bruhn et al., 2012).

For instance, intensification may lower the abundance, the richness and the functional diversity of soil organisms, even though observed responses may vary between taxa (Ponge et al., 2013; Postma-Blaauw et al., 2012, 2010). Wen et al. (2020) found that intensification affects plants diversity and functional diversity and their interactions with soil bacterial diversity, which may indirectly affect several soil functions *e.g.*, carbon and water storage, nutrient cycling and fertility. At the opposite, less intensive set-asides within an intensive crop rotation system have a positive effect on nematode abundance and richness (Landi et al., 2018). If the type of cultivated crops itself affects soil biodiversity (El Mujtar et al., 2019), the overall crop rotation has an effect as well *e.g.*, on microbial communities (Li et al., 2018) or earthworms (Crittenden et al., 2014). Crops rotations are promoted in agronomy for they generally limit pests' pressures, have different levels of nutrients requirements, *i.e.*, nutrients uptake varies, and influence soils' structuration (*e.g.*, because of various rooting systems) or fertility (*e.g.*, the introduction of legumes between crops allows for bringing Nitrogen into soils). Diversifying crops on farms has become a mandatory requirement from the EU in the frame of the "greening" measures of the CAP (EU regulation 1307/2013).

Tillage practices

Tillage is usually used to control weeds, to incorporate organic matter in deeper horizons and to prepare the soils before seeding (Tab. 2); in areas that are more subjected to drought and erosion, tillage can also be perceived to benefit to water infiltration and moisture (Hillel, 2008). Tillage induces changes in soils characteristics like water content, temperature, aeration, level of contact between organic and mineral particles and on soil biota (Kladivko, 2001) and functions, like carbon storage (Dawson and Smith, 2007).

Table 2 | Simplified summary of soil management intensities along a gradient ranging from direct seeding to inversive ploughing (adapted from Morris et al., 2010; Agasse, 2019). The agricultural model is designated in commonly used terms in the agricultural sector: "Conventional" refers to practices that have been promoted with the use of pesticides, while "Organic farming" refers to labelled models with reduced use of pesticides. None of these terms is meant to carry a value judgment here.

	Reduced tillage (no soil inversion)		Inversive ploughing	
	Direct seeding / No Tillage	**Minimum tillage**		
Characteristic of the soil management system	Most simple soil management: the farmer intervenes at the seeding period and on the seeding row only.	Whole range of intermediate techniques between direct seeding and ploughing, with the same objective than the latest.	Soil put upside down (the surface horizon is brought to depth).	
Soil preparation before seeding and depth	None	Non-inversive preparation 5-20 cm of depth	Inversive preparation 20-30 cm of depth	
Seeding depth		2-5 cm		
Management of crop residues	Usually, conservation of almost all the residues but not systematic	Partial and shallow mixing and incorporation of crop residues into the surface of the soil	Distribution of manure and fertilizers at the surface of the topsoil and burial of crop residues into the soil	
Use of phytosanitary substances	Common use to remove weeds	Can be	Can be	Forbidden
Agricultural model	"Conventional" agriculture			Organic farming

One of the reasons explaining the modifications of tillage on soil functioning is related to its effect on soil organisms. For instance, a recent meta-analysis of de Graaff et al. (2019) showed that tillage tends to negatively affect bacterial and faunal taxonomic diversity; increasing tillage intensity may also reduce microarthropods diversity (Cortet et al., 2002), earthworm functional diversity (Pelosi et al., 2014) and abundance (Crittenden et al., 2014). The effects of tillage differ between trophic groups *e.g.,* organisms feeding on roots are particularly impacted by tillage (van Capelle et al., 2012), and can be temporary *e.g.,* Crittenden et al. (2014) showed that earthworm can recover from ploughing by the next season after the practice was implemented. The extent of tillage effects on soil biota also varies according (i) to the nature of the soils *e.g.,* in terms of texture, (ii) to the intensity of the practice and (iii) to its coupling with other practices such as crop residues and organic matter management (Crittenden et al., 2014; van Capelle et al., 2012; Zhu et al., 2018).

At the opposite, less intensive tillage practices may enhance earthworm diversity, biomass and abundance (Briones and Schmidt, 2017; Ernst and Emmerling, 2009; Kuntz et al., 2013) and microbial biomass (Murugan et al., 2014). Reduced tillage practices (Tab. 2) have been developed to save fuel, time and to limit erosion (Morris et al., 2010) by setting a mulch of crop residues at the surface, which may also limit the loss of organic matter and water evaporation (Hillel, 2008). A review from Soane et al. (2012) indeed showed that reducing tillage intensity may (i) allow to reduce costs, which can overcome a potential (but not systematic) decrease of yields, (ii) improve soil structure which facilitates plants roots implementation. Yet, such systems have been criticized for their dependence upon herbicides to control weeds (Hillel, 2008). Moreover, reduced tillage systems may not fit equally between different farming situations. For instance, sandy and light soils may be way less easy to manage without any tillage than clay (Morris et al., 2010); in northern regions, no-tillage may favor a higher soil moisture and lead to lower soil temperatures in spring, delaying the spring cultural work; moreover, the carbon balance of no-till compared with ploughing remains dependent upon local climatic conditions (Soane et al., 2012).

Fertilization

Knowing nutrients contents in soil helps farmers to have a better idea about which type of crops could fit the best in one given field or which management should be planned in order to improve the production. The three most important macronutrients for plants are nitrogen, phosphorus and potassium (often summarized as “N, P, K”). In farming systems, plants biomass is exported, which depletes the quantity of nutrients given back to the system. **This is one reason why fertilization has been used for so long in agricultural systems and even more since modern**

agriculture have intensified their management. Initially, farmers used organic fertilizers that derived from livestock manure, previous crops residues or minerals transformed into powder (de Souza and Freitas, 2018). Other indirect measures have also been developed to enhance soils fertilization such as crop rotations and green cover crops of legumes. The specialization of agriculture, the need to increase production to respond to food demand and the evolution of land uses like urbanization have conducted to the production of artificial mineral fertilizers. They present the advantage of being immediately available to the plant (de Souza and Freitas, 2018). In general, though, the effects of mineral fertilizers on soil biota are depicted as negative, while organic ones may favor some soil organisms, *e.g.*, in terms of abundance or biomass (Sandor et al., 2016) or occurrence (de Souza and Freitas, 2018).

Use of pesticides

Agriculture pesticides cover different substances (herbicides, insecticides, fungicides) that target different pests, with a global objective to preserve or to increase the production. In some cases, the use of agrochemicals can have deleterious consequences on soil biodiversity, which may thereby impact soil functioning (Thiele-Bruhn et al., 2012). For instance, it has been shown that collembolan abundance may decrease due to the use of certain pesticides, particularly some insecticides, in arable land (Frampton, 1997) while earthworms are known to be sensitive to pesticides and heavy metals (Uwizeyimana et al., 2017). Van Hoesel et al. (2017) suggested that some effects of pesticides on soil organisms may become noticeable after several applications only.

Soil biota preservation at stake for the future of agriculture

Functions ensure ecosystems stability, *i.e.*, resilience and resistance (Srivastava and Vellend, 2005). Many agricultural practices actually sought to replace some functions of agroecosystems: as such, in the case of soil biota, its role in soil functioning had been little consider for long (Barrios, 2007). Yet, because some replacements might remain impossible or would be too costly, it is now widely admitted that through soil functioning, soil biota is crucial for agriculture. But soil biota also mediates the effects of management practices on soil functioning (Brussaard, 2012) and recent works have depicted negative effects of agricultural systems on soil biota and biodiversity. Damages that occur on soil biota and biodiversity may threaten soils ecosystems functioning and, consequently, the continuity of human activities, particularly in terms of food security and nutrition (El Mujtar et al., 2019). Consequently, the preservation of soil biodiversity now appears to be at stake, particularly in agriculture (Geisen et al., 2019). In political terms, to uptake such a challenge may require to develop appropriate policies and tools. Moreover, for land managers, designing one's soil management in order to preserve soil biota and, thereby, soil functioning, may be a complex decision that requires to consider several parameters at once and, maybe, to make compromises between different organisms, functions or objectives.

Policy discourses and measures about soil and soil biota: an historical overview with a focus on Europe

Public interest on soils is not new and the 20th century has witnessed initiatives all around the world to improve their characterization *e.g.,* the FAO launched the first Map of Soils of the World in 1961 and the first draft of a European Soils map was published in 1962 as an initiative from the European Soil Survey Organization. More recently, the importance and relevance of addressing soil preservation, in relation with sustainability issues, has been acknowledged in European and world organizations (Bonfante et al., 2020). In 2015 in particular, the United Nations (UN) adopted the 2030 Agenda for Sustainable Development, based on the definition on 17 Sustainable Development Goals of which seven actually rely on the good functioning of soil ecosystems (EEA, 2019, Fig. 3).

Soils in EU policies

At the European level, the preservation of soils has been tackled by different strategies.

Commitment, policies and regulations

The governance of soils has been adressed by different policies that fall under the regulation of various sectors. In agriculture specifically, when the Common Agricultural Policy (CAP) was implemented in 1962, it aimed at enhancing food production, and its further reforms at regulating it to avoid over-production (Virto et al., 2015). The need to preserve soils as an important resource, and often conceived as a factor of production, has progressively emerged later on (Berge et al., 2017). The first environmental measures in EU agricultural policy appeared in 1992 (Council Regulation (EEC) No 2078/92) and were integrated into the Second Pillar of the CAP when it was created in 1999 (Council Regulation (EC) No 1257/1999). In

2003, decoupled payments and cross-compliance added new environmental requirements. In both reforms, some measures concerned soil management, with a noticeable focus on the reduction of soil erosion and on the enhancement of carbon storage (*e.g.*, in the Good Agricultural and Environmental Conditions in the framework of cross-compliance). Besides, the Nitrate Directive (1991) and some measures of the Water Framework Directive (2000) may also frame agricultural soils management, for instance by providing rules on fertilization to preserve the quality of water bodies.

Figure 3 | Sustainable Development Goals of the United Nations that rely on soil ecosystems preserved enough. From EEA (2019).

A more soil-specific policy project on soils emerged in 2006 with the creation of a soil Thematic Strategy (COM(2006)231 final of the European Commission) that addresses soil preservation issues, as well as a proposal for a Soil Directive (COM(2006) 232 final of the European Commission), that would have provided a global, cross-sectorial frame for soils governance. However, the withdrawal of this Directive proposal in 2014 (Official Journal of the European Union 2014/C 153/03) reflects the difficulties that Member States have encountered so far to agree on a global strategy to address soil protection in the European Union. Nowadays, European policy for soils protection and conservation has been criticized for being scattered and lacking of binding measures (Paleari, 2017). Besides, at national scales, the efficiency of European incentives for soil protection is quite limited and varies a lot between Member States (Turpin et al., 2017).

The creation of dedicated institutions

Several institutions and networks specialized on soil issues have been progressively created in Europe like the European Soil Bureau Network, belonging to the Joint Research Center in 1996 and a specific Soil Awareness group in 2009. In 2013, an agricultural European Innovation Partnership (EIP-AGRI) emerged to favor innovation development, which includes supports provided to research on the topic of soils, and the European Soil Partnership was launched (as was the FAO Global Soil Partnership and a proposition of the United Nations to organize an International Year for Soils, that took place in 2015).

The publicization of knowledge about soils

Several reports have been published for decades, *e.g.*, by the European Council between 1979 and 1989, and several events have taken place, *e.g.*, workshops on “Soil Protection Policies within the EU” in 1998, “The Support of Soil Science Research to the European Sustainable Development” in 2001 and a European Soil Forum in 1999, in order to publicize issues and stakes related to soils.

In 2012, a report from the JRC was published that identified the eight main threats on European soils, *i.e.*, soil sealing, soil erosion, desertification, salinization, soil acidification, soil biodiversity loss, landslides and soil contamination (European Commission 2012).

Soil biodiversity conservation in EU policies

The particular importance of soil biodiversity has progressively raised as a core issue over the last two decades. At world scale, the topic was initially stressed under the influence of the Conference of the Parties (COP) and then further initiatives from the Food and Agriculture Organization of the United Nations pursued the impulse (Fig. 4). This led to the publication of a Global Soil Biodiversity Atlas co-authored by the FAO, several international organizations involved in soil protection as well as the European Commission in December 2020 (FAO, 2020), that has been introduced as the "*first ever report on global soil biodiversity*" (GSBI, 2020) (Fig. 4). A similar publication had already been made ten years earlier in the European Union, when the Environment Directorate-General (DG Environment) of the European Commission, together with the JRC and four European researchers edited a European Atlas for Soil Biodiversity (Fig. 4).

However, in terms of policy, the protection of soil biota may appear insufficient within the EU. No European conservation policy actually focuses on soil biota (Fournil et al., 2018) and soil ecosystems. Thus, their protection may rather consist in an indirect and collateral consequence of environmental regulations (Virto et al., 2015), *e.g.*, in the case of the Habitat Directive (European Commission, 2010). Traditional conservation tools appear to be insufficient to preserver soil biota because there is a limited number of species in soils that could appeal for an emotional reaction on people ("*flagship*" species) or that would have been identified as particularly important for the functioning of the whole biotic community ("*key-stone species*") Usher (2006). Thus, for Ushe (2006) the focus on soil ecosystems sustainability rather than biodiversity would be more appropriate. Moreover, recent initiatives of the EU, in the frame of the European Green Deal, are perceived as a promising way to better preserve European soils, by integrating a specific focus on agricultural activities, by addressing climate change but also by better linking soils regulation with biodiversity policies (Montanarella and Panagos, 2021).

Conceptualizing the values of soils in EU policies

Since the beginning of the 21th century, and particularly over the last ten years, soil biodiversity has triggered the interest of scientific communities, international organizations and politics, like the FAO and the European Union.

In particular, the way soil biota is considered and integrated into European regulation reflects how it matters, *i.e.*, for which reasons it is considered as important, to what extent, what would be the relevant and legitimate means to preserve it. In other words, this amounts to attribute a certain value to soil biodiversity. For Frelih-Larsen et al. (2017) one lack in current European policies on soils is actually the limited conceptualization of soils value(s).

Therefore, discussing the values of soil ecosystems appears to be one task that the EU need to undertake. This may already be in the way: in December 2020 the European Soil Observatory was launched, a platform that aims to support soils preservation in the EU and to discuss soils values within European societies (Lange, 2020). This may allow to follow the recommendation provided by Techen and Helming (2017), who advocated for a better understanding of "*the value of soil functions for societal value systems, particularly in terms of ecosystem services, resource efficiency, and ethical and equity considerations*". As such, the authors emphasized the fact that in agriculture soils functions could actually matter for plural reasons beyond biomass production only.

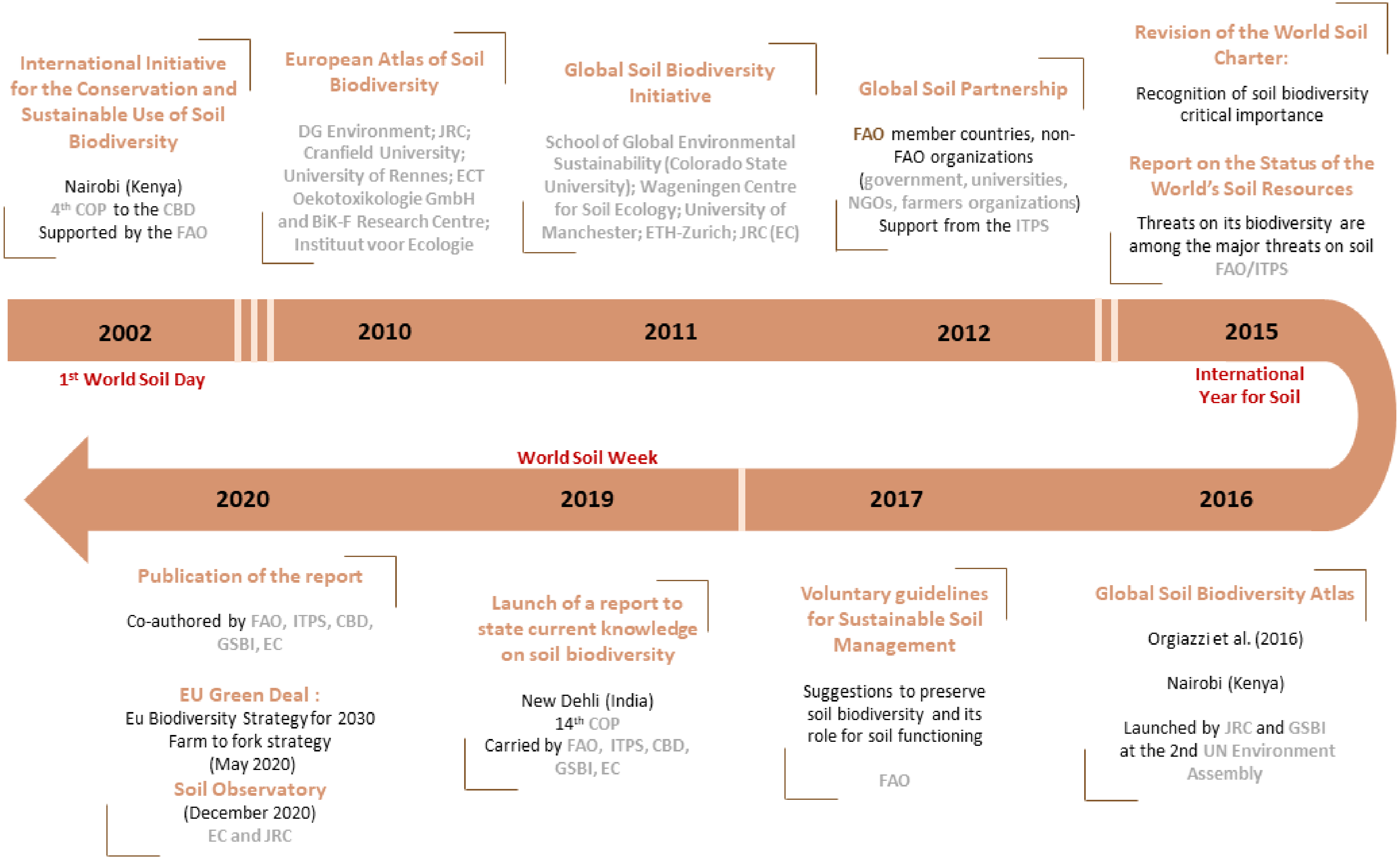


Figure 4 | Overview on a few world and European initiatives to preserve and to enhance knowledge about soil biodiversity over the last twenty years. COP: Conference of the Parties; CBD: Convention on Biological Diversity; DG: Directorate-General; JRC: Joint Research Center; EC: European Commission; NGO: Non-Governmental Organization; FAO: Food and Agriculture Organization; ITPS: Intergovernmental Technical Panel on Soils; GSBI: Global Soil Biodiversity Initiative

The integration of soil biota when designing farming practices

Bartkowski and Bartke (2018) stressed the need to "*understand the behaviour of those who manage the fields*" at an individual level, in order to improve the governance of agricultural soils. Through their management decisions, agricultural land managers like farmers are key actors of soil preservation (Doran, 2002) and their decisions can be seen asembedded within and depending on singular situations of management (Ahnström, 2009; Mills et al., 2017). Modifying the factors that influence farmers' behaviour has been perceived as one of the easiest ways to achieve more sustainable farming activities in Europe (Bartkowski and Bartke, 2018). As such, an extensive field of research has tried to identify which factors motivate farmers to adopt certain management practices, in particular those that benefit to the environment in general, or to specific (agro)ecosystems like soils *e.g.*, Gould et al. (1989).

Farmers' decision-making related to their soil management practices

Farming activities embedded in complex contexts

Farmers' decisions are influenced by various factors (Alskaf et al., 2020; Bartkowski and Bartke, 2018; Prager and Posthumus, 2010), that are context and region specific (Bijttebier et al., 2018) and farmers themselves belong to different networks that may influence them (Frelih-Larsen et al., 2018). Thus, Frelih-Larsen et al. (2018) qualified farmers as "*actors in context*" and suggested to classified factors influencing farmers' decisions into three categories:
(i) farmers' agency, *i.e.*, the elements that characterize farmers themselves (*e.g.*, personality traits), their perceptions and preferences as well as the way they understand their environment;
(ii) the farm level, in particular the farm and farming system characteristics (size, orientation, economic conditions, tenure status…);
(iii) external environmental features, like regulations and incentives, the existence of extension services, the influence of society and of networks.
This renders agricultural contexts particularly complex, creating numerous elements that farmers have to cope with. In other words, farmers' management decisions do not rely on agronomic considerations only but they also respond to structural elements of the farming sector (Roesch-McNally et al., 2018b).

Factors driving farmers' decisions

Numerous factors have been investigated as possibly influencing farmers' management practices. For instance, in their literature review, Knowler and Bradshaw (2007) retained 46 factors in their analysis, a fraction only of all the variables they recorded. Thus, this section does not aim to introduce each of these factors, but only to illustrate a few of the multiple elements that potentially play a role in soil management design. For extensive reviews and meta-analysis on the topic the reader can refer, for instance, to Baumgart-Getz et al. (2012), Knowler and Bradshaw (2007), Morris et al. (2010) or Soane et al. (2012).

The economic factor is one of the most influencing on farmers' soil management decisions (Bartkowski and Bartke, 2018; Lahmar, 2010; Sastre et al., 2017). Bijttebier et al. (2018) for instance showed that the adoption of non-inversion tillage is particularly favoured by farmers who believe it to be less costly in terms of working time and fuel. But the economic reasoning, defined at seasonal scale (Roesch-McNally et al., 2018a), can also jeopardize the adoption of certain management practices that may be more beneficial to soil functioning (Techen and Helming, 2017). In the US for instance, costs related to the implementation and the termination of cover crops sometimes limit their use by farmers (Roesch-McNally et al., 2018b; in Europe though, farmers have to apply a minimal soil cover in order to respect cross-compliance measures and to receive CAP subsidies ; regulation (EU) No 1306/2013).
Other factors participate to drive farmers' management beyond economic consideration. In Germany, Techen and Helming (2017) showed that consumers' demand, policies, farmers' own attributes (age and education in particular), an increasing knowledge about soil threats, climate change and technologies altogether encourage farmers to implement management practices favouring the provision of multiple soils functions. In Ireland, Daxini et al. (2018) policies influenced farmers' intentions to fertilize their soils after a soil analysis. As a result, in Europe, farmers' decisions about soil management have been characterized as "*a mix of personal, socio-cultural, economic, institutional and even environmental variables*" (Prager and Posthumus, 2010). For Mills et al. (2017) these multiple factors may have two types of influences: (i) on farmers' ability to adopt environmentally-friendly management (they correspond to external drivers related to environmental biophysical elements, finance, human capital, labour, social capital and time); (ii) on farmers' willingness to uptake alternative practices (they may correspond to personal characteristics of farmers and have been investigated under different concepts such as belief, attitudes, behavioural control, response efficacy, self-identity or norms).

Mills et al. (2017) also emphasized the influence of other actors *e.g.,* public and private advisors, farmers networks (*e.g.,* familial) or local governance structures, situated at community and societal level, *i.e.,* beyond the farm. In Spain, Sastre et al. (2017) noticed that the first reason underlying the use of ploughing in olive orchards was the reproduction of traditional and usual ways of doing things while lacks of training were reported by farmers. In this US, education had been identified as a factor favouring the adoption of soil conservation practices (Gould et al., 1989). In Italy, Salvia et al. (2018) showed a positive influence of farmers' participation into long-term scientific projects on their level of adoption of soil conservation practices.
Because multiple factors can drive farmers' decision and behaviour, Bijttebier et al. (2018) suggested to develop diversified strategies to facilitate the adoption of more sustainable soil management practices, *i.e.*: (i) coercive global (EU level) and site-specific regulations, to be combined with (ii) more important education and extension, (iii) enhanced social exchanges like pee-to-peer learning, (iv) economic incentives that cover the possible increasing costs or decreasing revenues and (v) the availability of adequate tools and machineries. In this paper, social exchanges in particular are described as vectors for knowledge transfer but also of evolutions of farmers' values.

Studies focusing on the factors leading to farmers decision may allow to detect trends in practices choices within a given population *e.g.,* tendencies among farmers of the same age (Gould et al., 1989; Potter and Lobley, 1992). Moreover, the frequently used quantitative approaches rely on study designs that generally allow to survey a huge number of farmers (*e.g.,* Daxini et al., 2018). Identifying the factors playing a role in farmers' decision-making is necessary but may not always allow to understand how decisions are actually formed. For instance, it hardly informs on why some farmers may consider that the economic factor comes first, while others may try to better preserve their soils, even though their system becomes less profitable in monetary or production terms. Besides, study designs have a great influence on the obtained results: when factors are already defined by the researchers, the range of possible answers for farmers during a survey is constraint. This may limit the investigation of farmers' own perception of their environment and of their decisions.

Answering these issues requires to adopt more comprehensive approaches on farmers' management decisions. For instance, Coughenour (2009) investigated the influence of farmers' networks on the adoption of conservation agriculture and Compagnone and Priebetich (2017) investigated the importance of soil management practices on farmers' self-identity.

Soil biota integration in farms' management

Plethora of indicators are used by farmers either to define their management strategy or to evaluate its results *a posteriori*. Some of these indicators relate to the characteristics of soils themselves, but soil organisms like macro-invertebrates may be used as well (*e.g.*, Dawoe et al., 2012). In their worldwide review of farmers' knowledge about soil organisms, Pauli et al. (2016) found that soil biota was particularly used as an indicator of soil fertility and as a discriminant criterion for soils classifications among farmers. But soil organisms can also be considered as pests. Pauli et al. (2016) also observed that earthworms are among the most mentioned organisms in the literature. In Colombia for instance, Zúñiga et al. (2013) reported that farmers were able to differentiate between different earthworm species and that they associated them with soil quality and functioning (*e.g.*, organic matter decomposition). Similarly, in Wartenberg et al. (2018), farmers associated earthworm to soil loosening. Finally, Pauli et al. (2016) noticed that only a few studies have investigated farmers' knowledge about soil organisms in Europe, where research has rather focused on soils physicochemical properties.

The actual integration of soil biota in management decisions is not always very clear. In Europe, soil biota appeared to be poorly considered when farmers choose their soil management practices (Bechini et al. 2020). One may assume that it is related to a limited knowledge on the matter. In Barbero-Sierra et al. (2016), farmers' knowledge of soils mostly covered easily visible elements at landscape scale and physical parameters that influence crop production, while biotic soil components remained overlooked. Moreover, soils organisms are small, barely visible, and their crucial roles in soil functioning may still be largely ignored (Ludwig et al. 2018). However, Pauli et al. (2012) hypothesized that the amount of farmers' knowledge about soil biota does not necessarily relate to the size of the organisms, the biggest being more easily observed, but also on farmers' ability to link soil biota with their farming activities and with soil quality. Actually, Bampa et al. (2019) reported that land managers like farmers may have a deep understanding of the effect of management on soil functioning. Besides, for Frelih-Larsen et al. (2018) and Techen and Helming (2017), farmers' awareness of and knowledge about soil functions would represent a key factor of their willingness to adopt conservative soil management practices, which may also include a better preservation of soil organisms. Thus, the reasons underlying a limited integration of soil biota into management practices design remain quite unclear.

Considering farmers' values to better understand the importance of soils and soil biota in their management practices

Recent studies showed that farmers may not always integrate the effects of their practices on soils when planning or evaluating their management (Prager and Curfs, 2016). Thus, while extensive knowledge already exists about management practices that would benefit soils, their functioning and their biodiversity (Tamburini et al., 2020), its practical application may rather be challenging. On that account, (1) making soil biota matter when designing agriculture practices is still a challenge and (2) its effective preservation at the EU scale may require a global transition of agricultural systems. Triggering events (*e.g.,* financial, political) can lead farmers to deeply modify their usual decisions, *i.e.*, to develop a transition of their farming system orientation, while little changes would be rather incremental and progressive (Sutherland et al., 2012). For Bager and Proost (1997), farmers' environmental behavior partly depends on different values that play a role in setting their priorities. Relying on the concept of values for theorizing farmer's decision-making can be a relevant way to improve our understanding of their choices. Management actions are decided according to a specific situation, within which farmers are valuing individuals who designate what matter to them, and in particular here, to what extent soil biota may be considered as important in the perspective of soil management.

Characterizing the values of agricultural soils and soil biota to better preserve them

Helming et al. (2018) identifies three challenges to ensure a sustainable management of soils, *i.e.,* "*(i) understanding the impacts of soil management on soil processes and soil functions; (ii) assessing the sustainability impacts of soil management, taking into account the heterogeneity of geophysical and socioeconomic conditions; and (iii) having a systemic understanding of the driving forces and constraints of farmers' decision-making on soil management and how governance instruments may, interacting with other driving forces, steer sustainable soil management.*". In the third perspective, studying values may be particularly relevant, since they play the role of indicators that represent socioecological processes involved, for instance, in biodiversity loss (Maris et al., 2016a). Thus, investigating specifically (i) how farmers value soil biota, *i.e.,* to what extent and why such valuations are integrated or not in their management practices and (ii) which elements influence such valuations should provide elements that answer to the third point.

The values of nature have been extensively used as proxies to investigate and qualify the myriad of relationships that human-beings have with their environment. Studying values allows for improving knowledge, communicating, raising awareness and supporting decision-making (Maris et al., 2016b), in particular to protect the environment (Chan et al., 2016). As such, scientific literature is brimming with studies assessing the values of nature (*e.g.*, De Vreese et al., 2016), landscapes (*e.g.*, Gómez-Sal et al., 2003), specific organisms (*e.g.*, Blanco and Carrière, 2016; Foale et al., 2016), biodiversity (*e.g.*, Foale et al., 2016), ecosystems (*e.g.*, Edwards et al., 2016).

When it comes to soil organisms in particular, Jiménez Jaén et al. (2001) associated soil fauna with a "*natural resource*" that may allow for improving the sustainability of management in agroecosystems. More recently, the European Commission has compared the actions and influence of soil biota on soil ecosystems with the functioning of a "*factory*", within which organisms are "*workers*", "*supervisors*" and "*architects*" (European Commission, 2010). Some researchers have tried to estimate the economic value of soils functions and associated services (Dominati et al., 2014) and of soil organisms involved in soils ES (Pascual et al., 2015; Plaas et al., 2019). These discourses and the use of the ES framework are mostly utilitarian, *i.e.*, the values of soil organisms are estimated on the basis of their utility for human beings. Yet, values may not necessarily amount to monetary measurements:

> Values and systems of values structure the way some things or some states of affairs can be considered as good, fair, desirable, and thus, they overreach the way in which, through individual behaviours and institutional arrangements, economic values. (Maris et al., 2016; our own translation)

Consequently, one can notice a clear academic movement that urges for considering and assessing the plurality of nature's values (Cooper et al., 2016; Himes and Muraca, 2018; Jacobs et al., 2018). As such, Arias-Arévalo et al. (2017) defined the values of nature as the "*multiple ways in which nature, ecosystems or ecosystem services are important for individuals or social groups*". One declared objective is to support decisions and policies framing the management of ecosystems (van Riper et al., 2017), natural resources, and land use (Jacobs et al., 2016). This rising interest may participate to attribute or to acknowledge the importance, worthiness or role of soil biota beyond monetary terms only. Decaëns et al. (2006) illustrated values plurality of soil biota for conservation, *e.g.*, ecological, patrimonial, recreational, scientific or education values. Usher (2006) as well expressed the values of soil in a conservation perspective in multiple terms. The author first referred to the values of undisturbed soils where particular soil biota has got time to develop. Then he emphasized the particular "*importance*" of soil microbial communities in sustaining soil functions. Finally, he stressed the "*importance*", again, of soils as a "*vital*" support for terrestrial ecosystems and the subsequent need to restore those that have been damaged.

Despite its relatively frequent use, the concept of "value" remains generally blurred (Horcea-Milcu et al., 2019) and may still lack a precise and shared definition (Bidet et al., 2011), even in studies that actually use it (*e.g.*, Schoon and Grotenhuis, 2000). This can lead to misinterpretation since numerous definitions coming from various disciplines exist (Arias-Arévalo et al., 2018; Kenter et al., 2019). For instance, values may be associated with quite stable characteristics of individuals that may take time to change and that cannot be challenged *e.g.*, in research that focuses on farmers' behaviour (*e.g.*, Mills et al., 2017). Other conceptions may be more flexible. The pragmatist epistemology conceives values as active expressions in language and acts that designate what we hold as precious and what we care for, that may change and evolve between different situations (Renault, 2012). Investigating the values of soil biota and soils on farmers' perspective thus requires to clearly express the theoretical background upon which the inquiry is made, *i.e.*, what is a value, who forms values, what is actually valued, why it is valued and what are the (expected) outcomes of valuations.

Redline of the thesis and objectives

Against this background, the effective preservation of soils and soil biota at the EU scale appears to require a wide transition of agricultural systems beyond the innovation of technical practices. It needs to investigate why and to what extent soils and soil biota matter, what is currently problematic about them for society and which would be the relevant ways to solve this. **If politics, from local to EU levels, want agriculture to deeper rely on soil biota and biodiversity, they need to acknowledge their crucial role for farming activities and to first legitimize changes in management practices before actually applying them in the field. Such a transition cannot happen without integrating different actors of agricultural systems and understanding their own perspective on the stakes associated with soils and soil biota.**

Agricultural transitions can certainly be conceived at the level of farmers, who may change their practices at the scale of their own farm. However, values formation actually occurs at various levels, both individual and collective (*e.g.,* regional, municipal or within a farmers' working group). **As such, valuations of soils and soil biota and their evolution or variations across Europe may be conceived as a process particularly dependent upon local spatial and territorial characteristics. Considering the wide scale of application of European policies in agriculture, it may be crucial to determine whether valuations of soil biodiversity occur in the same terms among European farmers.**

On the basis of these elements, our objectives are:

OBJECTIVE 1	To collect the values that are associated to soils and soil biota by European farmers and to investigate the co-existence of plural values.
OBJECTIVE 2	To characterize the situations within which value formation regarding soils, soil biota and soil biodiversity occurs, which may result in spatial and temporal dynamics of values.
OBJECTIVE 3	To understand how territorial characteristics within which farmers are embedded may play a role in the formation of values related to soil biota,

Thus, in this doctoral thesis, I looked into values that are at the basis of farmers' soil management in wheat culture. In particular, I aimed to investigate the potential existence of a plurality of values at stake in farmers' decisions, which has not yet been explored for soil biota and in relation to soil management (CHAPTER 3). Furthermore, I sought to refine this first inventory by inquiring the dynamic formation of values. As such, I paid a particular attention to the potential existence of geographical and temporal variations in valuation processes by considering the specific situations within which values are formed (CHAPTER 4). In a third step, starting from farmers' description of their valuation situation, I adopted a wider perspective on transitions of farming practices. To do so, I investigated the relevance of the "valuating milieu" (VM) as a driver for territorial transitions (CHAPTER 5). Finally, I introduced a case-study from Brittany, that focuses on one particular process depicted in the VM, this is value publicization, and that may play a role in the formation of values (CHAPTER 6).

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Chapter 1

Theoretical background (I)

Conceptualizing the value(s) of nature and ecosystems

Maris (2014) reported an evolution of the ways in which interactions between human-beings and nature can be conceptualized across History. The Antiquity was marked with dependence upon nature. At that time, the first warnings on the destruction of natural resources and of the harmony or balance of the world appeared. During the occident Christianity, nature was seen as a threat, a place where to work or an object to dominate, but some texts also emphasized the importance to respect the divine creation. In a simplified way, modernity can be characterized by a will to control natural features in order to decrease uncertainties in the world.

The 19th century witnessed the beginning of a real environmental reflexion (Maris, 2014; Fig. 5), with an emphasize on the beauty of nature's "wilderness" in the US; the movement ran until the 20th century and was represented by writers and artists like Thoreau, Emerson Muir, Leopold… (Larrère and Larrère, 2015a). From that period on, numerous authors and researchers have tried to qualify our relationships with a wild "nature" to be preserved.

Environmental struggles encountered during the 20th century have led to new questions about the protection of nature. In particular, there were questions about the reasons that could justify damages of nature or, at the opposite, about the moral considerations that could imply to preserve it (Fig. 5). Several domains have intended to tackle these questions about the relationships between human-beings and their environment (Flint et al., 2013).

In this perspective, the concept of "values" has been particularly mobilized and by very different disciplinary backgrounds (Arias-Arévalo et al., 2018): ecology, environmental and ecological economics, geography, sociology, conservation biology, or landscape ecology. Consequently, multiple definitions of values are available and the methodologies used to assess them are numerous as well. Some concepts and approaches are still discussed nowadays and may even influence the ways research and politics have evolved (Fig. 5). In particular, monetary values of nature are widely spread but also much discussed.

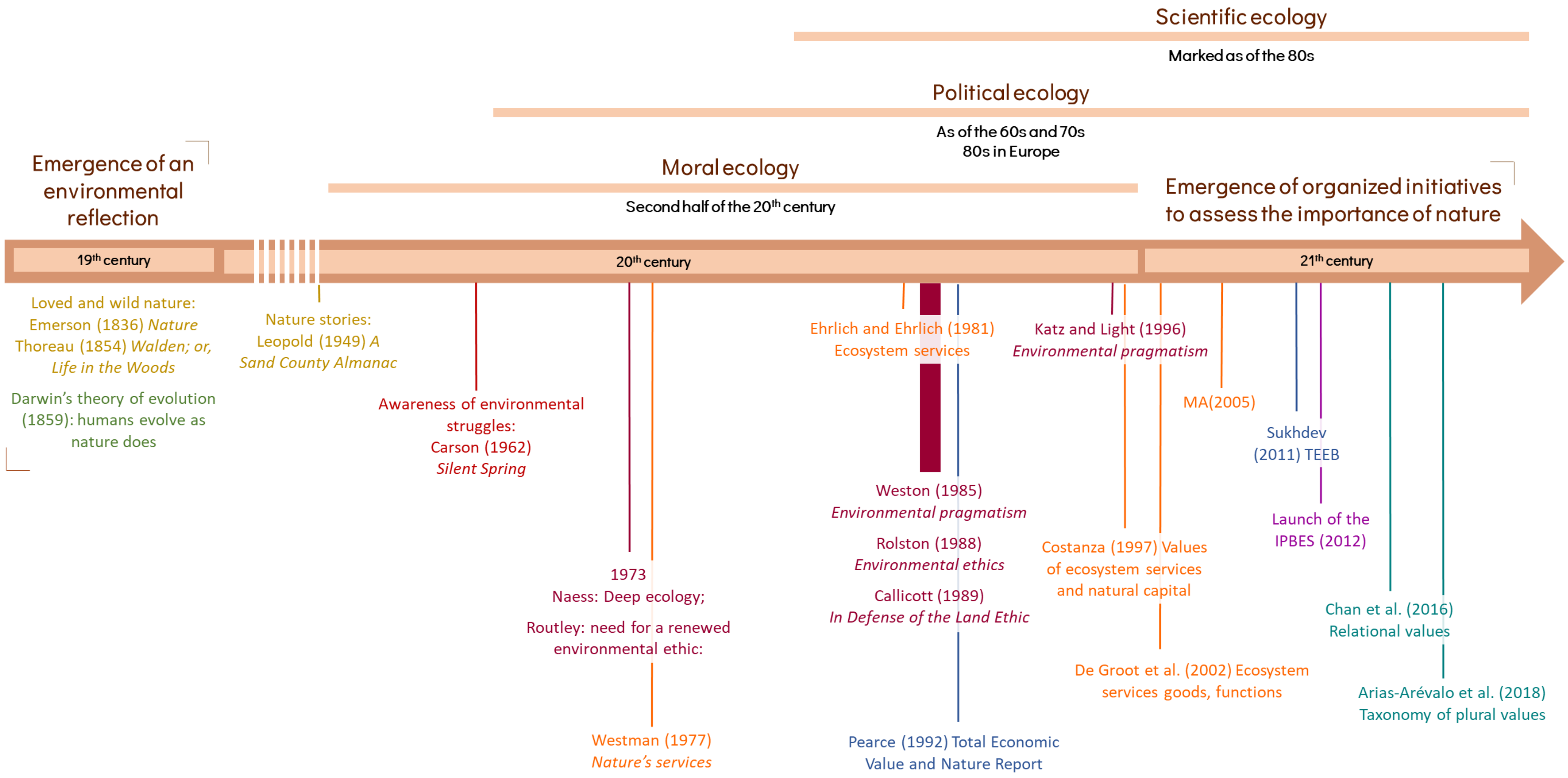

Figure 5 | Timeline of selected events and publications illustrating the evolution of conceptions of human-nature relationships and of the evaluations of nature's values since the 19th century (own realization, with adapted content from Maris, 2014 and Larrère, 2010). Under the timeline: in **yellow**: elements related to American writers who wrote about wilderness and wild nature; in **green**: the scientific conceptualization of the theory of evolution as a changed perspective on human-beings compared with other organisms (all evolving); in **red**: Carson (2002)'s book as a marker of raising preoccupations about environmental degradations; in **orange**: elements related to the emergence of the ecosystem service concept; in **dark red**: key publications at the origin of environmental pragmatism formalization; in **blue**: publications related to economic measurements of the values of nature; in **purple**: the launch of the IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) that has publicized the necessity to consider and reconsider the relationships between human beings and nature and in **turquoise**: the development of the concept of relational values as an attempt to fulfil the lack of the ES framework.

Economic conceptions of the values of « nature » and the case of the Ecosystem Services framework

An economic conception of the value of nature

Generalities

In economics, values are instrumental (Salles, 2011) and designate a quantifiable attribute (Maris et al., 2016) that reflects utility, *i.e.*, the benefits provided to human beings. For instance, it may mean the benefits from nature that address material needs, participate to the well-being or develop aesthetic satisfaction (Bourdeau, 2004; Elliot, 1995). Economic values have been conceived as "*a relation of subjective equivalence between goods that depends on their utility and their scarcity*" (Salles, 2010). Recent approaches have been marginalist (Salles, 2010): the economic value of an item decrease while the number of units of this item increases.

Monetary "*values*" imply to consider that a quantitative measurement of nature's worthiness is possible (Thompson and McDonald, 2013). Economists traditionally distinguish between two types of values (Maris, 2014): (i) use values, *i.e.*, "*to what extent an item is useful for us*", and (ii) exchange values, that correspond to prices that are expressed in monetary terms. Exchange values can be measured in two ways (Weber, 2013): (i) a measure based on the price of elements that nature provides, or substitutes of these elements, and that have a place on a market (Weber, 2013): the value is revealed by the market (Maris and Revéret, 2009); (ii) an indirect, more challenging, measure of elements that are not placed or placeable on a market (Fourcade, 2011): values are revealed by the agents (Maris and Revéret, 2009). In this case, the measure relies on the construction, by an evaluator, of a fictive market for the elements that do not have one, and by testing how much people are willing to pay to preserve or to be compensated for the loss of this element (Weber, 2013). Thus, different methodologies have been developed to assess monetary values, either directly or indirectly (Tab. 3).

One of the major concepts developed in economic valuation of nature is the Total Economic Value (TEV; Fig 6) of natural resources, that may have been introduced as of the 60s (Dushin and Yurak, 2019) and later popularized, by publications from David Pearce and R. Kerry Turner (Weber, 2013). TEV is conceived as the sum of different kinds of values (Fig. 6). Initially conceived on the basis of use and non-use values, latest versions have rather distinghuised two main "families": instrumental values and intrinsic values.

Table 3 | Illustration of the diversity of possible methodologies to assess economic values of nature (modified and combined from Christie et al., 2012 and Hernández-Blanco and Costanza, 2018).

Monetary approaches	Methods
Market price: direct and actual price of a market good as a proxy for value	Market prices
Market cost: costs from a market good as a proxy for value	Replacement costs: valuation through the costs associated with the replacement of a function, a species, an ES.
	Avoided damage costs: valuation through the amount of costs avoided by a function, a species, an ES.
	Production function: economic valuation of the impact of an ecosystem function
Revealed preference methods: observations of real markets to measure the value of a good	Travel cost
	Hedonic pricing: indirect valuation based on purchases on markets related to a good or a service
Stated preference methods: willingness to pay for a good or to accept to give up on it on a hypothetical market	Contingent valuation: according to one policy option
	Choice modelling: assessment of policy's attributes
	Conjoint analysis: choosing or ranking of different scenario or ecological conditions
Participative	Deliberative valuation: combination of stated preferences and group deliberation
Value transfer	Value transfer: inference values in a place on the basis pf values recorded somewhere else at another moment

The first family relates to values that are supposed to reflect and to measure the different ways in which nature is useful for humanity's sake. The second one should relate to the benefits of nature for itself in terms of auto-support and intrinsic value (*i.e.*, valuable in itself). For Weber (2013), the aim of the TEV is to measure how individuals or collective well-being change when the availability and the quality of environmental goods and services vary.

In the TEV concept, most values are supposed to be measurable in monetary terms, except for instance the benefits to nature (Dushin and Yurak, 2019). Weber (2013) explains that even non-use values could be monetarized, for human-beings may value the fact that a natural feature (considered as a resource here) exist, even though they actually do not use it. More recently, there has been also an emphasize on non-monetary valuations (Christie et al., 2012) or mixed-approaches, in order to better capture "benefits to nature" values, *e.g.*, via participative tools that allow for debate or to focus on the definition or validation of different scenario (Hernández-Blanco and Costanza, 2018).

In the case of soils, most valuations are performed in agricultural contexts and they often relate to soils and soil nutrients direct use, to indirect use of soils off-farm and to the measurement of societal appreciation of limited agricultural runoff (Comerford et al., 2013). Pascual et al. (2015) considered soil biodiversity as a "*natural capital asset*" whose degradation would hinder ecosystem services (ES), thereby generating costs for society.

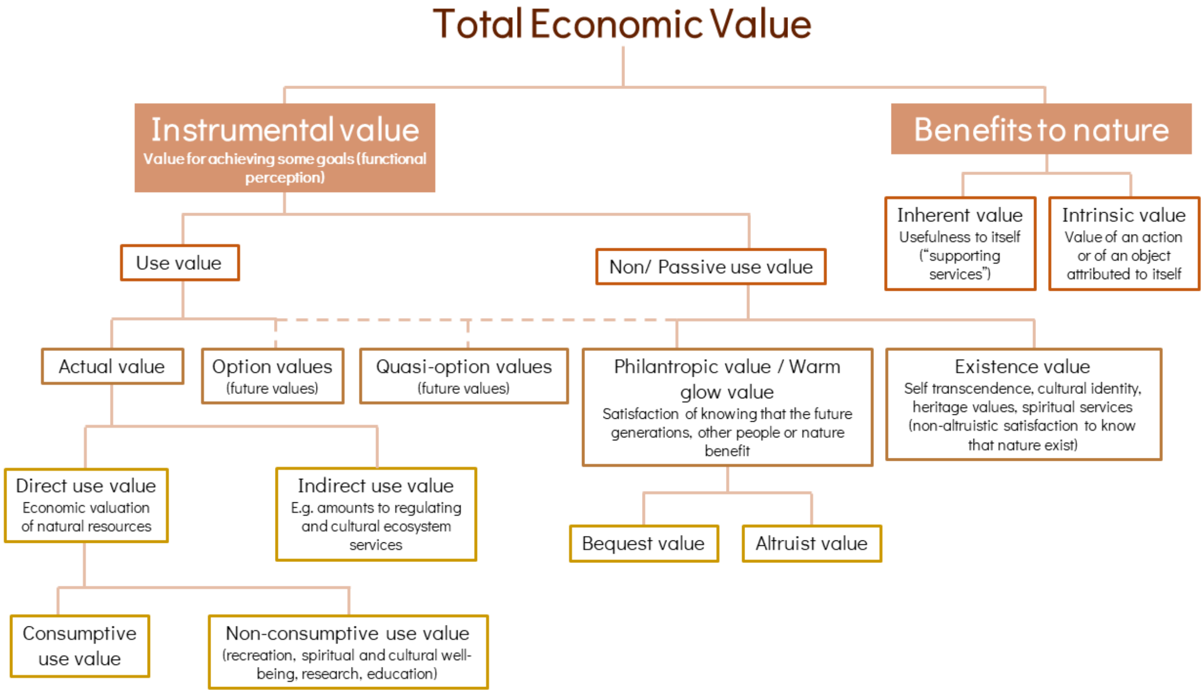

Figure 6 | One possible representation of the different values upon which the Total Economic Value can be measured (modified from Baveye et al., 2016; Davidson, 2013; Dushin and Yurak, 2019). The reader may be aware that scholars still debate about it and that this representation is only one of a multitude of TEV conceptions that may be found in the literature.

The particular case of the Ecosystem Services Framework

The Ecosystem Services framework is one example of an instrumental conception of nature's values, through the assessment of the good and services that derive from it. The concept of ES has been introduced in the late 70s and at the beginning of the 80s, the paper from Westman (1977) being one of the key publications that have first used it (Fig. 6). At the turn of the 21th century, Costanza (1997), Daily et al. (1997) and de Groot et al. (2002) participated make the concept well-known (Fig. 6). A major publication on the topic, resulting from the work of a large consortium of researchers across the globe, is the Millennium Ecosystem Assessment published is 2005 (MA, 2005) (Fig. 6), that defines ES as:

> "the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other nonmaterial benefits." (MA, 2005)

Jax (2005) associated the study of ecosystems functioning to mechanistic explanations of natural processes while the concept of ES would rather be normative, integrating a certain judgment of value of such functions on the basis of human needs.

Soils provide multiple ES, *e.g.*, medicines, material, nutrients, biomass: food, feed, fuel (provisioning services), nutrient and water cycles control, wastes degradation and detoxification (regulating services), cultural heritage and recreational activities support (cultural services) and habitat for biodiversity (supporting service) (see, *e.g.,* Adhikari and Hartemink, 2016; Comerford et al., 2013 for reviews on the topic). The review of Jónsson and Davíðsdóttir (2016) illustrated the already important literature on soils ES monetary valuations. Dominati et al. (2014) for instance quantified and valued soil ES in pastoral systems in New Zealand by combining several methodologies (market prices, replacement cost, provision cost, defensive expenditure). More recent studies have estimated the specific monetary value of earthworms on the basis of their contribution to soils ES. For instance, Plaas et al. (2019) evaluated earthworms' economic value by calculating the variation of standard gross margin according to their pest control activity, while Schon and Dominati (2020) estimated their economic value by considering the prices of equivalent management practices performed by human beings.

Stated assets of monetary valuations of nature

Monetary valuations of nature[2] have encountered an important development among academics over the last decades (Christie et al., 2012). Monetary units are often perceived as a neutral, objective expression of values (Maris, 2014), easily understandable by people (Hernández-Blanco and Costanza, 2018); monetary valuations would allow to compare the worthiness of goods and services from the natural capital[3] with those provided by other forms of capital (social, physical) (Maris, 2015) by expressing values under a common unit. As such, monetary valuations have been promoted as relevant approaches to assess the costs of human impacts on ecosystems (Salles, 2011) like soils (Brady et al., 2015), to estimate the worthiness of agricultural functions beside food production (Weber, 2013), to integrate the environment into rational choice (Plottu and Plottu, 2007) and thus, as relevant tools to inform and support trade-offs resolution in management decisions (Maris, 2014; Pascual et al., 2015; Salles, 2011).

In the field of ES valuation, monetary tools have been presented as (i) emphasizing the dependence of human-beings on ecosystems functioning and (ii) stressing the importance to preserve entire ecological systems, including human beings but not only (Hernández-Blanco

[2] We use nature as a very general term here, but we are aware that it can actually cover various meanings, which has been discussed elsewhere (*e.g.*, Descola, 2005).
[3] The concept of "natural capital" introduced by Pearce (1988) can be defined as "'*a stock of natural resources (i.e., ecosystems) that yield a flow of goods and services (i.e., ecosystem services)*'" (Hernández-Blanco and Costanza, 2018) which is (i) a mechanistic view of nature that is compared to a manufactured capital, and as (ii) an economic conception of nature that is associated with a source of profits (Maris, 2015).

and Costanza, 2018). But, the ES concept has also encountered several criticisms over the last decades, that focused on: (i) the anthropocentric perspective adopted; (ii) the risk to reduce human-nature relationships to consumption; (iii) conflicts that may emerge from the conservation of ES instead of biodiversity; (iv) the way ES valuation is dominated by economic and monetary approaches; (v) the risk of nature commodification; (vi) the lack of precision of the concept itself; (vii) the biased picture depicted by a lack of investigation on ecosystem disservices, which may induce a normative bias on the concept itself, that would carry positive meanings only (Schröter et al., 2014). These criticisms encompass challenges reported in the field of economic valuation in general.

Challenges associated with economic valuations

For Baveye et al. (2016), the dominance of monetary valuations is such that in the ES literature, many researchers do not even bother to precise their position, and simply refer to “valuation”. Yet, economic valuations are only one way among many others to define and to express values. Despite their stated usefulness as tools to enhance discussions about the importance to preserve ecosystems, economic valuation and monetary approaches have also encountered conceptual and methodological criticism.

The issues of commensurability and substitutability

(i) Commensurability acknowledges the possibility to quantify and express nature values by using a unique measurement unit and scale (Thomspon and McDonald, 2013), which implies for instance to consider that money can reflect different forms of worthiness as a “*universal reference*” (Weber, 2013). Commensurability allows for aggregating very different values since they are expressed through a single unit (Maris, 2014) like in the TEV. Incommensurability conceive values as the aggregation of a potentially infinite number of different points of views that challenge this perspective (Renault, 2017). For Maris et al. (2016), some values of nature are not simply individual preferences to be aggregated, but rather the basis upon which human preferences and representations are built. Moreover, the whole humanity has not the same relationship to money, so that monetary valuations, far from being neutral, are also relational. Besides, monetary valuations would mostly tackle values related to human utility, while intangible values would be poorly captured (Maris, 2015); for instance Stålhammar and Pedersen (2017) showed that people do not always express the benefits of spending time in natural environment in commensurable terms. Thus, it is sometimes simply not possible at all to translate certain values into measures (Maris, 2014). In economy itself, this led to the progressive apparition of a specific field: ecological economics, that acknowledges the co-existence of plural valuation systems in the world, thereby rejecting the hegemony of monetary valuations (Funtowicz and Ravetz, 1994). Internationally, the term "*nature's contributions to people*" has been introduced as a more inclusive alternative to ES (Pascual et al., 2017).

(ii) Substitutability means that one form of capital can substitute to another form. This implies that the loss of one form of capital can be counterbalanced by the increase of another form of capital. In this perspective, the sustainability of a system can be maintained as long as any loss of capital is compensated by a gain in another one *e.g.*, a loss of a "natural capital" can be mitigated by a replacement under another form of capital. This is particularly risky since environmental goods and services present specificities that may not be substitutable in reality (Maris, 2015).

(iii) Prices observable on markets do not always reflect the real economic values of natural items for : they are often non-exclusive nor rival; competitiveness can be shaped by policies and rules; damages on nature can have impacts far greater than the sole loss of a few goods; and market prices do not always reflect what is at stake in the human-nature transaction (*e.g.*, admiration of the beauty of a landscape, feeling of satisfaction when observing animals…) (Maris and Revéret, 2009). Actually, markets may also poorly reflect the value of nature because, perceived as unlimited, the offer would appear more important than the demand, lowering the related prices. However, nature is limited and current crisis observed worldwide show that this should be better integrated into evaluations.

(iv) Associating expressed agents' preference to a monetary value may be biased since it assumes that these agents are rational and stable, which is not always the case, and that they are competitors on markets, while they could be also ethical agents (Thompson and McDonald, 2013). Besides, human preferences are formed and reconfigured across time (Maris and Revéret, 2009), and between cultures, and monetary tools may not be suitable to capture value in some contexts.

About soil biodiversity, Jónsson and Davíðsdóttir (2016) even stated that it "*is inherently difficult to value and should not be valued*". Such a marked opinion may indicate that monetary valuations may not be always suitable to express values that should rather be conceived in ethical terms.

Methodological issues

Other issues are rather methodological. For Frame and O'Connor (2011), economic valuations performed on ecosystems or in the field of sustainability issues may be criticized because they have been initially designated for other purpose and may thus not be always applicable in environmental studies, that focus on "*non-produced and largely non-commodified natural environment*", on long-term patterns of ecological change and sustainability concerns, and integrate a wide range of values that rather require discursive approaches. About soil biodiversity in particular, ecologists themselves stress the fact that much is yet to uncover about soil organisms themselves and about their role for soil functioning. Providing an estimation of the monetary value of soil organisms may be possible to a certain extent, within the realm of the known, but it may show much more difficulties when it comes to value organisms or specific functions that are not even known, and that may not be before quite some time (see Maris and Revéret, 2009 for a discussion of "option values").

For instance, it may appear quite strange to express the benefits that nature obtains and would "*attribute to itself*" (Dushin and Yurak, 2019) by using the concept of value, a human construction to apprehend and define worthiness and importance, while we have no clue about the way "nature" would actually conceive it itself (if it did). If we follow Baveye et al. (2016)'s comment on the inclusion of such an "intrinsic value" in the TEV, the justification rather lies in the objectives of those who value nature in multiple ways beyond human-orientated interests:

> "This proposal to include intrinsic value presents the advantage that all functions of nature are now accounted for, and not just the subset of functions (*i.e.,* services) that benefit humans" (Baveye et al., 2016)

As such, economic valuations are conceived by Maris and Laurans (2017) as "*an argument rather than a neutral measure*", thereby rejecting the idea that monetary units are an objective way to express worthiness.

Relying on market prices only could thus mask some values that may be associated with soils: (i) first because prices reflect an exchange value that does not necessarily express the importance of ecological features and (ii) second because only a fraction of a given population is actually involved in setting prices (Baveye et al., 2016).

Maris (2015) thus evoked alternative methodologies like multi-criteria assessment or participative designs as approaches that allow to complexify values expression and improve the accuracy of their description. In the field of ES research, this has been developed as well (*e.g.,* Cheng et al., 2019; Oteros-Rozas et al., 2014; Pietrzyk-Kaszyńska et al., 2017), even though

ES valuations remain dominated by economic conceptions of values and by the use of monetary units (Hernández-Blanco and Costanza, 2018).

Overall, the point would not be to reject all monetary valuations, but to avoid its domination and to ensure the coexistence of different values assessments that would better express the complexity of the human-nature relationships and to reflect on the very values that are formed (Maris and Revéret, 2009). Simplifying monetarization by focusing on price/quantities relationships masks the fact that prices may be judged as good or fair on the baiss of "*references of evaluation*", that may belong to an ethical or moral or even aesthetical dimension (Cotterau, 2015). This actually requires a theoretical framework that conceives values, not as fixed and unquestionable characteristics of individuals, but as "*a dynamic social production, very sensitive to the context, to the problems society has to cope with*" (Maris and Laurans, 2017).

What economic valuations may tell about our relationships with nature or ecosystems

Economic approaches rely on a utilitarian vision of nature, perceived according to the benefit it may bring to human beings (Weber, 2013), even indirectly, even in a possible but uncertain future. As such, nature has become an economic agent, a conception that thereby acknowledges the separation between nature and culture (Weber, 2013) or human systems and ecosystems. For instance, the inclusion of the "*benefits to nature*" form of values in the TEV may mark an increasing awareness of this issue and reflect attempts made to improve the consideration of benefits beyond pure human-centered considerations. Meanwhile, though, because the "*benefits to nature*" are still clearly separated from the other values in the TEV, in the end, it seems that there are still human interests on one hand and "natural" interests on the other hand and that both remain intrinsically different and thus separated, even though one intends to aggregate them into one single total value. Already criticized in our occidental societies, both economic approach and associated methods may turn out to be particularly ill-adapted when it comes to assess the values of "nature" in other places of the world, where the very object of such valuations becomes itself irrelevant. Descola (2005) for instance showed that the human-beings/nature duality is completely inexistent in some societies, that use completely different criteria to assess what belongs to their world or not. Cartesian conception of the wolrd leads to efinitions of values differentiating the benefits for humans from those from nature, emphasize a dualistic, vision of human-beings who would not belong to nature. This has been criticized by some philosophical schools.

Elements for the thesis

Among the arguments used to encourage the use and development of economic valuations lies the idea that it would be one of the sole ways to effectively convince policy-makers to tackle the issue of ecosystems degradation. Yet, current struggles encountered by societies worldwide associated with the ongoing destruction of ecosystems show that economic approaches have not managed to fully achieve this objective any more than conservation approaches that may have emphasized non-monetary valuations of nature (Maris et al., 2016; *e.g.*, Soulé, 1985). For Maris and Revéret (2009) the very approach of monetary valuation is challenging because economical systems are at the origin of biodiversity loss and ecosystem degradations:

> "One may notice the irony lying in evaluating biodiversity on the basis of markets prices while the very excessive commodification of natural resources is a major factor causing biodiversity erosion" (Maris and Revéret, 2009; our own translation of an original sentence in French)

Moreover, while ES economic valuation has been perceived as an asset to support decision-making in the field of conservation, limited investigation in research does not allow to provide strong evidence supporting this idea (Laurans et al., 2013). Besides, if scholars adopt and publicize this kind of valuation only, they may also participate themselves to legitimate the idea that solely economic valuation is useful.

Environmental ethics – Values of and moral considerations on nature

Environmental ethics is a philosophical movement and one of the academic fields that have greatly contributed to formalize and to debate about the way we interact and value "natural" features.

Moral considerability of nature and non-anthropocentric values

The second half of 20th century has been marked by a raising awareness of environmental issues due to pollutions, decrease of biota populations… (*e.g.*, through Carson (1962)'s book *Silent Spring*; Fig. 6) This conduced to growing reconsideration and criticism over the dominant economic growth paradigm seen as responsible for environmental problems (Larrère, 2010).
In this context, Routley (1973) pointed to the need to renew the field of environmental ethics, advocating for a "*change in the ethics, in attitudes, values and evaluations*". This introduced

the idea of a "*moral considerability*" of natural features that can be integrated in "*moral evaluations and judgments*" (Elliot, 1995). Ultimately, the existence of a moral value of nature implies for duties human-beings not to harm it:

> "nature is the dominion of man and he is free to deal with it as he pleases (since-at least on the mainstream Stoic -Augustine view -it exists only for his sake), whereas on an environmental ethic man is not so free to do as he pleases". (Routley, 1973)

As such, environmental ethics also acknowledge the particular responsibility of human beings towards "*the rest of nature*", organisms and ecosystems (Larrère and Larrère, 2015b). This had challenged a so called "*basic (human) chauvinism*" (Routley 1973), a conception where harming other organisms is not a moral issue.

Ethical philosophers have traditionally distinguished between (and often argued about) the existence of two types of values (Maris, 2014):
- on one hand, instrumental values refer to a value attributed to something that represents a mean for something else;
- on the other hand, intrinsic values are attributed "*to a thing, a person, a state of the world for itself, independently from the benefits that one may obtain from it or that other could obtain*".
By acknowledging intrinsic values, environmental ethics conceive nature's values independently of human-beings' utility (Maris, 2015): in other words, the existence of natural features is valuable regardless of human needs (Larrère, 2010). This is the position that is taken for instance in the Convention of Biological Diversity of the United Nations in 1992:

> "Conscious of the intrinsic value of biological diversity and of the ecological, genetic, social, economic, scientific, educational, cultural, recreational and aesthetic values of biological diversity and its components" (UN, 1992)

For long, occidental moral and political philosophies have associated values that are not instrumental to human beings or to some of their ends only, following a so-called anthropocentric conception of values. The rightness or wrongness of humans' actions is independent on whether they degrade natural elements *per se* but relies on their effect on human well-being or on whether they fit with human rights norms. The attribution of intrinsic values to nature allows to integrate it in moral debates: this is a non-anthropogenic approach. The objective of environmental ethics is thus to emphasize that, because they have intrinsic values, natural entities should also be considered it moral debates (Larrère, 2010).
Ethical philosophers have not only introduced the non-anthropocentric conceptions of nature values, they have also debated on their genesis (Maris et al., 2016):

(i) intrinsic value per se is seen as inherent to an item or to an organism, *i.e.*, it exists independently of any human valuator to form it; such a values is non-anthropogenic. This point of view may be criticized in logical terms: it appears difficult to conceive, in practical terms, that values are independent from a human individual to conceive them;
(ii) intrinsic value as a non-instrumental value that designates the value of a natural entity for itself but that is attributed by a valuating agent; such values are anthropogenic.
Various theories that have further developed the question of non-anthropocentric values of nature, with various theoretical implications. Two important directions are biocentrism and ecocentrism.

Biocentrists consider all living beings are of value (Bourdeau, 2004). As summarized by Larrère (2010), the biocentric ethic considers that there are ends in nature, and more precisely, that any living being is an end in itself, for living organisms in general develop multiple strategies in order to live their life and to reproduce. Taylor (1981) for instance conceived "*respect for nature*" as moral attitude toward nature based on "*moral obligations that are owed to wild plants and animals themselves as members of the Earth's biotic community*" and for their own sake, considering that the well-being of all for, human or not, is an end-in-itself. For the author, natural entities are valuable for the very reason they exist on Earth and intend to survive. According to Larrère (2010), integrating the concept of intrinsic value in practical decisions could force human actors to justify any intemps of destruction of a natural entity . However, the author emphasizes that this rarely happens, because considering all organisms as equal in virtue of their intrinsic value may render real decision-making and arbitrations impossible.
Some ethicists were unsatisfied by the biocentric approach for it would not encompass the whole complexity of nature, *e.g.*, ecological systems and the whole biosphere, and thus founded another so called ecocentric movement (Elliot, 1995). Ecocentrists suggested to use a broader definition of nature intrinsic value, attributed not only to living beings as individual entities, but also to higher organization levels, from species, communities to global ecosystem networks, integrating both its living and non-living components (Anquetil, 2016; Bourdeau, 2004). In this perspective, human beings, because they are only one among many other parts belonging to a wider system, have the responsibility and the duty to respect other elements of this system (Larrère, 2010).

The strong dichotomy between anthropocentrism *versus* non-anthropocentric approaches has been extensively debated (Elliot, 1995) but the dispute may have appeared sterile in terms of its practical effect. Such ethical positions, based on the consideration of sole intrinsic values of nature, have been globally criticized because of their abstract character and because they don't support the development of practical solutions to environmental problems (Létourneau, 2010), among others because stakeholders would be barely convinced by them (McShane, 2007). In brief, other criticisms related to their conception of values as (i) atomistic, *i.e.*, values are "stand alone" properties rather than outcomes of relational processes, and (ii) as existent before any human beings formulate it (McShane, 2007). As a response, in the 80s, an alternative movement called environmental pragmatism emerged, that challenged previous ethics (Afeissa, 2008).

The emergence of environmental pragmatism

Environmental pragmatism emerged 35 years ago with the founding paper of Weston (1985). It consists in the adaptation of a pragmatist epistemology, developed by in the late XIXth century and first half of the XXth century, to environmental issues. It represented a renewed way to conceive values, beyond the crystallized dispute between tenants of the existence of an intrinsic value of nature *versus* those who subscribed to so-called anthropocentric approaches. The objective was to support, in the field, those who are confronted with environmental issues in practical terms.

Values plurality - going beyond crystallized debates on intrinsic/instrumental values

Instrumental valuations of nature are marked by a dualistic conception of human-nature relationships, but some approaches from environmental ethics may actually encounter the same criticism (Larrère and Larrère, 2015b). This has been shown in particular in the discourse of the tenants of nature wilderness in the US, that emphasized the need to preserve a nature free of any human influence in order to preserve its supposedly original (and desirable) state (Larrère, 2017). There indeed, nature is defined as a place where there are no humans-beings, which clearly implies that nature and humans would be, by definition, different.

Weston (1985) rather introduced a pragmatist conception of the values described as plural, dynamic and interrelated, as a way to escape from such a dualism. Environmental pragmatism considers that because human-nature relationships can take very diverse forms, values are plural and cannot be reduced to a single dimension (unless this makes sense in a given community for a given person) (Maris, 2014; Maris et al., 2016). Reducing the values of nature to one single and unique intrinsic values would amount to adopt a monist point of view (Larrère, 2010). Thus, pragmatism also rejects the idea of pre-existing values of natural entities that are not formed by humans (Lee, 2008), even though this have been subjected to debate (*e.g.*, Santas, 2003). Moreover, for Norton (1984), environmental ethics would not need to entirely reject anthropocentric values, but should rather conceive nature's values along a gradient ranging from strong to weak anthropocentric values. Pascual et al. (2017) also presented a continuum made of nature non-anthropocentric (intrinsic) values, nature's contributions that call for anthropocentric instrumental values and elements for good quality of life (beyond basic human needs), and instrumental values. Acknowledging that plural values co-exist implies, in practice, to accept that nature may be protected both because "*our human life depends [on]*" or benefits from it, and "*because it is worth it to be itself respected*", without necessarily considering that one reason prevails over the other, even though in real situations, arbitration is sometimes necessary (Létourneau, 2010). As such, values plurality also emphasizes values' relational nature, *i.e.,* their dependence upon the place and moment within which they are defined and the individual that define them (Larrère, 2017). As such, environmental pragmatism conceives the formation of values as situated (Minteer et al., 2004). There, "*values are a permanent process of relationship to the world and to the other*" (Maris, 2014) and transactions between human-beings and their surroundings play a role in values formation and human activities (Parker, 1996; Thompson, 2008). This relational nature of values, while not explicitly associated with a pragmatic epistemology, has also been emphasized in more recent works led by interdisciplinary researchers' collaborations, *e.g.*, from Chan et al. (2016).

Main elements for the thesis

Usually, economic valuations are perfomed by experts that only provide one point of view on the expression of worthiness (*e.g.*, in Weber, 2013, the evaluator is the one who seeks to reveal people's willingness to pay, not the people themselves). Environmental ethics emphasize the need to reconsider our relationships to nature and not to restrain the definition and expression of what matters to us to economic terms only. The pragmatist epistemology in particular conceives human beings as one element of natural systems among many others. This rejects dualistic human-nature representations (Larrère and Larrère, 2015b) and emphasizes the fact that human well-being depends on natural environment's integrity in a subtler way than what is apprehensible through instrumental values only (Elliot, 1995). For Kallis et al. (2013) the issue is not to avoid monetary valuations of nature per se but to be able to reflect on the conditions within which monetary valuation is actually performed (in which context and with which goals) and to ensure the possibility of plural values to be expressed. Recently, Arias-

Arévalo et al. (2018) provided an extensive literature review that highlighted the wide range of values that can be associated with nature. The pragmatist epistemology, that considers valuations as dependent on the situation within which they are performed and based on discursive exchanges, has been seen as a promising path to follow even though it was initially not developed in the field of environmental ethics.

The pragmatist epistemology

Pragmatism is a philosophical school developed at the turn of the 20th century in the United States by Charles Sander Peirce, William James, John Dewey and George Herbert Mead. The initial focus was related to social issues. Its application on environmental thinking initiated in the 80s only with an article published by Weston (1985).

Pragmatism acknowledges the fact that human as well as ecological systems are not static but change over time (Dewey, 1939). For Mintz (2004), in a pragmatist epistemology, knowledge thus represents "*an open-ended question for greater certainty, grounded in practice experience, and motivated by a desire for successful actions*" (Mintz, 2004): it is fallible and perfectible. Our relations with the world are constructed through experience and this is through experience that we encounter moral problems, or more precisely, "*morally problematic situations*" (Kupper and De Cock Buning, 2011). As a result, our moral judgements, that rely on previous knowledge and experiences, can evolve (Kupper and De Cock Buning, 2011).

The concept of situation

In 1939, Dewey wrote his "*Theory of Valuation*", in which he presents how human aims and purposes, based on desires, are also dependent from the conditions that surrounds human beings (Wahl, 2011). As such, valuations are conceived as the result of an organic body (i) situated within an environment, both shaping each other to various extents, and (ii) embedded within a human society that may collectively agree upon certain values (Wahl, 2011). A situation consists in both a cultural and a physical contextual environment that is experienced and interpreted by one individual (Cutchin, 2008; Weisser, 2010). Specific location, scale and moment are as many dimensions that define a context (ecological, climatic, cultural, political, historical). The perception of these contextual elements by an individual forms a situation. Therefore, a situation differs from a context for individuals and their environment are considered as interacting, shaping and affecting each other (Zask, 2008). Because pragmatism conceives values as reflecting our constant but evolving relation to the world, values rely upon the particular situation within which they are formed and as such they can be themselves dynamic (Maris, 2014).

The notion of "inquiry"

The pragmatist definition of social inquiry offers an interesting notion to conceptualize processes of knowledge creation and value formation within a given, dynamic situation. Here, the meaning of "social inquiries" is close from "scientific investigations", in terms of methods, procedures, and social matters, that are necessary to capture the characteristics of increasingly complex situations (Boulanger, 2014). It highlights the importance of experimentation and "*innovative problem solving*" (Mintz, 2004) and of their collective dimension. Individuals lead inquiries to clarify and to unify problematic, uncertain situations by discovering "*what is at stake […], the actors themselves becom*[ing] *cognizant of what had previously been taken for granted.*" (Stark, 2009). Deweyan pragmatism emphasizes the "*experimental, open, and flexible*" character of inquiry, that develops "*creative-intelligent responses*" to singular, unique situations (Kupper and De Cock Buning, 2011). On that account, inquiry amounts to an intelligent exploration of (i) the ins and outs of a problematic situation, (ii) the desirable ends to solve the problem, and (iii) the available means to achieve it, and their expected consequences. Situations are constantly redefined and therefore the satisfying character of a solution may be constantly reflected and refined as well. As a result, the process of inquiry never really ends. Inquiries acquire a social dimension when new actors are involved in the process, each bringing their own vision of the world, upon which values can be modified (Maris, 2009). As such, they rely on intersubjective exchanges (Weisser, 2010) that emphasize the incommensurability of values (Renault, 2017).

Social inquiries allow for clarifying an "*incoherent; indeterminate, contradictory*" situation by collectively setting a problem, by agreeing on the definition of an end-in-view and on the means to solve it (Boulanger, 2014). Boulanger (2014) divides the social inquiry process into three stages. First, a problem is progressively identified within a situation. Second, the particular constituents of the situation and of the problem are identified in order to search for potential solutions. At this stage, values are developed or, using Dewey's terminology, valuation takes place, and is contingent of the situation within which it occurs. Third, ideas of solutions (that Boulanger compares with "*scenario*") are developed and their expected consequences, conceived. In political terms, a social inquiry may correspond to a gathering of people discovering their common interest for a given issue and who decide to work out a collective solution: they start to form a "*public*" (Boulanger, 2014). Debated, shared and diffused along social inquiries, values are also a social act. They have altogether an individual and a collective aspect, that cannot be separated from each other. As such, values also matter when it comes to collectively legitimize some practices, an innovation, a way to define and to evaluate agricultural performance or a whole agricultural model.

The formation of values and its consequences

In a pragmatist perspective, values are qualities attributed, under certain conditions and with certain consequences, to an event, a situation, an object or a person (Dewey, 1939). They amount to practical ways of taking care of things and emerge from transactions between individuals and their environment. As such, the very first step of value attribution consists, simply and mainly, in giving attention (Bidet et al., 2011). This is also why instead of values, some authors have preferred the terminology of valuation, that better translate this active dimension (Muniesa, 2011). In this work, we consider « *what matters* » to people (Renault, 2016) and what they consider to be *good* (Thompson and McDonald, 2013) as valued elements. For instance, it may amount to what farmers pay attention to, to what they define as important, and to what they try to obtain when managing their fields. For Maris (2014), in a pragmatist perspective, values are an inherent part of our identities and they constitute the basis upon which collective and individual preferences are formed (*i.e.*, values do not amount to individual preferences that should be satisfied at all cost).

Values are formed in uncertain, troubled situations where a problem or a lack is encountered (Dewey, 1939), constraining individuals to modify their habits (Morgan, 2014) and routines. Valuation corresponds to the dynamic formation of reasoned desires and interests regarding available means, their costs and their potential consequences (Bidet et al., 2011; Wahl, 2011). This rejects a conception of values as fixed, pre-existing qualities of objects or characteristics of individuals (Dewey, 1939; Wahl, 2011) and impliesthat pursued ends are not fixed and that moral inquiry can happen (Kupper and De Cock Buning, 2011). Dewey (1939) introduced the term *end-in-view* to reflect these interdependency and dynamics between the definition of objectives and available and desirable (or not) means to achieve them. Besides, *ends-in-view* in a certain situation can become means to reach other *ends-in-views*: they form a continuum (Bidet, 2008).

Dewey's conception of values rejects any dichotomy between an instrumental rationality versus a values-orientated rationality, where values would be either pure emotions or *a priori* qualities of objects (Wahl, 2011). The author rather differentiates between immediate values, that define what is *desired* but do not result from experience and critical judgment, and reasoned values, that emerge from the evaluation of the consequences of an action, and that designate what is actually *desirable* (Thompson and McDonald, 2013). Hence, for Dewey (1939), valuation has a "*dual meaning*" as it combines *valuing* and *evaluation*. *Valuing* refers to *prizing*, *i.e.*, holding something dear or precious (Dewey, 1939). It defines an immediate, "*de facto*", more sensitive and emotional appreciation or depreciation of something by an individual, which leads them to desire or to avoid it (Bidet et al., 2011). *Evaluation* refers to "*putting values upon*" or "*assigning values to*", summarized under the term *appraising* (Dewey, 1939). It consists in a reflective activity that intends to determine what is desirable through exchanges with other perspectives Experience and knowledge also participate to define what is desirable as they relate events and objects with other events and objects (Bidet et al., 2011) and with previously experienced situations (Stark, 2012).

Valuation leads an individual to act (to reject, to take care…) and to produce evaluative discourses (Bidet et al., 2011). Because there is a link between values and objectives of actions in a given situation (De Luca, 2016), attributed values can be detected through the reasoning or the formulating of those evolving objectives. Of course, individuals' actions are also shaped by a wide range of factor: "*financial, educational, and other resource restrictions* […] *institutional barriers* […] *costs* […] *other spheres of well-being*" (Thompson and McDonald, 2013). Nevertheless, values can be observed as behaviours and attitudes (Bidet et al. 2011) or activities (De Luca, 2016), *e.g.,* as farmers' environmental behaviour (Vogel, 1996). Put in a nutshell, values consist in questioned and discussed facts that are observable through behaviours and language.

Values are understood as the result of relations, connections and transactions between personal attitudes and extra-personal, dynamic situational elements (Dewey, 1939; Bidet et al., 2011). Social, cultural, linguistic and physical milieu influence valuations (Stark, 2009; Bidet et al., 2011; Thompson and McDonald, 2013) that are characterised by a moment, a place and a situation (Hutter and Stark, 2015). Values also integrate knowledge and experience that have been previously obtained. In the end, formed values are likely to vary "*across time, space and culture*" (Minteer and Manning, 1999). Therefore, valuation appears situation-dependent (*e.g.,* on animal values in the Netherlands by Kupper et al., 2011) and objective within a given situation, with its specific and practical context (Dewey, 1939).

Because of this embedment of valuation and ethical issues within particular situations, pragmatism conceives moral values and principles "*as hypothetical solutions to a morally problematic situation*" (Kupper et al., 2011). As highlighted by Kupper et al. (2011), this amounts to criticize monistic conceptions of values, in which one type of overreaching value would be considered as a fixed, superior moral principle to follow. Pragmatism actually acknowledges the existence of a great diversity of values, whose relevance varies between situations and according to moral issues that are encountered. Thus, pragmatism could be qualified as an epistemology of pluralism.

Main elements for the thesis

The pragmatist epistemology embeds valuations in particular problematic situations, recognize the co-existence of plural values and their potential evolution across situations. CHAPTER 3 AND 4 rely on this theoretical background to investigate soils and soil biota valuations by European farmers and their potential variations between geographical regions. Investigating the existence of multiple values implies to develop adequate tools and methods. While Dewey's pragmatism may offer an interesting frame to think what matters to us or to people, it remains quite elusive when it comes to its practical application. In other words, defining a precise pragmatic methodology to lead an investigation on values is a challenge that researchers like Cottereau (2015) and Renault (2016) have uptaken in social studies, but that could apply also on ecological questions. In particular, it would imply to develop operational methods that invite and involve different points of view to investigate and traduce values plurality.

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Chapter 2

General methodological overview

Most of this chapter has been submitted as Appendices in: Hervé, M.E.T., Renault, M. Plaas, E., Schuette, R., Potthoff, G. Pérès, M., Cluzeau, D., Nicolai A. *International Journal of Agricultural Sustainability* (208585471).

Crop model and brief introduction of the study sites

Crop model: wheat culture in Europe

This thesis is associated with the European BiodivERrsA research programme "SoilMan" (https://www.soilman.eu/), running from 2017 to 2020. Data collection took place in five European regions: in France (FR), Germany (DE), Romania (DE), Spain (ES) and Sweden (SE), covering a great variety of geographical contexts along a double gradient (latitudinal and longitudinal, Fig. 7). “SoilMan” studies the impact of soil management practices on soil biota functions and subsequently the economic impact at farm scale. It also examines how farmers value soil biota and how these values can be integrated in European policy and regulation. The researchers belong to a wide range of disciplines in natural and human sciences: soil ecology, soil physics, ecological statistics, agriculture economy and socio-economy.

Due to the high variability of farming systems in Europe and to the great diversity of possible cultures, it has been necessary to find a crop that is spread all over the studied perimeter. Wheat was chosen: winter wheat in FR, DE, RO and SE (used for human food, *e.g.*, flour for bread, biscuits, but also as food for the cattle) and durum wheat in ES (the one used to produce semolina and pasta). Between 2008 and 2018, wheat was by far the most important crop production in Europe; in 2018, it represented 49.7% of the main cultivated cereals (the second rank is occupied by maize with 23.7%), with an annual production ranging between 120 and 140 billion tons (Eurostat, 2019). France, followed by Germany and then Romania were the three most important wheat producers in Europe in 2018 (Eurostat, 2019).

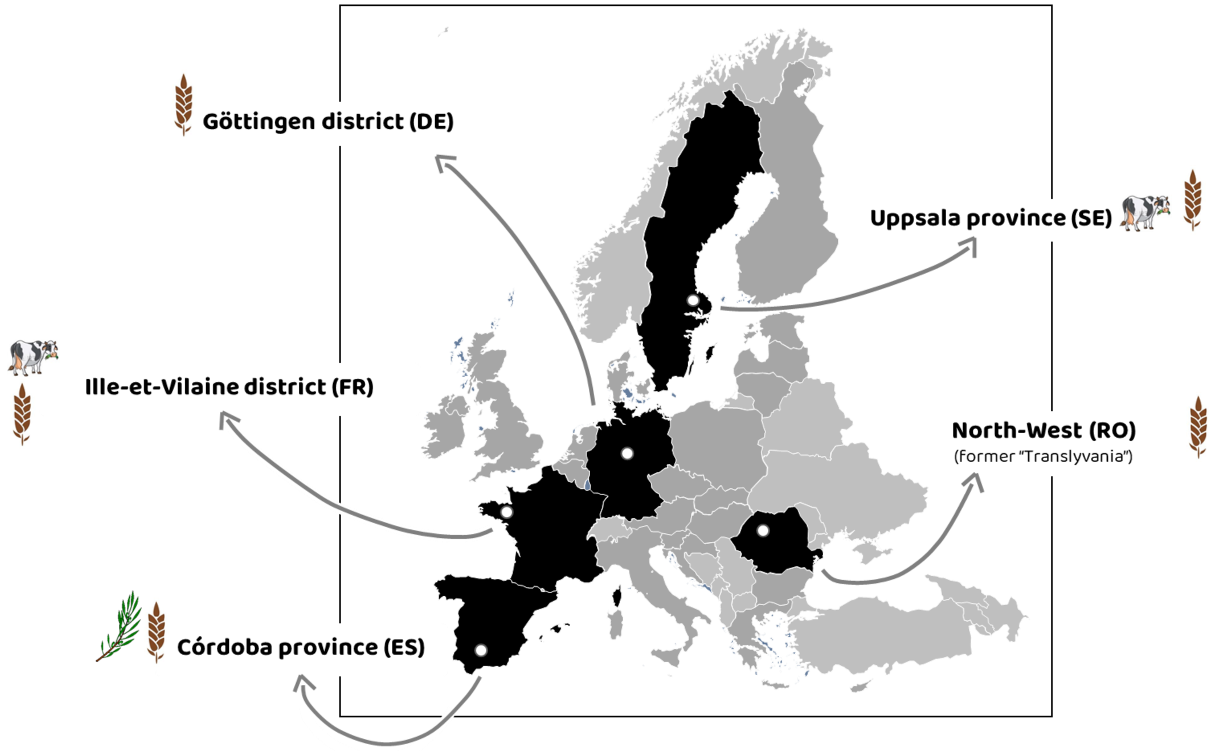

Figure 7 | Location of the study sites.

When sowed in autumn (generally in October or November), wheat usually takes up to 9 months to reach its harvestable stage, *i.e.*, around July or August. Yet, the planification of the operations and the maturation of the plant are highly dependent upon local climatic conditions. For instance, in Autumn 2019 in Brittany, the level of precipitation was so important that farmers struggled to find a time window when they could go in the field without risking to compact wet soils with the machineries.

Studied regions

Ille-et-Vilaine *department*, France

In France, the study site is the *department* of Ille-et-Vilaine (Brittany), in the North-West of the country. In this area marked by an Atlantic climate, dairy farming represents the major orientation, except in the surroundings of Rennes, the main city of the department, where most farms grow vegetables in the field (Lesaint, 2019a). Mixed-farming systems are still common. Farmers often have pastures and grow cereals, most of which is dedicated to cattle feeding (Lesaint, 2019b). In 2018, soft wheat was grown on roughly 20% of the total cultivated area of the department (Lesaint, 2019a).

Göttingen county, Germany

At the centre of Northern Germany, the district of Göttingen is studied. The local climate is temperate, under continental and oceanic influences. The area belongs to Lower-Saxony, a Land where agricultural activities represent the highest share of land uses and one of the major economic sectors (NMELV, 2020). Dairy, chicken and pig farms are particularly important in Lower Saxony (Pouch, 2015). Within the Göttingen district itself, the diversified landscapes (Busch and Meixner, 2015) are also dominated by agricultural land uses that occupy more than half of the surfaces, mostly as arable lands (Busch, 2017; Busch and Thiele, 2015). Oilseed rape is an important crop locally (Racca et al., 2015). Forests also occupy a noticeable surface in the hillier areas.

Cluj-Napoca county, Romania

In the North-West of Romania, Transylvania tableland is studied. The Transylvanian tableland is among the Romanian sectors that have witnessed the most important land use changes between 1990 and 2006, after the end of the communist regime and before the accession to the European Union (Popovici et al., 2013). In the area, social factors, land use form and climatic difficulties led to agriculture extensification coupled with afforestation, particularly between 1990 and 2000 (Popovici et al., 2013). In 2014, arable land and pastures represented respectively 42% and 35% of the total agricultural land use in Cluj-Napoca County, the largest city in this area of the country (INS, 2018). In 2018, wheat culture accounted for nearly 10% of arable land use in Cluj-Napoca county, far beyond maize, the dominant crop culture (INS 2018).

Córdoba county, Spain

In Southern Spain, the province of Cordoba in Andalucia is studied. The area is marked by a Mediterranean climate and exposed to important erosion issues due to heavy rainfall events and sometimes to inappropriate soil management (Gómez et al., 2019). Consequently, conservation tillage practices were introduced in Spain in the eighties, in order to mitigate soil erosion and to increase water storage (González-Sánchez et al., 2012). Andalusia is one of the most important cereal producers in the Mediterranean area (Quiroga and Iglesias, 2009). However, wheat production, mainly durum wheat for human consumption, covered less than 10% of the entire arable land use in Cordoba province in 2017 (Eiriz Gervás et al., 2019). Indeed, since its entry in the European Union in 1986, Spain has encountered an important increase of olive orchards surfaces (Guzmán and Alonso, 2008). Nowadays, Andalucia accounts for a major share of Spanish olive culture (Oteros et al., 2013), and in 2010 the Cordoba province was the second most important producer of the region in terms of surfaces (CAPDR, 2015).

Uppsala province, Sweden

Uppsala county is studied in Sweden. The area is situated in the central eastern part of the country (roughly 70km north of Stockholm). The region is mostly flat, and the Baltic sea constitutes a boarder at the West. In general, Sweden is characterised by a marked difference in agricultural conditions between the North and the South, cereals and oilseed being more easily cultivated in the southern lands (Ekman et al., 2013). In Uppsala county, climatic conditions are quite homogeneous (Malinga, 2016). There, Cereals crops (mostly wheat and barley) are among the most common arable land uses together with temporary grasslands (SCB, 2018). Organic agriculture is particularly important in Sweden, encouraged by the Swedish Government as of the early 1990s (FAO et al., 2001).

Analytical position and data collection

Pragmatism considers (Renault, 2009):
(i) that individuals are "intrinsically social", *i.e.*, that the construction of their personal self-identity and subjectivity actually relies on the acknowledgment of the subjectivity of the others;
(ii) that there is no transcendental reality that would form a universal truth that individuals should discover, but rather than visions of the world are plural and that the state of knowledge about it is relevant and true at a given moment, in a particular situation that is defined by the way people interpret reality;
(ii) that intersubjective communication between individuals allow transactions that may change the involved participants and lead them to modify their actions (see also Létourneau, 2010).
Thus, to investigate the nature and the formation of values, it appeared necessary to use a methodology that could allow the surveyed people to tell how and why and in which particular conditions soils and soil biota or biodiversity (SBB) mattered to them or to exchange with other people about that. Such an approach is close from the deliberative paradigm that may be applied to assess the social values of ES in Raymond et al. (2014), where the perspective is that:

> Reason is process and context-dependent. Evaluation takes place through the communication of social constructions and through social representations, without claim to objectivity. Focus on both transcendental and contextual values. Emphasis is on participation and social learning (Raymond et al., 2014).

In this perspective, Focus Groups (FGs) appeared as a particularly suitable method. FGs are "*a semi-structured group session, moderated by a group leader, held in an informal setting, with the purpose of collecting information on a designated topic*" (Carey and Smith, 1994). The main aim of such a social science tool "*is to understand, and explain, the meanings, beliefs and cultures that influence the feelings, attitudes and behaviours of individuals.*" (Rabiee, 2004). A FG is different from a group interview as the moderator facilitates a discussion *between the participants* and remains as much as possible in periphery of the talk not to interfere with the relationship they develop (Parker and Tritter, 2006). FGs are a common tool in agriculture research, allowing to investigate farmers' practices (Roesch-McNally et al., 2018), such as conservation activities (*e.g.*, Bewket and Sterk, 2002), farmers' identity (*e.g.*, Rotz, 2018) and attitudes (Schütte and Bergmann, 2019), farmers' environmental constraints perceptions and adaptation strategies (*e.g.*, Makuvaro et al., 2018), farmers' risk management (Hanson et al., 2004) or rural stakeholder's values (*e.g.*, Stein, 1999). When dealing with research on policy topics, focus groups allow to obtain a substantive quantity of qualitative data compared to the time spent for data collecting (Parker et Tritter 2006). In total, ten FGs were organized, and two took place within each of the studied regions (Tab. 4).

Table 4 | Characteristics of the farmers who participated to the Focus Groups (FGs). All farmers grow wheat at least in one field of their farm. Wheat culture sometimes represents only a marginal surface compared with other occupations. In the category "Gender", "Male" holds for male and "F" for Female. The category "Studied area" indicates if the farmer belongs to one of the five studied areas. "SoilMan" indicates if the farmer is involved in the SoilMan program; "FG1": through their participation to a first round of FG hold during winter 2017-2018, "FS": one of their fields has been sampled in the SoilMan program (soil ecological and physicochemical parameters). OF refers to "Organic Farming". NP: information was Not Provided.

	Id	Gender	Three main land uses	Cattle	Studied area	SoilMan (FG1/FS)	OF
France	FR-1	M	Winter wheat Maize Rapeseed	(Pig cattle but a different farm company)	✓	×	×
	FR-2	M	Winter wheat Maize Grazed pastures	Dairy farming	✓	×	×
	FR-3	M	Mowed and grazed pastures Maize Winter wheat	Cattle	✓	×	×
	FR-4	M	Winter wheat Mowed and grazed pastures Maize	Dairy farming	✓	×	×
	FR-5	M	Winter wheat Mowed and grazed pastures	Dairy farming	✓	×	×
	FR-6	M	Mowed and grazed pastures Mix of protein cereals Maize	Dairy farming	✓	×	Conversion (s. 2018)
Germany	DE-1	M	NP	NP	×[†]	FG1	×
	DE-3	M	NP	×		FG1	×
	DE-4	M	Arable farming	×	×[†]	FG1	×
	DE-5	M	NP	NP		FG1	×
	DE-7	M	Head experimental economies	×	✓	×	×
	DE-8	M	Arable field Biogas plant	Dairy farming	×[‡]	FG1	×
Romania	RO-1	M	Wheat Rapeseed Maize	×	×[§]	×	×
	RO-2	M	Maize Alfalfa Pastures	Dairy farming	✓	×	×
	RO-3	F	Wheat Maize Sunflower	Dairy farming	✓	×	×
	RO-4	F	Maize Wheat Mowed and grazed pastures	Sheep cattle (mostly)	✓	×	×
	RO-5	M					
	RO-6	M	Maize Sunflower Wheat (very little)	"A few animals"	✓	×	×
	RO-7	M	Wheat Maize Soybean	Cows	✓	×	×
	RO-8	M	Maize Wheat, Sunflower, Mowed and grazed pasture	Cows	✓	×	×
	RO-9	M	Maize Winter wheat Alfalfa	Dairy farming	✓	FS	×
Spain	ES-1	M	Perennial crops (olive, lemon)			FG1	
	ES-9	M	Cotton	×	✓	FG1	×
	ES-11	M	Various cereals crops			×	
	ES-2	M	Wheat Sunflower	×	✓	FG1	×

	ES-3	M	Chickpeas Olive trees orchard			×	
	ES-4	M	Vine Crops fields (decreasing)	×	✓	FG1	×
	ES-5	M	Wheat Sunflower Rapeseed	×	✓	FG1	×
	ES-6	M	Wheat Sunflower Barley	×	✓	×	×
	ES-7	M	Wheat Barley Anise	×	✓	FG1	×
	ES-8	M	Wheat Barley Protein cereals	×	✓	FG1	×
	ES-10	M	Wheat Sunflower	×	✓	FG1	×
Sweden	SE-1	M	Winter wheat Other cereal Potatoes	Horses	✓	FG1	✓
	SE-2	M	Winter wheat Maize Rapeseed	Cows	✓	FG1	✓
	SE-3	M	NP	×	✓	×	✓
	SE-4	M	NP	× (stopped)	✓	×	✓
	SE-5	M	Winter wheat Grass ley Grazed and mowed permanent pastures	NP	✓	FG1	✓
	SE-6	M		NP	✓	×	✓

†. These farmers come from a district situated at ~30km at the East of the southern border of Göttingen district.
‡. Situated 16km South from the southern border of Göttingen district.
§. Situated in the North-East of the country.

The qualitative analysis that have been performed in Chapters 3 to 5 mostly relies on an interpretative approach, that fits particularly well with the pragmatic epistemology:

> "Generally speaking, those who espouse the interpretive approach hold an ontological view that acknowledges a concrete and real world, full of tangible entities. However, the epistemological apprehension of that real world, and the meanings ascribed to it, are determined by a web of inevitable factors made up of language, symbol, culture, history, and individual situatedness. For this reason, most qualitative methodologies focus on exploring the contextually based, lived experience of individuals and social groups. For most interpretivists, 'truth' is a result of constructed and intersubjective meanings" (Zimmer, 2006) [our own emphasize of the text].

Such an interpretative approach can be associated with hermeneutics, *i.e.*, "*the study of interpretation*" that, in certain disciplines like social sciences, is applied to uncover the "*meaning of human intentions, beliefs and actions or the meaning of human experience*" (George, 2020). In other words, when some meanings are not explicit at first, adopting a hermeneutic position amounts to try to discover and to clarify them through interpretation. It is particularly relevant in situations marked by intersubjectivity, where different visions of the world may confront and interact with each other. Hermeneutics seek to determine the meaning of an experience lived by individuals in particular situations or of a given practice (Busck, 2002), a meaning that is dependent on both the surveyed individuals and the researchers (Miller et al., 2018). This approach has been mobilized to complete results obtained by quantitative statistical analysis by enhancing the comprehension of farmers' behaviours and actions rather than by describing causal relationships and measuring frequencies (Mann, 2007). For Boonstra et al. (2011), contrary to quantitative or semi-quantitative approaches, hermeneutics acknowledge that "*Farmers' consciousness, self-experience and the meaning they give to their acts and context are considered essential for understanding their actions*". The authors used this approach to investigate "*the variety in the ways that farmers relate to nature and [agro-environmental schemes]*" in Sweden (Boonstra et al., 2011). By analogy, our objective was to study how European farmers relate to soils and to soil organisms, conceiving the relationships through the concept of valuation (Dewey, 1939).

Other tools and records can be used in the frame of hermeneutics, such as semi-structured interviews (SSI) or indirect material like pictures and artwork (Mann, 2007). CHAPTER 5 included both FGs and SSIs and the qualitative interpretation we made of the collected material served as a basis to further construct, as a complement, CHAPTER 6. We quantitively analysed SSIs with 31 Breton farmers (Tab. 5) and of publications from a regional agricultural journal, adopting a complementary approach that differs from the previous ones. Our analysis combined both a quantitative approach to describe discourses, based on (i) multivariate descriptive statistics and (ii) inferential statistical tests, that we interpreted in the light of the overall qualitative interview.

Table 5 | Descriptors of the 31 interviewed farmers in Chapter 6. All of them are men. RD: Reduced tillage; T: Tillage with soil inversion; DS: Direct seeding. Bac: until the end of high school ("Baccalauréat" diploma obtained); Pre_Bac: studies ended before high school (often a short professional training); Post_Bac: studies after high school (*e.g.*, university or technical degree obtained in two or three years).

ID	Farm size class	Age class	Education level	Organic farming (Yes/No)	Soil management	Use of plant protection chemicals (Yes/No)
1	0_99	32_45	Post_bac	No	RD	Yes
2	0_99	32_45	Post_bac	No	RD	Yes
3	0_99	56_65	Bac	No	RD	Yes
4	100_300	46_55	Pré_bac	No	T	Yes
5	100_300	56_65	Pré_bac	No	RD	Yes
6	100_300	32_45	Post_bac	No	RD	Yes
7	0_99	46_55	Pré_bac	No	T	Yes
8	100_300	46_55	Bac	Yes	T	No
9	100_300	32_45	Post_bac	No	T	Yes
10	0_99	46_55	Post_bac	Yes	T	No
11	0_99	46_55	Bac	No	T	Yes
12	0_99	46_55	Bac	No	T	Yes
13	0_99	46_55	Post_bac	No	RD	Yes
14	100_300	46_55	Pré_bac	No	T	Yes
15	0_99	46_55	Post_bac	No	T	Yes
16	0_99	32_45	Post_bac	Yes	T	No
17	100_300	46_55	Post_bac	No	RD	Yes
18	100_300	32_45	Post_bac	No	RD	Yes
19	100_300	32_45	Bac	No	T	Yes
20	0_99	46_55	Pré_bac	No	T	Yes
21	0_99	56_65	Pré_bac	No	T	Yes
22	100_300	32_45	Post_bac	No	DS	Yes
23	0_99	56_65	Bac	Yes	T	No
24	0_99	32_45	Post_bac	Yes	T	No
25	100_300	46_55	Bac	No	DS	Yes
26	0_99	32_45	Post_bac	No	DS	Yes
27	0_99	46_55	Post_bac	Yes	T	No
28	100_300	46_55	Bac	Yes	T	No
29	100_300	32_45	Bac	Yes	T	No
30	0_99	32_45	Bac	No	DS	Yes
31	100_300	56_65	Pré_bac	No	RD	Yes

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Chapter 3

From practices to values: farmers' relationship with soil biodiversity in Europe

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Abstract

Agriculture benefits from soil functions, whereof many depend on soil biota, but some management practices can threaten soil organisms. We inventoried values that European farmers associate to soils and soil biota into their soil management decisions. We used Dewey's pragmatic epistemology, stating that values can be observed through active behaviours, attitudes and communication acts. We applied a plural values framework on a dataset composed of 35 scientific articles and five focus groups. Farmers addressed soil as a single object but hardly identified its biological elements, that appeared poorly known and little valued. Besides instrumental values, many other values, such as soil ecosystem resilience, influence farmers' management choices. We conclude that soils and soil biota values are plural and that they can evolve along with changes in farmers' practices. Further studies investigating values dynamics in time and space could be beneficial for designing an effective European soil conservation policy.

Key-words | Agriculture; Soil biota; Pragmatism; Plural values; Focus Group

Introduction

Soil represents a thin layer of finely fragmented rocks and decomposed organic materials at the basis of most terrestrial ecosystems (Whalen and Sampedro, 2010). Many soil functions depend on the functional diversity (Kardol et al., 2016) and the response diversity (Ludwig et al., 2018) of soil biota. While soils and soils functions play a major role for human activities (Wall et al., 2005), soil degradations have been reported worldwide since the early 90’s (*e.g.*, Oldeman, 1992). At European scale, agricultural activities occupy 40% of the soils (Eurostat, 2015). Because soils are not renewable at the scale of several human generations, avoiding their degradation, in particular in agriculture, has become a central issue (Powlson et al., 2011). Agricultural land managers like farmers are key actors to be addressed for soil preservation since their management decisions determine how the soil will be affected (Doran, 2002). This paper, therefore, looks into values that are at the basis of farmers' engagement in soil management, which encompasses various practices, *e.g.*, soil tillage (including a range of practices from ploughing to soil conservation, like direct seeding), irrigation, fertilisation, crops rotations, crops diversification or grazing. Sustainable management of agroecosysems links their ecological resilience with economic and sociological dimensions of socio-ecosystems (Milestad and Hadatsch 2003). While the sustainability of agricultural production relies on practices that preserve soil ecosystems and associated functions (Plaas et al., 2019), inadequate management practices may impact soil biota (Thiele-Bruhn et al., 2012).

It is widely recognised that people’s actions or practices at a given moment only partially reflect their value system and that external constraints and influences also contribute to their decision-making. Hence, social sciences have extensively studied factors influencing the selection of soil management practices by farmers, *e.g.*, in the context of adopting new conservation farming practices (Goulet and Vinck, 2012; Prager and Posthumus, 2010). Economic considerations have an important influence on farmers’ choice to adopt or to reject agro-environmental measures (Siebert et al., 2006; Wilson and Hart, 2000) or to change their soil management practices (Brussaard, 2012), *e.g.*, to lower expenses (Ingram, 2010) (for labour, machineries and material, fuel). De Krom et al. (2017) identified this as “productivist” norms and dispositions. However, at European scale, it has been observed that farmers’ behaviour rather consists of “*a mix of personal, socio-cultural, economic, institutional and even environmental variables*” (Prager and Posthumus, 2010). Social networks and interactions also influence farmers’ practices (Compagnone 2014; Compagnone and Hellec 2015). Perceptions, beliefs (Prager and Curfs, 2016), knowledge (Compagnone et al. 2008) and the social dimensions of learning processes (Ingram, 2010; Ingram et al., 2010) are important drivers. Soil management practices also appear to carry some meaning for farmers' professional identity and shared norms (*e.g.,* Compagnone and Pribetich, 2017). For Bager and Proost (1997), farmers' environmental behaviour partly depends on a number of values that play a role in setting their priorities. However, this plurality of values at stake in farmers' decisions was not yet explored for soil biota and in relation to soil management.

The pragmatist epistemology of values developed by John Dewey (1939) embeds values formations in a given geographical, institutional, and cultural context, and stresses the role of social inquiry in values formation (Renault, 2012). Defining values as what matters to people, what they feel attached to and therefore what they will care for (Renault, 2012), we capture farmers' relationships with soils and soil biota within concrete situations rather than determining which external constraints and influences affect farmers' attitudes and behaviours. Farmers tend to start talking about their relation with nature by "*what* [they] *were doing on the farm*" (Boonstra et al., 2011), as their perception of biodiversity is strongly related to their daily life (Kelemen et al., 2013). We consider words, manners of speaking of farmers talking about their soil management to reflect values related to soils and soil biota which are revealed through the inquiry process. We designed an original methodology to gather those values combining a meta-analysis of qualitative data (Greenland and O'Rourke, 2008) and Focus Groups discussions with European farmers. Investigating farmers' values appears essential to improve our understanding of their soil management practices and of the way in which they care about soils and soil biota.

Theoretical background

For long, ecosystems have been considered, at least in western and Judaeo-Christian cultures, as elements to be dominated and used by human-beings in order to address their own needs (Minteer, 2005; Renault, 2017). It has led to a dominant dualistic anthropocentric perspective in which nature is separated from humanity, the first being valuable to the second for the benefits it may provide, *e.g.,* primary products, well-being, and aesthetic satisfaction (Bourdeau, 2004; Elliot 1995). Monetary valuations of nature rely on this conceptualisation and they have encountered an important development among academics over the last decades. They are perceived as facilitating comparisons between goods and services emerging from the natural capital in opposition to those provided by other forms of capital (social, physical) (Maris, 2015).

Monetarisation of nature's benefits is also seen as useful tools to present trade-offs in management decisions (Salles, 2011). An example related to soils can be found in Pascual et al. (2015) who proposed to evaluate the insurance value of soil biodiversity on the basis of (expected) profits. Moreover, Plaas et al. (2019) evaluated the effect of earthworms' functions considering winter wheat standard gross margin. Yet, economic valuation of nature or biodiversity, particularly in monetary terms, has been presented as a limited way to embrace the plurality of the human-nature relationships. Indeed, it homogenises the expression of values in one dimension, using the monetary unit, which is neither a standardised nor neutral unit, and may have important impacts on policy making (Maris, 2015; Maris and Réveret, 2009).

Environmental ethics

Environmental ethics have developed from the early 70s as an answer to social movements and a growing awareness on environmental issues brought to light by philosophers who addressed the moral considerability of nature (Larrère, 2010; McShane, 2009), independently from the use of nature for humanity's sake only. Different theories have emerged from this field, sometimes with deep oppositions (Létourneau, 2010) *e.g.*, human-centered ethics *vs* those considering species or ecosystems as valuable for themselves, independently from human needs (biocentric, ecocentric approaches). More extensive reviews on the main philosophical schools can be found for instance in McShane (2009), Larrère (2010), and Palmer et al. (2014). In summary, these classical environmental ethics theories have encountered much criticism addressing their lack of efficiency when it comes to provide operational answers to environmental issues (Létourneau, 2010). Resulting from these concerns, environmental pragmatism has emerged in the middle of the eighties. In his founding paper based on John Dewey's epistemology, Weston (1985) stressed the dynamic, interrelated and plural nature of values which are constantly evolving within changing situations hence contesting the separation between ends and means. Environmental pragmatism was presented as a way to overcome crystallised theoretical debates in environmental ethics, particularly between those who advocated marked dichotomies *e.g.*, anthropocentric vs non-anthropocentric values, intrinsic vs instrumental values (Rosenthal and Buchholz, 1996), and thereby to be more practically effective.

Dewey's pragmatism

While, originally, American pragmatist philosophers' work did not focus on the issue of nature *per se*, several of their epistemological positions were relevant for environmental ethicists (Parker, 1996; Rosenthal and Buchholz, 1996): pragmatism (1) defines organisms' experience as the result of transactions between them and their surrounding environments, (2) recognises values as dynamic, situation-dependent properties emerging from such transactions, (3) considers that the human beings' sphere is embedded in a larger natural sphere, both interacting and co-evolving and (4) states that human beings develop a knowledge that structures the way in which they perceive the world. This represents an important break with approaches based on dualistic epistemologies in which thought and action, mind and body are separated (Armitage, 2003; Renault, 2016). Values are attributed under certain conditions and with certain consequences to an event, an object or a person (Dewey, 1939; Renault, 2012): they are objective in a given situation (Dewey, 1939). Hence, values, are not exogenous, un-rational or fixed cultural elements pre-existing to action; they consist of observable and dynamic facts and result from the definition of desirable ends in problematic situations (Bidet, 2008; Bidet et al., 2011) by a "*desiring intelligence*" (Mitchell, 1945). They reflect an appreciation that leads the individual to act in response (to reject, to take care…) and to produce evaluative discourses (Bidet et al., 2011). Values are expressed through active behaviours and attitudes; they are also subjected to reflexive examination and can be detected through the reasoning and the formulating of the evolving objectives for actions, *i.e.*, within communication acts (Bidet et al., 2011).

Values plurality in environmental pragmatism: using a "taxonomy" of values[4]

Pragmatism integrates the plurality of meanings actors might attach to a given object when investigating values (Renault, 2016). Hence, values plurality is a key-stone concept of environmental pragmatism (Callanan, 2010). Plural values encompass the '*multiple ways in which nature, ecosystems or ecosystem services are important for individuals or social groups*' (Arias-Arévalo et al., 2018). Values plurality has been described as the best way to reflect on and to conjugate diverse dimensions of human-nature relationships (Van Riper et al., 2017), and to potentially strengthen protection or conservation measures (Larrère, 2010). Decaëns et

[4] Term used by Arias-Arévalo *et al*. (2018) to name their typology of values of nature and ecosystem services.

al. (2006) provide examples of the various ways in which soil biota could be valued for conservation. Weston (1985) stated that pragmatism, by considering interrelated, interdependent and dynamic values, allows for forming "*a kind of 'ecology' of values*". Along this line, we used the taxonomy of values from Arias-Arévalo et al. (2018) (Fig. 8) to describe a "community" of interacting values related to agricultural soils and soil biota in Europe, referring to the concept of "*species community*" in ecology (McIntosh, 1985).

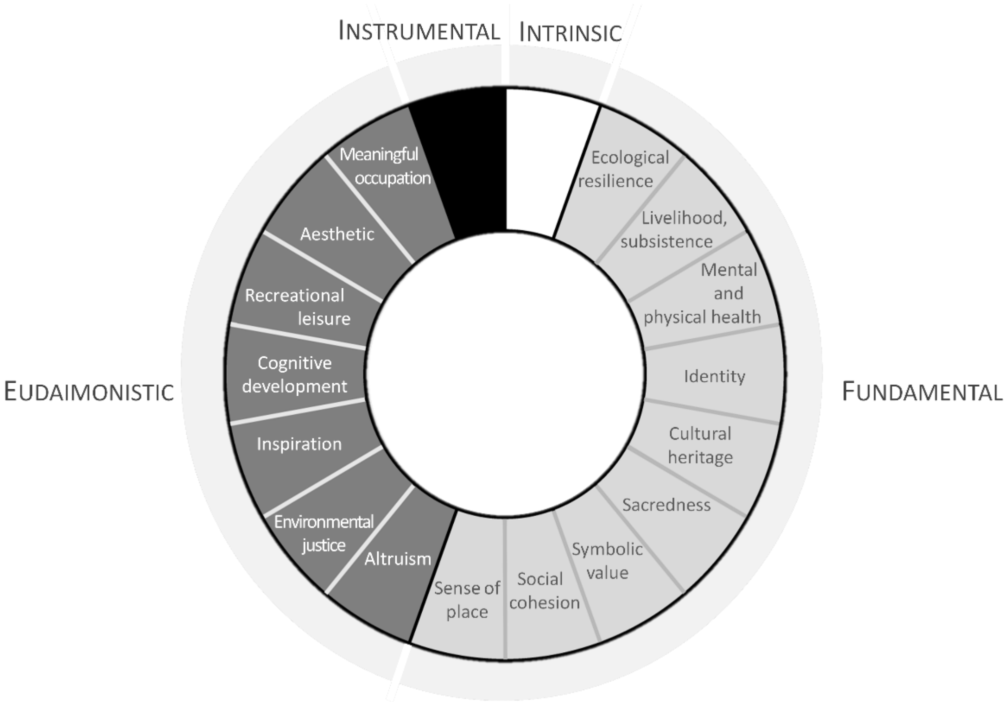

Figure 8 | Value taxonomy adapted from Arias-Arévalo (2018). Each box corresponds to one value category. Values domains are written in capital letters. There is no subdivision into categories of the intrinsic and instrumental value domain as they represent moral duties towards nature and monetary values, respectively.

Material and methods

This study is part of the European BiodivERrsA research programme "SoilMan" (https://www.soilman.eu/), running from 2017 to 2020. This programme is implemented in five regions covering a great variety of geographical contexts along a double gradient (latitudinal and longitudinal, Fig. 9). "SoilMan" studies the impact of soil management practices on soil biota functions and subsequently the economic impact at farm scale. It also examines how farmers value soil biota and how these values can be integrated in European policy and regulation. The researchers belong to a wide range of disciplines in natural and human sciences: soil ecology, soil physics, ecological statistics, agriculture economy and socio-economy.

A first pan-European value inventory of soils and soil biota was implemented using a three-step design (Fig. 9). In the first step we collected data about farmers' management practices decisions (i) in pre-existing literature and (ii) in five Focus Groups (FGs) we organised with farmers. We constructed our own two data sets, one based on the FGs and one for the meta-analysis of scientific literature. A second step consisted in collecting quotations that illustrate how soil and soil biota mattered to farmers. Environmental pragmatism devotes a large space to "*inclusive, collaborative discourse in the evaluation and justification of practices and policies*" (Palmer et al., 2014), considering that values can be investigated through language and communication acts (Létourneau, 2010). Thus, we considered the descriptions and explanations of soil management choices by farmers as an active expression of their values for soils and soil biota in specific situations. In a third step we then translated the quotations we collected into a list of frequently mentioned values using the typology proposed by Arias-Arévalo et al. (2018). In the following, we explain the three steps more in detail.

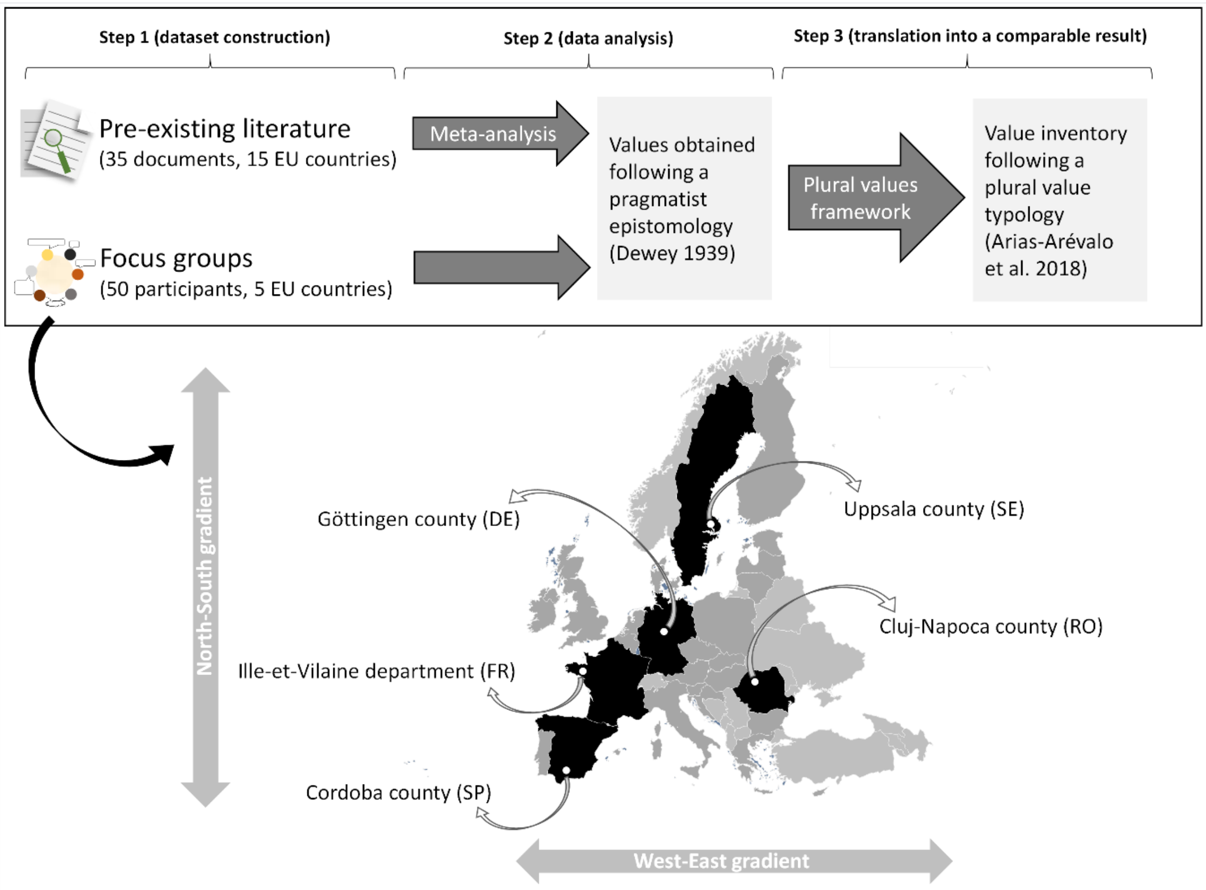

Figure 9 | Three-steps study design applied in our pan-European soil and soil biota values investigation.

Values emanating from scientific literature across EU within the last 25 years

We performed an analysis of the existing body of literature, using a qualitative meta-analysis approach (*e.g.,* Lastra-Bravo et al., 2015). A meta-analysis can be performed on multiple scientific studies addressing the same overarching question (Greenland and O' Rourke, 2008) usually to identify patterns among quantitative results. We based our qualitative meta-analysis on raw quotations or authors reporting farmers' opinions. Hence, we did not review previous conclusions from the surveyed literature but executed a secondary analysis of the qualitative data presented in those studies.

The meta-analysis included current studies on farmers' soil management, collected in peer-reviewed and academic publications*, i.e.,* articles in scientific journals, books chapters, and PhD theses. Scientific literature was searched in the Web of Science database as well as in Google Scholar using the words "soil", "farmer", "value", "environmental value", "soil biodiversity", "representation", "perception", "agriculture", and "management decision". Documents were pre-selected when the title indicated that either the farmer's decision-making, environmental behaviour or soil management practices, such as (1) no tillage, (2) soil tillage, (3) cover crops use, (4) crops rotation or (5) fertilisation, were addressed. Studies directly investigating values related to soils or soil biodiversity were rare; most studies were designed according to socio-economical or behavioural approaches, and only few were based on environmental ethics philosophy. Papers that did not present how farmers view their practices were excluded from our dataset. The final dataset was composed of 35 documents written between 1996 and 2018 (App. 1). It included studies from in 15 European countries, and three documents presented pan-European studies. Although literature dealing with farmers' practices and behaviour has been written in earlier periods, soil or values were not tackled or the values were not extractable and therefore these documents could not be used.

Inventory of current values related to agriculture soils and soil biota in Europe

Focus Groups are "*a semi-structured group session, moderated by a group leader, held in an informal setting, with the purpose of collecting information on a designated topic*" (Carey and Smith, 1994). Their main aim "*is to understand, and explain, the meanings, beliefs and cultures that influence the feelings, attitudes and behaviours of individuals.*" (Rabiee, 2004). A FG is different from a group interview as the moderator facilitates a discussion between the participants and engages as little as possible with the discussion in order not to interfere with the relationship they develop (Parker and Tritter, 2006). For the time spent, FGs are very effective tools to gather a substantial amount of qualitative data (Parker and Tritter, 2006) and they are commonly used in agriculture research (*e.g.*, Roesch-McNally et al., 2018). Following Dewey's (1939) pragmatist epistemology, we collectively define what is desirable through communication. FGs, hence, appeared as a relevant tool to uncover values while allowing farmers to discuss and collectively reflect on what matters to them.

Five FGs were organised, one in each of the five countries involved in SoilMan, during winter 2017-2018 to complement data collection. Farmers were recruited either by the local researchers' network or with the help of the local agriculture advice organisation (Tab. 6).

Table 6 | Key information on the Focus Groups realized in each country (AEM: Agri-Environmental Measures).

Country	Number of participants	Farmers characteristics
Lower Saxony Germany	9	All men Born between 1954 and 1989 6 with vocational training, 1 with technical college degree, 3 with university degree Conventional farming 2 farmers engaged in protection soil measures
Andalusia Spain	17	All men Born between 1941 and 1992 4 with vocational training, 11 with university degree (one did not complete it) 3 without degree Conventional farming; 2 with organic farming on a part of the farm and 2 with integrated production 5 participants engaged in soil protection measures
Brittany France	6	1 woman – 5 men Born between 1960 and 1988 2 with a college degree, 4 with vocational training Conventional farming 5 engaged in conservation tillage; 2 engaged in AEM (dealing with global environmental issues)
Transylvania Romania	10	All men Born between 1954 and 1996 5 with university degree, 1 with technical college degree, 2 did not specify Conventional farming; 2 farms with parts certified in organic farming 3 engaged in soil protection measures but no information whether it is an officially funded measure or not
Uppland Sweden	8	All men Born between 1947 and 1975 3 with university degree, 5 with vocational training 4 in conventional farming; 4 in certified organic farming All engaged in soil protection measures

A monetary reward was proposed in order to increase the chances of acceptance to participate. All farmers who participated have their farm in one of the studied regions of the "SoilMan" programme and their crop rotations include wheat. We first invited farmers whose fields served for biodiversity analyses within "SoilMan"; then this sample was extended to farmers who were not involved in the programme and therefore potentially less aware of or interested in soil biota issues. The sampling strategy was progressively extended according to the response rate because we needed to control the number of participants of the groups. The composition of some groups was homogenous, not reflecting the regional heterogeneity of farming practices. For instance, in the French FG all participating farmers were involved in conservation tillage as we did not succeed in recruiting other farmers. It is likely that in such situations, the variety of opinions may be low, which can limit the debate. Yet, homogeneous composition within groups may facilitate exchanges between participants (Krueger and Casey, 2009) as they can have the feeling they are alike and start a discussion more easily. We considered it particularly important for setting FG with farmers who have never met before.

Each FG started with a presentation of all participants, researchers included. The moderators took some minutes to present the “SoilMan” programme and the thematic of the discussion. Then farmers were asked to describe their farm, their crops rotations, their current management, the constraints they identify for their farming activity and the way they cope with them as well as the opportunities they perceive. Questions asked in the FG were non-constraint in order to observe how farmers present their management practices and choices and to facilitate collective exchanges. In doing so, we were confident that farmers would be able to reflect on what they want or like to do and why (Floux and Schinz, 2003). At the end of the FG, farmers were asked to fill in a questionnaire to collect sociodemographic data and more information about their farm. Foods and drinks were offered and farmers were invited to stay after the meeting to share a convivial time if they wished to. For each FG, at least one observer was present in order to manage the sampling material and to take complementary notes on farmers’ behaviour or particular gestures. The role of the observer is important to help interpret some expressions and sentences or to detect particular social interactions that would influence the expression of certain values. Just as with the literature dataset, values were not directly addressed, but rather detected later through farmers’ engagement in the description of their practices and the explanations of their management decisions.

The FGs lasted roughly 2 hours each and they were transcribed and translated into English. The material we used to investigate values consists of quotations from these transcripts.

Data analysis

Data was qualitatively analysed, which is particularly well adapted for exploratory studies (Yuhas Byers and Wilcox, 1991). The method consisted of tracing back the decision-making process in the specific situation of each farmer, described in their narratives in the FGs or in the collected studies (literature dataset). We inferred values by interpreting the reasons that the farmers state for implementing a management practice in the light of Arias-Arevalo's (2018) definitions and taxonomy of values.

Transcripts of the FGs and documents of the literature dataset were entirely read a first time in order to get a general overview. For both, a second reading focused on the parts in which soils or soil management practices were addressed, which were then extracted. For the FG dataset, we collected raw quotations from the discussion between farmers. Following Parker and Tritter (2006), we also considered whether the farmer answered a direct question or remark from the moderator or responded to another farmer to complete or to oppose his/her words for the interpretation. From the meta-analysis of scientific literature, we extracted raw quotations when available or authors' transcriptions of farmers' explanations and choices. At that stage, selected quotations from the FGs and the literature survey were characterised following an inductive coding ultimately addressing practices, explanations, and farms and situations characteristics and completed our datasets. The third step consisted of categorising values at stake in the selected quotations using Arias-Arévalo et al.'s (2018) typology of values (Fig. 8). Finally, we obtained a number of practice choices or statements about soils, the underlying reasons, the value we associated to them and either the quotations from the FGs or a reference to the documents obtained by the literature survey (see App.1, 2).

Results

In the literature and in the focus groups we could identify ten different values belonging to all four value domains defined by Arias-Arevalo (2018): intrinsic and instrumental values, four fundamental and three eudaimonistic values (Fig. 10). Besides the economic importance of soils and its organisms for agricultural production, farmers also value processes in the ecological system and various dimensions of their relationship with soils which sustain their professional activity and their well-being. In general, farmers addressed soils as a whole system, seldom expressed values for soil biota and never considered soil biological diversity. In the FGs, farmers tended to interact by comparing the characteristics of the region in which they are situated or their respective practices, and by asking each other some technical details about their farming system. Farmers did not explicitly focus on values *per se*. This is not surprising: the FGs were designed to gather information about what matters when implementing practices, without directly referring to the concept of values.

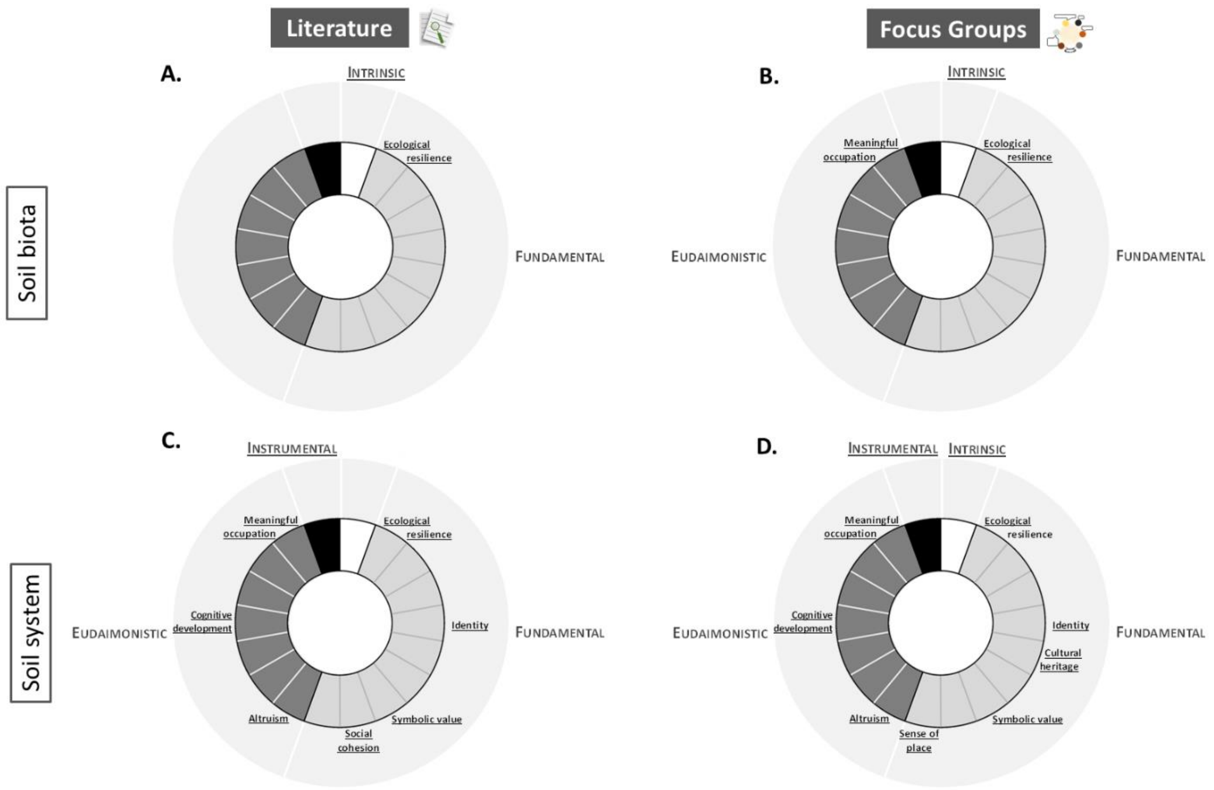

Figure 10 | Values related to soil biota (A and B) and to the soil system as a whole (C and D) resulting from the analysis of two Europe-wide datasets: literature from 1996 to 2018 (N=36 documents, A and C) and Focus Groups in 2017/2018 (N=5 sessions, B and D). Each box corresponds to one value category following the plural value typology of Arias-Arévalo et al. (2018, see Fig. 8). Only indicated values are actually found in the dataset.

Values of soil biota

When soil biota was valued for ecological resilience, farmers recognised their role in soil functioning and chose management methods that they considered adequate for soil organisms. For instance, farmers linked the importance of earthworm preservation in their soils to organic matter degradation and to benefits for their production.

> "[...] the group of Hungarian conventional farmers named ecosystem services useful for agriculture, such as pollination and decomposition, on the concept map as the most important benefits provided by biodiversity. 'In order to have orchids or good quality hay on your fields, all these things (worms and pollinators) are needed.' (HU conv)" Kelemen et al. (2013, p.323).

As such, earthworms were qualified as a real "livestock" to be fostered in farm's soils (App. 2):

> I just said, my CIPAN[5], between two cereal crops, it is a real dérobée[6], excepted that while some people might harvest it for cattle feeding, I leave it on the soil for my earthworms. And they are super important. I guess you are going to talk about that, but this earthworm livestock needs to be fed, because if we don't bring them food, they will never develop neither. (FR-5)

[5] 'Culture Intermédiaire Piège A Nitrates' that is, intermediate culture between two other cultures aiming to capture nitrogen.

[6] An intermediate culture between two main crops which is also expected to be economically profitable.

Some farmers noticed a global development of awareness about the role of soil biota for the ecological resilience of soils ("*There is an increasing awareness about soil life and its importance on the natural character of culture systems*", FR-4, App. 2) and its potential use as an indicator to describe soil quality (Wahlhütter et al., 2016; App. 1). Through the integration of new farming concerns and purposes, indicators used to assess agriculture and farming practices can evolve over time and soil biota could become a criterion (*e.g.*, Coll et al., 2012). Saunders (2016) enlarges this perspective by stating that "*environmental action*" itself can become a criterion defining a "*good agriculture*". Favouring soil biodiversity by their own practices can also become an element of pleasure for farmers indicating a meaningful activity value (App. 2):

> Usually, it is only superficial tillage, but during autumn that is a real pleasure, it is fed, it is full of earthworms, we find them everywhere, this is the most impressive culture, we can't observe this as much after a forage corn. (FR-3)

In the Spanish FG one farmer explained how he organises ploughing in order to favour earthworms. As he does not explicitly link it to his production he potentially expressed a value that relates to the intrinsic domain, even though he remained quite vague on his motivations (App. 2):

> Otherwise I plough very late in the season, perhaps also because I think of leakage and worms. You think about having a place where the worms can get down. And I, I don't, I imagine that they can find their way down if I prepare it for them. (SE-5)

In general, farmers expressed a limited knowledge of soil biota. Only few organisms, mainly earthworms, were mentioned (*e.g.*, Kelemen et al., 2013, App. 1). In particular, farmers mentioned soil biota most frequently during the French FG (*e.g.*, FR3, FR5, App. 2), where most participants actually use reduced tillage (Tab. 6).

Values of the soil system as a whole

Instrumental value domain

Overall, instrumental values attributed to the soils were widely spread in the dataset (Fig. 10C, D). Soil is valued as a support of production that should be managed in order to enhance profitability. In this case, soil conservation practices were economically valued for maintaining yields while limiting costs, time and workload (App. 2, see also App. 1):

> I think there is a collective awareness about yield stagnation; the lack of labour availability in the farms, which is going to become a central issue within the next years, soil management workload will need to be reduced. (FR-5)

Some farmers decided to maintain ploughing because they perceive it as a tool to avoid soil compaction, which would damage crops and machineries (RO-5, App. 2). For some farmers, the impacts of practices changes such as crops rotation complexification can be more costly *e.g.*, in terms of workload. Yet such impacts are not always acknowledged, and therefore not integrated into production prices or subsidies amounts ("*[…] we diversify [our cultures] as much as possible, we get a maximum workload, and we are less and less paid*", FR-2, App. 2). Positive outcomes of practices for soil functioning can be perceived as beneficial in the long-run and then reinforce or legitimate farmers' decision (App. 1; 2):

> We used to plough half of it and what pushed me to stop ploughing on the whole surface is the lack of labour. That was for this reason at the beginning, more than because of soil aspect, and afterwards I realised that it worked very well for the soil. (FR-2)
>
> "Promoters and farmers alike recognise that the transition from ploughing to reduced tillage can be troublesome and that it takes time before the benefits are apparent […]: 'We always claim that it takes at least three years to get this cycle going. Year one after you've ploughed the crops are usually good, year two you take a bit of a dip in yield because you've lost the good structure you had from ploughing yet you haven't got the natural structure or the worms but in year three yields start to go up again and of course an awful lot of people bunk out after year two'." (Ingram, 2010; p.192)

Fundamental values domain

Our results show that soil values can also directly relate to ecosystem resilience (Fundamental value domain, Fig. 10C, D). In the literature dataset, these values are linked to soil constitution as well as to the maintenance of its functions which can be achieved with a great variety of farming practices (App. 1, *e.g.*, Compagnone et al., 2013; Schneider et al., 2010). In the FGs, for instance, maintenance of soil organic matter content was particularly important (App. 2):

> I think we are going to perform a corn-wheat-rapeseed-wheat rotation, even if corn is not profitable. But regarding weeding, regarding the whole rotation, when we are going to produce corn, we are going to bring back material to the soil. (FR-3)

Farmers were also aware of the soil's role in biological pest and disease control when implementing crops rotations on the farm ("*In our case, when wheat culture follows wheat culture, we always use ploughing and generally use ploughing after wheat to prevent it from spreading, grass stocking, foot diseases...*", D1, App. 2). Very often resilient ecological functioning of soils appears to be important, because it ensures production in a long-term ("*This [crop rotation] is important for soil fertility later on, and this is important to farmers, because that's our capital*", D-8, App. 2).

Soil is also, directly or indirectly, a support of farmers' identity in the community as it can be at the basis of a shared definition of a "good farmer" (App. 1, 2), which can be also associated to a symbolic value (fundamental value domain, Fig. 10C, D). For instance, for a Romanian farmer his knowledge about his soils seems to be important to define his skills as a farmer in front of the group ("*So far, I have not done agrochemical analyses, but I want to mention that I know my soil as much as I know the need of plants for nutrients*", RO-8, App. 2). In the FGs, farmers described shared visions of soil management practices that should be used in a region ("[…] *rationally speaking it is better not to have to plough so much. Yet, it is generally seen as something that is necessary*", SE-2, App. 2). This can be associated to "*traditional image of farming*" (Schneider et al., 2010), from which cultural heritage values could stem. Social environment attributes cultural meanings and identity-building roles to agriculture practices:

> "When it comes to social motivations, they focus on the emergence of a norm related to practices and shifting towards no-tillage application. Farmers notice that this practice is more and more applied in their professional environment, which confirm their idea to show interest for it too, and even to persevere when they have innovated in that direction. 'But well, what makes… I mean what pleases me a bit is that nowadays… […] You feel like you were a little bit among the pioneers I mean […]'." (Compagnone et al., 2013; p.152; shortened quotation)[7]

Eudaimonistic values domain

Soils can support the cognitive development of farmers, who insisted on the deep mental transformation associated with a stable adoption of soil conservation practices (Eudaimonistic value domain, Fig. 10C, D). In the dairy farming region of Brittany (France) for instance, farmers described the adoption of reduced tillage methods as cognitively stimulating, because they can develop their own management decisions compared to their traditional farmer neighbours who consider soils as manure spreading and cattle feeding surface (App. 2):

> - […] historically we used to delegate and the technician from the cooperative used to come, and, for my parents it was "you apply that, you apply that", and it took that in charge, but I personally got interested because I like it and I realised you could increase the margins [….] But nowadays considering the workload in cattle breeding, the surfaces that have increased, a lot of farmers have delegated and they are not interested. They want a simple system: ploughing, sowing, and that's that. This is livestock farming. Soils are a support for manure spreading, and that's that.
> - It [the soil] is a support of cultures, that's all. There is not even soil observation any more, when we adopt those practices, our perspective on soil and on cultures completely changes. (FR-1 and 5)

[7] Translation from the authors, original version in French.

Farmers interviewed by Compagnone et al. (2013, App. 1) stressed the intellectual changes caused by a shift from a ploughing to a ploughing-free system and Ingram (2010, App. 1) showed that changing soil management practices can be satisfying as a challenge in terms of learning and knowledge development.

Our study also showed that soil ecosystems can carry meaningful occupational values (Eudaimonistic value domain, Fig. 10C, D). Farmers values related to the way they want to live and to work as farmers are related to soils: being autonomous, having qualitative production, being proud of a certain lifestyle:

> "An IP farmer made a similar observation about organic farmers and commented: 'Today they know the soil and the techniques. They have to think and not just follow a treatment plan. That causes an improvement in quality' (IP)." (Home 2018, pp.8–9)

Altruist values (Eudaimonistic value domain, Fig. 10D) were expressed by a farmer in relation to ploughing-free systems supporting global sustainability and carbon storage (App. 2):

> Well, no, but basically if I understand research correctly then agriculture is a problem of the sustainable aspects of our planet. We let all this carbon out into the atmosphere and we don't sequestrate carbon. That would correspond to the amount of greenhouse gases that we let out. And I think that agriculture could be not only a way to produce food it could also be a way to repair lots of the main system that actually keeps us alive. (SE-5)

Intrinsic values related to soil were (i) absent from our literature dataset and (ii) barely expressed by farmers during the FGs, sometimes even absent, such as in France (Fig. 10C, D). Nevertheless, some management choices may be evaluated on the basis of expected positive effect for soil biota (App. 2):

> The more soil cultivation is done, no matter in which form, the fewer earthworms there are. When it comes to tillage, also in depth, the more earthworms we have. That's why we all like to do little tillage. (D-13)

Discussion and conclusion

Thanks to a comprehensive dataset composed of farmers' narratives on soil management deriving from a meta-analysis of scientific literature and focus groups discussions, we captured a great variety of values that play a role in farmers' decision-making and concerns for soil management in Europe.

Values plurality of soil biota and soils

Instrumental values

Soils and soil biota were found to be of instrumental value. In a highly subsidised and homogenised agricultural system, it is easier to use productivity to compare farming performance in a short term (Burton, 2004); other values may seem more difficult to use for comparing oneself to other farmers. This could also be rooted in a productivist paradigm placing production levels as the sole reference for evaluating the success of agriculture (Thompson, 1995). Based on our results, the adoption of environmentally-friendly soil management practices was primarily influenced by economic considerations, whereas soil biota conservation appears to be of secondary importance. Yet, farmers appreciated practices integrating environmental benefits as well. Prevailing instrumental values do not exclude the existence of other values related to the soil such as the importance of ecological resilience and farmers' identity.

Fundamental values domain

Farmers from the FGs were aware that their management influences the functioning and the resilience of soil ecosystems. The relevance of ecological resilience values confirms the results from other studies showing that beliefs about conservation effects on soil structure and functioning influence farmers' practices (Werner et al., 2017).
Similarly, to ploughing which can carry identity values, reduced tillage also contributes to farmers' professional identity (Goulet and Chiffoleau, 2006). This illustrates the unfixed character of farmers' professional identity that can be questioned (Deuffic and Candau, 2006) and redefined (Riley, 2006). Farmers' professional identity may also rely on their ability to integrate ecological perspectives when managing soils. Some farmers may integrate society's

expectations in their soil management too (App. 1). Thus, valuation regarding soils in particular is also informed by the societal definition of what matters in agriculture. But farmers set different priorities on their farm (*e.g.,* Greiner et al., 2009) which opens the door for questioning how some values come to prevail over others.

Eudaimonistic values domain

A great variety of complex interacting processes takes place in soils with farmers needing assistance in taking relevant management decisions (Watson et al., 2002). Soil management changes do not only question farmers' identity, they encourage them to consider new aspects of soils, beyond a simple crop support, which can be challenging but also rewarding. Regarding weed-management, which is highly influenced by social interactions and shared symbols depicting "a good farmer", Sutherland et al. (2012) found that the cognitive development is crucial when shifting practices. Indeed, the productivist model that has been favoured since the 60s would require less knowledge (Rivaud and Mathé, 2011). Farmers tend to consider independence as important (*e.g.,* Greiner et al., 2009) yet, in France for instance, they have become more dependent on the assistance of technical advisors (Rivaud and Mathé, 2011). We hypothesise that new soil management practices represent a challenge that may help farmers to reengage in the complexity of farming and create a satisfying feeling of autonomy in their professional occupation.

Focus on soil biota values

We considered that valuation processes take place along with soil management practices, and values were expressed in farmers' communication about these practices. Our approach was original in that it (i) introduced a precise framework for values definition and investigation, (ii) considered plural potential values dimensions associated with soils at once and (iii) focused on soil biota itself and not only on soil or on management practices. Our results show that farmers attach a plurality of values to soil but to a less extent to soil biota. Farmers addressed soils mostly as a system and hardly distinguished between its biological elements. Organisms that appeared to be known and valued were mostly limited to earthworms. Pauli et al. (2016) described spiritual and sacred knowledge related to soils or soil biota in subsistence farming systems from different regions of the world (*e.g.*, Southern Africa, Central America) but they barely got such information in European systems. We did not detect values of sacredness, aesthetics or spirituality neither concerning soil biota nor soil as a whole even though such values have been recorded elsewhere in Europe (Cooper et al., 2016). Already 25 years ago, Thompson (1995) described a dominant conception of "*depersonalized, liveless*" soils, *e.g.,* in the EU, even if modern agriculture would have acknowledged, to a limited extent, the role of soil organisms for soil functioning.

Situation considerations in values formation

In a pragmatist epistemology, individuals lead an inquiry which allows them to progressively capture the whys and wherefores of problematic situations (Bidet, 2008). Valuation operates when desirable ends are defined to solve a problem, considering available means (Dewey, 1939). Farmers provide quite precise details on the characteristics of situations that they have to integrate in their management decisions, *e.g.,* weather (Werner et al., 2017) and price variations on the global crop market (Posthumus et al., 2011). In their responses, they seek to maintain their flexibility to react to external constraints and their adaptability to cope with unpredictable events (*e.g.*, Schneider et al., 2010). In doing so, they evaluate the outcomes of practices, *e.g.,* by giving importance to an "*adequate and secure income rather than profit maximization at any cost*" (Dury et al., 2013). Hence valuation processes are not restricted to soils and soil biota objects. In that regard, conflicts of values are likely to occur and it would be relevant to further investigate how farmers address them.

Since situations are not static, values may evolve, influenced by exchanges and confrontation with other individuals as well (Létourneau, 2010). And indeed, farmers participating in our FGs explained that social interaction facilitates the adoption of new practices (App. 2) which was also shown for adopting agro-environmental measures (Rivaud and Mathé, 2011) and soil conservation practices (Franco and Calatrava, 2012). For future research, we suggest case-studies to capture (i) how farmers investigate problematic situations (why is it problematic, which causes do they identify and how do they characterise them, how does that question their usual habits?), (ii) how they define objectives to solve this problematic situation (how do they define what is desirable, on the basis of which criteria, and how do they consider the relevancy of a mean?) and (iii) how valuation may evolve in changing situations and along communication acts.

Comments on the methods and on the approach

Our dataset was composed of different studies: (i) on various production systems, *e.g.*, intensive or extensive agriculture, (ii) combining various sampling strategies (iii) mainly on soil management and conservation, and (iv) a few focusing on the implementation of agro-environmental measures regarding soil aspects. Scientific documents could be used in this meta-analysis as long as they adequately linked results to interpretations. This was actually our main issue when collecting data because (i) a lot of studies had a constraining design, *i.e.*, pre-defined statements or questions limiting farmers' freedom of answer and therefore preventing them to express their concerns in their own words; (ii) reasons associated with farmers' decisions were not always clarified or explained, in particular in the case of soil issues. Another challenge was that soil is sometimes valued as an intermediary among a chain of successive values. In a pragmatist epistemology, this is qualified as a continuum of ends-in-view and means. For instance, in Kaltoft (1999), farmers' care about soil is translated into their management practices but this interlinks with further objectives in terms of production. Our results show that qualitative meta-analysis can be a relevant tool to analyse value systems and can increase sample size, especially for studies at large scale. While we think that going in the studied region and listening directly to farmers is a real asset, applying the FG method at a European level in five countries has been challenging. Moderation had to be delegated to local members of the "SoilMan" programme because of the language barrier. Common guidelines allowed standardising the process. Data collection still varied with group dynamics, of which the moderators were an integral part. All moderators had previous knowledge related to soil or agriculture and the "SoilMan" programme as a common background. This helped to clarify the objectives and to focus on topics particularly relevant for the studied areas. In a few cases, after translating the transcript, we realised that it would have been interesting to deepen the investigation of some items. Therefore, collective training has to be carefully considered for organising FGs, especially when working in interdisciplinary research teams and this should not be underestimated. Yet, we are convinced that once shared expectations are reached, different and complementary expertises are a real asset to moderate FGs. The second challenge lied in the translation of the FGs content. We asked native speakers who were familiar with the soil topic to transcribe the FG discussion in their native language and then to translate it into English. Except for Sweden, all translators also attended the FGs and witnessed the discussion which assisted both the transcription and the translation steps.

Conclusion and perspectives

The pragmatist epistemology proposed by J. Dewey (1939) stresses the recognition of values as observable facts revealed through communication acts. Authors who have adopted this perspective insist on the need to recognise the plurality of ways in which nature can be valued (*e.g.*, Larrère, 2010; Létourneau, 2010). Values plurality encompasses stakeholders' variety of perspectives on a topic (van Riper et al., 2017) providing elements to better integrate socio-ecosystems complexity into policy and land management (Jacobs et al., 2016). This article proposes an operational application of the pragmatic epistemology to analyse soils and soil biota values in Europe in the agro-environmental field. Constructing our dataset on these foundations, we used existing literature and implemented focus groups. Rather than focusing on one type of value, our study design allowed for the collection of multiple values associated with soils and, specifically, with soil biota in Europe. In the end, we obtained a list of observable soil and soil biota values across Europe (an *inventory* so to say) based on farmers' discourse. It suggests that eluding several of these values to focus only on one dimension (i) should be justified as it might only partially reflect farmers' relationship with their soils and (ii) could limit the significance of scientific studies and policy recommendations. At the scale of the European Union, the integration of diverse human-nature relationships is seen as a major challenge for the next 30 years of environmental protection policies (van Zeijts et al., 2017). Our original methodology and the environmental pragmatism epistemology provide an operational tool for investigating human-nature relationships, which will help to develop strategies for ecological transition in agriculture.

More precise investigations should focus on farmers' values in their "*specific national histories and agricultural constitutions and the societal, political and economic environment*" (Siebert et al., 2006). Along with Dewey's theory (1939), which defines values and valuation processes as a cultural phenomenon, values analysis has to be done according to the social and cultural context in which they appear (Bidet et al., 2011). Therefore, the following step of this work should look into the spatial variations of the inventoried soils and soil biota values.

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Chapter 4

How does soil biota matter in soil management in Europe? Exploring temporal dynamics and situation dependence in valuation processes

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Abstract

The concept of values has been extensively used as a proxy to investigate relationships between human-beings and their environment. Using a pragmatic epistemology, we investigated valuation processes at stake when farmers choose their management practices, focusing on soil biota valuations. We sought to determine to what extant values are situation-dependent and likely to evolve over time. We used five Focus Groups, in France, Germany, Romania, Spain and Sweden, where farmers described soil management situations and evaluated the outcomes of their practices. Soil management practices were reasoned according to local and current situations and not chosen "by principle". Soils were mentioned in the assessment of practices outcomes rather than as a criterion for practices choices. Values appeared dynamic, influenced by social consensus on good practices and farming objectives. Implementing a new practice might develop knowledge that is further integrated in valuations, thereby reforming the references upon which farmers evaluate their practices. Overall, debating on what matters in agriculture in different regions before defining management measures or soil indicators might be necessary to design a sustainable European policy on soils.

Key-words | Pragmatism; soil biota values; soil management practices; agricultural soils; European farmers; Focus Groups

Introduction

Human activities such as agriculture rely on soil functions (Brussaard et al., 2007) and thereby on soil biota (Bender and van der Heijden, 2015). On one hand, researchers have estimated the economic value of soils functions, soil organisms and associated services (Dominati et al., 2014; Plaas et al., 2019) to assess their importance for humankind. At a societal level, soil classification does not integrate soil biological criteria (*e.g.*, IUSS Working Group, 2015) and is often developed according to users' objectives (Soil Survey Staff, 1999), *e.g.*, crop production. As those soil classifications may underlie economic valuations such as the "Bodenschätzung" in Germany, a tax system based on soil characteristics, the recognition of the role of soil biota for soil functioning in monetary terms appears to be limited. On the other hand, Decaëns et al. (2006) listed several values of soil biota for conservation while, in agriculture, Hervé et al. (2020) observed that European farmers attach plural values to soils and to soil biota, beyond pure instrumental considerations.

Agricultural soil management responds to a wide range of factors rooted in socioecological systems, *e.g.*, economic considerations, regulations, pro-environmental attitudes, and past experience (Bartkowski and Bartke, 2018); weather, soil characteristics, and pests (Alskaf et al., 2020). Soil biota remains sometimes poorly considered in choosing soil management practices (Bechini et al., 2020). Moreover, in the academic field, Pauli et al. (2016) observed that in high-income countries, studies tend to focus on farmers' knowledge about soil physical and chemical parameters, and to neglect soil biota.

We suggest to investigate soil agroecosystems and biota values in order to provide insights that may support a transition in the way soil preservation is conceived in agriculture. Values are proxies used to investigate and qualify the myriad of relationships existing between human-beings and "nature". Studying values allows for improving knowledge, communicating, raising awareness and supporting decision-making (Maris et al., 2016), in particular to protect the environment (Chan et al., 2016). Hence, literature is brimming with studies assessing the values of nature (*e.g.,* De Vreese et al., 2016), landscapes (*e.g.,* Gómez-Sal et al., 2003), biodiversity (*e.g.,* Foale et al., 2016), ecosystems (*e.g.,* Edwards et al., 2016). But despite its relatively frequent use, the concept of "value" remains generally blurred (Horcea-Milcu et al., 2019) and, in particular, is not always defined in studies that use it (*e.g.,* Schoon and Te Grotenhuis, 2000). This can lead to misinterpretation since plethora of definitions coming from various disciplines exist (Arias-Arévalo et al., 2018, Kenter et al., 2019). Here, we define values following John Dewey's (1939) pragmatist epistemology, *i.e.*, as practical ways of taking care of things, emerging from transactions between individuals and their environment. Because of its focus on soils agroecosystems, our work relates to environmental pragmatism (Weston, 1985), a philosophical ethic that conceives values beyond a “traditional” dispute between tenants of the existence of an intrinsic value of nature versus more anthropocentric approaches.

We propose to investigate the dynamic formation of values by farmers considering their geographical and temporal variations. We are interested in particular in values related to soil biota. In a pragmatist perspective, soils and soil biota may matter to farmers, (i) as elements belonging to management situations, (ii) as objectives of their actions or (iii) as means to reach them. Minteer et al. (2004) and Flint et al. (2013) underline the relevance to consider spatial and temporal variations in values formation (i to iii). Therefore, we hypothesized that soils valuation (i to iii) differs between European regions. This represents a core asset of our paper, that explicitly address local diversities of values. Minteer et al. (2004) also suggested to use deliberative tools, such as Focus Groups, to study values formed within a social unit. To test our hypothesis, we implemented one Focus Group with farmers in five different European countries, in the context of the European programme SoilMan (https://www.soilman.eu), that investigates the relationship between soil biodiversity, soil functions and soil management practices.

Epistemology and framework development

Soil biota and ecological functioning at stake

Ecosystems functions are “*processes that regulate the flux of energy and matter through the environment (e.g., primary productivity, nutrient cycling, and decomposition)*” (Laureto et al., 2015). They ensure ecosystems stability, *i.e.,* their resilience and resistance (Srivastava and Vellend, 2005). Soil agroecosystems’ functioning results from local physical and chemical characteristics, climatic conditions, soil organisms (Fitter et al., 2005) and management practices. Hence, soils ecosystems are not considered as mere, fixed supports (Pankhurst et al., 1997), but as complex, dynamic and living systems (Doran et al., 1996) whose functioning depends on soil biodiversity (Wagg et al., 2014; Trivedi et al., 2019).

Management practices affect soil biota and communities (*e.g.,* Pelosi et al., 2014), and intensive management practices in particular cause the loss of soil biodiversity in Europe (Tsiafouli et al., 2015). Even though the link between soil biodiversity and ecosystems functions still needs to be clarified (Bünemann et al., 2018), inadequate management is likely to deeply modify the overall functioning of soil ecosystems (Nielsen et al., 2011). Land managers like farmers can have a deep understanding of the effect of their practices on soil functioning (Bampa et al., 2019). Yet, soil biota itself remains often poorly known. Most of the organisms are small, barely visible, and their roles for soil functioning remain largely ignored (Ludwig et al., 2018).

Biological indicators have been increasingly developed since the 90s (Doran and Zeiss, 2000), for soils assessment and monitoring (*e.g.,* Cluzeau et al., 2012; Stone et al., 2016). They can inform European (Griffiths et al., 2016) and national (Ritz et al., 2009) policies. Yet, foremost indicators for soil assessment rely on physicochemical parameters (Arshad and Martin, 2002, Bünemann et al., 2018). Moreover, indicators inform on soils current state compared with a reference of "good" condition. But indicators are also "*bearers of a certain vision of the world, of a moral orientation and are fundamentally political objects*" (Renault, 2016; own translation). They are performative for they designate what matters, and which relevant measurement systems to make use of. Thus, the definition of a *good* soil is set by given policies at a given moment (Griffiths et al., 2018) and may vary between individuals or periods (Doran et al., 1996). For instance, indicators and associated thresholds used to assess soils can depend on socioeconomic goals, *e.g.,* to ensure crops growth (Arshad and Martin, 2002) which barely reflects other, maybe more ethical, considerations related to soil preservation.

Framework: a pragmatic approach to the valuation of soil biota by farmers in Europe

The framework of this study (Fig. 11) is drawn upon a pragmatic epistemology. Weston (1985) introduced the pragmatist epistemology to study the values of "nature", that he considered as plural, dynamic and interrelated. While the perspective is thus not novel, one can notice an increasing academic movement that urges for considering and assessing the plurality of nature's values (Cooper et al., 2016; Himes and Muraca, 2018; Jacobs et al. 2018) to support decisions and policies framing the management of ecosystems (van Riper et al., 2017), natural resources, and land use (Jacobs et al., 2016).

Situation

Understanding people's actions requires to understand their situations (Mills et al., 2017). In a pragmatist perspective, a situation (Fig. 11) consists in a world, *i.e.,* a cultural and physical environment, experienced and interpreted by an individual who tries to solve a problem (Cutchin, 2008; Weisser, 2010). Transactions between human-beings and their environment, may thus have a role in values formation and human activities (Parker ,1996; Thompson, 2008). A situation differs from a context for individuals and their environment interact and affect each other (Zask, 2008). Specific location, scale and moment define a context (ecological, climatic, cultural, political, historical). The perception of contextual elements draws the situation. For instance, farming activities are embedded in a dynamic, constantly changing environment. When a lack or a problem occurs (*e.g.,* dry soils), it challenges farmers' usual management; in return, adapting management changes soil characteristics. Situations are unique in time, space and in their qualitative aspects (Cutchin, 2008): at European scale, they appear likely to vary between geographical locations and with time.

Social inquiry

Individuals lead inquiries (Fig. 11) to identify, clarify and unify problematic, uncertain situations by discovering "*what is at stake*" (Stark, 2009). The situation is here understood as "*an actual, practical social situation*" (Boulanger, 2014). Boulanger (2014) divides social inquiry in three steps. In the first one, a problem is identified within a pre-existing situation; in the second one, the particular constituents of the situation and of the problems are identified (causes and consequences) in order to investigate potentialities for a solution: valuation takes place here; in the third, last step, ideas of solutions (the author compares them with "scenario") are developed and their expected consequences, conceived. A social inquiry may question people's habits (Morgan, 2014) and relies on discussions and on intersubjective exchanges (Weisser 2010) as other individuals are integrated (*e.g.,* colleagues, extension services, consumers), each bringing their own vision of the situation, upon which values can be modified (Maris, 2009). As such, an inquiry allows for collectively defining what is good. The inquiry never really ends: a satisfying solution is always likely to evolve since situations are constantly redefined.

Valuation: valuing and evaluation

In a pragmatist perspective, values are not fixed or pre-existing qualities of objects, events and persons; they are attributed while an individual intends to define what is desirable to happen to solve a problem encountered in a given situation (Dewey, 1939). Values result from transactions between personal attitudes and extra-personal, situational elements (Dewey, 1939).

Social, cultural, linguistic and physical dimensions of situations influence valuations (Stark, 2009; Bidet et al, 2011). As such, values can be considered as dynamic "*across time, space and culture*" (Minteer and Manning, 1999). In this study, we considered values as "*what matters"* (Renault, 2016), *i.e.,* what farmers pay attention to, what they define as worth for them, and what they try to obtain when managing their fields. Farmers need to harmonize plural, perhaps contradicting, values in order to develop a coherent management action. A major challenge lies in understanding how conflicting values are arbitrated or even ranked (Palmer et al., 2014).

For Dewey (1939), valuation has a "*dual meaning*"*:* it combines valuing and evaluation (Fig. 11). Valuing refers to prizing, *i.e.*, holding something dear or precious (Dewey, 1939). It defines an immediate, "*de facto*", more sensitive and emotional appreciation or depreciation of something which leads the individual to desire or to avoid it (Bidet et al., 2011). For instance, for a farmer, it could be being outside and breathing fresh air, driving a tractor, liking how a field looks like with ploughing lines. Evaluation refers to "*putting values upon*" or "*assigning values to*", summarized under the term appraising by Dewey (1939). It is an intellectual activity that consists in reflecting on the desirability and relevance of contemplated ends and available means. It relies on communication and confrontation with other perspectives. As such, the criteria upon which farmers perform an evaluation can be adopted and legitimised by exchanging with other individuals. If some issues remain unsolved, valuation may go on.

End-in-view

In a pragmatist perspective, ends and means are co-determined along the decision-making. Far from being independent, they influence and redefine each other. As such, valuation corresponds to a dynamic formation of reasoned desires and interests regarding available means and their potential outcomes (Dewey, 1939, Bidet et al., 2011). Dewey (1939) introduced the term "*end-in-view"* to reflect these interdependency and dynamics (Fig. 11). Farmers set desirable ends-in-view for their action as they define desirable objectives that can be reached by means they judged as acceptable in a given situation. *Ends-in-view* in a certain situation can become means to reach other *ends-in-views*: they form a continuum (Bidet et al., 2011).

Active behaviours

Values consist in facts that can be observed, questioned, and discussed through active behaviours (Fig. 11) and communication. They are expressed within farmers' management actions and language use: they are not pure mental products.

Experience

Experience and knowledge participate to define what is desirable as they relate events and objects with other events and objects (Bidet et al., 2011) and previous experienced situations (Stark, 2012). For instance, a given practice can be rejected because it implies unsatisfying consequences previously undergone).

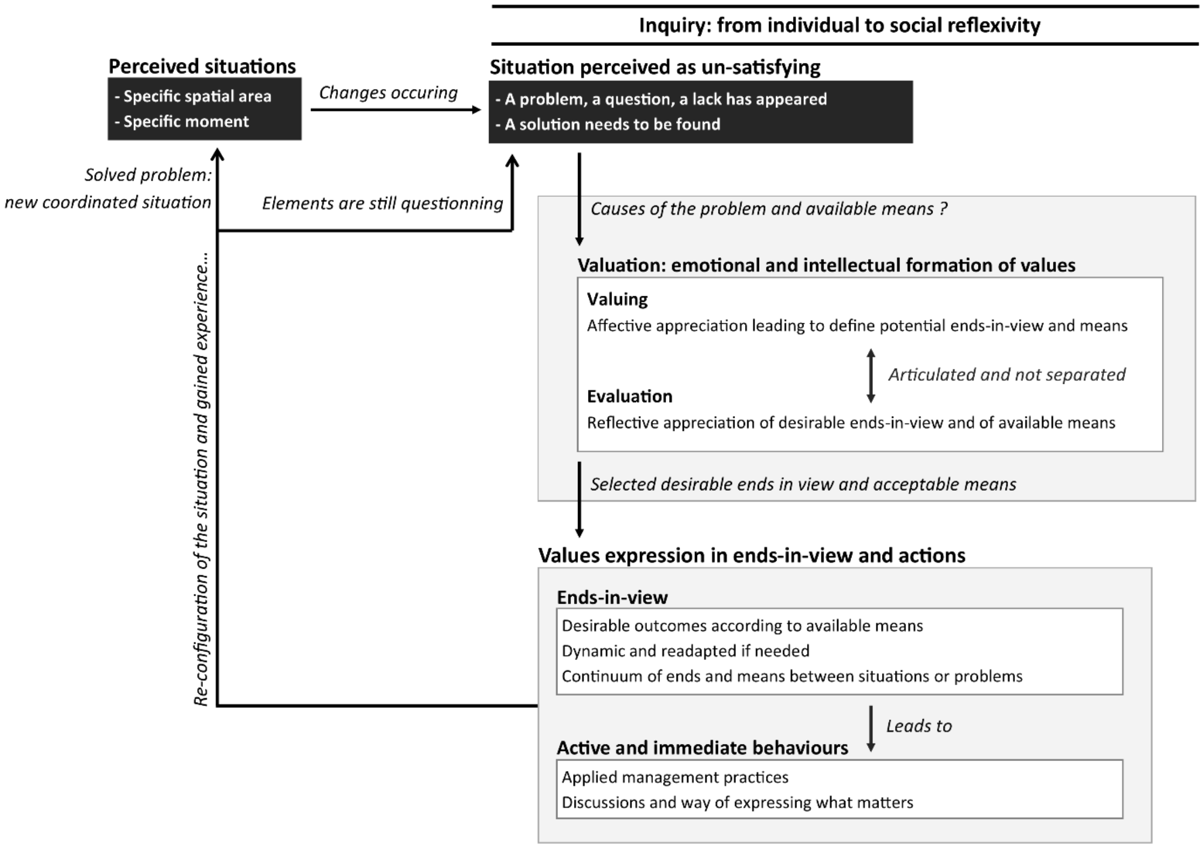

Figure 11 | Framework of the valuation process based on a pragmatism epistemology (Dewey, 1939) and applied to analyse values of soil biota in wheat culture across Europe. Focus groups were set up to leverage social inquiry.

Material and methods

Sampling took place in five countries: Spain (Cordoba province, Andalousia; ES), France (Ille-et-Vilaine district; FR), Germany (Göttingen district, Niedersachsen; DE), Sweden (Uppsala province; SE) and Romania (North West, former Transylvania; RO), situated along a West-East and a North-South gradient of pedoclimatic situations (Appendix A). Wheat is grown in each region and has been chosen as the model crop in the research programme as the most widely grown crop in the world.

Data collection using Focus Groups

The "Focus Group" method

In the pragmatist epistemology, inquiries play a core role in values formation (Dewey, 1939). Because of their transactional nature, words and narration are a relevant media to detect what matters to people, reflecting both individual internal "*conversations*" and the influence of social and collective contexts (Renault, 2016). Focus Groups (FGs) consist in group discussions that are generally semi-structured. They allow for investigating participants' personal perspectives on a given topic and collective processes of discussion, confrontations and negotiations of opinions (Warr, 2005). Each FG represents a unique social unit that may develop differently with a different set of participants. As Evans and Miele (2019) state, FGs are places of knowledge creation that might have not happened otherwise, framed by the research process itself. On that account, we considered FGs as a relevant tool to leverage social inquiry, *i.e.*, to create conditions in which farmers reflect together on what matters for them.

We implemented one Focus Group in five of the countries involved in the SoilMan programme during winter 2019-2020 (Fig. 12). First, we invited farmers who had already participated to a series of FGs held during winter 2018-2019. When personal constraints did not allow a sufficient number of participants, we extended the recruiting campaign. In this case, we used a snowball sampling method, starting with contacts in extension services and from previous research programs. Eligible farmers had to grow wheat, at least on a part of their farm. Most farmers belonged to the studied areas; due to sampling constraints, we occasionally invited farmers living further away (Appendix B). We aimed to gather different perspectives, but we did not intend to study a given population of farmers (a stratified sampling of this population would have been needed). Between 6 and 11 participants were present in the FG, which lasted around 2 hours each. All farmers were not equally familiar with the scientists nor with each other (*e.g.*, some of them had met during previous projects).

Design of the Focus Groups

To allow an inter-region analysis, we designed common guidelines to carry out the FGs (Fig. 12). These guidelines played a crucial role to communicate our objectives to the respective moderator. Before and after the discussion, we asked farmers to define soil biodiversity in their own words, individually and collectively, respectively (Fig. 12). This clarified the topic at the beginning and offered a conclusion to the FGs at the end. These questions were not designed for the present study: we will not present their results here.

The discussion really started with the moderator asking farmers why they choose their current soil management practices (Fig. 12). There were no pre-listed questions and farmers pursued the talk freely. As a result, targeted topics came up differently between the five FGs, according to the conversation dynamic and the interest of the participants. The moderator facilitated the discussion and introduced specific topics if needed, *e.g.*, conflicting objectives, adaptation to extreme weather events, criteria to choose a practice. The FGs were transcribed, anonymised and then translated into English by native speakers. These transcripts represent the raw data of our study.

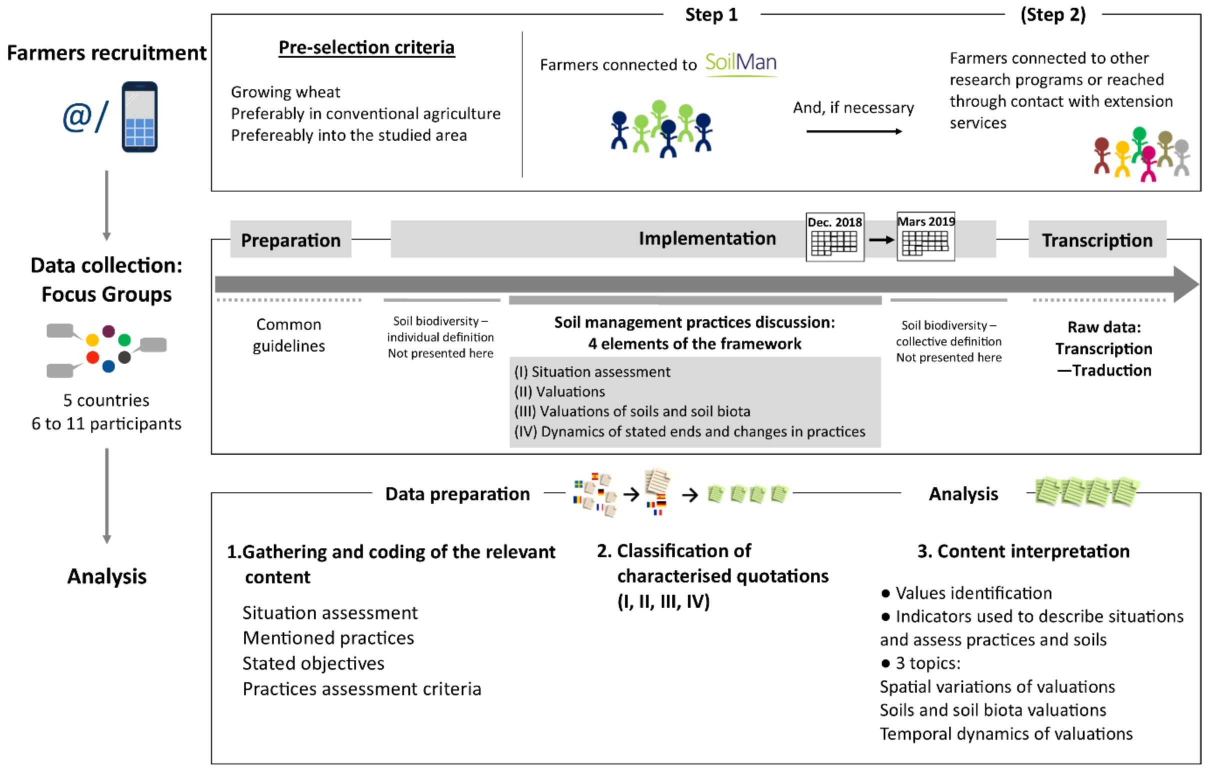

Figure 12 | Study design and analysis process applied on data collected during the five Focus Groups. Investigated framework elements (I-IV) and blocks of related research questions are outlined in App. 3.

Investigating on four elements of the framework

Moderators ensured that data collection covered the topics described in our framework (Fig. 11), *i.e.*, (I) The elements that farmers perceive as important to assess the situation in which their management takes place from their own words and own vision, *i.e.*, their own description of their farm characteristics and of the evolution of soil management situations.

(II) Valuation processes at stake in soil management practices: the ends-in-view that farmers set for their actions and the means they use. We collected the objectives of soil management that farmers presented in front of the group, the description of the practices they use and the reasons underlying their choices. We also paid attention to the criteria used by farmers to assess the (expected or real) outcomes of the practices they consider.
(III) The way in which soil biota or soil functions may matter to farmers, *i.e.*, if they are valuated or evaluated, if they consist in ends-in-view or in means and if this has changed over time. Moderators were encouraged either to rekindle the topic if it was mentioned but rapidly abandoned or to launch it if it remained absent, *e.g.*, by asking if some organisms are observed, why, since when.
(IV) The temporal dynamic of values: their potential evolution along with practices implementation and experimentation. Farmers presented how their practices had evolved over time, either as systemic evolutions of the farm or as punctual adaptations to specific events (*e.g.*, the drought during summer 2018). Then, we investigated a possible evolution of farmers' objectives or criteria to assess practices outcomes.

Analysis

Data preparation

A first reading and description of the transcripts allowed to get familiar with the content of the FGs and preparing our data (Fig. 12). We created one single file in which we gathered quotations from all the transcripts, *i.e.*, sentences or longer talks, where farmers:
- described their management situation,
- mentioned management practices,
- referred to the objectives of their management practices and
- specified the criteria they use to assess practices, either before implementation (*i.e.*, expected outcomes) or after (*i.e.*, to judge on their suitability regarding the objective and, sometimes, unexpected consequences)

The two latest points reflect valuation processes that underlie farmers' actions.
We coded each quotation over the reading, following a semi-inductive process. That allows for summarising the information and facilitating further analysis.
In a second phase, we associated characterised quotations to four categories (*i.e.*, I to IV; App. 3) corresponding to the four investigated elements of the framework (Fig. 11); we developed

sub-categories (*e.g.*, Ia; App. 3) according to the content of the quotations. Each quotation could be assigned to one or several categories.

Data analysis

We identified and named values formed when farmers manage their soils, according to the nature of their objectives and to the criteria used for practices assessment. We used the typology of Arias-Arévalo et al. (2018) and the method described in Hervé et al. (2020). Thus, we focused on mentioned indicators and on the objects that farmers characterise, considering that they reflect (i) what farmers consider worth taking into account and (ii) the measurement system they use. We paid attention to the origin of those indicators, to their nature (qualitative, quantitative) and to the conditions for their implementation (observation, laboratory analysis).
On the basis of these elements we investigated the existence of:
(i) spatial variations of values. This part focuses on similarities and differences between the situational elements that mattered to farmers, their objectives and the criteria they use to assess practices;
(ii) soil and soil biota valuations. This part refers to the importance given to soil biota in the management process through situation assessment or values formation. It analyses differences between countries and over time on that specific topic;
(iii) temporal dynamics of valuations. This part reports changes of criteria for practices evaluation. We paid attention to the sources of information that can influence changes.

Results

Spatial dependence of valuations

Various contexts for soil management

Contexts varied between regions (Fig. 13). While all farmers cultivated wheat, farm orientation patterns differed. In ES the group referred a lot to olive orchards culture. In FR and SE, most farmers had dairy farms; wheat and meadows feed their cattle. In RO and DE, farmers had mostly only crop cultures. Romanian and French farmers evoked farms structure evolution, towards larger, less familial farms.

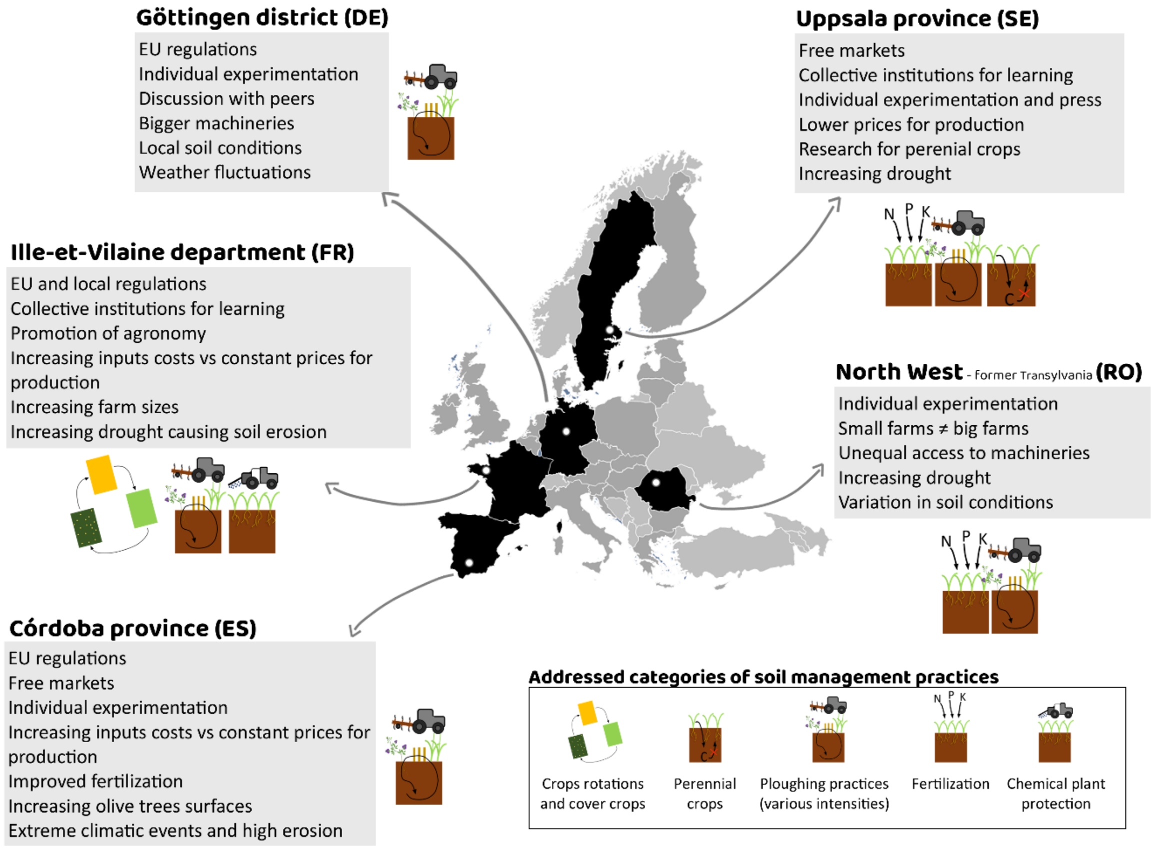

Figure 13 | Characteristics of soil management contexts as described by farmers of the five Focus Groups. The elements presented were the one mentioned the most often or the most discussed within each group.

In all groups, farmers referred to regulations: from the EU, on practices (burning, ES; fertilization, DE; agro-environmental measures and cover crops, FR) and locally, on chemical use, water protection (FR) and irrigation (DE). At large scale, global markets rules, standards and prices, European subsidies (*e.g.*, on cover crops for soil protection, FR; carbon storage, SE) partly circumscribe local situations. Farmers reported evolutions of technical solutions (on machineries, FR; on soil diagnosis, ES), to which the access remains unequal (between farming systems, RO; according to institutional situations, FR). Moreover, in FR, SE and, to a lower extant, in DE, farmers cited institutions and organisations that facilitate material sharing and knowledge co-construction (between farmers, sometimes with the support of extension services). Overall, climatic conditions were the most mentioned environmental characteristic and highly connected to their consequences on soils (moisture, erosion rate, structure).

Valuation processes related to soil management

In terms of valuing, and regardless of the group, farmers barely reported immediate, feelings-related appreciations of practices or desirable ends. At most, some explained that practices implementation depends on a certain pleasure felt while working:

> […] it's good for the soil, it's good in terms of energy efficiency and it's not that uncomfortable for the driver. D-1 (about adapting the pressure of tires on tractors to preserve soil structure)

Evaluation of the outcomes of practices hinged upon multiple criteria. Since ploughing practices were mentioned in all groups (Fig. 13), associated valuations could be compared between them (Tab. 7). Instrumental valuations were predominant in all groups (Tab. 7, FR-4). For the Spanish farmers, this responds to economic exogenous, contextual constraints. But there was a clear coexistence of multiple criteria beyond a pure economic reasoning to evaluate the potential outcomes of ploughing; this included soil erosion levels (Tab. 7, ES-5, 8, 10) and ecosystem functioning (Tab. 7, SE-6, 4). Sometimes ploughing is chosen because there is no other efficient alternative (Tab. 7, RO-7). Practices assessment also occurs after their implementation (Tab. 7, DE-1).

Overall, farmers pointed out a close relationship between practices choices and local situations:

> We can reach the same point but out of three, four different directions (RO-9)
>
> […] there are sometimes several ways that lead to a similar destination. (DE-3)

Differences in the discussed practices (Fig. 13) reflected this, *e.g.*, French farmers work in a water basin where local regulation against pollution of groundwater is prominent and they discussed a lot about chemical use issues; irrigation was intensively addressed in DE and SE, where drought highly impacted agriculture in summer 2018. In ES, farmers perceived current European policies as encouraging ploughing rather than herbicides use, which they use to legitimate their practices, initially devoted to erosion control. Overall, agricultural systems as well as environmental parameters contributed to designate good and desirable practices:

> Well, it wasn't easy with the parents, was it? It was the old generation… It was not easy. We were rapped on the knuckles. (FR-2)
>
> […] they didn't understand. (FR-3)
>
> Moreover, everyone did like that at that time. […] (FR-2)
>
> What's more the system around us that was like that. […] (FR-5)
>
> Even the Chambers, eh, at the time. (FR-2)

Table 7 | Elements of valuations associated with ploughing practices and evoked values (Arias Arévalo et al., 2018) in each of the five FGs. Since FGs are considered as one social unit, we merged the elements mentioned by several farmers within each group.

	Situation	Expected outcomes of ploughing	Stated end-in-view of management	Assessed outcomes of ploughing	Evoked values	Example
FR	Lower production levels perceived Personal observation; Collective learning; Relatives' suggestions	Soil structuration (compaction risks) Effects on earthworms' activity Prejudices about a lack of efficiency of the practice	Reduce costs Destroy cover crops Preserve soil biological activity	Workload Soil state Weed pressure Yields levels and regularity Earthworms' activity Erosion levels Costs and margin	Instrumental Ecological resilience Meaningful activity	FR-4: Well, personally, about no-till, this is, this is my brother. It was my brother who told me, he told me, maybe try the no-till on this... on a plot, we'll see how it goes. […] And then it worked so well, that well, the next thing you know, we did the ¾ in no-till. Because we realized that there was a better bearing capacity, because the yields were also... were there, there was no... there... there.
DE	Adaptability needed to face weather events Soil state (moisture, structure)	Potential cost reduction Effects on soil structure (compaction risks)	Keep water in the soil Improve soil structure Distribute organic matter	Soil structure Humus balance (long-term) Observed earthworm activity	Instrumental Ecological resilience	D-1: […] what has changed in terms of non-plowed areas is that we tend to work shallower than we did 10 years ago. And usually, in the plow-less variations, we still try to till the soil also at 25 cm depth of the topsoil, to interfere with appropriate organic material and so on. I have the impression that in recent years the soil has also changed a bit in its activity and that it is not so necessary anymore to cultivate so much and so deeply. What does not mean no-till, but means shallower processing horizons. […] also straw distribution, has quite, very much to do with, but also activity, earthworm activity, implementation ability from the ground. That's also an argument to work flatter, both.
ES	Ploughing presented as better than herbicide use in EU policies Erosion levels and risks of heavy rainfalls	Controlled weeds Water evaporation in dry conditions Erosion in try conditions Effects on soil structure (erosion risks)	Reduce costs levels Protect olive trees leaves from sunlight Improve water infiltration and avoid erosion	Costs and margin Yields levels Weeds pressure Erosion levels (awareness in the group but not considered in practice) Soil state	Instrumental Ecological resilience Symbolic value	ES-10: If you think that a plough is cheaper than herbicide application, well, you use ploughing. […] You don't think in terms of ecology, you don't think that you will avoid erosion. The economy drives you. Several farmers: I don't agree. […] ES-5: Actually, ploughing the soil removes a lot of weeds. ES-8: What's more, raining water infiltrates more easily. […] ES-5: As of autumn rains start, I do not use disc harrow, because of compaction. […] Soil cultivation, most people apply it following what is logical.
RO	Access to machineries Local idiomatic phrase: ploughing at the basis of all the work to do (ploughing, fertilizing, soil rotations)	Water evaporation in dry conditions Effects on soil structure (compaction risks)	Keep water in the soil Fertilize (incorporate manure) Preserve soil structure	Soil moisture Yields levels	Instrumental Ecological resilience	RO-7: I have tried over the years many practices, and have a lot to say about how to work the soil and preserve soil quality. Now, considering the fact that we have animals, dairy cows, and that we have manure, by the way we have a free-straw system, ploughing is very important for us to incorporate manure. We tried other techniques to administer manure, we did not have good results. The best way to incorporate manure is to plough. There are (maybe you know, maybe you don't know) three A in agriculture: ploughing (a*răt*ura), the amendment (*amendament*) and the crop rotation (*asolament*).
SE	Weeds pressure Soil moisture Crops characteristics and rotations Organic matter content Local, specific climatic conditions Information given by journals	Carbon loss and greenhouse gas emissions due to machineries Controlled weeds	Control weeds Store carbon Facilitate next culture implementation Reduce pathogens in the soil	Weed pressure Starting to consider effect on soil « life » Costs and margin Soil state Soil moisture	Instrumental Ecological resilience	SE-6: It is the weeds that determines what tillage I use, not the soil life. Moderator: Is that the case for all of you? SE-4: No, I look at the moisture in the soil, what the weather is like, if it is dry or not. I have quite diversified fields, from rigid to some clay soils with high humus content, that are easier to till. If it is dry and good conditions, I might skip ploughing, and if it is very muddy then it is not possible to till neither. You must wait until it is dryer and then you can at least plough. It also depends on the previous crop you had on the field and, if you are going to use autumn seeds for example, if you have a lot of straw. I read in a newspaper a while back, that ploughing is like an earthquake. Here, in Uppland, it is hard to relinquish ploughing but if it is dry with good conditions then I try to avoid ploughing.

Valuations of soil biota

Soil biota as a component of the situation

Soil biota integration differed between the groups (Tab. 8). In FR and RO, farmers described soil organisms as a basis for soil functioning. In DE and SE, farmers mentioned soil life but did not explicit why they consider it. In ES, farmers did not refer to soil biological elements as elements of the management situation.

Table 8 | Soil biota considerations while assessing management situation and processing valuations in farmers' discussions. "×": soil biota was not mentioned in the discussion; "✓": soil biota or soil biodiversity was mentioned as such: "✓": mention of "soil life" or "soil biodiversity" without more details at least once; "✓✓": specific taxa were mentioned at least once; "✓✓✓": specific taxa were associated with specific soil functions or farmers stressed a relation between soil functioning and soil biological diversity at least once. "✓--" indicates that soil biota or biodiversity presence is associated to something to be avoided (*e.g.,* end-in-view: to avoid pathogens). "✓⁰" refers to a statement where soil biota or soil biological diversity is clearly mentioned as something that does not matter.

	Description of the situation	Valuation		
		End-in-view (objective)	Expected mean (acceptable way to reach the goal)	Mean assessment (a posteriori assessment of practices)
Ille-et-Vilaine (FR)	✓✓✓	✓✓	✓✓	✓✓✓
Göttingen county (DE)	✓✓	×	×	✓✓
North-West (former Translyvania) (RO)	✓✓✓	×	✓✓✓	✓✓✓
Córdoba province (ES)	×	✓^{0}	✓	×
Uppsala county (SE)	✓	✓--	✓	✓✓

Farmers referred to several indicators for soil assessment before choosing a management practice:

(i) Physical characteristics: structure, erosion intensity; texture; moisture and water storage capacity; topography and orientation;

(ii) Chemical characteristics: levels of nitrogen, potassium, phosphorus, sulfur and other nutrients; pH; organic matter content;

(iii) Standardized measurements and technical services support were associated with these characteristics;

(iv) Biological characteristics: earthworms; microorganisms; spontaneous vegetation; roots implementation and degradation level of crop residues.

Soil colour was used to perform an empirical and sensitive assessment of soil texture and fertility while "crumbling" soils or birds indicated earthworm presence. Spade and digging a hole were the two methods mentioned to observe soil organisms (earthworm).

Soil functions and soil biota in valuations

Soils were generally considered as a resource for agricultural production. As such, “high quality soils” were valued according to their potential to provide good yields, which relied on soil organic matter content for RO-5. Accordingly, preserving soil functions, *e.g.*, fertility, water infiltration and storage appeared both as an objective of management and a mean for production purposes. One farmer summarized it as:

> Since nature can do part of the work, we must try to put it in place. (FR-3)

Only the French and Romanian farmers explicitely linked soil biota and soil functions (Tab. 8); in FR, earthworms were even associated with a kind of “*cattle*” to take care of. At the opposite, in ES, farmers would care about “*biodiversity*” because it conditions their production but they did not explain concretely to what extent; they explained soil functioning according to climatic events and management practices only.

Soil biota were barely presented as an end-in-view; Swedish farmers mentioned the objective to avoid soil pathogens (Tab. 8, SE). Soil organisms themselves or in relation with soil functioning were mostly criteria for practices outcomes assessment *a posteriori*, rather than as elements reasoning management choices *a priori* (Tab. 8). There, practices relevance and worth regarding soil biological elements may need to be assessed beyond one cultural season (RO-9) and in qualitative terms:

> […] Hoeing takes me two days, but after all, I tell myself that in the end I improve my health because I no longer use chemicals. And, there are things like that too, that we put on the other side… that balance, I mean. (FR-5)
>
> These are… these are non-measurable things […] (FR-6)
>
> Like the life of the soil has just improved […] (FR-5)
>
> And it’s not measurable or not measurable right away, hu.” (FR-6)

Temporal dynamics of valuations

Changes occurring in dynamic situations may modify on-going valuations. For instance, tools that farmers use to capture reality evolve, leading them to redefine elements that are worth considering. Such evolutions are sometimes allowed by farmers’ exchange with peers, *e.g.*, in DE, the participants reflected on how younger relatives introduced “*a/the spade*” to assess soils, thereby modifying the way they are observed. In other cases, technical progress, *e.g.*, weather forecast in FR, allows for integrating new information.

Observing other fields, ideas transmitted by peers, medias, family, and extension services influence farmers' management considerations. The participants reported an evolution of agriculture representations, *e.g.*, in agricultural studies in FR, where productivism appears less promoted; or in the agricultural press in SE, where soil biota has emerged as an important issue. As a result, French farmers felt that by the time, management practices such as reduced tillage have become more socially acceptable, while they were "*a little criticised*" (FR-2) a few years ago. This may modify the range of means evaluated as good, acceptable. While in ES, farmers judged that EU agricultural policies actually legitimate the current use of ploughing, in FR, farmers cited the EU regulation on cover crops as having indirectly modified their considerations on soils. Some of them started to implement cover crops as a mere response to legal requirements, *i.e.*, initially, this did not question previous valuations. But once they assessed unexpected benefits on their soils, they started to integrate new criteria for practices evaluation, *e.g.*, based on the structure of their soils. Farmers enriched their definition of what is "good" or "better" as they learnt by doing, which sustained their practices changes here.

Daily routines were defined by a French farmer as inherited, fixed practices that sometimes prevent management changes. Breaking such routines requires farmers to question the relevance of their practices. As such, experimentation appeared as an intrinsic component of farmers' activity, permitting constant learning for adaptation. For French farmers, individual prejudices and certitudes can constrain practices shifts more than technical difficulties.

Both spatial and temporal variations require farmers' adaptations:

> What I pay attention to when deciding on a soil management method, that it is operational and that it is site-adapted. [....] (D-1)
>
> What the colleagues said is important to me, too… But for me the most important thing is always the current moment of time. (D-4)

Discussion

Situation-dependent valuation processes

Valuations associated with management occur when farmers break their management routines to address a problem that they encounter in a specific situation.

In all groups, experimentation appeared as a part of farming work *per se* (see also Ingram, 2010), as "*a process of re-cognizing an aspect of the world*" (Stark, 2009) that enhances farmers' flexibility, *i.e.*, their ability "*to redefine and recombine assets*" (Stark, 2009).

However, knowledge construction was uneven between the FGs, *e.g.*, access to technical and organisational means differed. Collective experimentations, knowledge and material sharing, facilitated by local organisations, were highlighted in FR, SE and DE. In RO, smaller farms have apparently less technical options and do not receive as much technical support either. There, farmland division and restitution that followed the end of the communist regime resulted in a high share of small, less economically competitive, agricultural holdings, compared with other EU Member States (Burja and Burja, 2016, Eurostat, 2018). According to the local scientist who moderated this group, in this region, it would be usually difficult to promote collective work and there would be a lack of structures offering technical support to farmers. Local situation characteristics thereby influence the range of available means in terms of access to technologies and of organisation of agriculture activities and farmers' relationships. Thus, while farmers' networks have been recommended to enhance learning and exchanges (Alskaf et al., 2020), we add that their efficiency cannot be taken for granted. They need to be articulated with local farming cultures, *i.e.*, sets of shared mental representations and accepted, selected and reproduced ways of organizing and practicing their activities (Cefaï, 2015).

In the FGs, multiple evaluation criteria reflected plural values at stake in management decisions, *e.g.*, ecological resilience, meaningful occupation, instrumental value. Local and short-term environmental and social changes serve as a basis for farmers' management; at the opposite research and policy indicators on sustainability rather refer to longer term and larger scale dimensions (Morse et al., 2004). While indicators are seen as drawing context-independent conclusions and observations compared with individual expertise (Granjou et al., 2010), valuation appeared here as intertwined within cultural, social (Bidet et al., 2011) and natural situations. Shared representations and consensual opinions about farming partly influence evaluations that define "good" practices and objectives. For instance, farmers evoked the influence of agricultural media, education systems or practices imposed by local and international regulations. Sometimes, symbolic meanings and society's expectations perceived by farmers have a greater influence on their choices than yields or profitability *per se* (Lémery, 2003). Therefore, in a pragmatist perspective, the issue is first to negotiate on "*what is valuable and dear to us*" (Renault, 2016), *e.g.*, to discuss goals and "*strategies*", before developing indicators for sustainable soil management (Doran, 2002). Environmental pragmatism encourages democratic practices to address environmental issues (Minteer and Manning, 1999). Rather than to oppose or to impose new desirable (fixed) ends and means, encouraging the co-formation of values in soil management could be favoured through social inquiries, *i.e.*, by debating and discussing (Maris, 2012). Collective action is crucial to address environmental issues (Maris and Béchet, 2010) and requires public policies to create spaces and tools for values debates and co-creation (Huguenin and Jeannerat, 2017). This requires a real collective debate on what matters in agriculture and about agricultural soils, for whom and at which term.

Soil biota in valuation processes

Environmental conditions have a crucial role in valuation processes attached to soil management. Weather and its effects, particularly on soils, outline farmers' management action and participate to select acceptable means in a given situation. In that regard, soils are valued as intermediate objects whose state and response to management practices condition further production and easiness to work (instrumental values). Soils can also be valued for other reasons, *e.g.*, through a symbolic recognition by peers of one's skills to avoid soil erosion (ES). Farmers assess soils using the sight, the senses of smell and of touch (Compagnone et al., 2013), while soil biota often remain a marginal, descriptive element of the situation that is not further integrated in valuations. Soils chemical and physical dimensions may receive more attention since they, respectively, "*clearly affect production*" and "*are visually recognizable*" (Barbero-Sierra et al., 2016). In Mexico, de Lima and Brussaard (2010) also identified a gap between farmers' discourse and actions, *i.e.*, earthworms were presented as a criterion of soil quality, but did not orientate farmers' practice choices.

Measuring implies to negotiate and to agree on what is worth to measure (Bidet and Jany-Catrice, 2017). Soil biological indicators are mostly conceived in academic or technical institutions, and rarely integrate stakeholders' knowledge (Ritz et al., 2009): as such they are maybe less applicable among practitioners (Bünemann et al., 2018) like farmers (Stockdale and Watson, 2012). Hence, the integration of stakeholders and end-users has been urged when developing such indicators (Bünemann et al., 2018), tools for diagnosis (Chemidlin Prévost-Bouré et al., 2018) and measures (Dietze et al., 2019). This could favour the formation of values associated with soil biological elements. In other cases, farmers considered soil biota as a criterion to assess practices outcomes *a posteriori*, integrating another level of complexity (see Cristofari et al., 2018). We are aware that this may have also consisted in a form of social and evaluative discourse (Krzywoszynska, 2019), used to be legitimized in front of the group.

Generally, farmers of the FGs did not associate soil functions with soil organisms; if they did so, preserving soil biota was an intermediary objective to preserve soil functioning, itself being a mean to improve crops. Overall, this may reflect an historical trend to focus on ecosystems functions for human activities, *e.g.*, organic matter decomposition, soil fertility, tending to elude soil biota itself (Lepart and Marty, 2009).

We observed geographical variations; in FR, knowledge co-construction has apparently enhanced awareness on soil biota. Spanish farmers were rather preoccupied by erosion and barely mentioned soil organisms. This might be explained by the local pedo-climatic conditions that constraint the presence of certain organisms, like earthworms. Besides, policies frame nature management according to the way they conceive nature itself (Rodriguez et al., 2018) and norms generally conceive nature as a resource to be efficiently managed, even in nature conservation (Maris, 2012). French legal arguments for soil protection in agriculture actually rely on instrumental and productivist considerations (Fournil et al., 2018) and in Brittany, conservation agriculture discourses associate soil biota with a potential for production, rather than an object of nature conservation (Goulet and Vinck, 2012). Finally, practices effects on soil biota might be observed after a few years only, which differs from monitoring soil management outcomes using annual economic results. Quick temporal and physical changes may push farmers to focus on their immediate surroundings, which may hinder considerations on the evolution of soil biota at long term.

Temporal dynamics

All FGs highlighted the need to adapt to day-to-say changes (weather, regulations, and markets). Soil management practices are thus not chosen "by principle" but according to spatial and temporal characteristics of problematic situations. In some cases, despite a change of practice, ends-in-views and evaluation criteria remained the same. There, "adaptation" consists in a modification of routines that does not challenge valuations: "*the underlying moral values remain the same*" (Maris and Béchet, 2010). Values' dynamics imply an evolution of desirable ends and conditions to assess practices' acceptability.

Farming tools evolve and their use also depends on farmers' knowledge (Cristofari et al., 2018). Tools participate to mediate farmer's access to reality and to designate what is worth taking into account, *e.g.,* when the spade is introduced by younger relatives for earthworm empirical observation (even though it was not always clear if soil biota observations eventually played a role in valuations). This may refine what is important to consider in problematic situations. New tools do not always consist in cutting-edge technologies: *e.g.*, conservation agriculture has been defined as an innovation by withdrawal of the plough (Goulet and Vinck, 2012) and more generally of all forms of tillage, combined with the implementation of soil covers and the diversification of crops grown within one plot. New artefacts like a spade can mediate a closer relationship between farmers and their soils (Goulet, 2008).

Farmers may refine their evaluation criteria as they exchange with peers (Cristofari et al., 2018) and observe the outcomes of implemented practices. In FR, discussion about the EU cover crops regulation indicated that practices initially implemented for economic or legal reasons led farmers to consider and value soils and their functioning later. In this group, soil biota considerations were particularly significant. Values underlying a change of practice were, themselves, at stake and evolved as farmers' mindset and representations were challenged. Developing new practical beliefs can lead individuals to question the meanings of their acts, words, gestures configurations (Cefaï, 2015). In other words, values emerge through farmers' learning by experimenting. Implemented practices themselves may contribute to raise awareness and develop knowledge. As such, values may have the power to challenge farmers' visions on the role of agriculture and of the definition of *good* farming. Adequate indicators could monitor such evolutions of values and better inform policy-makers, *e.g.*, to assess "*a progressive revision of values*", necessary to cope with biodiversity loss (Maris and Béchet, 2010).

Conclusion

We used soil management situations descriptions and practices outcomes evaluations expressed during FGs with European farmers to investigate valuations associated with soil management. Instrumental values and the valuation of soil ecosystem functioning for production purposes dominated the discussions. Valuation appeared as situation-dependant and dynamic, influenced by experience and knowledge farmers have acquired. Soil biota barely represented a criterion to choose practices. At most, it was used to assess them *a posteriori*. New ways of defining why and how soil biota matters and what agriculture practices should care for can be seen as a condition for a sustainable soil management throughout the EU. Pragmatism offers a promising epistemology to integrate values dynamics when designing agricultural soils policies.

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Chapter 5

Theoretical Background (II)

Linking values formation and the perspective of changes in soil management practices in European agriculture

Transition in agricultural practices start in the field, at the bottom, with the farmer being aware of a negative impact on the ecosystem and go up to a societal demand for more sustainability in agriculture accompanied by political discourses and tools promoting certain changes. At the bottom, Caquet et al. (2020) described how farmers can realize that something is wrong in their system and requires them to modify their practices, but do not necessarily know yet how to do it. Interpreted in the light of a pragmatist epistemology, this may refer to a problematic situation that questions one's habits and usual ways of doing things (Morgan, 2014). Solving problematic situations requires to define a suitable solution and acceptable means to reach it. In other words, it amounts to designate what matters to us, *i.e.*, to form values as a response to a problem. In that perspective, values result from both previous knowledge and social interactions, as they are discussed through "intersubjective" exchanges (Létourneau, 2010). Being discussed, shared, diffused, values are also a social act. They have altogether an individual and a collective aspect, that cannot be separated from each other. As such, values also matter when it comes to collectively legitimize some practices, an innovation, a way to define and to evaluate agricultural performance or a whole agricultural model.

For instance, Geels (2002) and Boulanger (2008) explained that the justification and assessment of technological functions in transitions are constructed in a given specific economic, social, cultural and institutional context. Thus, what makes the quality of an innovation may differ (i) between situations and according (ii) to the domain from which the qualification emerges and (iii) to the existence of other innovations that it can be compared to (Garud et al., 2010). An innovation does not only consist in the substitution of a technology by another one (Geels, 2002), but also changing practices. Such an innovation depends on a whole socio-cultural dynamic (Livi et al., 2015).

Generally, socio-technical analyses of transitions still rely on "*mainstream economics*" that hardly respond to preoccupations related to ethical issues or to the visibility of plural values (Foxon et al., 2009). For Caquet et al. (2020), launching a transition implies to collectively define both good practices to use and an objective to pursue; besides, shifting to a new agricultural model would require a change of values as much as a change of practices *per se*. Therefore, implementing changes of practices in an agricultural system would require some space to debate about the direction to take, by which means and how to assess the success of the undertakings. Conveying new perspectives, knowledge, opinions can change actors' evaluation discourses. For instance, it may broaden the range means considered as possible and relevant, while previously perceived as unsuitable (Dolinska and d'Aquino, 2016).

In other words, the legitimacy of innovative tools is socially constructed (Cerf et al., 2009) and can be challenged along transition processes (Caquet et al., 2020), *e.g.*, ploughing. Far from being a neutral artefact, a tool can also become a support to "*think the change*" (Caquet et al., 2020). While thinking about the means to use and entering into collective discussions, one may also come to question pursued objectives. Thus, like Geels (2010), who mentioned the key role of debates in transitions, Dolinska and d'Aquino (2016) stressed the crucial role of discursive spaces to question and to justify choices between different options, referring to the co-construction of a "*story*" that may become the reference within a given community. For Caquet et al. (2020), agroecological transitions rely on collective learning where solutions are developed at a given moment, integrating current uncertainties, then tested, approved or rejected locally. For the authors, this amounts to a progressive process in which objectives and path taken to reach them are constantly questioned. On that account, transitions are constantly questioned, negotiated in regard with gained experiences and perceived potential futures (Garud and Gehman, 2012). This is actually quite close from a pragmatist conception of knowledge as fallible and perfectible through experience: "*an open-ended question for greater certainty, grounded in practice experience, and motivated by a desire for successful actions*" (Mintz, 2004). The pragmatist epistemology offers an interesting notion to conceptualize processes of knowledge creation and value formation through the term of inquiry and the importance attributed to experimentation and "*innovative problem solving*" (Mintz, 2004). Inquiry allows one to clarify and to unify problematic, uncertain situations by discovering "*what is at stake*" (Stark, 2009). It relies on intersubjective exchanges (Weisser, 2010) as other individuals are integrated, each bringing their own vision of the situation, upon which values can be modified (Maris, 2009). Hence, farmers who meet and talk are likely to challenge what matters to each of them, how and why. This could ultimately lead to changes in the configuration of values within the agricultural sector. In that perspective, experimentation and learning processes are highlighted as key elements for value formation and as necessary to ensure a democratic debate when dealing with environmental issues. This may be necessary to avoid a misalignment of values between different levels of organization or different locations. In the field of energy production for instance, Huguenin (2017) noticed a gap between "*universalists values of transition*" carried by energy policies developed at large scale, and "*local cultural values*" expressed within smaller territories.

Against that background, it is not surprising that values often account among the elements considered as likely, or even necessary, to change, along transitions. For instance, Schaller (1993) considers that changes in societal values are necessary to ensure a transformation of agricultural systems towards a higher sustainability. While not directly mentioned, traces of values (in a pragmatic epistemology) can be found in Vankeerberghen and Sassart (2016)'s paper through the shifts of characteristics and criteria used by farmers (i) to characterize and identify *good* soils (ii) to assess the success of their production (quality instead of yields; use income margins), and (iii) of their objectives: "*the most important thing to preserve*" becomes "*the biological life in the soil because of the essential roles it plays in production*". Dominant agricultural sociotechnical regimes are framed, stabilized and strengthened by diffused representations and shared legitimation processes (Tittonell, 2014). Dominant visions of the world and associated tools designate what to care for and thereby play a role in values formations. As such, they can influence the relationships between actors of agricultural systems and other components of their environment. For instance, tools and institutions supporting farmers in their decisions designate what matters in agriculture, *i.e.*, what is worth considering, in particular about the biophysical dimension of reality, and thereby play a role in the conception and formulation of agricultural problems (Cerf et al., 2009). In that perspective, agricultural systems also shape transactions between human beings and ecosystems. In a pragmatist perspective, human systems belong to a wider natural sphere, both being in constant transactions (Mintz, 2004). Through these transactions, values emerge. Thus, "*the natural sphere*" (Mintz, 2004) must be integrated when investigating values formation and pure sociotechnical conceptualizations of transitions in human systems may lack such an insight. Assessing the values attributed to ecosystem components may help to foster sustainable transitions by (i) better translating some aspects of the human-nature relationships within a given system and (ii) highlighting key elements for managing changes (Dendoncker et al., 2018). Again, engaging with changes in practices and in our relationships with the biophysical dimension of reality requires to debate about the object of these changes and the relevant means to implement them.

Against this background, we believe that studying conditions for values formation and their potential role in stabilizing or at the opposite in changing farmers' practices might be interesting; in particular it could represent a relevant but still overlooked insight to nourish measures for a better protection of agroecosystems like soils. This may ultimately resonate within calls for broader transitions in the European agriculture.

Therefore, my objective is to adapt a framework on values formation within the dynamic processes that farmers meet in their territory in order to understand how values may contribute to agricultural transition. The following questions have guided my work:

- **How:** defining a framework that conceptualize values formations and in return informs on values as conditioning practices changes;
- **Where:** choosing a framework that allows for comparing values and values formation between areas;
- **Who:** developing a framework in which farmers can be considered as actors of the system and that acknowledges the role of their values for their practices choices, that may foster transition processes;
- **What:** integrating ecosystems and their functioning within the framework to picture more accurately agricultural situations.

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Chapter 6

Applying the Valuating Milieu framework to investigate soil biota and soil biodiversity valuations by farmers in two European regions

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Abstract

Better preserving soil biota and biodiversity (SBB) in Europe requires a transition in the way soils are managed. Fostering such a transition implies to better understand, from farmers' perspective, soil biota and biodiversity valuations in soil management situations. The concept of Valuating Milieu (VM) was used to conceive valuations that occur through farmers' interactions with their social and biophysical environment. Farmers and professional of the agricultural sector in Ille-et-Vilaine (France) and Transylvania (Romania) were (i) individually interviewed or (ii) met during Focus Groups. Their descriptions of their management decisions were associated with the elements that compose the VM theoretical framework. Soil biota and biodiversity can be valued by farmers, which may lead to alternative management practices. This requires a local VM that favors the emergence of soil organisms as something that matters. In particular, publicization and opportunities for farmers to meet and discuss may facilitate the formation of values associated with SBB. Our approach allowed to conceive values formations as a collective process, beyond individual reasoning only. Furthermore, our results emphasized the importance of natural features on valuation processes. Ultimately, it appears crucial to create spaces for collective debates on whether the preservation of SBB is to be integrated as one of the expected outcomes of European farming activities.

Key-words | Pragmatism; Agricultural Transition; Farmer; Soil management; Focus Group

Introduction

Soils are living systems (Doran et al., 1996), whose functioning depends on climatic and physico-chemical conditions, diversified and interacting organisms, and is influenced by management practices. Over the last decades, scientific knowledge about soil biota (Powell et al., 2014) and their importance in soil functions (Barrios, 2007; Kardol et al., 2016) has noticeably improved, even though much is still to be discovered (Eisenhauer et al., 2017). This increasing knowledge has allowed scientists to progressively develop biological indicators to assess and monitor soils (*e.g.,* Bispo et al., 2009; Cluzeau et al., 2012; Griffiths et al., 2016). In practice though, farmers do neither systematically consider the effects of their practices on soils (Prager and Curfs, 2016) nor on soil organisms (Hervé et al., *submitted*) when designing their management. Such indicators may thus remain poorly understood by practitioners and less used than more traditional physico-chemical ones.

In the meantime, the protection of soil agro-ecosystems has emerged as one of the major stakes in European agriculture. Soil erosion (Verheijen et al., 2009), soil organic matter decline (Costantini et al., 2020), climate protection (Verschuuren, 2018) and soil biodiversity loss (Tsiafouli et al., 2015) are as many recorded challenges. Yet, policies in Europe (Turbé et al., 2010) and at national level (*e.g.,* in France, Fournil et al., 2018) barely integrate soil biota and biodiversity (SBB) in conservation initiatives. Moreover, the preservation of SBB in other regulations remains often implicit (Frelih-Larsen et al., 2017).

Soils and soil organisms can be of great monetary value in agriculture (Brady et al., 2015; Plaas et al., 2019); in the field, farmers may associate many other values to soil systems and soil biota (Hervé et al., 2020). Yet, knowledge about soils varies across Europe and between stakeholders (Bampa et al., 2019) and soil values are dynamic and situation dependent (Hervé et al., *submitted*). At a political level, while the (withdrawn) Soil Directive proposal had been perceived as an opportunity to define quality thresholds reflecting soils intrinsic values beyond utility considerations (Desrousseaux, 2011), for Frelih-Larsen et al. (2017) current European Union (EU) policies do not enough conceptualize the value of soils to ensure their protection. This may be evolving: the European Union launched on December 2020 the European Soil Observatory, a platform that aims to support soils preservation in the EU and to discuss soils values within society (Lange, 2020). On that account, (1) scientific knowledge on SBB is not always mobilized in the agribusiness sector, (2) the integration of SBB as an element to consider in practices choices is still not understood, and (3) the effective preservation of SBB across the EU may require a transition that includes changes in its valuation.

In the field of transition studies (TS), Livi et al. (2015) developed the concept of "Valuating Milieu" (VM), considering that valuations are grounded in specific spatial, cultural and institutional contexts (Huguenin, 2017; Livi et al., 2015). In agriculture, a transition could be conceived at farm level, but farmers are also embedded into broader contexts that they experience, thereby forming particular situations that shape their valuations and actions. European agriculture is highly depending on local and territorial characteristics despite the overreaching frame of the CAP and regional organization of farming activities is highly variable. In this perspective, our objective is to understand how values of soils and soil biota are formed in farming situations across Europe. We hypothesize that local conditions for collective values formation may highly differ between European territories. In order to test our hypothesis, we apply the VM as a framework to compare two contrasted European regions: Transylvania in Romania and Brittany in France.

Theoretical background

Introduction to the Valuating Milieu

Köhler et al. (2019) defines sustainability transitions as co-evolutive and long-term processes of non-linear changes that occur in socio-technical systems. In their view, (1) transitions are enacted by different and interacting actors; some of them favor changes while others behave to preserve the stability of the dominant sociotechnical system; (2) sustainability transitions challenge values and may be controversial; (3) they differ from other transitions because they are marked by normative directionality "*since sustainability is a public good*". Changes of values may lead to transitions and still evolve along the process. Yet they are barely investigated in the TS literature (*e.g.*, Caquet et al., 2020; Schaller, 1993). Besides, socio-technical analyses of transitions mostly rely on "*mainstream economics*" that generally focus on a single type of values and hardly integrate ethical issues (Foxon et al., 2009). The notion of Valuating Milieu (VM) has been introduced by sociologists who studied sustainability transition in the energy sector with the aim to better understand processes of socio-economic valuation of innovations in territories (Huguenin, 2017; Livi et al., 2015).

The VM explicitly considers the role of values in transition processes. Referring to pragmatism, Huguenin and Jeannerat (2017) consider that the value of technical and social innovations is discussed and negotiated in society, which participle to their legitimation and acceptation. The value of an innovation may not only rely on its competitiveness in economic terms. For instance, photovoltaic panels are not the most performant and low-cost energy-producing devices. Yet, their value may not reflect a production performance *per se*, but rather an "*opinion-value*", *e.g.,* how consumers consider this mode of production of energy as more responsible and sustainable (Livi et al., 2015). This relates to "*symbolic and communication values*" conveyed by pedagogic and commercial discourses, used to legitimate innovations beyond technical and functional arguments (Livi et al., 2015). As such, the valuation of innovations ultimately articulates economic, cultural and environmental considerations (Huguenin, 2017).

Furthermore, the VM considers that valuations of innovations are anchored within territories that are characterized by proper knowledge and socio-cultural characteristics, rather than being the result of a regional advantage (Livi et al., 2015). In Huguenin (2017), the value of photovoltaic panels is formed at the scale of a municipality by different, interacting actors (*e.g.*, energy producers, traders and consumers, city council). Moreover, Livi et al. (2015) highlight the valuating multi-local nature of the VM, which implies that innovations are not purely endogenous products of isolated territories. Innovations are valued through networks of interacting local actors, who also have production and consumption relationships at medium and larger geographical distances. In the case of agriculture in the EU, local networks can be well developed, *e.g.*, through working groups of farmers covering a few municipalities and moderated by a regional institution like the Agricultural Chamber, agriculture NGOs (CETAs), and cooperatives. But farming activities are also embedded in larger frameworks, *e.g.*, in relation with international material or input firms, crops markets, and European regulation.

Conceiving a Valuating Milieu framework

The VM relies on a pragmatist epistemology to conceive the role of values, which is a novel approach to understand changes desired by society and the means judged as acceptable to reach them (Huguenin and Jeannerat, 2017).
The VM conceives innovation development as the result of an "*endogeneous will*" of actors of a given territory (Huguenin, 2017); as such innovations are created because local territorial policies as well as private actors desire them, facilitate them or carry them (Fig. 14). Display measures (Fig. 14) allow for practicing, testing, presenting innovations, and may lead local actors to debate about their values (Livi et al., 2015; Huguenin, 2017), *i.e.*, to assess whether they are acceptable or not (Mouret and Porcher, 2018). The criteria used to assess the legitimacy of an innovation are likely to vary between "*societies, social groups, and historical periods*"

(Faure et al., 2018). Livi et al. (2015) pointed out how companies hence develop discourses that seek to relate their innovations with local agreed values (Fig. 14). Thus, interactions between actors of a territory, driven by power distribution and forms of organization, have a crucial role in transitions (Huguenin, 2017). For Huguenin (2017), values underlying the development and the legitimation of innovative solutions are also subjected to publicization made by media (Fig. 14). Publicization may play a role in the diffusion of debated values towards actors of the VM (Fig. 14).

Values may diffuse beyond the spatial and organizational boundaries of a territory, either horizontally (*i.e.*, towards other territories situated at the same level) or vertically (*i.e.*, to higher organization levels) (Huguenin, 2017). **Overall, the VM can be defined as the milieu, territorially anchored, in interaction with other organizational levels and other geographical territories, within which a social group performs valuations that orientate and select innovations within transitions.**

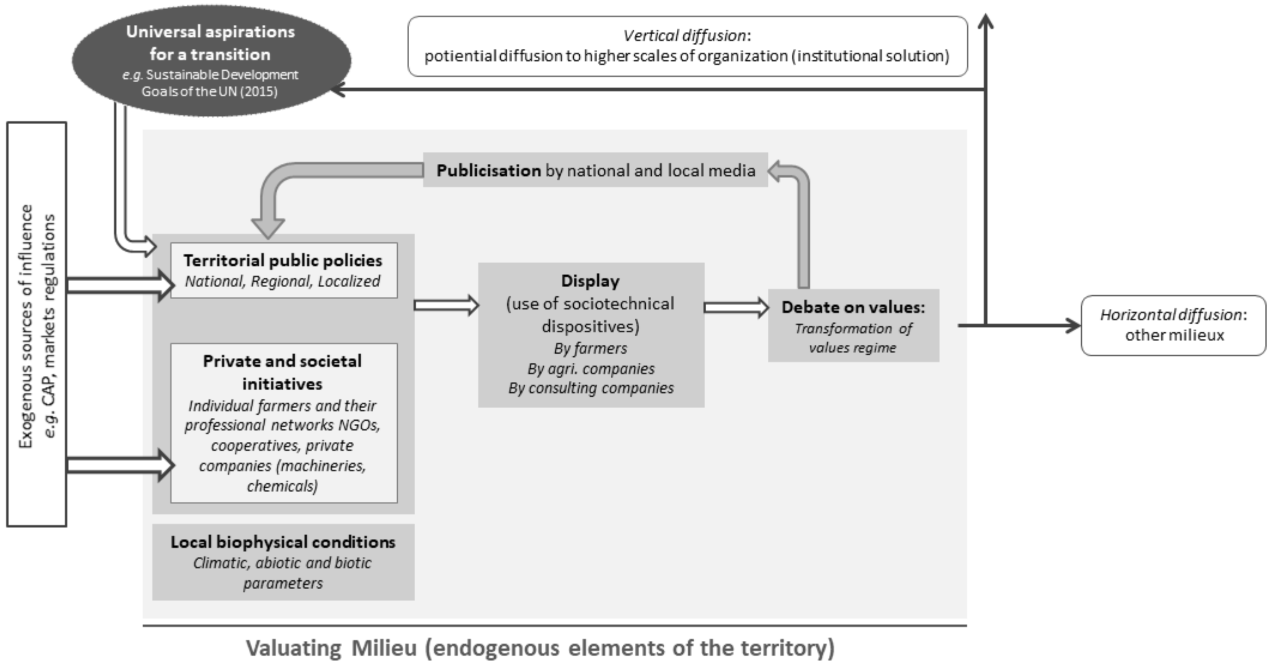

Figure 14 | The Valuating Milieu framework. Modified from Huguenin (2017).

In order to use the VM as a framework to analyze territorial process within regional context within the EU, we added another component in the framework, that does not belong to the VM but that could still influence it, *i.e.*, exogenous influences (Fig. 14). In Europe in particular, agriculture within regional territories is shaped by policies developed at a supra-level (*e.g.*, the CAP, the Nitrate and Water Directives) that is itself anchored in another scale of definition of the territory (*i.e.*, the European one). These regulations constraints farming organizations, practices, subsidies and markets; on the other hand, they can be adapted to local constraints (*e.g.,* for national and regional Rural Development Plans and lists of available agro-environmental measures). Thus, it appeared necessary to clearly conceptualize the relationship between such elements that are exogenous to the milieu and its endogenous components and dynamics.

Pragmatism emphasizes the crucial role of transactions between human beings and their biophysical environment in values formation. For Huguenin (2017) the VM allows for considering actors' representations of their "*spatial environment*" but this "environment" is not further defined. So far, studies based on the VMs framework have never explicitly referred to the influence of the biophysical dimension of situations of valuations. Yet, in agriculture, local biophysical conditions, *e.g.,* climate, soils or biota, can influence management decisions. Applying the VM framework to investigate transitions in agriculture may thus require adaptations to better understand how values are formed.

Material and methods

Launching a transition implies to collectively define both adequate and good practices to use and an objective to pursue (Caquet et al., 2020). Dolinska and d'Aquino (2016) stressed the importance of discursive spaces to question and to justify choices between different options. Therefore, Focus Groups (FG) and semi-structured interviews (SSIs) appeared as a relevant method to analyze valuating milieux (VMs) across Europe. Debates have a key role in transitions (Geels, 2010), especially in values formation (Huguenin, 2017). Ultimately, this appears quite close from the acknowledged role of social inquiry in Dewey's pragmatism (Boulanger, 2014).
We investigated the existence of different VMs across the EU by considering farmers' perspective as soil managers and their interactions. Two FG were implemented in Ille-et-Vilaine (France) and in Transylvania (Romania) during the winters 2017-2018 and 2018-2019 (Tab. 9).

The first FG focused on soil management practices in wheat culture. The aim of the second group was to get a deeper understanding of the reasons underlying farming practices and the influence of surroundings elements on farmers' choices (for more details see Hervé et al., 2020; *submitted*). The first FG campaign was completed by SSIs with professionals of the agri-business sector in each studied area, to obtain a global picture of their agricultural sector (Tab. 9).

Table 9 | Characteristics of the interviewees; N: number of people. The country code (FR-France; RO-Romania) is followed by a number that refers to each farmer, within a Focus Group (FG: FG1- winter 2017-2018, FG2-winter 2018-2019) or a semi-structured interview (SSI). Additionally, SSI were also implemented with stakeholders in the agricultural sector: CUMA (Cooperative of Agricultural Material Use); AC (Agriculture Chamber); COOP (Cooperative); CETA (Center of Agricultural Technical Studies); ECO (Economist); NGO (Non-Governmental Association); PEDO (Office for Pedologic and Agrochemical Studies).

Country	Method	Position	N	IDs
Ille-et-Vilaine, France	FG1	Farmers	6	FG1-FR1 to FR6
	FG2	Farmers	6	FG2-FR1 to FR6
	SSI	Farmer (previously in the Young Farmers union)	1	SSI-FR1
		Farmer and crop trader (own small company)	1	SSI-FR2
		President of the CUMA federation in Ille-et-Vilaine	1	SSI-CUMA
		Advisor at the AC of Brittany	1	SSI-AC1
		Responsible of a field station from the AC of Brittany	1	SSI-AC2
		Responsible of the crops trade service of a cooperative	1	SSI-COOP
		Advisor at the CETA35	1	SSI-CETA
Transylvania, Romania	FG1	Farmers	10	FG1-RO1 to RO6
	FG2	Farmers	9	FG2- RO1 to RO6
	SSI	Farmer	1	SSI-RO1
		Farmer	1	SSI-RO2
		Agricultural economist at the University of Agriculture and Veterinary Sciences of Cluj Napoca	1	SSI-ECO
		Advisor (non-governmental organization)	1	SSI-NGO
		Engineer (Office for Pedologic and Agrochemical Studies)	1	SSI-PEDO

Following an interpretative approach, our qualitative analysis consisted in identifying, in the transcripts of the FGs and the SSIs, the elements that appear to play a role on the formation of SBB values and in associating those elements with the components of the VM framework developed by Huguenin et al. (2017; Fig. 14). Thus, we used the FG and SSI to:

(1) inventory the elements that farmers pay attention to when they define their production system and practices;

(2) collect the sources of information and knowledge that led farmers to consider those elements;

(3) categorize these elements according to the different components of the VM (Huguenin et al. 2017; Fig. 14).

Case study : Ille-et-Vilaine (FR)

The department of Ille-et-Vilaine, in Western France, is marked by agriculture, particularly by dairy farming (Lesaint, 2019a). Mixed-farming systems are still common: farmers often grow cereals to feed their livestock and have grasslands (Lesaint, 2019b).

Four singularities caught our attention in Ille-et-Vilaine: (i) the role of local water regulations in raising awareness about soil and soil biota issues (Territorial public policies, Fig. 15), (ii) the richness and the importance of collective modes of organization as means of empowerment to tackle soil preservation issues, *e.g.*, by testing alternative managements (Display, Fig. 15) and finally (iii) the existence of plural, evolutive channels of publicization on soil issues (Publicization, Fig. 15), (iv) Evolutions in valuations.

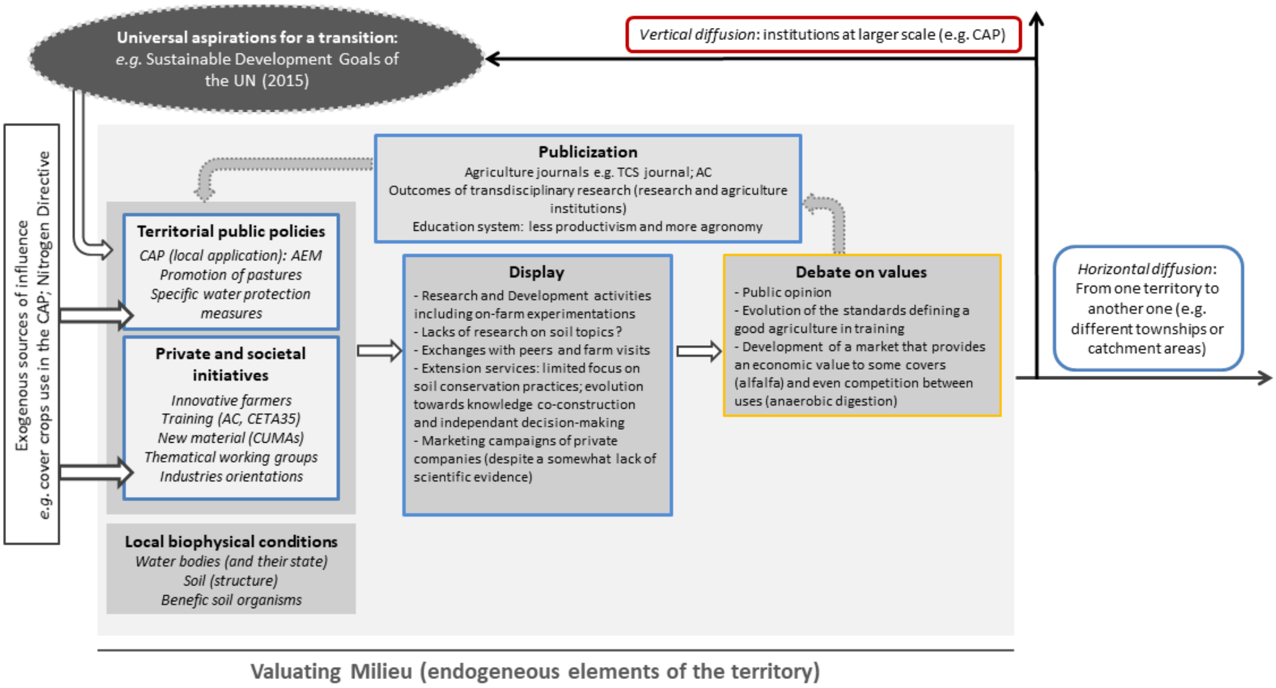

Figure 15 | The valuating milieu (VM, following Huguenin et al. 2017, Fig. 14) related to soil and soil management in Ille-et-Vilaine. CAP: Common Agriculture Policy; EU: European Union; AEM: agri-environmental measure; AC: Agriculture Chamber"; CETA: Center of Agricultural Technical Studies; CUMA: Cooperatives for the Use of Agricultural Material; TCS: Simplified Cultural Techniques. A blue frame indicates an element of the VM that was particularly highlighted in the material we analyzed. A yellow frame with dashes indicates an element of the theoretical VM that may have been briefly mentioned but for which we hardly obtained details, *e.g.*, farmers integrate public opinion on environmental matters into account when choosing their practices (SSI-AC2) but we do not know exactly how farmers and society interact. A red dotted frame refers to an element of the theoretical VM that was not mentioned at all or that was explicitly stated as lacking by the interviewees. Simple black arrows indicate a diffusion of valued innovations and values formed within the VM to other territories or scales of organization. Large white arrows refer to the direction of influence between external and internal components of the VM that lead to the formation of values. Grey, doted arrows refer to a potential retroaction of values that are within the VM on its own actors (private and political).

Evolutions in valuations

For SSI-FR2, achieving maximum yields often remains the dominant objective in agriculture. This way to evaluate farming activities is particularly encouraged by cooperatives and manufacturers and leads to agriculture intensification for FG2-FR3. However, SSI-FR2 has also noticed that new farming objectives emerge, that rather target the optimization of the practices and the reduction of inputs. He had started to test soil conservation practices by himself to reduce his expenses (*e.g.*, on gasoil). The objective of this private initiative (Fig. 15) is not to reach very high yields but rather to decrease the use of inputs, *e.g.*, by selecting appropriate crop varieties. Nowadays, in agriculture, farming systems evaluations would (i) deeper focus on financial accounting and (ii) include new, non-monetary calculations:

> Let's say that 20 years ago, a farmer who wanted to do things properly, he used to drive his culture to a correct state and with a high yield. That was the indicator used to assess his success. Nowadays, I think that the level [of knowledge] of the farmers leads them to use different indicators to assess their achievement, that refer way more to financial accounting aspects. Financial accounting, working time, and quality of life too. (SSI-AC2)

Furthermore, soil biological dimension has become associated to "*soils that are good*" for SSI-AC2, which may also challenge the conditions required to transmit a good land. According to SSI-AC2, farmers nowadays consider soil biota, particularly "*symbolic*" organisms (earthworm, ground beetle), as a form of production factor, that can be favored by conservation practices and that can substitute to other factors (*e.g.*, material or human).

Territorial public policies: local regulations to raise consciousness about soils and SBB issues

Brittany has encountered important water quality issues over the last decades. Among others, nitrogen pollution has strikingly affected aquatic ecosystems (eutrophication problem leading to algae development, human health issues, economic disasters) and the use of nitrogen in agriculture has become particularly regulated in the region (DREAL Bretagne, 2019). Such regulations can force farmers to change their practices.

Farmers of the second FG initially conceived alternative soil management as an indirect mean to preserve water bodies. These farmers have worked collectively on water issues in their catchment area, where specific agri-environmental measures (AEMs) such as chemical input reduction had been introduced. The farmers reported that working together facilitated the adaptation of their management system, raised their awareness on environmental issues and, ultimately, constituted a first step towards deeper changes on their farm. Consequently, they maintained their working group about soil management practices (Private initiatives, Fig. 15).

SSI-AC2 and farmers of the second FG also explained that, in the region, cover crops in winter have been compulsory since the beginning of the 2000s. FG2-FR3 already voluntary used this practice to preserve his soils (Private initiatives, Fig. 15). Initially, the others farmers did not perceive the usefulness or assets of cover crops and merely followed the regulation. Afterwards, they observed improvements on their soils, *e.g.,* in terms of structure. As a result, they began to integrate cover crops not only as a legal requirement but as a full agronomic "*tool*", particularly important for those engaged in a reduction of tillage intensity (SI-AC2), so that nowadays, for FG1-FR1 "*a good cover is also a good agriculture*".

Display: collective organizations as vectors of discussion and learning

Farmers' capacity to learn by themselves was stressed during the interviews. FG1-FR3 and FG1-FR6 explained that shifting to soil conservation practices requires a long and progressive adaptation. New practices need material and organizational adaptations, but also an evolution of their whole mindset: "*But indeed, it needs a transition of the soil, it needs a transition up there* [pointing to his head] *as well*" (FG1-FR5). Observing their own fields and their neighbors' ones was reported as a first way for farmers to question their work, but exchanges with peers and extension services may also play a great role here.

In Ille-et-Vilaine, collective modes of experimentation and knowledge and material sharing appeared particularly important (Display, Fig. 15). One reason could be a local, traditional culture of mutual aid in dairy farming (SSI-AC2). Technical groups accompanied by agricultural engineers are a major form of collective work. The regional Agriculture Chamber (AC) and the Center of Agricultural Technical Studies of Ille-et-Vilaine (CETA35) are the two major groups coordinators that were mentioned in the FGs and the SSIs. ACs are public institutions representing actors of the agricultural sector. A group of elected representants of these actors leads each AC. They set working groups with advisors to support collective knowledge production (Private and societal initiatives, Fig. 15). Farmers are encouraged to exchange with each other and to experiment practices by themselves:

> And putting something new in place is much easier when you are in a group, talking about it together..., talking about it, experimenting it, in the end." (FG2-FR7)

Advisors' main role is to support the group and to ensure a bottom-up functioning. The support provided by the AC advisor in terms of knowledge and coordination can be very important:

> As we left agricultural schools [The guiding theme was to produce (FG2-FR3)], we had only one mode of production. [...] Then of course, we had partners, with the Chambers and others, the working groups, which... made things happen." (FG2-FR5)

CETAs are non-governmental associations that claim their independence upon political movements or farmers' unions. Yearly training programs are based on farmers' suggestions. In 2017, one training specifically targeted cover crops management, two other focused respectively on reduced tillage and direct seeding in mixed-farming, and two more on the reduction of pesticides and fertilization. Two engineers of the AC and the CETA35 insisted on the importance of knowledge co-construction to preserve farmers' autonomy in their decisions (SSI-CETA; SSI-AC1). For the farmers in FG1, this approach breaks with the local "traditional" soil management system in dairy farms, within which farmers have tended to delegate crops management planning to extension services, and to follow the instructions that they received (FG1-FR6; SSI-FR2). Besides AC and CETA35, Cooperatives for the Use of Agricultural Material (CUMAs) may also have a substantial role in leading farmers to discuss their practices and their own trials.

Publicization on soil issues: plural channels

Technical advisors and agricultural education participate to diffuse a model of the "good" objectives of agriculture. First, extension services influence values formation by orientating the definition of problematic situations. As such, SSI-AC2 identified a responsibility of extension services in the lack of focus on soil functioning in the past:

> […] in the agriculture education and in extension services from the Chambers, the cooperatives, we have left that a bit out. By necessity, basically, because the objective was to produce at low cost. And so… We suggested to all farmers to do what was necessary to produce nearly as if they were in the worst of the situations. In a situation with all the possible pests, with the worst soils ever, to ensure everywhere, easily, a maximum production. […] nowadays, the basis is different and thus, it requires different techniques too. (SSI-AC2)

Some farmers also felt that extension services would not focus enough on soils issues (*e.g.*, FG1-FR6). In both the CETA35 and the AC though, the advisors somewhat disagreed and presented several tools they use nowadays to tackle this topic, *e.g.*, use of a spade to look at soils and soil organisms during field visits (SSI-CETA), communication on the economic benefits associated with soil conservation practices (SSI-AC2), field experiments (SSI-CETA; SSI-AC1; SSI-AC2) and the publicization of their outcomes (SSI-AC2) (Display, Fig. 14). For SSI-AC2, farmers are already aware that soils need to be better preserved and have been convinced for long by soil conservation practices. What rather lacks in his eyes would be (i) a real comprehension of the link that exists between soil processes and soil biota, beyond the observation of organisms and (ii) an event that pushes farmers to really change their system (*e.g.*, SSI-FR2), *e.g.*, a technical constraint, a new regulation, a climatic pressure, or an economic objective coupled with a personal interest (*e.g.*, FG1-FR6).

Experimental sites, within farms or field stations of the AC and CETA35, are important vectors of display towards farmers:

> When we want to show something to farmers, it is often by a display… […] We tend to show this kind of things, well developed cover crops, when we dig holes, to show earthworm, to show the things." (SSI-AC2)

Experimentations can be performed in collaboration with researchers, *e.g.*, with a local group specialized in soil ecology and earthworm. At the opposite, some farmers explained that when they initially started to use reduced tillage, they did not feel supported by agriculture research institutions:

> […] we have to admit that, compared to 20 years ago, even those which were thundering like the INRA, Arvalis, and other tools of the State, that were against what we were doing…" (FG2-FR3)

FG2 represented several generations. All farmers depicted a change of focus in agricultural education by the time, and the integration of environmental issues in management has become more important than it was: "*At school, we were not asked to do agronomy, we were asked to produce*" (FG2-FR3). For SSI-AC2, better knowing soil processes, *e.g.*, the influence of organic fertilization on soils and the relationship between organic matter and the functions of soil biota, allows farmers to better understand the evolutions of regulations as well.

Private companies like suppliers of soil stimulation substances may participate to raise awareness about soils and soil biota, despite a perceived lack of scientific validity sometimes (FG2-FR3). For SSI-AC2, such commercial discourses may, ultimately, play a greater role to preserve agricultural soils than the substance that is sold itself, as farmers are told that:

> one may be careful not to compact too much when going in the fields, one may bring manure, have rotations and cover crops to be given back to the soil. In a way, the farmer is going to realize that, well, there is something in their soil, that it is not a support for cultures" (SSI-AC2)

Publicization can also be achieved through general and territorial or specialized agricultural journals. Farmers' capacity to search for and to gather information has evolved, which is also facilitated by the development of numerical technologies (SSI-AC2).

Finally, society can also play a role in the debated criteria used to evaluate the relevance of farming practices: "*And there is the regard from society that has changed too. Well, there are farmers who integrate that." (*SSI-AC2). In terms of soil management, FG1-FR6 explained that some farmers who had started soil conservation management finally decided to plough to remove weeds, because of society opposition to glyphosate.

Case study: Transylvania (RO)

At the end of the communist regime in Romania, in 1989, farms were split into smaller plots that were given back to their previous owners. This parceling out led to the creation of small, subsistence farms on a few hectares, or even less. Nowadays, this land is sometimes rented.

This brings new challenges: around Cluj-Napoca for instance, urbanization pressures land markets and landowners want to keep their land easily available for sale. This can result in noticeably short renting contracts with farmers constraining their crop rotations. In the region, crop cultures specialization is increasing, while dairy farming, particularly mixed systems, are decreasing (SSI-RO1).

The entrance of Romania into the EU in 2007 has increased international economic competition but also provided financial support to preserve small farms (FG1-RO6). Since 2014, in the Transylvanian plain, farms tend to get bigger and bigger (SSI-ECO; SSI-RO1), and nowadays, villages often encompass only one or two large farms (SSI-RO1), presented as business companies (SSI-ECO) or "*pure economic structures*" (FG2-RO9). Increasing farm size leads farmers to use reduced tillage to decrease their workload (FG1-RO7). Farmers benefit from technical and agronomic improvements, that allow them to better manage their soils:

> We can better work the soils, with more recent and more efficient machines, in a shorter time, with lower consumption than before and higher yields" (FG1-RO6)

But despite its good soils, Northern Transylvania is less marked by land grabbing than Southern Romania and the region still counts quite a diversity of farming models, from large, specialized structures to familial, self-sufficient farm-holdings (SSI-NGO).

Two elements caught our attention. (i) Institutions or organizations that could facilitate collective experiments and the display of alternative practices seemed very rare. Private initiatives that give value to soils exist, but from the content of the interviews, it appeared that, generally, they remain unformal. (ii) Related to this lack of organizational support, there is a limited influence of regulations on the formation of values related to soils and SBB.

Private and societal initiatives and display: informal collective work and limited extension services

Farmers' decisions, *e.g.*, to implement trials on their farm are crucial for innovations development and legitimation since collective organizations are limited (Private and societal initiatives, Fig. 16). Farmers can exchange:

> When you encounter a problem, you call a colleague who works in the field. If he cannot help you, then you will turn towards other sources as the Internet. (FG1-RO8)

However, these experiments are not shared within working groups. Discussions with peers are not structured by a professional training scheme. Consequently, farmers cannot apply for subsidies supporting inter-farmers organizations (SSI-RO1). Similarly, material sharing is generally an informal form of cooperation. For the smallest farms, those that are in a self-sufficient system, this might actually be the only way to purchase such machineries (SSI-NGO). Famers' rejection of cooperative forms of organization since the end of the communist period could, at least partly, explain the absence of institutions facilitating, directly or indirectly, co-learning and sharing (Display, Debate on values; Fig. 16). However, some of the farmers are aware that an improved collaboration could support them: "*We have great opportunities if we help each other*" (FG2-RO6).

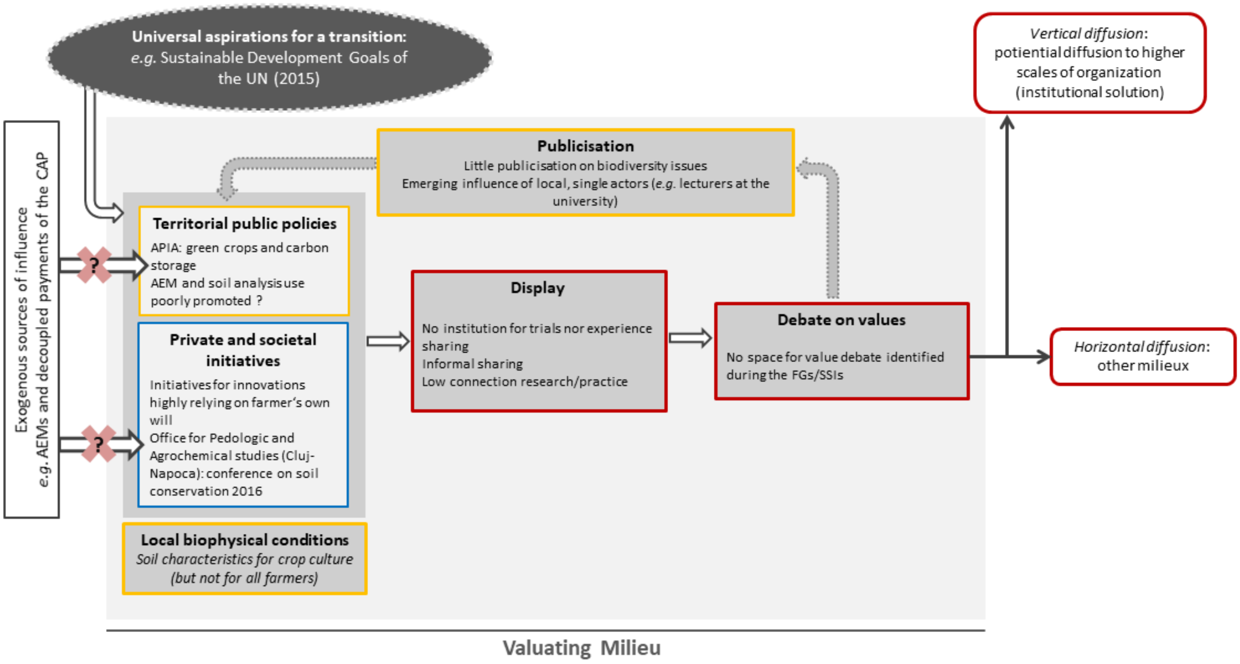

Figure 16 | The valuating milieu (VM, following Huguenin et al. 2017, Fig. 14) related to soil and soil management in Transylvania. A blue frame indicates an element of the VM that was particularly highlighted in the discussions of both FGs and SSIs (see Tab. 9) and appeared to play a great role on the formation of values related to soil biota and biodiversity. A yellow frame with dashes indicates an element of the theoretical VM that may have been briefly mentioned but for which we hardly obtained details Simple black arrows indicate a diffusion of valued innovations and values formed within the VM to other territories or scales of organization. Large white arrows refer to the direction of influence between external and internal components of the VM that lead to the formation of values. Grey, doted arrows refer to a potential retroaction of values that are within the VM on its own actors (private and political). The red crosses with the interrogation mark indicate a limited influence between the related elements.

Overall, extension services were rarely mentioned within the discourse of the people we met: some of them use soil analysis, but they barely mention other external, supportive input of information (Display, Fig. 16). APIA is the Romanian institution that distributes CAP subsidies to farmers and verifies associated requirements (*e.g.*, cross-compliance). It does not provide advice on technical issues. When asked about the role of Romanian ACs, SSI-RO2 explains that they do not provide technical extension services to farmers and regretted the difficulties to work with them. Farmers only briefly referred to applied research, and described its limited link with field-issues: "*I think research has its role but practice is more important*" (FG1-RO8), except for a field station in Turda.

In Romania, each administrative region has its own Office for Pedologic and Agrochemical Studies. Their role is mainly to analyze, characterize and map soils, and to provide advice to farmers (Private and societal initiatives, Fig. 16). So far, for SSI-PEDO there has been "*a lack of habits among farmers to perform soil analysis*", especially within the eldest generation (FG2-RO7). SSI-PEDO emphasized the necessity to preserve soil biota:

> Every time, I say to people: 'The soil, it is a kind of human-being, it is alive. Alive. There are organisms, micro-organisms, bacteria, also earthworm. It's alive!' And every time I discuss, and I see that many farmers understand the importance of the soil. (SSI-PEDO)

However, he reported farmers' focus on production growth rather than on soil issues (FG2-RO4).

Territorial public policies and exogenous influence: regulation's limited influence on valuation

Some farmers hardly knew about AEM (SSI-RO1); others mixed up AEMs and cross-compliance requirements (FG1-RO4) or regulation on fertilization (FG1-RO7) (Territorial Public Policies, Fig. 16). SSI-RO2 reported difficulties to have information about the available AEMs, and to contact APIA. For FG1-RO9, the objectives of AEMs are defined by APIA as: carbon storage and soil fertilization with green crops (FG1-RO6). However, the farmers may not perceive the benefits of these measures:

> Through green crops they try to force us to protect the environment but it represents energy consumption, to sow the green crops, to incorporate them, which eventually is pollution." (FG1-RO9)

AEMs and CAP decoupled payments were criticized several times during FG1 for they would penalize input-based systems, that would be more productive though, and thus more legitimate.

Greening measures of the CAP have also emphasized the need to extend crop rotations. Some rotations are based on opportunistic reasons (SSI-PEDO) which may not be the best choice for the soil:

> The crop rotation is defined according to current subsidies. [...] I would see things in a different perspective, normally, in a farm there should be a crop rotation of 3-5 years depending on what you want to cultivate, in order to protect also the soil [...]" (FG1-RO6)

Discussion

Researchers in agronomy consider that agricultural techniques result from "*a choice that depends on an individual situation and that has a social dimension*" (Deffontaines, 1993; our translation). Farming activities are organized at different scales, by regulations with different scopes and by various farmers' networks potentially situated in different territories.

Exogenous influences: European regulations as limited vectors for SBB valuation

During the FGs and the interviews, the most mentioned policy measures associated with agricultural activities referred to the CAP: cross-compliance and greening requirements of the First Pillar and Rural Development, mostly AEM. When they specifically target soils, most of these regulations focus on their physicochemical state and functioning (*e.g.,* fertility, carbon storage). At the opposite, SBB preservation is barely introduced as one of their objectives. For instance, the standards for Good Agricultural and Environmental Condition of land explicitly target the limitation of soil erosion or the enhancement of carbon storage, but SBB is not explicitly mentioned. This is also the case in the different Priorities that European Member States can define in the frame of their Rural Development Programs (Second Pillar of the CAP): priorities and focus areas related to soils do not explicitly relate to soil biodiversity. In Transylvania, this may correspond to farmers' focus on soil fertility and climate objectives, while little appeared to be known about soil biodiversity stakes. In Ille-et-Vilaine, the link between soil organisms and soil functions was clarified by extension services, a role encouraged by the EU regulation (Regulation EU No 1306/2013). Without political statements encouraging soil biota conservation, private initiatives in that direction may remain limited. The issue lies in the relatively little focus on SBB in European and national biodiversity policies as well (Fournil et al., 2018; Paleari, 2017), even if recent European environmental regulations and objectives show a marked interest for soil issues (see Montanarella and Panagos, 2021). In France, Desrousseaux (2011) reported that the Environment Code tends to neglect soils, that are mainly tackled by agricultural regulations, and foremost in terms of use and management. Soils are often conceived in instrumental terms for productivity purposes, and climate regulation even in the perspective of their conservation (Desrousseaux, 2011; Fournil et al., 2018). Issues may also lie in the application of regulations. Soil analysis is mandatory for farmers in Europe, and yet, several of them do not have recourse to it: access to basic knowledge may thus differ between farmers. Differences in the way values are formed between the two studied regions also illustrate the importance of considering the role of local contexts in shaping agricultural situations, problems and innovations.

Various actors of VMs involved in the formation of soil and soil biota values.

Agricultural soils are mostly private property or long-term rented land and individually managed with the primary purpose of individual economic activities before conservation purposes (Desrousseaux, 2011). Thus, defining shared, collective management standards appears particularly important to ensure an effective long-term preservation of soils in a given territory. Our results also show that specific local actors can facilitate changes of soil management practices. Mermet et al. (2014) conceptualized several paradigms of "*organized action*" that conceive collective actions related to biodiversity and environmental management. Following Mermet et al. (2014), in Transylvania, initiatives for soil biodiversity conservation appeared as "*minor action of change*", *i.e.,* as individual decisions from the Pedological Centre or a few farmers in contact with the university. It did not seem that a real *coordination* between different actors allowed the valuation of SBB. At the opposite, in Ille-et-Vilaine, *minor actions of change* were past individual initiatives from some farmers we met, *e.g.,* in the use of cover crops. These farmers reported an increasing *coordination* of local actors (farmers, cooperatives, ACs, NGOs, education institutions…) to tackle soil issues including SBB preservation. However, from the material we collected, we hardly identified a bidirectional influence between national or international policies and local, *coordinated* or *minor actions*. Farmers and their (horizontal) networks appeared influenced by regulations emerging from higher levels of organization. Yet, compared with the theoretical description of the VM proposed by Huguenin (2017), spaces for a bottom-up diffusion of the debate on values appeared to be inexistent or of little influence. The most noticeable bottom-up process was related to the French system: the definition of the local list of available AEM within a given territory. Therefore, both local *governance* of SBB and bottom-up publicization of local issues is still lacking. The relationships between horizontally coordinated actors remains overreached by top-down international and national incentives, that may neither allow to properly address local issues (Turpin et al., 2017) nor to enlarge debates on values. And yet, the existence and the nature of contacts within innovative networks and institutional environments may condition the success of innovations in transitions processes (Klerkx et al., 2010). According to Klerkx et al. (2010), through "*creating tangible visions*" actors can ensure innovations development, while they have only a limited impact on their institutional surroundings. For Klerkx et al. (2010) agricultural policies that aim to favor innovations should firstly facilitate actors' reflectivity on their relationships with changing environments. This particularly resonates with recent focuses on the innovating know-how of farmers and the importance of territory projects to debate on the relevance of innovations (Faure et al., 2018). But in return, it raises questions about the inclusion of practitioners in the formation of shared values at higher levels of organization in society.

The development of innovations and the analysis of agricultural transitions relies on the progressive diversification and inclusion of actors on a territory, even beyond the agricultural sector *per se* (Bui et al., 2016; Ryschawy et al., 2019). To tackle soil erosion issues in public policy, Derungs and Hertz (2016) even encouraged the construction of social negotiations beyond pure experts-opinions and the integration of the multi-dimensional nature of soil problems. In political terms, this amounts to allow the articulation of "*a diversity of viewpoints or even oppositions*" and "*to encourage knowledge production and learning*" (Triboulet et al., 2019). In a pragmatic perspective, it means to design spaces for a collective debate about (i) the range of available means to manage soils, (ii) the objectives of agriculture and (iii) the indicators used to monitor the state of soils. The latest in particular reflect both values of people (what matters) and way of valuating (in which terms values are expressed). Such spaces may also be a way to empower actors who might be (or feel) little heard. Here, reflectivity is at the basis of evaluation processes that participate to designate and to agree about what matter to us. Participation can allow different actors in a given territory to think together about the way they want agriculture to develop (Audouin et al., 2019). Thus, participative approaches have gained recognition as tools favoring innovation processes in agriculture and the collective definition of shared values (Toillier et al., 2018). Our study might be completed by involving the point of view of a broader range of stakeholders. These actors may be indirectly linked to soil management but still have an impact on farmers' management choices and on the values that they mobilize to legitimate their own practices, *e.g.*, ploughing to avoid the use of herbicides that may be highly criticized by society or favoring grazing because it should enhance animal well-being.

Display and publicization: multiple networks and diffusion processes influencing values formation

Mermet et al. (2014) emphasized the importance of performing "*action and observation*" for innovators. And indeed, in terms of display, (on-farm) field experiment appeared particularly important to share knowledge and provide a space to discuss the legitimacy of cultural results.

Several interviews also emphasized an ongoing evolution in both education and on-the-job training, towards more autonomy in farmers' decision-making.

Publicization processes might be crucial in the formation of values related to soils. In Ille-et-Vilaine, soils remained mostly valued as production supports and agronomic devices. Yet, the development towards caring for soils appeared to be favored by technical and coordinated organizations (*e.g.,* AC and NGOs) whose discourse can be articulated with local policy measures such as AEMs. Exchanges with peers, organized through informal meeting or within working groups may facilitate changes of practices and actually form spaces of valuation. Similar conclusions have been reported elsewhere in the literature (*e.g.,* on innovation development in Toillier et al., 2018; on agroecology transition in Ryschwary et al., 2019). At the opposite, in Transylvania, technical exchanges between farmers appeared mostly unformal. Tenuous connections were reported between farmers and existing external sources of knowledge and display like ACs or Pedological Centers and little possibility for working groups were mentioned, which has been highlighted as an important challenge for Romanian agriculture (NSU, 2015; Vasile, 2014). These institutions appeared to have a limited power to convey farmers to perform alternative valuations of SBB in our study.

The two Transylvanian FGs were noticeably composed of young farmers who have close links with the local researchers. Among them, SBB valuation was particularly marked. Thus, their interest and the extent of their knowledge related to SBB may have been already formed through their relationship with the research sector. In the Romanian context, scientific institutions could be a core asset to facilitate debates on values and alternative valuations. In Brittany, agriculture education appeared also as a vector of publicization, that may have not favored SBB valuation in the past. Toillier et al. (2018) referred to the concept of "*transformative*" learning from Mezirow (1991) to qualify forms of learning along with innovation development, leading to changes in individuals' values, thereby changing also their actions. Promoting innovative practices for SBB preservation in agricultural education is likely to encourage farmers to observe their environment differently and to define other criteria to evaluate their fields and practices.

Environmental (biotic & abiotic) features in values formation: a particularity of VMs related to agriculture?

For Touzard (2018) agricultural knowledge is partly constructed through adaptations to local environments, to their characteristics and to their variations; as such agriculture may differ from other sector because of its close relationships with "*the living world and nature*". Our results show that these relationships with the biophysical dimension of reality indeed play a role in valuation. First, they can become components of problematic situations that farmers attribute importance to (*e.g.,* avoid soil erosion). In particular, SBB can be integrated in valuations as objective (*e.g.,* to be able to observe earthworms in the field) or as criteria to validate or to reject a mean to reach a production objective (*e.g.,* avoid practices that put the soil upside-down which may affect soil life) (see also Hervé et al., *submitted*). Further investigations should aim to precise the territorial delineation of the VM on the basis of its biotic dimension: Transylvania is a large, diversified space were very different agricultural systems coexist; Ille-et-Vilaine is an administrative space where agriculture still varies according to various soils, climatic conditions or potentialities for crops trade. While initially chosen on the basis of their administrative boundaries, of their historical existence and of the relative homogeneity of productions, the territories could also be refined on the basis of environmental criteria.

Conclusion

Our study aimed to better understand, from farmers' perspectives, SBB valuations in soil management situations. The concept of VM allowed to conceive the formation of collective values, beyond a focus on individuals solely, which has been one of the most important criticisms addressed to pragmatism. In the field of agricultural activities, (i) SBB can be valued by farmers and (ii) transition of farming practices and systems towards a better preservation of SBB can occur. This appeared to require a VM that acknowledges and publicizes a role of soil functioning and soil biota, that allows for designating SBB depletion as a societal issue and that encourages practical innovations in the way soils are managed. We showed that such VMs are likely to vary across the EU and that European regulation itself has struggled to value SBB. Our results also emphasized a particularity of agricultural VMs compared with other sectors since farming activities are particularly marked by the environmental dimension of valuation situations. Changing the objectives of agriculture, the range of means judged as acceptable and introducing new indicators and tools to assess the performance of agricultural activities may actually consist in as many changes in terms of valuation. Such modifications may need a collective and reflective thinking to be widely accepted. In other words, creating spaces for collective debates on whether we are to integrate the preservation of European soils and SBB as one of the intended achievements of agriculture appears to be one great transition challenge to cope with.

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Chapter 7

La biodiversité des sols dans le discours d'agriculteurs bretons : sources de connaissances et comparaison des perspectives

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Soil biodiversity in the discourse of Breton farmers: sources of knowledge and comparison of perspectives

Hervé, MET, Agasse, C., Renault, M., Pérès, G., Cluzeau, D. and Nicolai, A. In preparation for *Développement Durable et Territoires*.

For this chapter, I sought to reach a broader audience than academics only. Thus, I plan to submit in a French-speaking joural that is known to be read by professionals as well. An extensive summary is provided in English for each of the sub-sections.

Introduction

Summarized English version

Agriculture is highly dependent on crucial soil functions ensured by soil organisms and their diversity (Bender et al., 2016). On the other side, agricultural practices may affect soils and their biota. The sustainability of agricultural activities thus relies on management practices that preserve soil functions (Plaas et al., 2019) and related biota. Some researchers have advocated for more extensive agriculture (*e.g.*, Breure 2004), since intensification has been identified as one vector of biodiversity loss across Europe (Tsiafouli et al. 2015).

Farmers appear as key-actor of soil management to address. They are in contact with the soil ecosystem and choose their management practices. Among the numerous factors that may play a role in farmers' decisions, *e.g.*, economic, political, social, technical or individual factors (Bartkowski and Bartke, 2018), farmers' personal knowledge in particular may be important (Blouin et al., 2013; Wartenberg et al., 2018). In this work, we conceive knowledge as a process of integration and accumulation of learned elements of different natures, through personal actions or experiences and external inputs. The latest may be of very diversified natures, *e.g.*, exchanges with peers, professional events and technical displays, agricultural press, farming organizations, the Internet and social networks or TV programs (Alskaf et al., 2020; Mills et al., 2019; Wang et al., 2016). In this work, we sought to answer to the following questions:

(i) From which sources do Breton farmers obtain their knowledge about soil biota and biodiversity (SBB)? Are these sources specific to this topic or more generalist? Do they all have the same degree of influence on knowledge acquisition?

(ii) Do farmers who have adopted different management regimes and farming systems refer to the same sources of knowledge about SBB or are they specific channels?

(iii) Which discourses are transmitted by knowledge sources about SBB? Do they reflect farmers' own discourse on the topic?

We interviewed famers in Ille-et-Vilaine concerning their knowledge about soil biotic elements and about the different sources of knowledge. We completed this approach by a text analysis of an agricultural journal.

La diversité des organismes du sol remplit des fonctions écologiques majeures, assurant les cycles du carbone ou des nutriments, la structuration des sols ou la production de biomasse (Bender et al., 2016). L'agriculture est fortement dépendante de ces fonctions, le sol représentant le support de cultures, d'activités d'élevage et un réservoir incontournable de matières minérales et organiques. Par ailleurs, les pratiques agricoles peuvent avoir un effet sur les sols et les organismes qu'ils abritent. L'usage de produits phytosanitaires peut ainsi affecter certains groupes similaires à ceux des ravageurs visés (Thiele-Bruhn et al., 2012). La pratique du labour peut diminuer l'abondance des collemboles (Dawson and Smith, 2007) et réduire la diversité fonctionnelle des vers de terre (Pelosi et al., 2014). A l'opposé, une réduction du travail du sol est bénéfique en termes de diversité, d'abondance et de biomasse des vers de terre (Briones and Schmidt, 2017 ; Ernst and Emmerling, 2009). La pérennité des activités agricoles repose sur des pratiques de gestion qui préservent les fonctions des sols (Plaas et al., 2019), donc sur une extensification des pratiques de gestion (Breure, 2004), tandis que le système cultural intensif est remis en cause (Tsiafouli et al., 2015). Dans cette perspective, les agriculteurs apparaissent comme des acteurs cruciaux de la gestion des sols. Ils sont au contact direct de l'écosystème et choisissent les pratiques à mettre en œuvre parmi les possibilités offertes par leur environnement naturel, réglementaire, technique et économique.

Comprendre la relation que les agriculteurs entretiennent avec les enjeux de conservation de la biodiversité requiert de *situer* leur prise de décision (Ahnström et al., 2009), *i.e.*, de saisir les multiples facteurs en jeu dans leurs choix. Ces facteurs sont d'ordre économique et politique, mais aussi sociaux, techniques et individuels (*e.g.*, expérience) (Bartkowski and Bartke, 2018). Les connaissances des agriculteurs sur leurs sols et leur fonctionnement peuvent jouer un rôle crucial dans leurs décisions de gestion (Blouin et al., 2013; Wartenberg et al., 2018). On entendra ici les connaissances comme étant un processus individuel d'assimilation et d'accumulation de savoirs de différentes natures, à travers des actions personnelles ou des apports indirects. Les sources de ces connaissances peuvent être multiples : échanges entre pairs, services de conseil agricole et formation continue, presse agricole, événements professionnels et démonstration technique, organisations agricoles, Internet et réseaux sociaux ou encore programmes télévisés (Alskaf et al., 2020; Mills et al., 2019; Wang et al., 2016). En Allemagne, les sources de connaissances au sujet des services écosystémiques des sols comprenaient : les communications scientifiques relatives à des programmes dans recherche, les obligations légales imposées par la PAC, des ateliers et des réunions, la formation initiale et la formation professionnelle (Dietze et al., 2019). Concernant spécifiquement la biodiversité des sols, les agriculteurs rencontrés par Pauli et al. (2012) obtenaient des connaissances en conjuguant leur propre expérience et des apports via les structures de conseil agricole et des échanges avec leurs pairs. Dans ces études, les auteurs ont dressé un inventaire des sources de connaissances sans nécessairement les hiérarchiser en termes d'influence. Pauli et al. (2016) ont mis en exergue la quasi inexistence d'études portant sur ce sujet en Europe. Dans le cadre de notre travail, nous avons interrogé des agriculteurs d'Ille-et-Vilaine (France) sur les connaissances du compartiment biotique des sols, sur une hiérarchisation des vecteurs d'acquisition associés et à leurs voies de publicisation. En complétant cette enquête par une analyse textuelle de revue agricole, nous avons cherché à répondre aux questions suivantes :

(i) Par quelles sources les agriculteurs obtiennent-ils des connaissances au sujet de la biodiversité du sol ? Ces sources sont-elles spécifiques à cette thématique ou sont-elles généralistes ? Toutes les sources ont-elles la même influence?

(ii) Des agriculteurs appliquant des modèles de gestion différents se réfèrent-ils aux mêmes sources de connaissances au sujet de la biodiversité des sols ?

(iii) Quel(s) discours ces sources de connaissances transmettent-elles au sujet de la biodiversité des sols ? Cela se reflète-t-il dans les connaissances exposées et les discours tenus par les agriculteurs à ce sujet ?

Matériel et Méthodes / Material and Methods

Summarized English version

We implemented the study in the department of Ille-et-Vilaine in Western France. Dairy farming, enclosed rearing, arable crops and field vegetables cultures are the most important agricultural activities; besides, mixed-farming systems within which farmers produce themselves the food for their cattle (corn, winter wheat, sometimes rapeseed and legumes, but also pastures and/or fodder) are still widely spread.

Farmers' discourse on soil biodiversity

We contacted by phone those farmers (i) that we already knew from research networks (SoilMan program, DEPHY farms networks) or (ii) spontaneously (meeting, Internet). The criterion of selection was the presence of arable crops on their farm; all of them also had a rearing activity (dairy farming, meat beef farming, porcs, poultry), while it was not a selection criterion at first. In total, thirty-one farmers were interviewed, and we characterized them according to their soil management before sowing (Tab. 10).

Each interview started with a presentation of the research program and of the researchers themselves. Two questions followed that directly asked farmers what "biodiversity" and "soil biodiversity" were for them. The questions were vonluntary direct because we sought to investigate the knowledge about soil biodiversity farmers had. The next steps, allowed to investigate more finely and less directly to what extent this knowledge was integrated in their practice choices. The final stage of the interviews was dedicated to farmers' education and sources of knowledge. The topic was first introduced as a free discussion. Then, in a more directive exercise, they were invited to place their sources of knowledge on two "targets" (like the ones used in archery for instance), from the most influencing – situated the closest to the center of the target – to the less influencing – at the edge of the target. The method is inspired from Oreszczyn et al. (2010) but we did not constraint the number of circle that the target could contain. The exercise was performed twice: the first to investigate sources of general agricultural knowledge mobilized in farmers' activity, and the second to precise the sources of knowledge about soil biota specifically.

We conceived the notion of soil biodiversity as an intellectual and constructed knowledge that enganges and reflects a certain relationship between farmers and soils and soil organisms, that we intended to describe at first. Thus, we conceived farmers descriptions of what soil biodiversity is as free-lists of items associated with the cultural domain (Sutrop, 2001) of soil biodiversity. The terms ranged from very general items, *e.g.*, "life" to more precise taxa, *e.g.*, "Carabids". We used Robbins et al. (2017)' salience index to evaluate the pregnance of each item (N=64) in the whole corpus of free-lists. The index discriminates the basic terms (often mentioned and generally at first in the lists) from more secondary ones.

The next step consisted in characterizing more precisely farmers' discourse about soil biodiversity by performing a text analysis. We used the specific software Iramuteq (Ratinaud, 2009) that identified lexical forms (words of interest for the analysis like nouns, adjectives…) and split the corpus into sections of 40 forms. A Factorial Analysis followed by a Hierarchical Agglomerative Clustering allows for regrouping the forms on the basis of their co-occurrence within the corpus.

Knowledge sources about and publicization of soil biodiversity

First, we investigated the sources of knowledge that farmers use, in general and about soil biodiversity. We classified the sources of farmers' knowledge into different modes of transfer (Tab. 12). The distribution of the different modes (i) within each of the two targets, (ii) between them and (iii) between the four profiles of farmers (Tab. 10) has been tested with Chi² tests and Fisher's exact tests (1000 repetitions), performed on R, v. 3.1.2 (R Core Team, 2020).

Second, we investigated in which terms the topic of soil biodiversity was covered by the sources of knowledge mentioned by the farmers, focusing on a regional agricultural journal "The Brittain Peasant". Because of the huge number of journals published since its creation in 1945, we sampled only four issues per year (March, June, September and December) between 1960 and 2018 (N=232 issues). Within each of them, we realized a first selection of articles that seemed to focus on (soil) biodiversity or organisms on the basis of their title and, where appropriate, of their lead paragraph. A second reading allowed for checking their relevancy. In total, 23 articles related to fauna and flora or biodiversity in genereal (without soil biota) were sampled and 18 additionnal articles encompassed only soil biota or biodiversity. They formed a corpus analysed with Iramuteq as well.

Zone d'étude

En Ille-et-Vilaine, les espaces agricoles représentent 65% de l'usage des sols, une proportion relativement similaire à la moyenne nationale (60%). L'assolement est principalement constitué de céréales et de prairies temporaires. Les trois principales productions du département sont les bovins lait (31%), l'élevage hors sol (16%) et les grandes cultures et légumes en plein champ (15%). Le modèle de polycultures-élevage est encore prégnant. En 2017, 700 exploitations représentant 7.3% de la SAU du département étaient engagées en agriculture biologique (Srise, 2019).

Discours des agriculteurs sur la biodiversité des sols

Trente-et-un entretiens semi-directifs ont été mis en œuvre avec des agriculteurs, démarchés par téléphone et sur la base de plusieurs réseaux de l'équipe de recherche (programme Soilman[8], fermes du réseau DEPHY[9]) ou de façon spontanée (rencontre, recherche internet). Le principal critère de sélection était la présence de grandes cultures sur l'exploitation. Tous les agriculteurs avaient une activité d'élevage (bovins, porcs ou volailles). Nous ne sommes pas parvenus à obtenir d'entretien avec des agricultrices, bien que les femmes représentent 31% des cheffes d'exploitation et coexploitantes en Ille-et-Vilaine au dernier recensement agricole (Février, 2012). En termes de pratique, les agriculteurs rencontrés ont été caractérisés au regard du travail du sol mis en œuvre avant semi (Tab 10).

Tableau 10 | Profil des agriculteurs rencontrés (N=31) selon les pratiques culturales appliquées. PP : produits phytosanitaires ; LAB : labour ; TCS : techniques culturales Simplifiées ; SD : semi direct. (a) : agriculteurs en modèle dit « conventionnel » ; (b) : agriculteurs en modèle biologique ; (c) : agriculteurs en agriculture de conservation. **// Farmers profiles (N=31) according the crops management before sowing. PP : plant protection products ; LAB : ploughing ; TSS : reduced-tillage practices; SD: direct seeding. (a) farmers in so-called "conventional" model; (b) farmers in organic farming; (c) farmers engaged in conservation agriculture).**

	Gestion des sols // Soils management		
	LAB	TCS	SD
Avec PP // With PP	10[(a)]	9[(a)]	4[(c)]
Sans PP // Without PP	8[(b)]	0	0

Les rencontres ont eu lieu sur le siège d'exploitation. Une trame commune a circonscrit le déroulé des entretiens, harmonisant la progression des échanges et garantissant leur comparabilité par la formulation de questions et de relances selon cette trame (Punch, 2005).

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[8] Programme de recherche européen (Biodiversa) interdisciplinaire étudiant les liens entre biodiversité des sols, gestion agricole et services écosystémiques en culture de blé. Voir : https://www.soilman.eu/

[9] Réseau d'exploitations engagées dans une démarche de réduction des produits phytosanitaires en France, qui s'inscrit dans le plan Ecophyto. Voir : https://ecophytopic.fr/dephy/quest-ce-que-le-reseau-dephy-0

Chaque entretien débutait par une présentation du programme de recherche et des enquêteurs eux-mêmes (Tab. 11). Suivaient deux questions fermées (Q1 et Q2, Tab.12) invitant l'agriculteur à exprimer ce qu'est pour lui « la biodiversité » et ce qui lui vient à l'esprit lorsqu'il entend « biodiversité des sols ». Ici, la question était volontairement très directe puisqu'il s'agissait d'obtenir un aperçu des connaissances que ces agriculteurs pouvaient avoir conscience de posséder. La suite de l'échange permettait d'enquêter plus finement sur la façon dont les agriculteurs peuvent intégrer des considérations et connaissances au sujet de la biodiversité (des sols) dans leurs pratiques, même sans en avoir totalement conscience. La phase finale de l'entretien abordait la question de la formation des agriculteurs et de leurs sources de connaissances (Tab. 11). Dans un premier temps, nous introduisions la thématique dans une discussion libre. Chaque agriculteur était ensuite invité à placer ses sources de connaissances sur des cercles concentriques, de la plus influente (*i.e.*, proche du centre du cercle) à la moins influente (*i.e.*, la plus à l'extérieur). L'outil est similaire à celui proposé par Oreszczyn et al. (2010) qui présentent une « cible » (comme dans un sport de tir) cependant nous n'avons pas contraint le nombre de cercles. Nous avons utilisé l'outil deux fois : pour les sources de connaissances associées à l'activité agricole en général et pour les sources spécifiques à la biodiversité des sols.

Tableau 11 | Déroulement général des entretiens semi-directifs et objectifs associés.

Etapes de l'entretien	Phase	Objectifs associés
Présentation de l'étude et des enquêteurs	Entretiens semi-directifs	Assurer une transparence des enquêteurs et de leur travail pour faciliter les échanges suivants
Présentation de l'exploitation et de la situation personnelle		Fonction brise-glace, obtenir les informations descriptives principales concernant l'agriculteur et son activité
Connaissances autour de la biodiversité (générale et des sols)	Entretiens semi-directifs avec questions directives	Appréhender les connaissances de l'enquêté au sujet de la biodiversité des sols Q1 : « Comment définiriez-vous la biodiversité ? » Q2 : « Qu'est-ce qui vous vient à l'esprit en entendant biodiversité des sols ? » Pour chacune des deux questions : invitation en 3 à 5 minutes à mentionner tous les termes qui viennent en tête
Gestion des sols	Entretien semi-directif	Connaître les pratiques de travail du sol de l'enquêté
Formation agricole (initiale et continue)	Entretiens semi-directifs avec atelier directif « Cibles »	Connaître les sources et les formes de formation et d'information de l'enquêté (phase d'inventaire dans la discussion) ainsi que leurs importance relative (phase de hiérarchisation sur les cibles) Cible 1 : connaissances générales liées au métier Cible 2 : connaissances relatives à la biodiversité des sols

Dans l’analyse des discours d’agriculteurs, nous avons envisagé la notion de biodiversité des sols comme un domaine intellectuel construit qui engage et reflète un certain rapport aux sols et aux organismes qui s’y trouvent et que nous avons cherché à décrire dans un premier temps. Ainsi, les termes évoqués dans les réponses à la question Q2 (Tab. 11) ont été traitées comme des « listes libres » de termes associés à un domaine culturel (Sutrop, 2001), celui de la biodiversité des sols, incluant par exemple des taxons[10] allant du plus général (*e.g.*, « vie ») au plus précis : la famille (*e.g.*, carabe). Un indice de salience a été calculé afin d’évaluer leur prégnance relative dans le corpus. Les indices de salience permettent de prendre en compte la fréquence d’un terme mais aussi son rang moyen dans les listes. On considère en effet que le rang moyen permet de discriminer les termes « basiques » d’un domaine (*i.e.,* souvent mentionnés parmi les premiers) de termes plus secondaires (Sutrop, 2001). Ici nous avons utilisé l’indice de salience développé par Robbins et al. (2017), car il se prête bien à l’analyse de listes de longueurs différentes : $B(A_j)$ correspond à l’indice de salience de l’item *j* dans la liste d’un agriculteur *i* (1) et B’ est l’indice de salience de *j* au sein de l’intégralité du jeu de données (2).

$$(1)\ \mathrm{B}(A_{ji}) = \frac{\mathrm{k} - \mathrm{r}_{(\mathrm{i})}}{k-1}$$

$$(2)\ \mathrm{B}' = \frac{\sum(\mathrm{B}(A_j)) + \mathrm{F} - 1}{2Z - 1}$$

Où : k est le nombre total de termes mentionnés dans la liste d’un agriculteur A_j ; $r_{(i)}$ est le rang de l’item *i* dans la liste de l’agriculteur A_j, ; $\sum(B(A_{ij}))$ est la somme de l’ensemble des indices de salience calculés pour l’item *i* ; F est le nombre total de listes dans lesquelles le terme i apparaît (*i.e.,* le nombre d’agriculteurs ayant mentionné le terme i); Z est le nombre total de listes prises en compte dans l’analyse. Ici 29 répondants ont donné une réponse qui puisse être envisagée comme une liste : Z=29 et $j \in [1 ; 29]$. L’analyse a porté sur un total de 64 items, chaque item pouvant à l’occasion regrouper un ou plusieurs termes fortement similaires selon le contexte du discours (*e.g.*, ver de terre et vers de terre ; microbe et vie microbienne).

Dans un deuxième temps, nous avons cherché à caractériser plus finement le discours des agriculteurs au sujet de la biodiversité des sols. Une analyse de texte a été réalisée sous Iramuteq (Interface de R pour les Analyses Multidimensionnelles de Textes et de Questionnaires, v. 0.7 alpha 2, Ratinaud, 2009). Elle a porté sur le corpus les retranscriptions des 31 entretiens (jusqu’à

[10] Un taxon est une entité regroupant des organismes vivants selon des caractéristiques communes. Différents niveaux taxonomiques sont utilisés, les plus courants sont les niveaux de l’espèce, suivi par la famille et ensuite la classe.

la discussion sur les pratiques ; Tab. 11). Le logiciel sectionne le corpus en segments d'environ 40 caractères en ne retenant que des formes dites « pleines », *i.e.*, les verbes, noms communs, adverbes, adjectifs et des formes spécifiques d'intérêt pour l'étude telles que des noms propres. Une lemmatisation permet d'associer des formes présentant des variations grammaticales ou de conjugaison sous une unique forme (*e.g.*, mise au singulier des formes au pluriel). Au total, 720 formes ont ici été identifiées par le logiciel. Ensuite, une Analyse Factorielle des Correspondances et une classification ascendante hiérarchique décrivent les co-occurrences entre certaines formes au sein du corpus et des regroupements lexicaux sont ainsi effectués.

Sources de connaissances et publicisation de la biodiversité des sols

Le premier objectif était de caractériser les sources de connaissances mobilisées par les agriculteurs, notamment sur les sources de connaissances au sujet de la biodiversité des sols. Nous avons développé une classification des différents modes de transferts associés aux sources de connaissances (Tab. 12) indiquée par les agriculteurs (Tab. 11, Atelier directif « Cibles »). Ainsi, les formes de transfert VERTICAL (Tab. 12) sont envisagées comme des démarches descendantes de partage de connaissances depuis un « expert » vers l'agriculteur. Le transfert HORIZONTAL (Tab. 12) se réfère à des échanges entre pairs ou avec d'autres acteurs du secteur qui ne relèvent pas d'un positionnement expert-formateur/apprenant formalisé. Le transfert MULTIPLE (Tab. 12) mélange ces deux approches, *e.g.*, dans des groupes d'échange où se trouve également un technicien médiateur. Le transfert NARRATIF (Tab. 12) recouvre une acquisition de connaissances passant par des sources plus « passives » (*e.g.*, revues) auxquels l'agriculteur choisit activement de s'intéresser associée à l'expérience et à des observations personnelles.

Les analyses statistiques ont été réalisées sous R, v. 3.1.2 (R Core Team, 2020). La répartition des modes de transfert sur les cercles des cibles et entre les cibles a été testée à l'aide de tests de Chi² ou par des tests exacts de Fisher (1000 répétitions) qui ont également été utilisés, dans un second temps, pour tester la répartition des modes transfert entre les quatre profils d'agriculteurs interrogés (Tab. 10).

Tableau 12 | Typologie des modes de transferts pour des sources des connaissances évoquées par les agriculteurs au cours de la seconde phase de l'entretien.

<table>
<tr><th>Transfert // Tranfert</th><th>Définition // Definition</th><th>Formation associée Associated training</th><th>Source de connaissances possible // Associated sources of knowledge</th></tr>
<tr><td rowspan="2">VERTICAL</td><td rowspan="2">Type de transfert descendant, partant d'un acteur considéré comme légitime sur un sujet de connaissance, afin de former une personne moins qualifiée
Top-down tranfer from an expert judged as legitimate on a given topic to an individual with less knowledge</td><td>Formation initiale
Formal education</td><td>- Formation initiale
Formal education</td></tr>
<tr><td rowspan="4">Formation continue
Professional training</td><td>- Formations/Conférences
Professional training/Conferences
- Conseil technique (individuel ou collectif mais sans co-construction)
Technical avising (individual or collective but without co-construction)
- Conseil commercial **Commercial advising**
- Economie et politiques actuelles (*e.g.*, régulation agricole) **Economic and policy measures (*e.g.*, agricultural rules)**</td></tr>
<tr><td>HORIZONTAL</td><td>Transfert de connaissances entre deux partis de niveau de connaissance équivalent et/ou pluridisciplinaires
Knowledge transfer between two actors with the same level of knowledge or in pluridisciplinary approaches</td><td>- Entourage professionnel (autres agriculteurs, mécaniciens, conducteurs d'engins, rencontres sur des salons, forums…)
Professional relationships (peers, technicians on machineries and drivers, meetings during agriculture events…)
- Société (entourage non professionnel : famille si non agriculteurs, amis, clients et visiteurs…)
Society (non-professional relationships, friends, clients and visitors)
- Héritage familial
Familial traditions and habits</td></tr>
<tr><td>MULTIPLE</td><td>Type de transfert associant le transfert vertical et horizontal, un formateur légitime dispense une formation et les formés échangent entre eux
Type of transfer associating vertical and horizontal form (an advisor provides the training and the farmers also exchange with each other)</td><td>- Groupes d'échange
Exchanges groups</td></tr>
<tr><td>NARRATIF (ET CONNAISSANCES EMPIRIQUES)
NARRATIVE (AND EMPIRICAL KNOWLEDGE)</td><td>Type de transfert ou le formé est aussi le formateur ou se réfère à des sources de connaissances matérielles, non humaines, empiriques et expérimentales
Type of transfer in which the one who obtains knowledge also produces it or refers to materual, non-human, empirical and experimental</td><td>- Lectures
Readings
- Expérience personnelles et observations
Personal experiences and observations
- Radio
- Médias numériques (internet…)
Digital media (internet)</td></tr>
</table>

Le second objectif visait à caractériser le discours portant sur la biodiversité des sols dans les sources de connaissances mentionnées par les agriculteurs. Le Paysan Breton (Transfert narratif ; Tab. 12) est une revue hebdomadaire publiée à échelle régionale depuis 1945 qui était particulièrement mentionnée. Compte-tenu du grand nombre d'exemplaires parus depuis la première publication (près de 3800, sans compter les hors-séries), un sous-échantillonnage de 4 exemplaires par an (mars, juin, septembre et décembre) pour la période janvier 1960 à décembre 2018 (N=232 numéros) a été effectué.

Au sein de chaque numéro, les articles susceptibles de traiter de biodiversité ou des organismes du sol ont d'abord été repérés par leur titre dans le sommaire et en parcourant les chapeaux. Une seconde lecture plus poussée a permis de valider leur pertinence et de ne sélectionner que ceux qui se référaient à la faune et à la flore en général hors sol (23 articles) ou à la biodiversité et aux organismes des sols en particulier uniquement (18 articles). L'ensemble des articles regroupés dans ce second corpus, dans lequel 62 formes ont été identifiées, a été analysé sous Iramuteq.

Résultats et discussion / Results and discussion

Summarized English version

Farmers' discourse about soil biodiversity

The highest salience indexes were obtained for items that mostly relate to soil organisms (Tab. 13). In total the farmers identified 19 groups of soils organisms. Earthworms are particularly important, which fits observations made in other studies (*e.g.,* Pauli et al., 2012). Most other organisms were little mentioned though. Because salience indexes were generally low besides the "earthworms" item, famers may have quite a heterogeneous conception of soil biodiversity.

The lexical analysis identified three classes of items (Fig. 17). The two first referred to general conceptions (life, material, time), to farming activities (ploughing, cereals) and to grasslands. The third class is mostly composed of items referring to soil organisms. Its distance with the two others may indicate a limited link between practices and soil organisms in farmers' discourse, even though the soil is indeed associated with a living ecosystem. Soil organisms have been compared with a "natural resource" useful in agriculture (Jiminez et al., 2001), which farmers did not directly seem to perceive here, as already observed by Pauli et al. (2012).

Modes of knowledge transfer used my farmers

Farmers' general knowledge related to their profession and their specific knowledge related to soil biodiversity were supplied by the same modes of transfer: mostly professional training and conferences (vertical transfer), readings (narrative transfer), their professional environment (horizontal transfer) and exchange groups (multiple transfer). Moreover, within each target, no mode of transfer was dominant in terms of influence and the different profiles of farmers refer to the same modes of transfer. Yet, certain profils were represented by a very low number of farmers and further investigations should be recommended.

Vertical transfer, generally dominant but incomplete

Vertical modes of transfer are the most often mentioned by farmers (Fig. 17). They are represented by various types of sources of knowledge, which may allow for reaching a greater number of farmers (Prager et al., 2016). Advice in particular was quite frequently mentioned, even though a few farmers were somewhat circumspect about the level of independence of the advisors: they felt that there might be sometimes a motivation to sell inputs beyond what they really need. In other studies, at the opposite, the relationships between farmers and advisors were described more positively (*e.g.*, Goulet, 2008). The farmers we met are all in mixed-farming systems. They may encounter a greater variety of opinions and advices, that could, maybe, sharpen their critical thinking. Farmers reported that vertical modes of transfer usually little tackle soil biodiversity knowledge. This could be due to lacks of knowledge updates from academic sources, *e.g.*, in private companies that have little interactions with the research sector (Prager et al., 2016). In formal education, this has already been reported in other regions of the world (*e.g.*, Baumgart-Getz et al., 2012 aux Etats-Unis). Finally, scientific research was nearly absent of the farmers' targets, because direct interactions between science and practioners are rares, inherited from a tradition of top-down knowledge transfer mediated by "translators" like extension services.

Horizontal and multiple transfers: interactions in knowledge sharing

Tools for knowledge sharing and co-construction appeared also very important in farmers' discourse. They combine various forms of exchanges, both formal (working in groups) and informal (spontaneous discussions). As such, networks played a particularly important role. The importance of horizontal and multiple transfers may also reflect an evolution in the way advice is provided in agriculture. This may reflect and certain "empowerment" of farmers (Demeulenaere et al., 2017) that acknowledges their skills and give them more independence in their decisions.

Narrative transfer, a diversified mode

Narrative transfer and the various sources that are associated should not be neglected. In particular, agricultural journals were often mentioned by farmers. Their content may influence what farmers aim to experiment in the field, could help to construct their knowledge through experience.

"The Brittain Peasant" was one of the most cited journals. We collected several articles that mentioned soil biodiversity, but the associated terms were less diversified than in farmers' discourse. Except for microorganisms, soil biota was not associated to soil functions. In general, three types of discourses about soil biota have been recorded in the collected articles, *i.e.,* (i) advertisements, particularly against pests; (ii) technical articles about soil management and the way to favour soil organisms; (iii) introduction of soil diagnosis tools.

Personal observation and experience were also important sources of knowledge, particularly about soil biodiversity. They may come from personal tests and on-farm experimentation. Experimentation is usually a prevailing form of knowledge acquisition in agriculture (Hansson, 2019). It is sometimes considered as a real activity of "Reasearch and Development" by farmers.

Overall, our results also illustrate the porosity that exists between the different modes of transfer that we identified. This may facilitate the complementarity of resources, particularly interesting to reach all farmers whatever their interests and preferences of a particular mode of transfer. Additionnaly, multiple references about soil biodiversity by different sources may legitimate that soil biodiversity matters and needed to care for.

Discours des agriculteurs sur la biodiversité des sols

Dans le discours des agriculteurs, les items ayant l'indice de salience le plus élevé se rapportent très majoritairement à des organismes des sols (Tab. 13).

Tableau 13 | Sept items à l'indice de salience le plus élevé (B'>0.1). Pour rappel B' ϵ [0 ; 1] ; Z=29 agriculteurs : deux agriculteurs ont fourni des réponses trop courtes ou non adaptées pour être traitées par le calcul d'un indice de salience ; ∑(B(Aij)) est la somme de l'ensemble des indices de salience calculés pour l'item i ; F : nombre de listes dans lesquelles l'item i apparait ; B(Ai) : indice de salience de l'item i dans la liste d'un agriculteur j. **The seven items with the highest salience indexes (B'>0.1). Reminder : B' ϵ [0 ; 1] ; Z=29 farmers : two of them provided too short or unadapted answers that could not be treated with a salience index; ∑(B(Aij)) is the sum the single salience indexes calculated for an item I; F: number of free-lists within which the item i appears; B(Ai) : salience index of the item i in the list of a farmer j.**

Item	$\sum B(A_{ij})$	F	Z	B'
Vers de terre, vers // **Earthworms, worms**	15,1	22		0,63
Insectes // **Insects**	7,54	16		0,4
Bactérie // **Bacteria**	5,07	9		0,23
Champignons // **Fungi**	3,64	8	29	0,19
Vie microbienne // **Microbial life**	3,94	8		0,19
Carabes // **Carabidae**	2,17	5		0,11
Vie du sol // **Soil life**	1,5	5		0,1

Au total, les agriculteurs ont ainsi distingué 19 groupes d'organismes du sol témoignant ainsi d'une certaine diversité des organismes des sols connus. Pourtant, si les vers de terre occupent une place prépondérante dans les listes, à l'instar d'observations effectuées dans d'autres régions du monde (*e.g.*, Pauli et al., 2012), beaucoup d'autres organismes n'apparaissent qu'à une ou deux reprises. De manière générale, on note ainsi que les indices de salience restent relativement bas, reflétant finalement une relative hétérogénéité des items auxquels les agriculteurs se rapportent pour définir la biodiversité des sols. Trois catégories de discours émergent de l'analyse lexicale (Fig. 17). Les deux premières classes recouvrent 63.5% du corpus et se réfèrent à des notions assez générales (vie, matière, temps), à l'écosystème prairial et aux activités agricoles (labour, céréales). La troisième classe est largement marquée par des termes se référant à différents organismes des sols (Fig. 17), qui correspondent en grande partie aux items présentant les plus hauts indices de salience : vers de terre, insectes, bactéries, champignons, carabes (Tab. 13). Pourtant, dix agriculteurs laissent entendre qu'ils ont un manque de connaissance au sujet de la biodiversité des sols au cours de l'entretien. Au sein de cette classe, un jugement de valeur, marqué par le terme « important » s'opère en même temps que ce discours plus « biologique » est développé.

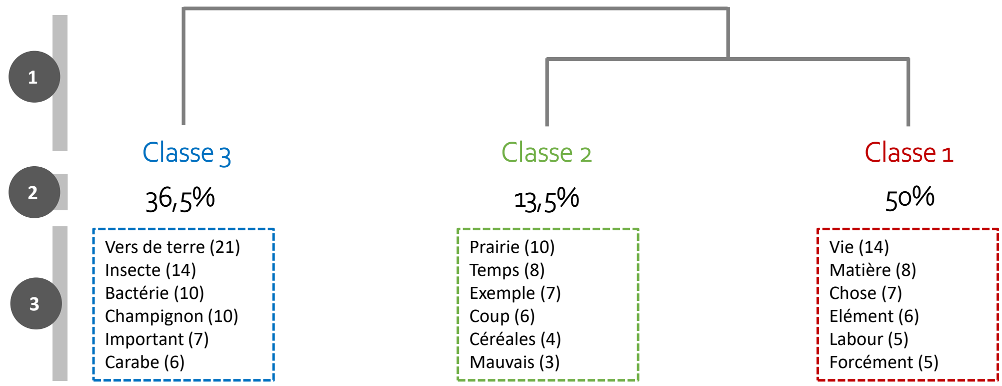

Figure 17 | Regroupements lexicaux associés à la biodiversité des sols dans le discours des agriculteurs produits sous Iramuteq (N= 28 réponses ; 702 formes au total). 1 : classes identifiées ; 2 : représentation de chaque classe dans le discours total ; 3 : liste des six premières formes actives dans chacune des classes (occurrence dans le jeu de données).

Selon Fournil et al. (2018), les sols « *demeurent largement perçus en termes de socle inerte fournissant son support matériel à l'existence biologique et sociale des êtres vivants qui peuplent sa surface* ». Ici, le sol n'est pas nécessairement un support abiotique et inerte : c'est bien un système vivant composé de différents organismes. Pourtant, la distance plus marquée du groupe 3 envers les groupes 1 et 2 indique que peu de liens directs sont faits entre les pratiques et les organismes en particuliers. De plus, nous avons relevé relativement peu d'explicitations du lien entre biodiversité ou organismes et leurs fonctions dans les sols. Ainsi, les agriculteurs semblent encore relativement peu considérer l'action des organismes des sols comme un outil de gestion, *i.e.*, une « ressource naturelle » utile en agriculture, comme l'avaient suggéré Jiminez et al. (2001). Et de fait, les relations entre connaissances et pratiques peuvent être ambiguës. A Honduras, Pauli et al. (2012) n'ont rencontré que peu d'agriculteurs qui mobilisaient effectivement leurs connaissances pour orienter leurs pratiques de gestion afin de limiter l'effet de la gestion sur les organismes ou de bénéficier davantage des fonctions de ces organismes dans le sol. Nos observations pourraient gagner à être rediscutées durant un second entretien avec les agriculteurs qui viserait à préciser les liens perçus entre les activités agricoles et les organismes du sol en interrogeant les connaissances sur les fonctions des organismes et des processus dans le sol.

Modes de transfert de connaissances mobilisés par les agriculteurs

Aucun mode de transfert n'apparait davantage associé à un type de connaissances, générales ou de la biodiversité des sols (Fig. 18, Test du Chi², N=285 occurrences des modes de transfert, df = 3, χ^2 = 3.00, p = 0.36). Les agriculteurs utilisent majoritairement les formations professionnelles et conférences (transfert vertical), les lectures (transfert narratif), leur entourage professionnel (transfert horizontal) et les groupes d'échanges (transfert multiple) pour obtenir des connaissances (Fig. 18). Trois types de sources sont spécifiques aux connaissances générales : les grands médias et radio, l'économie et les politiques actuelles et l'entourage familial est mentionné seulement pour les connaissances sur la biodiversité du sol. Néanmoins ces sources restent fortement marginales (une à trois occurrences).

Aucun mode de transfert n'a une influence plus grande sur les connaissances acquises par les agriculteurs interrogés (comparaison des occurrences des modes de transfert entre les niveaux d'influence, test exact de Fisher, connaissances générales : N=185, p=0.42 ; connaissances de la biodiversité du sol : N=100, p=0.37). Cette hétérogénéité pourrait être liée à la variété des profils d'agriculteurs (âge, orientation de la production) que nous avons interrogés. Enfin, les agriculteurs qui se distinguent par leurs pratiques de travail du sol (quatre profils, Tab.10) utilisent les mêmes modes de transfert pour acquérir leurs connaissances (test exact de Fisher ; connaissances générales, N=185, p=0.43 ; connaissances de la biodiversité du sol, N=100, p=0.51). Ici cependant, la pertinence du résultat est à mettre en regard avec les faibles effectifs d'agriculteurs au sein de certains profils (*e.g.,* profil « SD avec PP » : N=4).

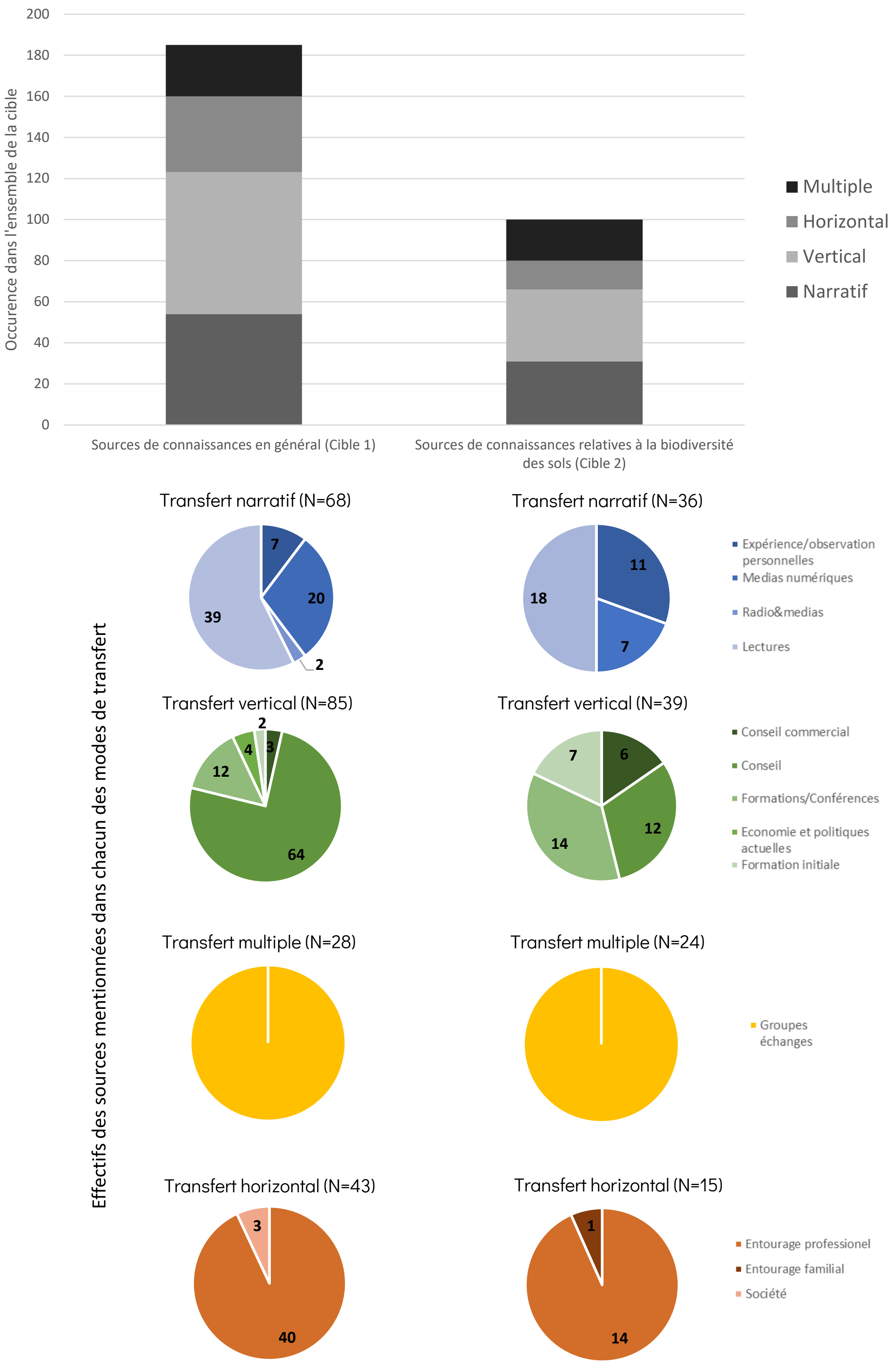

Figure 18 | Occurrence des modes de transfert sur chacune des deux cibles et nombre total de sources mentionnées pour chaque mode de transfert (*i.e.,* chaque type de sources peut donc être comptabilisé plusieurs fois pour une même cible s'il est associé à deux outils différents, *e.g.*, « Lectures » aura un effectif de deux s'il est associé à deux revues explicitement différenciées par l'agriculteur).

Le transfert vertical, dominant mais incomplet

Nos résultats indiquent une prédominance des modes de transferts verticaux dans l'acquisition de connaissances par les agriculteurs (Fig. 18). Ce transfert vertical prend lui-même des formes assez variées (conseil individuel, formation collective, conférences et, dans une moindre mesure, formation initiale). Cette diversité de l'offre, entre structures privées et structures publiques, peut permettre de toucher un plus grand nombre d'agriculteurs (Prager et al., 2016) et pourrait expliquer la prédominance de ce mode de transfert.

Dans notre étude, l'activité de conseil est pratiquée par les chambres d'agriculture, mais aussi par les coopératives et des structures privées. Menée en individuel, elle permet à l'agriculteur de recevoir des retours spécifiques à sa situation à travers un échange privilégié. Certains agriculteurs rencontrés se montrent néanmoins critiques au sujet des activités de conseil des coopératives ou des entreprises de vente d'intrants, une motivation commerciale étant parfois perçue chez certains conseillers (deux activités à séparer dès 2021 selon l'ordonnance n° 2019-36 du 24 avril 2019). Néanmoins, ce type de relations a pu être décrite de manière bien plus positive ailleurs, par exemple entre des agriculteurs en semi direct et le conseiller vendant du matériel de semis (Goulet, 2008). Dans notre échantillon, les agriculteurs en semi direct étaient très peu représentés (N=4) ; ils avaient une double activité d'élevage et de culture, qui les mènent peut-être à avoir recours à plus de techniciens différents. En ce sens, le discours d'un technicien-conseil pourrait être plus facilement comparable à celui d'autres conseillers, ce qui pourrait expliquer ces retours plus critiques.

Concernant le traitement de la question de la biodiversité des sols par les modes de transferts verticaux, certains agriculteurs ont affirmé qu'il était encore assez limité dans les formations auxquelles ils assistent. Ailleurs en Europe, Prager et al. (2016) ont émis l'hypothèse que le conseil prodigué par des structures privées en particulier pouvait davantage peiner à intégrer de nouveaux savoirs du fait de leurs liens plus faibles avec la recherche publique et les structures d'éducation agricole. Le contenu des formations initiales pose aussi question puisque les agriculteurs eux-mêmes affirment s'y référer assez peu, confortant de précédentes observations (*e.g.*, Baumgart-Getz et al., 2012 aux Etats-Unis). Cependant, d'autres études rapportent des agriculteurs décrivant une évolution récente du contenu des enseignements agricoles, incluant davantage de thématiques relatives à l'écologie des sols ou se rapportant à des conceptions plus agronomiques (Hervé et al., soumis). Il pourrait donc être pertinent de s'intéresser à l'évolution de la place accordée à la biodiversité des sols (i) dans la formation initiale des agriculteurs, (ii) dans les formations professionnelles, et (iii) dans la formation des techniciens agricoles qui fournissent du conseil.

Une seconde source qui s'inscrit dans un transfert vertical et qui est peu mentionnée dans notre échantillon est la recherche scientifique. Dans le secteur agricole, les institutions scientifiques spécialisées ont pendant longtemps pris en charge la production de connaissances et le développement de nouvelles technologies (Vanclay and Lawrence, 1994). Le rôle des structures de conseil était alors de diffuser les résultats des activités de recherches, afin de proposer des solutions aux agriculteurs (Leeuwis, 2004). Un tel fonctionnement largement descendant, est aujourd'hui remise en question (Compagnone et al., 2018). Néanmoins, les projets de recherche où l'objectif est de mener une étude sur les agriculteurs ou leurs parcelles, *e.g.,* pour répondre à leurs besoins ou comprendre leur comportement, et où les agriculteurs ne sont pas eux-mêmes invités dès le départ à participer à formuler les questions scientifiques, sont encore courants. Pourtant la recherche peut avoir un rôle de tremplin dans l'innovation technique et l'adoption de pratiques alternatives. Salvia et al. (2018) ont montré un taux d'adoption de pratiques de conservation des sols supérieur parmi des agriculteurs inclus dans des projets de recherche, en insistant sur l'importance d'une dynamique de collaboration à long terme. Si l'on compare le fonctionnement des programmes de recherche, souvent restreints en temps par les financements sur projet, avec celui des groupes de travail à long-terme des Coopératives d'Utilisation de Matériel Agricole (CUMA) et des Chambres d'agriculture (fortement mentionnés), il apparaît en effet clair que le temps pourrait être une contrainte majeure pour permettre d'intégrer les agriculteurs dans des relations de co-construction de connaissances.

Transferts horizontal et multiple : les interactions humaines au cœur du partage de connaissances

Une autre observation majeure de nos résultats réside dans l'importance des dispositifs permettant un échange et une co-construction de connaissances entre agriculteurs par des groupes de travail (mentionnés par 19 agriculteurs, pour les deux cibles confondues). Le partage de connaissances est également informel, via des discussions entre voisins, avec des proches, voire avec des visiteurs de la ferme (transfert horizontal), mais des dispositifs d'organisation collective (transfert multiple). C'est en particulier le cas des CUMA : initialement dédiées au partage de matériel, leur gouvernance nécessite des échanges qui peuvent favoriser des transferts de connaissances. Les réseaux jouent aussi un rôle important dans le développement d'innovation en agriculture (*e.g.,* Alskaf et al., 2020) et dans le choix de mise en œuvre de certaines pratiques comme le non-labour (Skaalsveen et al., 2020). Les structures clés dans ces réseaux peuvent être assez variées. Dans notre étude, le CETA est un acteur fortement associé aux groupes de travail, mais chez Bardsley and Bardsley (2014), c'est une coopérative qui joue un rôle fédérateur.

Ceci reflète, plus généralement, les évolutions en cours dans la façon de transmettre des connaissances le long de la vie professionnelle des agriculteurs. Plusieurs agriculteurs interrogés se sont révélés conscients de l'évolution de la manière dont le conseil est prodigué, où la prescription pure s'atrophie au profit d'une co-construction de la décision. Certains d'entre eux rapportent se sentir ainsi plus inclus, sollicités et parfois ont le sentiment d'avoir retrouvé une certaine autonomie dans leurs décisions. Ceci fait appel aux processus « d'encapacitation » des agriculteurs et à une remise en cause de la dominance du savoir technoscientifique au profit d'une reconnaissance accrue des compétences des agriculteurs observés par Demeulenaere et al. (2017).

Le transfert « narratif » : un vecteur diversifié à ne pas négliger

Le transfert narratif représente une part non négligeable des apports de connaissances à disponibilité des agriculteurs (Fig. 18). Les lectures y occupent une place prépondérante (Fig. 18) et sont souvent associées à des revues agricoles plus ou moins spécialisées (France Agricole, le Paysan Breton, Terra, Réussir Lait). Pour mettre en valeur la biodiversité des sols comme étant un élément qui doit être pris en compte, les sources généralistes pourraient être intéressantes puisqu'elles ont le potentiel pour toucher un public plus large que celui de revues spécialisées. Les agriculteurs se réfèrent également à leur propre expérience, à travers la pratique et l'observation sur le terrain (Fig. 18). Cette expérience peut être nourrie par l'application de ce qui a été lu.

La biodiversité des sols dans le Paysan Breton

Le « Paysan Breton » est l'une des revues les plus mentionnées par les agriculteurs (19 occurrences au total). Dans notre échantillon, les décennies 1990-1999 et 2010-2018 sont celles pour lesquelles nous avons trouvé le plus d'articles relatifs à des organismes ou à la biodiversité des sols (Fig. 19).

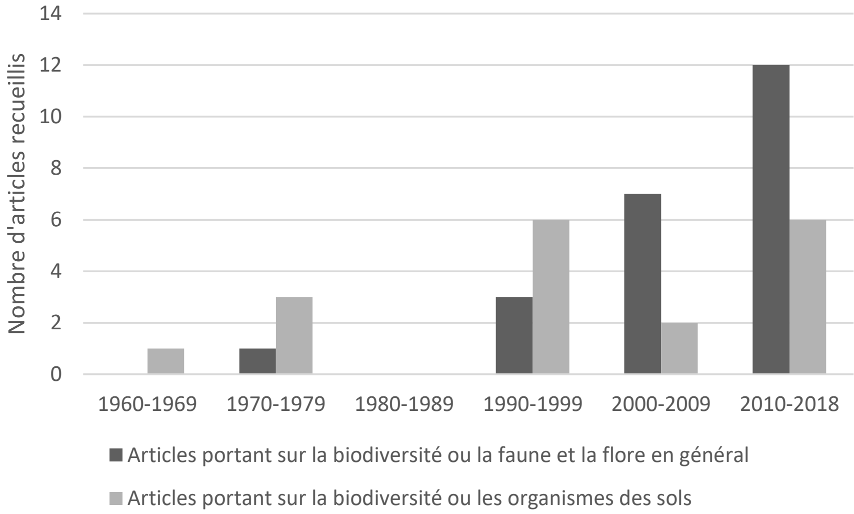

Figure 19 | Nombre d'articles récoltés par décennie entre 1960 et 2018, portant sur la biodiversité, la faune et la flore en général ou sur la biodiversité et les organismes des sols en particulier.

Le sol est le terme central des articles et est associé à des organismes similaires mais bien moins divers que ceux cités par les agriculteurs (Fig. 20). Bien que mis en avant dans la littérature scientifique, les vers de terre ne sont présents que dans un article et un dessin, tandis qu'ils sont fortement mentionnés par les agriculteurs interrogés. Hormis pour les micro-organismes, qui forment un regroupement à part, les organismes du sol ne sont pas associés à des fonctions (*e.g.*, minéralisation), comme dans le discours des agriculteurs. Le rôle des micro-organismes a reçu un intérêt marqué en recherche, et il existe aujourd'hui des produits disponibles sur le marché, censés les favoriser, ce qui a pu les rendre plus connus.

Une lecture qualitative des articles extraits du Paysan Breton permet d'observer une évolution de la façon dont les organismes du sol sont présentés et inclus dans le contenu. Sujet initialement plutôt secondaire, ils sont devenus l'objet même de certains articles. Trois catégories de contenu sont ici identifiées:

(1) Trois publicités, publiées entre 1978 et 1992, proposent des traitements contre les ravageurs (surtout des insectes, *e.g.*, le taupin) des sols. On retrouve aussi les insectes dans le discours des agriculteurs, seul taxon pour lequel certains répondants ont pris le temps de rajouter un qualificatif au sujet de leur caractère bénéfique ou négatif. En ce sens, le Paysan Breton pourrait refléter certaines manières de définir mais aussi d'évaluer les insectes des sols. Nos résultats ne permettent pas de conclure sur le rôle de cette revue dans la médiatisation de nouvelles connaissances sur la biodiversité des sols. Au mieux, une quatrième publicité propose un stimulant de « la vie des sols » et de la « vie microbienne » en 2017.

(2) Cinq articles traitent avant tout de pratiques de gestion des sols et intègrent à leur contenu au moins une mention relative aux organismes des sols, *e.g.*, les conséquences du labour (1960), les raisons motivant un amendement calcaire (1976, 2015), les bénéfices de l'usage de couverts végétaux (1990). Deux articles évoquent la limitation du labour et du tassement pour favoriser le rôle des organismes du sol (2011, contrôle biologique par les carabes ; 2017, décomposition et incorporation de la matière organique par les vers de terre).

(3) Quatre articles se rapportent davantage au diagnostic des sols en termes de matière organique et de fertilité (1976), à l'influence des conditions du sol sur la présence d'organismes (deux articles en 1998). L'un de ces articles complexifie le message transmis aux agriculteurs en faisant le lien entre pH du sol, activité biologique et bénéfices du fonctionnement des sols pour l'activité agricole. Un dernier article (2012) présente un nouveau bulletin d'analyse de sol dans lequel on retrouve un diagnostic biologique.

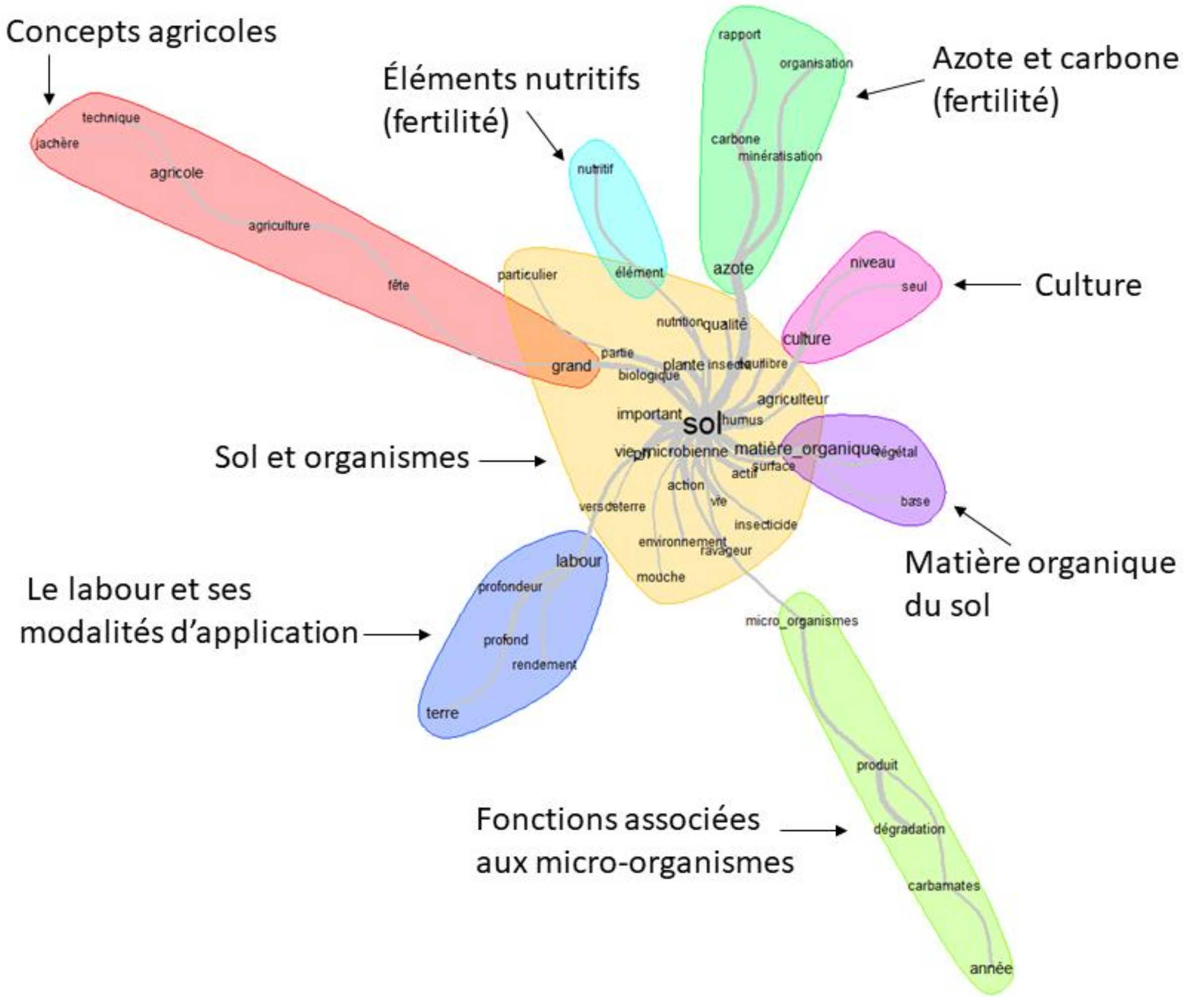

Figure 20 | Projection de l'analyse des similitudes dans le corpus d'articles du Paysan Breton mentionnant la biodiversité ou des organismes des sols, sur les formes dont la fréquence est supérieure à 5 uniquement. La taille de la police est proportionnelle à l'occurrence des formes au sein du corpus ; la largeur des liens entre les formes est basée sur leur degré de cooccurrence au sein du corpus.

Autonomie et construction des connaissances avec l'expérience

Au sein de notre échantillon, l'observation et l'expérience représentaient une source de connaissances non négligeable pour les agriculteurs, notamment en ce qui concerne la biodiversité des sols. En agriculture, l'expérience s'obtient en partie sur le terrain, lorsque les agriculteurs sont confrontés aux conditions naturelles (météo, hygrométrie, caractéristiques des sols, insectes auxiliaires et ravageurs présents etc.), mais également à travers l'adaptation au contexte économique et politique et à la disponibilité en matériel et main d'œuvre. L'une des caractéristiques de l'agriculture réside également dans l'expérimentation réalisée par les agriculteurs eux-mêmes sur leur exploitation. Pour Hansson (2019), il s'agit d'un mode d'apport d'information particulièrement prégnant en agriculture, en comparaison avec d'autres secteurs d'activité. Cependant dans des cas particuliers, comme une rotation 'longue' à 'très longue' (pouvant atteindre parfois 10 ans), où une culture définie n'apparaît que quatre fois dans la carrière d'un agriculteur, Soulignac et al. (2013) jugent la notion d'expérience trop fragile car s'appuyant sur des situations singulières, occasionnelles et dispersées dans le temps.

Interaction entre les catégories

L'expérimentation est parfois considérée par les agriculteurs comme une véritable activité de « recherche et développement » (Hervé et al., soumis). Elle résulte aussi de leurs observations aux alentours de la ferme et se révèle cruciale dans l'obtention de connaissances. D'une part l'expérimentation fournit du matériel autour duquel échanger avec des pairs, par exemple en CUMA, d'autre part elle est une composante clé du transfert multiple, où les groupes d'échanges encouragent le partage de résultats d'essais personnels. Deugd et al. (1998) se réfèrent au concept de praxéologie pour développer une approche de l'apprentissage par l'expérimentation permettant aux agriculteurs de se positionner comme experts. A ce titre, l'expérience semble pouvoir être aussi le résultat d'une démarche individuelle partagée au collectif.

Ces résultats mettent en avant la porosité qui existe au sein et entre les modes de transfert que nous avons définis (Tab. 12). Dans le cadre du transfert narratif, la porosité, ou la complémentarité des sources de connaissances est d'ailleurs un enjeu majeur puisque les agriculteurs peuvent se soustraire à une source de connaissances en ne poursuivant pas une lecture ou une mise en expérience. En ce sens, le transfert narratif pourrait rapidement rencontrer des limites s'il était utilisé seul pour mettre en avant la biodiversité des sols. Les interactions entre les différents modes de transferts pourraient permettre au contraire de mettre en avant la biodiversité des sols dans de multiples dispositifs et par de multiples acteurs. La légitimité des connaissances ainsi transmises pourrait alors augmenter et favoriser l'intégration de la biodiversité des sols dans la pratique agricole.

Conclusion

Summarized English version

The farmers obtain their general knowledge related to their professional practice and to soil biodiversity from diverse sources, in particular through vertical and narrative transfer modes, including mainly readings, independently of their soil management model. The study of a particular source of knowledge, « The Brittain Peasant », indicates that journals can help to convey knowledge about soil biodiversity that corresponds, to a certain extent, to that presented by farmers. However, the latter seem to have a greater body of knowledge on this subject, perhaps reflecting their recourse to multiple sources. The conjunction of several transfer modes could participate in building or reconstructing the way in which soil biodiversity is taken into account in agriculture. Huguenin (2017) developed the concept of Milieu Valuateur to try to grasp the conditions, within a territory, which allow the emergence and legitimization of technical innovations. From this perspective, Huguenin and Jeannerat (2017) notably highlighted the importance of the publicization processes which make it possible to reconfigure the conditions under which a socio-technical innovation is legitimized. Our study has demonstrated the importance, but also the need for media vectors highlighting soil organisms in order to promote differentiated and innovative soil management initiatives.

Les agriculteurs que nous avons rencontrés obtiennent leurs connaissances générales liées à leur pratique professionnelle et sur la biodiversité des sols par des sources diversifiées, en particulier par des modes de transfert vertical et narratif, dont surtout des lectures, indépendamment de leur modèle de gestion des sols. L'étude d'une source de connaissance particulière, le Paysan Breton, indique que les revues peuvent participer à véhiculer des connaissances au sujet de la biodiversité des sols qui correspondent, dans une certaine mesure, à celles présentées par les agriculteurs. Ces derniers semblent néanmoins posséder un bagage de connaissances plus poussé à ce sujet, reflétant peut-être leur recours à de multiples sources.

La conjonction de plusieurs modes de transferts pourrait participer à construire ou reconstruire la façon dont la biodiversité des sols est prise en compte en agriculture. Huguenin (2017) a développé le concept de Milieu Valuateur pour tenter de saisir les conditions, au sein d'un territoire, qui permettent l'émergence et la légitimation d'innovations techniques. Dans cette perspective, Huguenin et Jeannerat (2017) ont notamment mis en avant l'importance des processus de publicisation qui permettent de reconfigurer les conditions dans lesquelles une innovation sociotechnique est légitimée. Notre étude a démontré l'importance, mais aussi le besoin en vecteurs de médiatisation mettant en lumière les organismes des sols afin de favoriser des initiatives de gestion différenciée et innovante des sols.

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Discussion and perspectives

Back to our objectives

We recorded a broad range of values associated with soils and, to a lower extant, with soil biota and biodiversity (SBB). This plurality of values showed us that farmers may value soils and SBB beyond an instrumental perspective only (CHAPTER 3; **OBJECTIVE 1**). However, while soils and SBB are indeed valued, they may not always be prioritized in farming decisions, that also depend on the valuation of other elements and that are constraint by external elements on which farmers have little influence. Moreover, values are formed by farmers in very different management situations and as such, they are dynamic in time and variable across the EU (CHAPTER 4; **OBJECTIVE 2**). A particularity of agriculture may lie in the influence of the biotic and abiotic environment on the formation, selection and perpetuation of farmers' values (CHAPTERS 4 & 6; **OBJECTIVE 2**). Thus, despite a European, overreaching agricultural and environmental political frame that seems, to some extent, to emphasize the importance of preserving soils as an agricultural resource and soil biota as a support for useful soil functions, local specificities legitimate these policies to various degrees (CHAPTER 6; see Fig. 14 universal aspirations and exogenous sources; **OBJECTIVE 3**). Moreover, local sources of knowledge about SBB may have the potential to provide a diverse background for their valuation, even though the quantity and quality of transmitted knowledge may be variable (CHAPTER 7; **OBJECTIVE 3**). Besides, we may expect differences not only in the content, but also in the very availability of these modes of transfer across Europe, *e.g.*, technical support did not appear equally accessible to farmers between studied regions (CHAPTER 6). Ultimately, this impacts the way soils and SBB are really valued by managers in the field, and the indicators considered as relevant to assess their soils and the success of their practices (CHAPTER 4). This may explain why some farmers still consider that even if soils may be important to them, other objectives still prevail like productivity.

Considering valuations in agriculture as a collective process with plural outcomes

There are plural reasons to care for soils and soil biota

Acknowledging the plurality and dynamics of values in agriculture and the influence of a valuating milieu (Huguenin, 2017) may help to design effective regulations perceived as relevant by practitioners. This is particularly important since one can hardly identify consistent and identical patterns of factors influencing farmers' practices and management between different farming situations (*e.g.*, Knowler and Bradshaw, 2007 about conservation agriculture).

In CHAPTER 6, I showed that policies, territorial endogenous measures and external driving rules can change farmers' practices but also their valuations. For instance, cover crops were evaluated by farmers through their impact on soil functioning rather than through production levels or costs in CHAPTER 6. This is similar to the idea expressed by a farmer that Roesch-McNally et al. (2018b) met in the US:

> "And I think the cover crops really served as the kicker to get me thinking differently about, really, farming in general and to start thinking about something other than yield.". (Roesch-McNally et al., 2018b)

As stated by these authors, beyond economic reasoning, some farmers actually reshape their management system by developing an "*ethic of soil conservation*". Such an ethic can become an "*ethic of soil stewardship*" that progressively links "*short-term productivist goals with long-term conservation goals*", and included in farmers' responses to the risks provoked by local weather and to the observation of their neighbors' work (Roesch-McNally et al., 2018a). Such a perspective responds to the call of Thompson (1995), who emphasized how relevant it would be for environmental ethics to investigate agriculture-related issues, particularly about the soil. In my work, the words and discussions of the farmers appeared to support the idea that the conditions for the construction of an ethic of soil stewardship are met in Europe as well. Conceiving soils as a resource and soil biota as "*workers*" (*e.g.*, European Commission, 2010) amounts to carry and to diffuse one given conception about them, primarily centered on the production of agricultural goods. Yet, some farmers balanced the immediate benefits of their management practices with their long-term consequences or mitigated the hegemony of economic evaluations by paying attention to new forms of indicators like soil physical state or the response of soil organisms to agriculture management, both relating to longer-term thinking. In the light of my findings, an ethic of soil stewardship should acknowledge the plurality of values that can be associated to soils and to soil biota, and should consider the influence of particular farming situations in their formation.

Intersubjective exchanges and valuations

The observations reported in CHAPTERS 4 AND 6 illustrate how valuations are influenced by social interactions. The relationships between different actors of the agricultural sector such as farmers, cooperatives, associations and unions of farmers, extension services of agricultural chamber or NGOs, at local level, form a dense and rich network within which farmers may exchange about soils and about proper practices (*i.e.*, means) to management them. The pragmatic epistemology allows for conceiving exchanges between people as places were evaluations are performed, *i.e.*, where not only individual and personal farming experience and emotions play a role, but also the confrontation with other experiences and subjectivities (Létourneau, 2011). "Display" initiatives, *e.g.*, sharing of on-farm experimentations, may support such exchanges (Huguenin, 2017). And indeed, organizing collective networks of farmers has been showed as a way to favor the uptake of pro-environmental practices (Mills et al., 2011). McGuire et al. (2013) observed that the formation of a "community" of farmers working, at long term, on water issues within a watershed allowed for developing new goals by challenging and modifying farmers' identity. In the US, Roesch-McNally et al. (2018b) as well observed that farmers' trials about the use of cover crops was favored by the existence of a working group based in the watershed. This is close from the observation made during the second French Focus Group: for the farmers, soil had progressively become something relevant to pay attention to through their involvement in water quality preservation. Focusing on non-tillage practices, Schneider et al. (2010) argued in favor of a better consideration of knowledge co-production through networks by policy-makers. In CHAPTER 7, collective working groups in particular were highlighted as a way to obtain knowledge about soil biodiversity, while the influence of science appeared quite minor. In one of the most famous websites dedicated to soil conservation in France (https://agriculture-de-conservation.com/), the network of actors that is presented is diversified (farmers of course, but also constructors of farming material, technical advisors, institutions, NGOs) while research is not explicitly mentioned. Ingram et al. (2010) reported quite homogenous patterns of differences in understanding soils between farmers and scientists. The authors emphasized the contextual and cultural dimensions (i) of the relationships these two categories of actors have with soils and (ii) of their knowledge. In Nepal, Halbrendt et al. (2014) showed that farmers and scientists have different mental models about conservation tillage, *i.e.*, they expect different outcomes to this practice. The practice of interdisciplinarity since the setting of a scientific question on the research side, and the financial support of long-term projects that allow for the creation of true partnerships on the political side may be a way to favor intersubjective exchanges between farmers and scientists in order to reduce misunderstandings, but also to inform public debates (Boulanger, 2014).

The situated nature of valuations renders them dependent upon the possible transactions that valuating individuals can perform, both with their biophysical environment and with other individuals. Moreover, the level of availability of agronomic tools innovations appeared to vary between European regions, which may represent one factor of differentiation between valuating situations. CHAPTER 6 showed that the organization of the agricultural sector and the local working culture of farmers themselves further influence the adoption of innovation by determining different evaluative conditions that legitimize them. If farmers are not so much willing to work together, working groups may not be, the best tool to enhance awareness and to facilitate exchanges that may allow for an alternative valuation of soils. In the absence of complementary channels that (i) display alternative practices (and thus, alternative valuations) or just the considerations of soil biota (CHAPTER 7), or (ii) that open a debate about them, one may wonder what are the chances for alternative valuations of soils, favoring their preservation, to be performed.

Perspective. Integrating valuations of soils and soil biota within society to better preserve them

In CHAPTER 6, we observed that farmers barely referred to interactions between local networks and higher levels of organization when it comes to discuss values. Farmers mostly focused on quite local exchanges *e.g.*, to obtain new knowledge and sometimes to challenge the way or the reasons why they implement a given practice or evaluate its outcomes. That may be a problem if one seeks to place the lack of soil preservation as a real public problem (Fournil et al., 2018), for a public (Boulanger, 2014) and a public interest on the matter (Minteer, 2005) should be set at first. On the basis of Dewey's pragmatism, in Boulanger (2014), a public can be defined as a set of individuals aware that they are affected by the consequences of private activities that are external to them. The author splits the formation of a public into three steps:

> "The first one is the passive fact of being jointly affected by private activities; the second stage, an active one, is the fact of becoming conscious of a common interest in dealing with the problem and therefore looking for a solution, and the third stage is the designation of representatives for managing the problem. The second stage is crucial. It is the constitution of a community of interests between

> individuals hitherto only concerned with their personal, private activities and objectives. It is also the most problematic in modern, complex and technological societies." (Boulanger, 2014)

Dewey's pragmatic conception of the constitution of a public interest within a community (Minteer, 2005):

- emphasizes "*the role of community values and the contextual, situationally constructed nature of the public interest […]*"
- associates "*the public interest with the democratic method of dispute*"
- advocates "*a method of democratic social inquiry modelled after the ideal workings of the scientific community*"
- focuses "*on the key role of deliberation, social learning, and interest transformation*".

Practical, social inquiry are necessary for a public to identify and to understand problematic situations but also to form a public opinion (Boulanger, 2014).

Deliberation and interest transformation may lead a community's value to evolve. Maris (2012) referred to the role of the collective formation of values within a group that is "*situated in the time and in the space, commits itself into collective action*" in order to solve a management problem. Such an approach, where values can be challenged and changed through collective interactions, may allow to put into practice an *adjustment, i.e.,*:

> "the reflexive and evolving change in both human values and external conditions that resolves the tension. It is a holistic conception of the relationship between the agents and their natural environment. In this process, the whole person — or group — is changed, not some specific preference unsuited to specific environmental conditions." (Maris and Béchet, 2010)

In a soil-related case, this is close from Schneider et al. (2012)'s observation regarding how the practice of non-tillage transforms both human and non-human actors as they interact with each other, thereby breaking dualistic conception of human-nature relationships. In this perspective, the management of ecosystems, or management issues, can be solved but the solution partly lies in changes of values among those who have formed a public interest. In political terms, this requires to open spaces where values can be debated which follows a direction close to the "valuation policy approach" mentioned by Huguenin and Jeannerat (2017). In practical terms, participative approaches may be relevant, if their design allows "deliberation" and "social learning" (Minteer, 2005). In brief, a participative exercise can be defined as a specific and unique interaction allowed by the co-presence of different participants, forming a unique and non-reproducible entity within which communication is framed by a given objective and whose conclusions drive the decision of a system (Boulanger, 2017).

The new CAP 2020 acknowledges the importance of local particular farming situations and thereby allows, to a great extent, Member States to design their agricultural program and objectives. Implementing a valuation policy, at large scale, that allows for people to collectively debate about soil management or the degree of integration of soil biota in practices, may support the formation of local public interest about these issues. In the case of water management, the European Water Framework Directive defines "good state" references for water bodies on the basis of their physicochemical and biological parameters within large bio-geographical areas, and subsequently adapted and specified at the scale of smaller water-catchment areas. In terms of governance, objectives of "good" water quality and means to achieve them as well as their monitoring are all adapted locally. In France, the local management and monitoring of water quality is organized within those smaller catchment areas is partly organized by Local Water Committees, composed of various actors related to water management and preservation (representatives, industrials, farmers, associations, State services, NGOs). By analogy, one way of practicing a pragmatist perspective on soil management and governance, could consist in suggesting the formation of "Local Soil Committees", grounded in territories, reuniting various actors, also beyond the agricultural sector, and allowing to exchange about (i) the specific challenges identified by the members of such committees and (ii) the more general "*aspirations*" for a sustainable development that include soils. Influencing farmers' valuations may require to create bridges between them at a community level and with the rest of society as well (Mills et al., 2017). This is all the most important because soils may not be only threatened by management practices, but also by land use changes. Land use itself is subjected to evolutions that may ultimately damage soils locally (*e.g.,* land sealing). Farmers are aware of these pressures, that can constraint their access to the land. Opening a space for collective discussion on the management of soils, as it can exist for the management of water, can be an asset in territories submitted to pressures on land uses. It needs to form a "public", in pragmatist meaning, that identifies soils degradation and the loss of soil biodiversity as a societal issue. In this perspective, the initiative of People4soil in 2016, who launched a call for support in asking the EU to act for a better preservation of soils, may illustrate a possible intent for form such a public among European societies and to make them visible to higher levels of organization. On the other side, the new platform for soil launched in December 2020 by the EU may represent an opportunity to support the development of participative tools and initiatives to develop the emergence of public interests across the rich diversity of singular and unique situations characterizing agriculture.

Relevance and limits of our epistemological and methodological approaches

Using a pragmatist epistemology to investigate nature's value in agriculture

The approach developed here relied on various concepts in order to investigate the conditions in which soil and soil biodiversity valuations occur in the context of European agriculture. On the matter, pragmatism has been a particularly relevant epistemology to mobilize, for it conceives the formation of values as situation-dependent and the definition of problematic situation as something that is highly related to the point of view of the one(s) who state that there is actually a problem. In this sense, pragmatism highlighted and allowed to cope with farmers' variability of perspectives on soils (*e.g.*, on soil erosion, see Green and Heffernan, 1987).

Our analysis focused on the plurality of valuations of soils and soil biota and on the influence of a particular Valuating Milieu (VM). It showed a limited emphasize on power relationships between the actors of this VM tough. Yet, the distribution of power and the relationship between takeholders may actually structure characteristics of VM and could also explain within which conditions valuations occur. This may also relate to a general criticism of pragmatism: it may not conceive values as a process that can happen beyond the scale of individual people, at the level of social organization, enough. Better understanding the formation of values may be enriched by further describing, in a geographical and territorial area, who are the valuating individuals who interact which each other or at the opposite who may not exchange at all, what are the power relationship that allow certain actors to speak with a louder voice or whose legitimacy[11] is more important: all those elements play a role in setting the conditions of "intersubjective exchanges" that influence valuations. Moreover, Boulanger (2017)'s work on participation emphasized how important it is to understand from which position actors of different nature come to discuss with each other, so that the respective motivations of each participants are transparent. Beyond the application of a participative study, it may be relevant, in general, to consider the position and the stated role of VM's actors to better understand where the values they may publicize or the display measures they may encourage come from.

[11] *E.g.*, in chapter 7, several farmers explained that they only partly trusted technical advice from cooperatives since they perceived that the underlying objective of the advisors was to make them to purchase inputs.

Investigation tool: Focus Groups and interviews

Most of the material analyzed in the thesis has been provided by FGs, that we conceived as a space of valuation itself, and particularly of evaluation. Farmers were asked to reflect on what they usually do. The FGs method allowed further exchanges and, in the end, some farmers came to compare their practices, the conditions within which they apply, their objectives and sometimes agreed or disagreed, *i.e.*, expressed judgment of values.

Due to their nature of "*social units*", FGs were relevant to investigate processes of evaluations at the scale of a small group of farmers. But because of their very social nature, since all farmers did not know each other, the discussions may have been "*restrained*". The focus on changing practices set by the SoilMan project may also have preventeded farmers to speak freely in order to remain "*politically correct*"[12]. Trust construction between farmers and scientists may facilitate openness in the discourse, and requires much more time than a single meeting; besides, individual interviews could also help to uncover topics or ideas that may remain hidden in front of the group due to an actual or to expected reactions[13] of the peers (Kaplowitz and Hoehn, 2001). Therefore, it may be relevant, in the future, to further investigate farmers' management choices by following them directly on their farms and by observing the way they perform valuations daily. This could take the form of an ethnographic approach, combined with regular interviews that areacknowledged to be a useful complement of FGs when it comes to investigate nature valuations (Kaplowitz & Hoehn, 2001).

Among the farmers we met, most of them were already interested on the topic of soil. In some cases, it was because they were already involved in the development of conservation practices on their farm or already used to work with researchers. In other case, it was because they usually suffer so much from huge soil damages like erosion in Andalusia that they are looking for solution to preserve it. Thus, we might have missed a whole range of the farmers population across Europe. These farmers may belong to different networks within which they form also their own values, *e.g.*, supporting and legitimating ploughing. Starting a transition of soil management requires to find a way to reach these farmers, to investigate their own knowledge but also the values that are formed through their management practices and that lead to perpetuate it. Our work also showed that farmers suffering from soil problems or being aware about them may be already ready for some changes. Bringing farmers together confronting them with soil issues and giving them room to discuss what matters can help to launch transitions.

[12] Quoted from a discussion with the moderator of the second Spanish FG.
[13] During the first German FG, one farmer was much younger than the others. His words were often opposed by his peers, and, despite the moderation of the discussion, it seemed more difficult for him to transmit his ideas.

Perspectives: broadening the use of a pragmatic epistemology to investigate indicators or references set in agriculture

Considering values may provide a theoretical background for advocating a collective co-construction and reflection about what we consider to be a good soil and how to assess it.

The use of pragmatism to investigate the construction of soil indicators in agriculture

In the environmental field, sets of indicators are usually used to assess the state of ecosystems or the effects of a perturbation on them compared with a "good state" of reference, *e.g.,* of water bodies (EC, n.d.). Foremost indicators for soil assessment still rely on physicochemical parameters (Arshad and Martin, 2002; Bünemann et al., 2018). Soil biological indicators have been increasingly promoted and developed by the academic sector since the 90s (Doran and Zeiss, 2000), assessment and monitoring (*e.g.,* Cluzeau et al., 2012; Stone et al., 2016). At local level, our results showed that the farmers we met mostly relied on biophysical indicators to assess their soils. In a few cases only, earthworms were observed as well. They were not counted neither actively searched (despite a few farmers insisted on the importance of the spade): usually a mere observation of their presence was done. Most of these farmers associated earthworms with a soil in a good state, which was also used as a way to validate their own management system. Moreover, soil biological indicators have been presented as a way to inform European (Griffiths et al., 2016) and national (Ritz et al., 2009) policies. In agricultural policy, a set of indicators has been developed to monitor the level of "*integration of environmental concerns in the Common Agricultural Policy*" (Eurostat, n.d.). It indeed includes indicators based on several soil parameters of which soil biota or biodiversity is excluded; the sole indicator explicitly referring to biodiversity is related to birds.

The lack of mobilization of soil biological indicators is, on one hand, related to the fact that soils were longtime only envisioned in an agronomic perspective, and on the other hand, related to their novelty and to the difficulties associated to their implementation, even though they can be nowadays integrated into agronomic diagnosis performed by external expert (CHAPTER 7). Boulanger (2014) explained that indicators are used by observers to detect if there is a difference in the state of their environment; a difference observed becomes a real information it creates a change in the observers themselves. In this perspective, integrating soil biota in soil assessment is expected to lead farmers to change themselves as well. As stated by Renault (2016) indicators are also the markers of a certain vision of the world since they designate what matters to us. Soil biological indicators may be associated to an innovation, that not only modifies, technically, the way soils are managed; more generally, they define soil biota as something that is worth to be considered and that can tell something to farmers about their soils. Which is expected, following Boulanger (2014), to provoke changes in farmers themselves. The resistence to such changes could also explain why soil biological indictors are so little used.

Moreover, the legitimacy of soil biological indicators should not be taken for granted. The VM (Huguenin, 2017) suggests that, at the opposite, if we consider indicators as innovations, they should be tested through display and the values that underlie their use should be debated. Renault (2017a, 2017b, 2016) offered interesting examples of the application of a pragmatist epistemology to designate, in a participative and collective approach, indicators that translate what matters to people. Such an approach could serve as a way to construct sets of indicators of "good soils" or "good soil management practices" with farmers. At larger scale, is could be mobilized to support exchanges between people, *e.g.,* in "Local Soil Committees" or any group of people who have defined soils as a matter of public interest. The EU already offers some tools that could be mobilized like the SPIRAL method applied by Renault (2017) and Renault et al. (2017), *e.g.,* to define "good soils" targets and "appropriate" indicators at the scale of a given territory.
Finally, while indicators rather refer to evaluations, Dewey (1939)'s epistemology does not deny the emotional and more immediate dimension of valuations. Pure technical conceptions of soil may hinder such an approach and restrict human beings-soils interactions to evaluative and technical dimensions. Better preserving soils in Europe could, maybe, be advanced by re-considering our immediate relationships with them.

Investigating "good farming" standards associated with soil management

We reported the discourse of Spanish farmers who reflected on their role as farmers and on what they perceived as a responsibility to ensure food security, despite the negative impact on the environment that could co-occur. Romanian farmers thought that the EU should rather provide subsidies to farms that use a lot of inputs, even if this may pollute the environment, because the result in the end is a higher yield. In both cases, the set end-in-view is a productivity, and it provides the criterion for means (*i.e.*, agricultural practices) legitimation, *i.e.,* the impact on yields. By showing that soils and soil biota values formed by European farmers are variable in time and space and formed in specific problematic situations, we allow the possibility to conceive their changes as something possible. Such changes in valuations could ultimately lead to shifts in the normative conception of "*a good farmer*" related to the implementation of soil conservation practices (Burton, 2004; Roesch-McNally et al., 2018a), which may ultimately modify farmers' management practices.

In a pragmatist epistemology, valuations participate to define what is considered as "*good*": a good practice, a good production, or a good farmer regarding certain objectives set to solve a particular problem. Thus, the pragmatic epistemology may provide an interesting theoretical basis for the study of shifts in the definition of what is "good" in agriculture. McGuire et al. (2013)'s study on the reconfiguration of the "Good farmer" identity could provide a particularly relevant framework. While the authors did not explicitly refer to pragmatism, the process of transformation of a "good farmer" standard could easily be compared with a valuation process described in a pragmatist epistemology. In their study, McGuire et al. (2013) conceived the "good farmer" identity as dependent on particular, singular and unique situations. Within such situations, a farmer may assess if their action fits with a given "comparator" (*e.g.*, a criterion related to productivity) used to define a "Good farmer". Such an assessment is mediated by a "social appraisal", upon which the farmer can himself reflect and, maybe, re-define the "comparator", thereby changing their own "Good farmer" standards. Similarly to Dewey's (1939) conception of valuation: (1) the assessment makes sense in one given and specific situation, (2) there are criteria of comparison used to evaluate if an action and its result fit with an initial conception of a "Good farmer"; (3) the integration of a social situation brings new elements to the evaluation, and reflectivity may modify the initial comparator used to define a "Good farmer". Adapting McGuire et al. (2013)'s model may be relevant to investigate the role of valuations in the hypothetical emergence of a "good farmer" identity based on a the ability to perform a soil biodiversity-friendly management.

General conclusion

Pragmatism appeared as a relevant way to investigate soils and soil biota values in Europe. Such values are plural but also situation-dependent and dynamic. Changes of values may challenge conceptions of what is a good agriculture, with an enhanced integration of soil biological stakes as something important. As such, addressing values appears to be particularly important to foster agricultural transitions, may it be on agricultural practices in particular, or of the overall system. Besides, soils encounter numerous threats in Europe, some of them also related to other actors and stakeholders in society. Sustainable soil governance requires that a wider range of people than farmers only wonder (i) what are their relationships with soils and

(ii) in which terms and to what extent soils are worth being considered and preserved (I am currently working on a paper on the topic, that is not included in the thesis). Multiplying the points of view may lead to a real public interest for soils to emerge and a reconfiguration of its values across society.

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Appendices

Appendix 1 | Investigated values that can be derived from the content of the paper (quotations or authors' interpretation). In italic are elements directly focusing on soil biodiversity while other elements focus on soils in general. AEM – Agro-Environmental Measure

Value domain	Value category	Reason for practice choice /statement	Statement or soil management practice choice which the value is inferred from	Paper(s)
Instrumental value domain	Monetary values	Improved (or, comparing different practices, at least equal) production or profitability (market prices of production)	Soil conservation practices	Kaltoft (1999) ; Peigné et al. (2015)
			Increase soil organic matter content	Hijbeek et al. (2018)
			Use of manure	Ingram (2008)
			Low-input farming (*e.g.,* low fertilization)	Ingram et al. (2013)
			Organic matter decomposition by earthworms considered important for a good production	*Kelemen et al. (2013)*
			Practices increasing soil fertility for forage production	Lamarque et al. (2011)
			Crops rotation designing	Chongtham et al. (2016) ; Macé et al. (2007)
			Soil protection practices	Sattler and Jens Nagel (2010)
			Soil assessment and management dedicated to production	Ingram et al. (2010) ; Verhoog et al. (2003); Wahlhhütter et al. (2016)
			Use of synthetic fertilizers	Darnhofer et al. (2005)
		Costs and labor reduction	Reduced/Absent tillage	Chantre and Cardona (2014); Compagnone et al. (2013) ; Ingram (2010) ; Lahmar (2010); Mann (2018); Peigné et al. (2015); Posthumus et al. (2011); Prager and Posthumus (2010); Sattler and Jens Nagel (2010); Schneider et al. (2010); Wahlhütter et al. (2016)
			Reluctance for the use of white clover as organic N fertilization source	Garforth et al. (2004)
			Manure planning and use of slurry	Garforth et al. (2004) ; Larmarque et al. (2014)
			Reduced use of fertilizers	Sattler and Jens Nagel (2010) ; Chantre and Cardona (2014)
			Cover crops in orchards	Mary et al. (1999)
		Obtention of subsidies	Reducing fertilization (AEM)	Burton et al. (2008); Lahmar (2010)
			Constraint to the choice to adopt AEM (nitrogen-fixing crop)	Espinosa-Goded et al. (2010)
			Conservation tillage	Mann (2018)
			Soil conservation practices	Posthumus et al. (2011); Prager and Posthumus (2010); Schneider et al. (2010)

				Adoption of AEM (traditional grazing, not shifting pastures for cultures, no fertilizers)	Harrison et al. (1998) ; Boardman et al. (2017)
Intrinsic value domain		**Moral duties towards nature**	*Preserve soil biota*	*Reduced tillage*	*Ingram (2010)*
			Interest for wildlife or nature conservation	Low-input farming (*e.g.,* low fertilization)	*Ingram et al. (2013)*
				Adapted management allowing biodiversity protection	*Kelemen et al. (2013)*
				Maintain land under pastures rather than cultures	*Boardman et al. (2017)*
Relational value domain	Fundamental	**Ecological Resilience**	Erosion mitigation and control	Crops rotation including grass	Evans (2010)
				Field bounderies management	Evans (2010)
				Soil conservation practices	Posthumus et al. (2011)
				Adoption of AEM	Boardman et al. (2017)
			Soil structure	Manual soil management	Kaltoft (1999)
				No-tillage	Compagnone et al. (2013) ; Schneider et al. (2010)
				Ley farming	Chongtham et al. (2016)
			Improve/preserve soil organic matter content	Manual soil management	Kaltoft (1999)
			Soil fertility	Use of organic N fertilization source	Garforth et al. (2004)
				Perception: an important ecosystem service	Lamarque et al. (2011)
				Use of crop residues as litter	Lamarque et al. (2014)
				Cover crops in orchards	Mary et al. (1999)
				Ley farming	Chongtham et al. (2016)
				Agro-environmental measures adoption	Prager and Posthumus (2010)
			Water storage	Use of organic nitrogen fertilization source	Garforth et al. (2004)
				Perception: an important ecosystem service	Lamarque et al. (2011)
				No-tillage	Compagnone et al. (2013) ; Schneider et al. (2010)
			Benefits for "soil life", useful for the whole soil system	*Increase soil organic matter content*	*Hijbeek et al. (2018)*
				No-tillage	*Compagnone et al. (2013) ; Schneider et al. (2010)*
				Crop rotations	*Cristofari et al. (2018)*
			Biological control (weeds, pests)	Cover crops	Mary et al. (1999); Peigné et al. (2015)
				Crops rotation	Chongtham et al. (2016); Cristofari et al. (2018)
				No-tillage	Schneider et al. (2010)
				Choice for organic farming	Tybirk et al. (2004)
			General soil improvement or sustaining	Use of manure	Ingram (2008)
				Reduced tillage	Ingram (2010)

			Choice for organic farming	Tybirk et al. (2003)
		Soil quality assessement	*Good soil defined by soil biota*	*Wahlhütter et al. (2016)*
	Identity	Productors of food on healthy soils as defining good farmers	Soil conservation practices	Home et al. (2018)
		Building local identity as farmers	Maintain fertilization-free lands and pastures (tradition)	Harrison et al. (1998)
		Soil state and soil management as supports of farmer identity in the farming community	Organic farming management of soils	Wahlhütter et al. (2016)
			Reduced tillage	Ingram (2010)
		Soil support of practices defining a good farmer	Ploughing ability (here because production quality would depend on the precision of ploughing)	Burton et al. (2008)
			Having a healthy soil, *i.e.,* suitable for crop production	Saunders (2016)
		Soil as a criteria to define a good farmer/good practices	Practices choice in relation with the time spent for soil observation and understanding	Ingram (2008)
	Symbolic value	Soil support of practices defining a good farming and professional ethics	Ploughing ability traditionally recognized by peers	Burton et al. (2008)
			No erosion provoked by management	Schneider et al. (2010)
			Soil as a support for farmers' symbolic commitment to their job (weeding, drilling)	Burton (2004)
	Social cohesion	Answering society's expectation	Use of organic N fertilization source	Garforth et al. (2004)
		Soil as a support for meeting, exchanges, collective work between farmers	Reduced tillage	Ingram (2010)
			No tillage	Schneider et al. (2010)
		Soil support of management that could help to improve farmers' image for society	Positive assessement of reduced and mulch tillage	Sattler and Jens Nagel (2010)
Eudmaimonistic	**Meaningful occupation**	Pride related to soil management	Maintain fertilization-free systems and pastures (traditional "way of life")	Harrison et al. (1998)
			Reduced tillage	Ingram (2010)
		Soil knowledge as a mean of independence and autonomy	Management decision autonomy	Home et al. (2018)
		Responsibility to produce food of good quality	Biodynamic system adoption and related soil management	Kaltoft (1999)
		Lifestyle preservation	Low-input farming (*e.g.,* low fertilization)	Ingram et al. (2013)
		Time available for family	Reduced tillage adoption	Schneider et al. (2010)
	Cognitive development	Soil as an object of challenge	No-tillage	Schneider et al. (2010)
		Developing skills and knowledge: "awakening"	Adoption of soil conservation practices	Ingram (2008); Ingram (2010)
	Altruism	Ethical responsibility	Fertilization management	Kaltoft (1999)
		Limit CO2 emissions	Reduced tillage	Compagnone et al. (2013)
		Pollution risk control	Use of liquid manure for more control	Kaltoft (1999)
			Avoid leaching (*e.g.,* nitrogen)	Sattler and Jens Nagel (2010)
		Responsibility towards the neighbors to avoid erosion	AEM adoption to diversify cultures on soil	Boardman et al. (2017)
		A way of life to be preserved and transmitted, indirectly leading to nature conservation	No fertilization ; Pastures maintained and not cultivated	Harrison et al. (1998)

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Appendix 2 | Investigated values that can be derived from the content of the Focus Groups. In italic are elements directly focusing on soil biodiversity while other elements focus on soils themselves

Value category	Motivation of practice choice	Practice choice	Example
Instrumental values	**Production increase**	Crop rotations	I think a crop rotation should be done primarily to avoid diseases and pests, the main factor that affects a crop. You cannot grow rapeseed for 3 years or have a short 2-year crop rotation with rapeseed and wheat because you will fill your soil with pathogens, *Sclerotinia sp.*, you will have *Septoria* on wheat, and in 4-5 years you will reduce your yields up to 50%. (RO-9)
		Integrate pastures in the rotation	But for sure, when one has the chance to get a 5-years meadow before planting corn, it is not that bad. It remains quite clean and it makes work easier. Grass is actually an important asset when it is possible to have it on the farm. (FR-4)
		Use of cover crops as a fertilizing complement	I tend to produce more and anyway my soils need 250 kg N a.s. per ha, and APIA regulates the dose up to 160 kg, so I prefer to apply 150 kg of chemical fertilizer and the rest from mustard. (RO-7)
		Residues let in the field	In a methanization system, on my point of view, soil cover should not be forgotten, it is necessary to make soil produce, to fertilize it, and from time to time crop residues have to be let in the field. (FR-5)
		Use of organic fertilization	Nevertheless, we now note, since we fertilize much organic fermentation residues, that even at least in the root crops, the yields have become much more stable. (D-5)
	Time and costs saving	Direct seeding	I think there is a collective awareness about yield stagnation; the lack of labor availability in the farms, which is going to become a central issue within the next years, soil management workload will need to be reduced. […] Progressively I decrease soil tillage and all autumn crops are planted under a cover. So basically every cereal crops are directly seeded under cover. (FR-5)
		Crop rotations	We have areas in Hesse and there is a very interesting crop rotation program, crop diversification. Since you have to grow five crops and 10% legumes and that's a great thing. It's really about money. (D-5)
		Use of cover crops as a source of free organic matter	It is a free organic matter that we get, but it is done, but, well, it worth money too to shred [*soil*] as it is shred and it is not necessary to till it to remove the grass, it is worth money with cover crop. (ES-16)
		Use of ploughing instead of cover crops	It means that to maintain a cover crop in an olive field, it can be as expensive than to till it, no, that, that, to maintain a cover crop in an olive field is nearly more expensive that to till the soil. (ES-4)
		Minimum tillage	I prefer only minimum tillage. […] My farm is expanding, taking up new land. (RO-7)
		Fertilization level modulation	On the good* fields I try to make it a bit more intensive, usually basic fertilizer, phosphorus and potash, but on the areas with low producing levels, where some are also poorly supplied, there I abandoned the idea of turning them into interesting* areas. (D-2) **** both terms here refer to the capacity of the fields to produce (economic interest)***

	Intrinsic values	***Favor biodiversity***	*Late ploughing*	*I have also ploughed a lot so far and especially in summer time, for my autumn wheat. Otherwise I plough very late in the season, perhaps also because I think of leakage and worms. You think about having a place where the worms can get down. And I, I don't, I imagine that they can find their way down if I prepare it for them. (SE-5)*
			Limited ploughing	*The more soil cultivation is done, no matter in which form, the fewer earthworms there are. What we get down to tillage, also in depth, the more earthworms we have. That's why we all like to do little tillage.(D-13)*
Fundamental values	Ecological resilience	**Soil protection**	Choice of crops in the crop rotation	I would see things in a different perspective, normally, in a farm there should be a crop rotation of 3-5 years depending on what you want to cultivate, in order to protect also the soil. (RO-6)
		Erosion mitigation and control	No ploughing	And we can choose to plough because of various different reasons. It could be plant rests or type of earth. Some of my soil is full of sand and that's best to just let that this soil area rather than using a plough. (SE-3)
			Ploughing	There's a polemic about this thematic of erosion indeed. No-tilled soils are way more sensitive to erosion, they erode more than tilled soils. […] They are damaged because, logically water runs off along the surface and erodes cereal fields soil. (ES-15)
			Crop rotations	That we would recognize as a practitioner, there is a meaningful goal, the goal is, for example, diverse crop rotations, more cultures. The goal is, for example, erosion protection […]. (D-7)
		Soil structure	Cover crops	After wheat, I allocate a certain area for rapeseed, after which I sow mustard. I did not necessarily do this for the subsidy from APIA, because I had problems with soil compaction in the first years, and during the spring it was hard. I apply the APIA measure with mustard, it works very well, in spring the soil is much loose, but I apply minimum tillage. For maize it works very well. (RO-7)
			Limited machineries pressure in the fields	For weather reasons, we did not use that at all because we did not want any additional wheel loads in the field at the beginning of October. (D-5)
			Adapted ploughing period	We have to wait for soil to be dry to till the surface before seeding, while in ploughing system, sometimes, we used to plough, it was nearly not dry enough, and we saved 8 to 10 days sometimes whereas that was a mistake. (FR-2)
		Soil organic matter content	Crop residues management	About what you said on the economic reasoning shaping crops rotations, there is a group of fields we just got and we were wondering if we should chose a rapeseed-wheat-wheat rotation, which is profitable, because corn(*) might turn a bit dry there. Still, I think we are going to use a corn-wheat-rapeseed-wheat rotation, even if corn is not profitable. But regarding weeding, regarding the whole rotation, we are going to produce corn, we are going to bring back material to the soil, but we forget nearly any margin. (FR-3) **Here corn used for human feeding purpose*
		Soil enrichment	Cover crops	We have some erosion-prone locations, where plowing is subject to legal restrictions; on top of that, intercrop cultivation offers us the opportunity not only to reduce erosion but also to draw nutrients from autumn into spring. (D-7)

	Avoid water run-off	Reduced tillage to increase soil organic matter content	There another element favoring all of that, about the interest to reduce soil tillage, with the example that has just be cited. That is that we let all the organic material at the surface. […] when there is organic matter at the surface, there is also way less [*water*] run-off. (FR-6)
	Water storage	Green/cover crops	On the one hand you also lose out with these crops because the plant consumes nutrients from soil, and on the other hand with technology as appropriate as possible, an autumn crop is somewhat necessary for water storage. (RO-4)
	Integrating soil biota as a part of the agricultural soil system	-	*There an increasing awareness about soil life and its importance on the natural character of culture systems. (FR-4)*
		Designing soil management	*Yeah, generally microorganisms and things that exist within our soil. There are not only worms there but different types of [organisms?] eat stuff and it is perhaps part of soil management. (SE-6)*
		Crop rotation	*Crop rotation is not made only to avoid diseases and pests; you are also reorganizing your soil and restore flora and fauna in it. For example, you can now cultivate maize for 5 years, there is no problem, you make treatments, disinfecting the soil, fertilize it and grow only maize. (RO-6)*
		Cover crops	*I just said, my* CIPAN(*)*, between two cereal crops, it is a real "*dérobée*"*(**)*, excepted that while someone might harvest it for cattle feeding, I do let it on the soil for my earthworms. And they are bloody important. I guess you are going to talk about that, but this earthworms livestock needs to be fed, because if we to bring them food, they will never develop neither. (FR-5)* (*)*"Culture Intermédiaire Piège A Nitrates", i.e., intermediate culture between two other cultures aiming to capture nitrogen.* (**) *An intermediate culture between two main crops of which production is also expected to be economically profitable.*
		Reduced tillage	*In our country a few years ago, many soils remained abandoned, and to do minimum tillage I have to invest, to plough, to apply manure, to restore the fauna from soil, to avoid surface leakage, to drain. (RO-6)*
	Biological control of pests and diseases	Ploughing	In our case, when wheat culture follows wheat culture, we always use ploughing and generally use ploughing after wheat to prevent it from spreading, grass stocking, foot diseases... (D-1)
	Soil functioning	No-tillage	That's true, as you said, that for the mind, it is not easy to shift for this practice. Personally, I have adopted it progressively over the last 2-3 years on 50 hectares of cereal crops. We used to plough half of it and what pushed me to stop ploughing on the whole surface is the lack of labor. That was for this reason at the beginning, more than because of soil aspect, and afterwards I realized that it worked very well for the soil. (FR-2)
Identity	**Soil knowledge as a criteria to be a good farmer**	Adaptation of practices according to one's own soil specificities	So far I have not done agrochemical analyzes, but I want to mention that I know my soil as much as I know the need of plants for nutrients. (RO-8)
Cultural heritage	**Soil as the support of shared agreement on what are proper farm management practices**	Ploughing	At least this time it takes to work: rationally speaking it is better not to have to plough so much. Yet, it is seen as something that is necessary. (SE-2)
	Soil support of practices defining a good agriculture	Cover crops	A good cover crop, it is also a good agriculture. (FR-1)

	Symbolic value	**Soil support of a specific and personal seasonal management**	Ploughing	Although I have very small parcels, the autumn plough is a law for me, I try to make it every autumn, and in the spring the preparation of seedbed I do with a disc harrow. (RO-11)
	Sense of place	**Soil as an object of attachment to the farm land**	Reduced tillage	And then, one thing leading to another, from one contact to the other one, we see things, we hear things, and I thought why not, I have to try, and you adopt it for economical purpose at first, because we are always looking for economy, and backwards, we think "this, it's quite nice", and progressively we implement cover crops, we try things, and then it becomes seeding under cover crop. This is passion, because actually, I hope that my fields, the day I'll stop my activity, I will transmit them to someone who has the same passion that I have, because it would be harmful to transmit them to someone who would revert to the use of a plough overnight. (FR-1)
Eudaimonistic values	Meaningful occupation	***Soil biodiversity visible with management practices provides pleasure***	*Observation of soil along the rotation*	*There is a culture that can really help to realize this, that is rapeseed. We have fields with a corn-wheat-rapeseed-wheat rotation. Usually, it is only superficial tillage, but during autumn that is a real pleasure, it is fed, it is full of earthworms, we find them everywhere, this is the most impressive culture, we can't observe this as much after a forage corn. (FR-3)*
	Cognitive development	**Soil management as an intellectual challenge**	Adoption of reduced tillage system	But indeed, a transition of the soil is needed, a transition in the head as well, because sometimes we turn concerned, but we realize it works as well. (FR-2)
		Soil perception evolution	Managing soils	It [*talking about soils*] is a support of cultures, that's all. There is not even soil observation any more, when we adopt those practices, our perspective on soil and on cultures completely change. (FR-5)
	Altruism	**Carbon emission reduction and carbon storage for global sustainability**	Soil cultivation stakes	Well, no, but basically if I'm understanding the research correctly then agriculture is a problem of the sustainability aspects of our planet. We set out all this carbon out into the atmosphere and we don't collect carbon. That corresponds to the amount of greenhouse gases that we let out. And I think that agriculture could be not only a way to produce food it could also be a way to repair many of the main system that actually keeps us alive. And through that perspective, I think that soil management is difficult. It would be more fun if we did not have plants that died every year like ley, like fruit orchards. Berry bushes and other crops that could correct carbon… in the stems and in the roots and up into their branches and it could get their nourishment in some other way. (SE-5)

Appendix 3 | IFE (Investigated Framework Elements) refer to the components of the framework (Fig. 1) that framed data collection and analysis. Research sub-questions structured our analysis but they were not directly asked to the farmers. FGs discussion topics are the topics addressed in the FGs. "Collected quotations" describes the type of quotations used for the analysis

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IFE	Research sub-questions related to the framework	FGs discussion topics	Collected quotations
(I) Situation assessment	Which elements define farmers' soil management context (external elements) and situations (elements perceived and interpreted by farmers along the inquiry)?	- Elements taken into account when choosing a management practice - Soil assessment influence on practices choices - Perceived local evolution of agriculture in the future	(Ia) description of the contextual factors that influence soil management decisions; (Ib) description of soil management situation;
(II) Valuations related to soil managemen	Which ends are expressed by farmers in relation with their soil management? On the basis of which criteria do farmers choose a practice? How do farmers change their usual practices? Do they modify the values underlying their management practices?	- Objectives of the activity and expected outcomes of a given practice - Assessment of the efficiency of a practice - Influence of discussions and other perspectives on the definition of goals - Existence of competing objectives	(IIa) stated ends-in-views and objectives of activities; (IIb) justification of practices choices; (IIc) expected outcomes of mentioned practices (actually applied or not) and antagonist outcomes; (IId) criteria used to assess practices success;
(III) Temporal dynamics	Are described ends-in-views and chosen means evolving?	- Adaptations to punctual constraints, *e.g.*, drought in 2018 - Long-term evolutions operated in the farm	(IIIa) changes of objectives; (IIIb) evolution of the criteria used to assess a situation or a practice; (IIIc) assessment made on the success of a practice in the farm at long term; IIId) reflective description of changes operated in farmers' own way of thinking;
(IV) Soil biota and ecosystems in valuation	Which soil dimensions belong to management situations? Are soil ecosystems or soil biota components of situations described by farmers? Do farmers present soil biodiversity or soil organisms as potential targets of their management practices? Do farmers reflect on an evolution of soil biological elements role in soil management planning?	- Soil biota observed in the soil; - Use of soil biota to assess soil conditions; - Use of soil biota to assess practices outcomes/expected results.	Soils, soil functioning or soil biota considered: (IVa) in assessing the situation and the problem; (IVb) as ends-in-view of the activity; (IVc) as a mean to reach an objective; (IVd) as criteria to assess the outcomes of a practice.

Résumé étendu

Le sol représente la couche fine recouvrant la surface du globe, composée de matières minérales et organiques fragmentées entre lesquelles se trouvent des pores, remplis d'eau ou gaz. Il est également un écosystème à part entière, qui compte parmi les plus riches et diversifiés en organismes vivants. Ses caractéristiques chimiques, physique et biologiques déterminent les nombreuses fonctions qui lui sont associées *e.g.*, sa structuration, la décomposition de la matière organique, la régulation hydrique et la régulation des cycles du carbone ou de l'azote… Ces fonctions conditionnent alors également aux écosystèmes terrestres en surface. Nombreuses sont les activités humaines qui reposent ainsi sur le fonctionnement des sols et sur les organismes qui s'y trouvent. Parmi elles, l'agriculture fait figure de cas d'école. Pourtant, les avancées techniques et technologiques de l'agriculture moderne sont aujourd'hui contrebalancées par les conséquences négatives de certaines pratiques. La perte de biodiversité et la destruction des écosystèmes en particulier apparaissent comme des enjeux majeurs auxquels le secteur doit aujourd'hui faire face, ne serait-ce que pour assurer sa propre durabilité. En ce qui concerne les sols, l'utilisation de labours trop profonds ou fréquents, le manque de diversité culturale, l'appauvrissement en matière organique ou encore le recours à certains intrants chimiques ont été ainsi été identifiés comme des sources possibles de perte de biodiversité.

Les sols de l'Union Européenne n'échappent pas à cette tendance et pourtant, à ce jour, aucune législation ne se concentre spécifiquement sur la protection de leur biodiversité. Cette dernière relève encore largement des conséquences indirectes de régulations plus générales relatives à l'environnement ou à l'agriculture, bien que le dernier « Green Deal » soit envisagé comme un moyen potentiel de la préserver. Si les politiques, d'un niveau local jusqu'au niveau européen, souhaitent que le secteur agricole intègre davantage la biodiversité des sols dans ses activités, cela implique avant tout de considérer que cette biodiversité compte, que sa dégradation constitue un problème pour la société et qu'il est légitime de travailler à la préserver. En d'autres termes, cela revient à affirmer la valeur sociétale des sols et de leurs organismes, au-delà de considérations productivistes seules. Garantir la préservation effective des sols pourrait ainsi nécessiter une transition globale des systèmes agricoles.

À un niveau très localisé, une telle transition peut s'envisager dans les pratiques culturales adoptées par les agriculteurs, premiers gestionnaires des sols « sur le terrain ». La littérature scientifique regorge d'études visant à comprendre les déterminants des prises de décision et des comportements des agriculteurs. En ce qui concerne la gestion des sols, les choix de pratiques semblent reposer sur de multiples facteurs, où la dimension économique est souvent primordiale, mais où les caractéristiques personnelles des individus, les conditions de leur exploitation, les variables environnementales qui les entourent (climat, pédologie, topographie…) et les contraintes économiques et politiques imposées par le système dans lequel ils s'intègrent jouent aussi un rôle. De tels résultats sont souvent issus

d'approches quantitatives, qui ne permettent pas toujours de développer une approche compréhensive des processus d'arbitration entre différents facteurs pris en compte par les agriculteurs. De ce fait, il est souvent difficile d'expliquer pourquoi et dans quelle mesure un facteur en vient à devenir plus important ou pertinent qu'un autre dans une situation de gestion spécifique. En Europe en particulier, peu d'études ont porté sur la prise en compte de la biodiversité par les agriculteurs dans le cadre de la gestion de leurs sols, ainsi que sur leur degré de connaissance des organismes qui peuplent cet écosystème. Le concept de valeur a été ici mobilisé afin de mieux connaître et comprendre l'importance que peut revêtir, ou non, la biodiversité des sols dans le cadre des pratiques culturales. Les disciplines environnementales se sont assez intensivement référées au terme de « valeur » pour tenter de définir, voire de quantifier, les liens existant entre êtres humains et « nature » ; pléthore de définitions y ont été associées, qui ont été plus ou moins explicitées selon les études et les auteurs. On peut notamment souligner le fait que le terme « valeur » ne se réduit pas à l'expression d'une quantité économique (i.e., monétaire) mais peut en réalité se référer à de multiples expressions et reconnaissance d'importance de la nature. Ainsi, des études récentes mettent en avant la « pluralité des valeurs » de la nature, des écosystèmes, de la biodiversité, de certains organismes… La formation de telles valeurs a lieu à différentes échelles, certes individuelles mais aussi collectives. De ce fait, la valuation des sols et des organismes qui s'y trouvent par les agriculteurs pourrait varier à travers l'Europe, du fait de conditions environnementales et sociétales qui diffèrent.

A partir de ces éléments, les objectifs de cette thèse se sont articulés en trois temps :

(1) Identifier et qualifier les valeurs associées aux sols et à leurs organismes par des agriculteurs européens et, en particulier, vérifier leur caractère pluriel.

(2) Caractériser les situations au sein desquels l'attribution de ces valeurs a lieu, et déterminer s'il existe des variations temporelles et spatiales dans le processus de formation de ces valeurs.

(3) Comprendre en particulier dans quelle mesure les caractéristiques territoriales dans lesquelles se trouvent les agriculteurs jouent un rôle dans la formation de valeurs associées aux sols et aux organismes qu'ils abritent.

Cette thèse se concentre sur les valeurs qui sont à la base de la gestion des sols des agriculteurs en Europe. Dans un premier temps, une enquête a été menée pour vérifier l'existence d'une potentielle pluralité de valeurs en jeu dans les décisions des agriculteurs, qui n'a pas encore été explorée pour les organismes du sol et en relation avec la gestion de ce dernier (CHAPITRE 3). Dans un deuxième temps, cet état des lieux a été affiné en interrogeant la formation dynamique de ces valeurs. A ce titre, il s'agissait de comprendre s'il existe des variations géographiques et temporelles dans les processus de formation de valeurs, en considérant les situations spécifiques au sein desquelles il a lieu (CHAPITRE 4). Dans une troisième étape, à partir de la description par les agriculteurs de leur situation de valorisation, une perspective plus large portant sur les transitions des pratiques agricoles a été adoptée. Pour ce faire, la pertinence du concept de « milieu valuateur » (MV) comme moteur des transitions territoriales a été testée (CHAPITRE 5). Enfin, une étude de cas menée en Bretagne s'est concentrée sur un processus particulier décrit dans le MV : la diffusion des valeurs, qui peut jouer un rôle dans leur formation (CHAPITRE 6).

Dans le cadre de ce travail, la définition du terme «valeur» a été empruntée à l'épistémologie pragmatique et, plus précisément, à celle de John Dewey, l'un des fondateurs de ce courant philosophique développé entre la fin du 19ème et la première moitié du 20ème siècle aux Etats-Unis. Dans cette perspective, les valeurs sont envisagées comme des actions qui traduisent, de manière concrète, ce qui compte pour les gens dans des situations spécifiques. Ici, les valeurs sont le résultat de transactions entre un organisme et son environnement, « naturel » et humain, culturel et physique, les deux s'influençant mutuellement. La définition d'une situation de valuation est reliée à l'identification d'une insatisfaction ou d'un problème, qui mène l'individu à définir quel changement serait attendu pour les résoudre et à circonscrire, de manière contingente, les moyens souhaitables pour y parvenir. En d'autres termes, fins et moyens sont intrinsèquement liés ici et c'est à travers un processus d'enquête, proche de la méthode scientifique et intégrant une dimension sociale, que les individus parviennent à les définir. Pour Dewey, les valeurs ne sont alors pas des qualités prédéfinies et fixes qu'il s'agirait de découvrir, ni le résultat d'un mouvement purement émotionnel. Elles relèvent de qualités attribuées à des personnes, à des objets… à la suite d'un processus d'enquête tout à la fois émotionnel et intellectuel et elles sont traduites dans leur prise en compte active dans nos actions. L'épistémologie développée par Dewey met en exergue le caractère social de l'enquête, reconnaissant l'importance de la réflectivité, de l'expérimentation et des échanges entre les individus pour la formation de valeurs. Le second apport théorique utilisé pour cette thèse provient du concept de Milieu Valuateur développé récemment par des chercheurs du secteurs des sciences et techniques, tels que Huguenin, Jeannerat ou Livi. L'approche par le MV met en lumière le rôle des valeurs dans les processus de transitions. Elle envisage l'ancrage territorial de telles transitions, où une conjonction d'éléments permet de former, discuter et négocier les valeurs qui les favorisent. Dans cette perspective, une fois encore, la valeur est entendue comme un élément qui va bien au-delà d'une analyse en termes monétaires uniquement. Le concept du MV reste cependant encore novateur et l'un des objectifs de ce travail était également méthodologique, puisqu'il s'agissait de développer une méthodologie opérationnelle pour le renseigner, voire le compléter.

Cette thèse s'est associée au programme de recherche européen BiodivERrsA "SoilMan" (https://www.soilman.eu/), qui s'est déroulé de 2017 à 2020. La collecte des données a eu lieu dans cinq régions européennes : en France, Allemagne, Roumanie, Espagne et Suède, ce qui a permis de couvrir une grande variété de contextes géographiques le long d'un double gradient latitudinal et longitudinal. Pour y enquêter sur la nature et la formation des valeurs, il était nécessaire d'utiliser une méthodologie permettant aux personnes rencontrées d'exprimer comment, pourquoi et dans quelles conditions particulières le sol et les organismes qu'il abrite importent ou d'échanger avec d'autres personnes à ce sujet. A ce titre, les Focus Groups (FGs) (groupes de discussion semi-structurés sur une thématique donnée) sont apparus comme un outil particulièrement riche pour recueillir les paroles d'agriculteurs.

Au total, 10 FGs ont été organisés (2 par région d'étude). En complément, des entretiens semi-directifs ont également été mis en œuvre. Le matériel récolté à travers ces deux outils a été analysé qualitativement, sur la base d'une approche interprétative, proche des démarches herméneutiques, qui visent à découvrir et à clarifier le sens d'une expérience vécue par un individu dans une certaine situation (CHAPITRES 3, 4 et 6). Le CHAPITRE 3 est complété par une méta-analyse qualitative de 35 publications scientifiques. Le CHAPITRE 7 repose quant à lui repose sur une analyse quantitative et complémentaire d'entretiens semi-directifs réalisés avec 31 agriculteurs bretons et de publications d'une revue agricole bretonne.

Dans le CHAPITRE 3, un inventaire des valeurs des sols et des organismes associés que des agriculteurs européens peuvent développer dans le cadre de leurs pratiques culturales a été réalisé. Les résultats obtenus indiquent qu'il existe en Europe une large gamme de valeurs associées au sol et, dans une moindre mesure, aux organismes et à la biodiversité du sol. Outre les valeurs instrumentales, de nombreuses autres valeurs, telles que la résilience de l'écosystèmes des sols, influencent les choix de gestion des agriculteurs. Il est également important de relever qu'ici, les agriculteurs rencontrés ont abordé le sol principalement comme un tout, ne distinguant que peu sa composante biologique, qui semblait encore relativement mal connue et peu valorisée. En somme, la pluralité des valeurs rapportées par les agriculteurs dans leurs échanges indique que ces derniers peuvent valoriser les sols, les organismes et la biodiversité associés au-delà d'une perspective instrumentale uniquement (CHAPITRE 3 ; OBJECTIF 1). Cependant, même si les sols et les organismes qui s'y trouvent peuvent être valorisés, ils ne sont pas toujours prioritaires dans les décisions agricoles, qui dépendent aussi de la valorisation d'autres éléments, certains sur lesquels les agriculteurs ont peu d'influence. Dans le CHAPITRE 4, les pratiques de gestion des sols semblent raisonnées en fonction des situations locales et actuelles et non choisies « par principe ». Les valeurs apparaissent comme dynamiques, influencées par l'existence de consensus sociaux locaux sur les bonnes pratiques culturales à suivre et les bons objectifs agricoles à poursuivre. Pai ailleurs, la mise en œuvre d'une nouvelle pratique pourrait développer des connaissances qui sont davantage intégrées dans les évaluations, réformant ainsi les références sur lesquelles les agriculteurs évaluent leurs pratiques. Ainsi, les valeurs sont formées par des agriculteurs dans des situations de gestion très différentes et en tant que telles, elles sont dynamiques dans le temps et variables à travers l'UE (CHAPITRE 4 ; OBJECTIF 2). A l'aune des résultats obtenus, il semble que la formation, la sélection et la perpétuation des valeurs des agriculteurs soit particulièrement marquée par leur environnement biotique et abiotique (CHAPITRES 4 & 6 ; OBJECTIF 2). De plus, malgré un cadre politique agricole et environnemental européen général qui met en avant, dans une certaine mesure, la nécessité de préserver les sols comme ressource agricole et leurs organismes comme supports de leur fonctionnement, ces politiques sont localement légitimées à des degrés divers (CHAPITRE 6 ; OBJECTIF 3). Si la valorisation des organismes et de la biodiversité des sols semble pourvoir mener à des pratiques de gestion alternatives qui leur sont plus favorables, cela nécessite néanmoins l'existence d’un MV locale qui favorise l'idée que les organismes du sol sont quelque chose d'important (CHAPITRE 6 ; OBJECTIF 3). Les processus de publicisation et les opportunités pour les agriculteurs de se rencontrer et de discuter peuvent faciliter la formation de valeurs associées aux organismes des sols. Dans le CHAPITRE 7, les agriculteurs rencontrés ont rapporté obtenir les connaissances liées à leur pratique professionnelle en général et sur la biodiversité des sols en particulier par une grande variété des sources différentes. L’étude d’une source de connaissance particulière, le Paysan Breton, indique que les revues agricoles peuvent participer à véhiculer des connaissances au sujet de la biodiversité des sols. Les agriculteurs semblent néanmoins posséder un bagage de connaissances plus poussé à ce sujet, reflétant peut-être leur recours à de multiples sources d’information et de connaissances. Ce serait finalement peut-être la conjonction de plusieurs modes de transferts de connaissances qui pourrait participer à construire ou reconstruire la façon dont la biodiversité des sols est prise en compte en agriculture. La variabilité des sources de connaissances localement disponibles pour en apprendre davantage sur les organismes et la biodiversité des sols peut refélter des disparités intra-européennes en termes de conditions de formation de valeurs (CHAPITRE 7; OBJECTIF 3). On peut s'attendre à des différences non seulement dans le contenu, mais aussi dans la disponibilité même de ces modes de transfert à travers l'Europe (CHAPITRE 6). In fine, cela impacte (i) la manière dont les sols, les organismes et la biodiversité qui s’y trouvent sont valorisés par les agriculteurs, et (ii) les indicateurs qu’ils considèrent comme pertinents pour évaluer leurs sols et la réussite des pratiques de gestion mises en œuvre (CHAPITRE 4).

Une pluralité de valeurs entrant en jeu dans les décisions de gestion des sols des agriculteurs a été observée en Europe, grâce à une combinaison d’entretiens et d’analyses de littérature. Une enquête sur la dynamique de ces valeurs a montré que les évaluations se produisent dans diverses situations et dépendent ainsi des caractéristiques territoriales locales. L'application du concept récent de « Milieu Valuateur » a souligné l'importance des dispositifs de partage d’expérimentations pratiques et des lieux de débats dans la formation de valeurs, dispositifs qui peuvent alors participer à légitimer de nouvelles pratiques de gestion. Un focus sur les processus de publicitisation a montré que les agriculteurs peuvent se référer à de multiples sources de connaissances, bien que le sujet spécifique de la biodiversité du sol n’y soit pas toujours abordé et ni généralement lié aux pratiques de gestion. Notre étude démontre ainsi l’importance, mais aussi le besoin en vecteurs de médiatisation des organismes des sols afin de favoriser des initiatives de gestion différenciée et innovante des sols. En conclusion, envisager les processus de valuation comme dynamiques et dépendants de situations problématiques locales offre la possibilité de remettre en question la façon dont la vie souterraine est considérée en agriculture. De plus, l’approche développée a permis de concevoir les formations de valeurs comme un processus collectif, au-delà du seul raisonnement individuel. La formation de valeurs associées à la vie des sols nécessiterait donc de créer des espaces où un public peut (i) se constituer identifiant de la perte de biodiversité des sols comme un problème public, et (ii) débattre collectivement de ce qui est attendu du et pour le sol et la diversité des organismes qui s’y trouvent.

UNIVERSITÉ DE RENNES 1

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Prendre en compte les sols : Une enquête interdisciplinaire sur les valeurs des organismes et de la biodiversité des sols chez des agriculteurs européens

Mots clés : Valuation ; Pragmatisme ; Gestion du sol ; Agriculture ; John Dewey ; Milieu Valuateur

Résumé : Comprendre la façon dont les agriculteurs prennent en compte les organismes des sols semble nécessaire si l'on souhaite développer des politiques préservant la biodiversité des sols dans les activités agricoles. L'épistémologie pragmatiste conçoit les valeurs comme ce qui compte en pratique pour les individus et les collectifs. Cette thèse vise ainsi à caractériser les valeurs associées aux sols et à leurs organismes par les agriculteurs européens, à déterminer les conditions de leur formation, et à étudier la publicisation des enjeux de préservation de la biodiversité du sol en agriculture. Des entretiens et une analyse de littérature ont démontré la pluralité de valeurs en jeu dans les décisions de gestion des sols des agriculteurs européens. Les situations d'évaluations, liées aux caractéristiques territoriales locales rendent ces valeurs dynamiques dans le temps et l'espace. La mobilisation du concept de « Milieu Valuateur » a permis de souligner l'importance des dispositifs de partage d'expérimentations et de débats dans la formation de valeurs, participant à légitimer les pratiques. De multiples sources peuvent transférer des connaissances sur la biodiversité du sol, bien que souvent le sujet reste marginal et ne lie que peu biodiversité des sols et pratiques de gestion. Envisager les processus de valuation comme dynamiques offre la possibilité d'interroger et de remettre en question les façons dont la vie souterraine est considérée. La formation de valeurs associées à la vie des sols nécessite des espaces où un public peut se constituer pour débattre collectivement de ce qui est attendu du et pour le sol et la diversité des organismes qui s'y trouvent.

Caring for the life below-ground: An interdisciplinary inquiry on the values of soil biota and biodiversity among European farmers

Keywords : Valuation ; Pragmatism ; Soil management; Agriculture; John Dewey; Valuating Milieu

Abstract : If politics wish agriculture to more broadly build on soil biota and biodiversity, and seek to put forward its crucial role for farming activities, it is necessary to know how farmers themselves come to value soil organisms. Pragmatism conceives values as what matters, practically, to people. This thesis seeks to characterize values associated with soils and their biota by European farmers, to determine the conditions for such valuations and to investigate publicization processes about soil biodiversity in agriculture. Interviews and literature analysis stressed the plurality of values at stake in farmers' soil management decisions. Values appeared to be dynamic across space and time since they rely on situations of valuations that depend themselves upon various local territorial characteristics. The "Valuating Milieu" concept allowed to emphasize the importance of experimentation sharing and debates on the formation of values and on the legitimation of management practices. Multiples sources may transfer knowledge about soil biodiversity to farmers but the topic remains often marginal and unlinked to management practices. Conceiving valuations as dynamic offers the opportunity to investigate and to challenge the ways below-ground life is considered in our societies. The formation of values associated with soil biota requires to develop spaces where a real public can form and collectively debate on what is sought from and for European soils and the huge biodiversity they host.

Berücksichtigung der Böden: Eine interdisziplinäre Erhebung über die Werte von Organismen und die biologische Vielfalt des Bodens bei europäischen Landwirten

Stichworte: Bewertung; Pragmatismus; Bodenbewirtschaftung; Landwirtschaft; John Dewey; Bewertungsmilieu

Zusammenfassung : Es ist notwendig zu verstehen, wie Landwirte Bodenorganismen berücksichtigen, wenn wir Strategien zur Erhaltung der biologischen Vielfalt des Bodens entwickeln wollen. Die pragmatistische Erkenntnistheorie versteht Werte als das, "was zählt". Ziel dieser Arbeit ist es daher, die Werte zu charakterisieren, die europäische Landwirte mit Böden und ihren Organismen verbinden, die Bedingungen für die Wertebildung zu bestimmen und die Bekanntmachung der Werte zur Erhaltung der biologischen Vielfalt des Bodens in der Landwirtschaft zu untersuchen. Interviews und eine Literaturanalyse haben gezeigt, dass bei den Entscheidungen der europäischen Landwirte zur Bewirtschaftung des Bodens eine Vielzahl von Werten auf dem Spiel steht. Bewertungssituationen, die mit lokalen territorialen Merkmalen verknüpft sind, machen diese Werte Werte zeitlich und räumlich dynamisch. Die Mobilisierung des Konzepts "Bewertungsmilieu" ermöglichte es, die Bedeutung von Erfahrungsaustausch und Debatten bei der Wertebildung une -legitimierung zu unterstreichen. Mehrere Quellen können dabei Wissen über Bodenorganismen übertragen, obwohl das Thema häufig marginal bleibt und die biologische Vielfalt des Bodens nicht mit Bewirtschaftungspraktiken verknüpft ist. Das Betrachten von Bewertungsprozessen als dynamisch bietet die Möglichkeit, die Sichtweisen unserer Gesellschaft zu hinterfragen. Die Bildung von Werten, erfordert Räume, in denen ein Publikum gebildet werden kann, um gemeinsam zu diskutieren, was von und für den Boden und die Vielfalt der dort vorkommenden Organismen erwartet wird.