Contribution of diversified farming systems to the delivery of ecosystem services

Contribution of a research to agricultural transition

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Introduction

The ongoing agricultural transition questions current scientific practices

While being highly specialized in the production of biomass, conventional farming systems are often accused to considerably impact ecological structures and processes[1–3]. This affects humans (e.g. through water pollution, soil erosion, loss of rural landscapes harboring cultural and social values) and agriculture itself, which is highly dependent upon a wide range of ecological processes such as soil fertility or pollination[4].

A transition towards more environmentally and socially sustainable farming systems is considered as inevitable by many. Facing this challenge, several alternative farming systems are emerging around the world. It is suggested that the diversification of agricultural practices, through the introduction of functional biodiversity, supports ecological processes in turn favoring biomass production and providing other ecosystem services (ES) to society[5–7] (Figure 1).

However, the transition towards alternative and supposedly more sustainable agricultural systems is hampered by a lack of knowledge on the environmental and social impacts of these innovative practices[8]. To date, science is failing to capture the complexity and multidimensionality of socio-ecological agroecosystems. Classical science usually studies one component at a time and in a standardized environment (e.g. in a laboratory or in a experimental field) with the aim to produce generic results and conclusions. Rather than saying that research in conventional agriculture and following a biotechnological approach is no longer accurate, agricultural transition calls for exploring the spectrum of methods scientists use. The present paper introduces an innovative multi-actors and interdisciplinary approach to address, in a holistic way, the social and environmental impacts of alternative diversified farming systems. This method is applied in a recently launched PhD thesis (January 2015), hence, only preliminary results and fictive analyses are presented along the methodological approach.

Integrated ecosystem service assessments

An interdisciplinary method to grasp complexity

Agricultural transition implies looking at complex interactions between the environmental (e.g. physicochemical soil conditions, climate), technical (e.g. tillage depth, fertilization mode, crop rotation) and socio-cultural (e.g. stakeholders' values) elements. Hence, studying the topic requires relying on interdisciplinary methods. The method of 'integrated ES assessment' including a social and a biophysical assessment (Figure 1 - purple boxes) offers such interdisciplinary approach. Integrated ES assessment is an emerging method to get holistic insight into complex socio-ecological systems[9]. Indeed, identifying and quantifying ES bundles is essential to foresee impacts of land management on ES supply, tradeoffs and synergies, and thus on ES beneficiaries[10].

ES assessments including social valuation are scarce, though being highly relevant in agricultural contexts, as societal goals of today's agriculture go beyond the sole production of food. Indeed, consumers demand quality, are increasingly guided by their ethics[11], value traditional heterogeneous and complex landscapes as aesthetic and educational resources[12]. In return, in addition to earning a fair living, farmers call for recognition of their role played in society[13–15]. Moreover, addressing ES demand allows the assessment to be more sensitive and responsive to the needs and values harbored by the stakeholders[16].

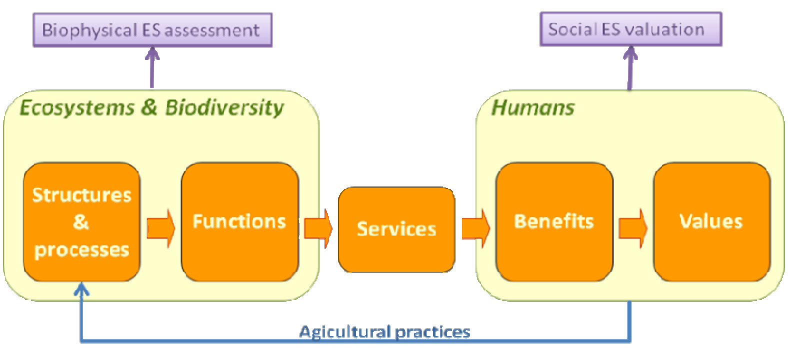

Figure 1 : ES cascade, inspired from Haines-Young and Potschin (2010). Ecological structures and processes provide ecological functions through biotic and abiotic interactions. These functions become ES once judged as useful by humans. ES provide benefits to humans who therefore value them. Agricultural practices (blue arrow) may alter positively or negatively ecological structures and processes hence modifying

the flow of ES. ES can be assessed biophysically or socially (purple boxes). Integrated ES assessments include both, sometimes along with an economic valuation, not addressed in this study.

Despite the growing body of literature on the topic, there exists, to the best of our knowledge, no study quantifying the contribution of diversified farming systems to the provision of ES. Indeed, most studies address the concept of ES in relation to agroecosystems *theoretically*[1,17–19] while the actual *quantification* of ES in agroecosystems remains largely unexplored, or focuses on one ES only (e.g.[20,21]). However, focusing on a single ES fails to provide a holistic picture of the socio-ecological components of agricultural systems. It fails, for instance, to highlight tradeoffs and synergies between ES, i.e. if one ES is increased through agricultural practices, do others ES increase along (synergies) or decrease (tradeoffs)[10]? A recent review by Kremen and Miles (2012) comparing the provision of 12 ES in conventional farming systems and in diversified ones concludes that 'integrated whole-system studies of the influence of different farming practices on multiples ES are critically needed'[7]; a conclusion confirmed by the few existing farm-scale ES assessments[22,23].

The present research aims at fulfilling this gap by analyzing several ES at the farm scale addressing the following questions:

1. Are there different synergies and tradeoffs among ES in diversified farming systems?
   This question will be answered by the biophysical ES assessment and will allow testing the hypothesis that diversified farming systems offer greater synergies among ES, as stipulated by Kremen and Miles 2012[7]
2. Is the stakeholders' satisfaction different in diversified farming systems?
   This question will be answered by the social ES assessment and will allow testing the hypothesis that diversified farming systems satisfy a greater diversity of stakeholders, as stipulated by Bacon *et al.* 2012[24].

Regarding the biophysical ES assessment, indicators for the assessment of each ES are selected according to precision and feasibility criteria (time and resource-wise). Table 1 shows examples of indicators which can be used. The ultimate choice is inspired by the expertise of researchers of Gembloux Agro-Bio Tech, by the few previous farm-level ES assessments[22,25] and literature specialized on the concerned ES. While estimates are based on biophysical field measurements for provisioning and regulating ES, cultural ES are assessed based on other types of indicators. For instance, cultural ES can be assessed based on the presence of landscape elements known for being appreciated by visitors, hence harboring aesthetic values (e.g. cultural buildings, tree lines, forest patches)[26].

The social ES valuation relies on individual interviews on the one hand and collective valuation on the other hand, both enquiring the stakeholders to assign scores to each ES representing the extent to which they value the ES. Individual interviews put forward the divergence of social values among stakeholders, while the collective valuation, through deliberation, includes reciprocal and altruistic attitudes within the valuation[27,28]

Table 1 : Examples of ES to be assessed along with examples of indicators which can be used for their biophysical assessment.

ES category	ES	Indicator	unit
Provisioning	Commercial crop production	Yield	t/ha
			t/ha/energy used
		Gross margin	€/ha
		Quality	variable
Regulation	Soil formation	Earthworm density	individuals/m 2
		Earthworm biomass	g/m2
		Earthworm maturity	% juvenile, sub-adults, adults
		Earthworm diversity	% Endogeics, Epigeic, Anecic
	Nutrient regulation	Nutrient input-nutrient output	Kg/ha
		Nitrogen potentially leaching (APL)	kg N-NO3/ha
		Ratio C/N	-
		Nitrogen fixation	kg N/ha
	Carbon sequestration	Soil organic carbon content	kg C/t of soil
	Pest control	Predation rate	surrogates removed/24h
	Soil quality	Microorganisms and inverterbates' activity (bait-lamina test)	empty holes/10days
		Microbial-C	%
	Pollination	Presence of pollinators	trapped pollinators/w eek
	Erosion protection	Water percolation rate	L/m2*h
	Habitat quality	Carabides beetle density	individuals/m 2
		Carabides beetle diversity	species number
Cultural	Physical experiences	presence of landscape elements	absolute value
		size of landscape elements	m or m2
	Education	farm visits	absolute value
		training sessions	absolute value

Study sites

Diversified farming systems at the center of attention

This research is carried out in real farms (conversely to research carried out in laboratories and experimental fields) in order to get as close as feasible to reality. Diversified farming systems are defined by Kremen et al. (2012)[29] as 'farming practices and landscapes that intentionally include functional biodiversity at multiple spatial and/or temporal scales in order to maintain ecosystem services that provide critical inputs to agriculture, such as soil fertility, pest and disease control, water use efficiency, and pollination'. Naturally, in the real world, there exist no sharp distinctions between diversified and conventional farming systems. Rather, a gradient of diversification can be observed among agricultural systems, with some only applying a couple of 'Agri-Environmental Measures' or growing crops organically, and others combining several of these practices.

Three diversified farming systems, considered as representing the extreme end of this diversified gradient, have been selected. All are located in the western part of the Hainaut province in Belgium, a cradle area of transition towards such diversified systems. All diversified farming systems are certified organic and rely on a wide variety of practices incorporating biodiversity. For instance, Demasy's farm, applies the principles of conservation tillage, living mulch, has set-up beetle banks and is planning to establish an agroforestry parcel; while the Graux Estate, among other practices, relies on conservation tillage, long crop rotations, living mulch, and recycles crop and animal residues as natural fertilizers. Since it is not possible to carry out a diachronic analysis of the transition that diversified farming systems have encompassed, adjacent conventional farming systems are selected to represent a distinct type of farming systems. Thus, the research relies on three diversified systems surrounded by conventional ones constituting three farm-sets and representing the three studied landscapes.

The field committee

The need for local relevance calls for multi-actors approaches

Knowledge regarding agricultural transition has proved being highly locally specific[30,31]. Hence, agricultural transitions require locally relevant research. This questions current scientific approaches seeking to produce generic results and conclusions. Therefore, the attempt to transform existing systems drives scientists toward action-oriented approach, i.e., approaches implying stakeholders from the start of the research. On the one hand, it aims at considering the gap that could be revealed between theoretical scientists' problem and everyday life stakeholders' problem. On the second hand, it aims at producing responses according to local conditions. In this way, it integrates contextual complexity and its inherent uncertainties to which generic solutions may not be adapted.

In order to fulfill this need, a '*field* committee' is set-up, composed of persons acquainted with the region, the different local initiatives, and the stakeholders. Among the stakeholders, farmers, citizens, non-profit associations are present in the field committee.

The main role of this field committee is to facilitate knowledge transfer between researchers and local actors. As the research is highly specific to the locality, it is important to conduct a research relevant in the eyes of local actors. Thus, throughout the research, scientific knowledge will be iteratively confronted with local knowledge to help to fit the study with local contexts. It is widely recognized that the involvement of people acquainted with local contexts in the earliest stages of ES assessments improves their accuracy and procedural quality[16,32–34]. This knowledge transfer is of course in both directions, as results of the research will further be communicated to the committee.

Additionally, this field committee will serve as cradle for networking among the different stakeholders, launching co-construction and co-learning processes through discussions and debates initiated during field committee meetings. This committee is a unique opportunity for different actors (e.g. farmers and consumers) to meet and get insights into each others' reality through discussions.

Outcomes of the first field committee consultation

The field committee has, for instance, been consulted to set the priority among ES to be assessed. Indeed, some ES, though relevant to agriculture in theory, may not be relevant for the selected farms according to the field characteristics or the values stakeholders attribute them. Hence, a meeting was organized to consult them on which ES they value the most to further guide our ES selection.

Participants were selected according to a 'purposive sampling' strategy (i.e. sampling of which the profile of participant was selected purposively in order to reach a wide variety of profiles interested in the topic rather sampling randomly in the population). In total, 22 participants (composed of farmers, locals, NGO's activists, members of farmers' organization, etc.) attended the first meeting. The aim of the first meeting was to 1) present the research project to local actors 2) consult them on which ES they find the most important to guide our subsequent ES selection and 3) compare their selection with the most studied ES in scientific literature.

The methodology relied on for this consultation consisted in a 'face-to-face Delphi' method. The classical Delphi method starts with a questionnaire sent around to 'experts'. Answers are then collected, summarized and made available to all experts, who are then given the opportunity to adapt their original answers upon examination of the group responses. In a face-to-face Delphi, as in our case, answers are presented to the whole group and are then discussed before adjusting the vote. The choice of this format allowed to highlight people's reasoning underlying their expressed values and preferences thanks to a more 'natural' context, which some claim as more similar to the environment in which people elaborate their opinion in real-life contexts[35]. Moreover, such format fitted best with time constraints.

More precisely, the below steps were followed:

1. Presentation of the research project and introduction to the ES concept;
2. Listing by attendees of all ES coming to their mind linked to agricultural systems;
3. Adding of the ES from this spontaneous list which are lacking in the scientific ES list (based on the CICES-Belgium classification[36]);
4. Ranking by attendees of the 5 most important ES based on the adjusted scientific ES list;
    a. Ranking per ES category (provisioning, cultural, regulating; leading to three top 5);
    b. Ranking across all categories (leading to one top 5);
5. Presentation of the votes to the whole group;
6. Discussion about the divergences and convergences of the votes ;
7. Reiterate step 4 if step 6 has led to changing minds.

Comparing their personal lists (step 2) with the scientific ES list, attendees wished to add two ES: 1. farmers' wellbeing (faire remuneration, no exposition to dangerous products, no pressure from lobbys, etc.) and 2. local employment. This is already a first illustration that local actors can bring complementary knowledge to science-generated knowledge.

Figure 2 depicts the result of the vote per category (step 4.a) and Figure 3 the votes across all categories (step 4.b).

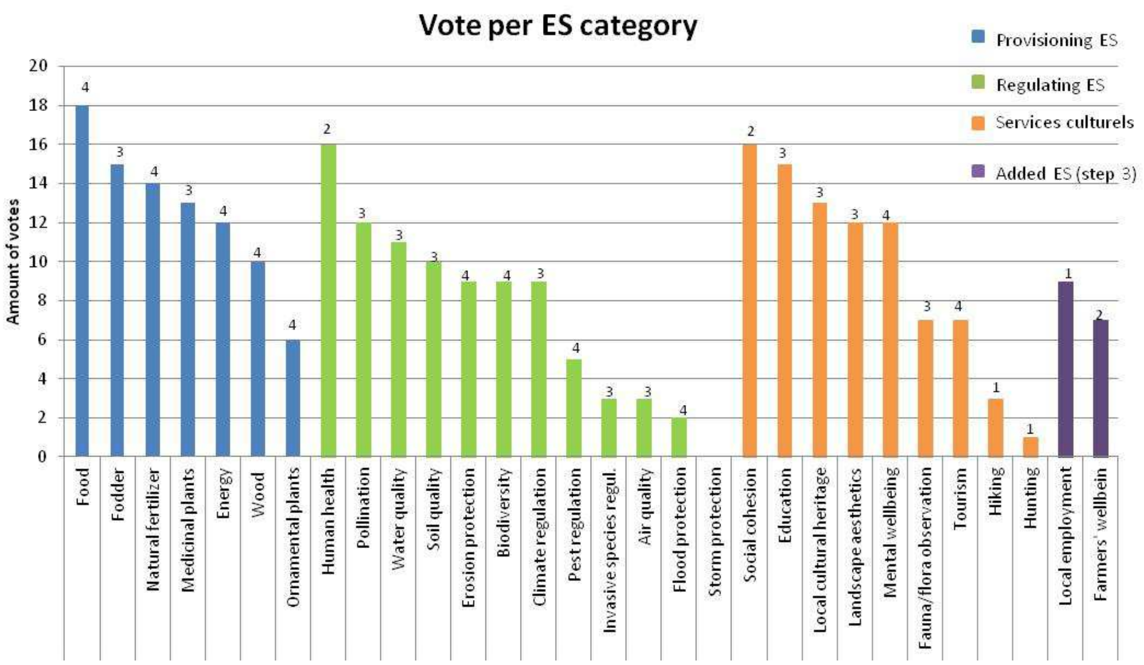

Figure 2 : Outcomes of local actors' votes regarding which ES they value the most. Local actors had to vote for 5 ES per category and rank them between 1 (most important) to 5 (less important). Number of votes per ES is represented of the vertical axis while average ranks are the numbers above each bar.

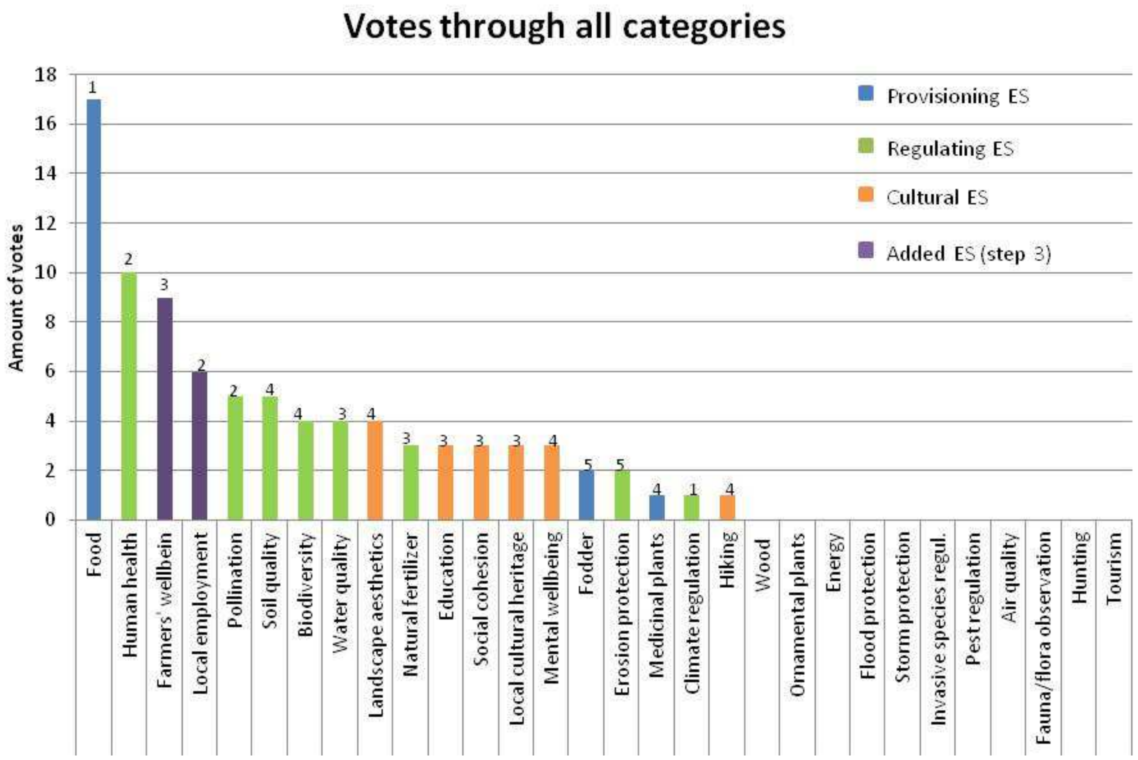

Figure 3 : Outcomes of local actors' votes regarding which ES they value the most. Local actors had to vote for 5 ES (not matter which category this time) and rank them between 1 (most important) to 5 (less important). Number of votes per ES is represented of the vertical axis while average ranks are the numbers above each bar.

Both Figures 2 and 3 show that the provision of food and regulation of human health are two very important components in the eyes of local actors. The two added ES from step 3 (farmers' wellbeing and local employement) have also been much voted for and attributed high scores (numbers above bars). This illustrates the fact that local actors can think about components science failed to identify. Conversely, some services gather no votes at all (Figure 3 : wood, ornamental plants, energy, protection against hazards, pest regulation, air quality, fauna/flora observation, hunting, tourism). Apart from these services which seem to encounter some agreements, we can observe a wide diversity of preferences across actors. Indeed, votes are spread across a relatively wide panel of ES, coming from all categories. Some ES receive very few votes, though presenting very high scores, illustrating the diversity of point of views: while most of actors did not include those ES, some rank them as the most important (e.g. Figure 2: hiking, hunting, Figure 3: climate regulation).

The 5 most voted ES and the 5 most studied ES in scientific literature only share two ES (Figure 4). This clearly illustrates how consulting actors can influence the choice of ES as in our case, people's preferences do not match with what science considers as most relevant to study.

We can thus conclude from these votes, that expectations towards agriculture are rather diverse across actors and differ from what science focuses on at the moment. Although most people are aware of agriculture's first role of providing food, a certain desire for a more multifunctional agriculture is clearly present. Our research will allow checking whether these expectations towards ES delivery are better met in diversified farming systems of the Hainaut province.

Methodology wise, this face-to-face Delphi method failed to trigger discussions and debates at step 6 which gave the feeling to participants that step 7 was unnecessary. On the opposite, animated debates took place at step 3, when their spontaneous list was confronted to the scientific ES list. An adapted version of the methodology has now been developed and will be tested in other regions. Results of these coming supplementary trials will be jointly published in an international scientific journal.

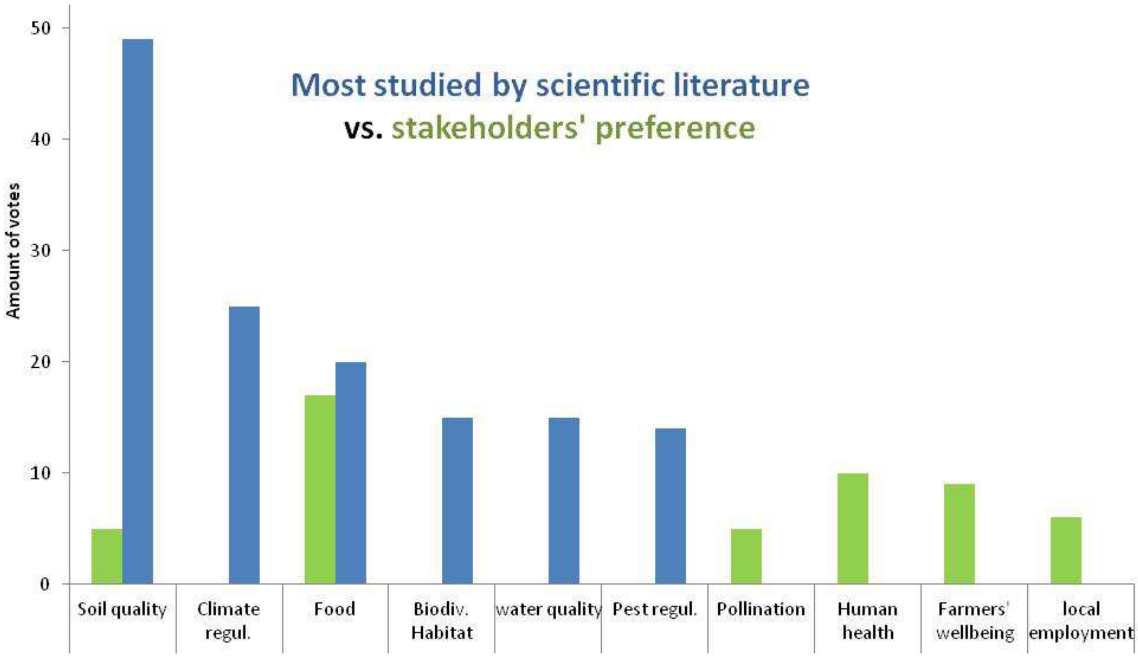

Figure 4 : Comparison of the 5 most studied ES in scientific literature (blue) and the 5 ES which gathered most votes at the first field committee meeting (green).

Multivariate analysis

The challenge of integrating complexity

The great challenge of integrated ES assessments is to integrate the multiple units of measurement into the data analysis[37]. Indeed, such assessment leads to a dataset harboring multiple units and both qualitative and quantitative data. This represents a key challenge in integrated ES assessments as it is increasingly acknowledged that defining one common unit is scientifically unsound[38–40].

Some doing integrated ES assessments simply present these diverse data in a Table (e.g. [16]), others transform all data into scores to then include them into flower diagrams[41,42] (also referred to as rose plots, radar plots, spider web diagrams, etc.). Only recently, some suggest to rely on multivariate analysis[10,42,43]. Such analyses allow dealing with datasets harboring distinct units of measurement (frequencies, abundance, rates, etc.) them being quantitative or qualitative. Unconstrained techniques are first applied to illustrate the (dis)similarity between farms based on ES values, revealing patterns in the dataset, as done by Maes et al. (2011)[43]. In order to explain these patterns (i.e. to explain which variable explains the pattern), constrained ordination techniques are then applied. These techniques are dedicated to relate several dependent ordinal variables to one or several independent ordinal variables, and to search for partial correlations. Discriminant analysis relates dependent ordinal variables to only one categorical independent variable, i.e. farming system type.

In order to illustrate the potential of multivariate analysis to integrate results of ES assessments, a fictive dataset has been elaborated and Principal Component Analyses (PCA; unconstrained multivariate analysis) were applied to it. Such analysis projects data for each ES on two axes called principal components, in such a way that the two components capture a great deal of the variance that is present in the data (Figure 5). ES values are represented as arrows pointing towards farm-sets (points) where they reach their maximum value. Angles between arrows represent their correlation: arrows pointing in the same direction (0°) are in synergies, arrows at 90° are uncorrelated and arrows pointing in opposite directions (180°) are in tradeoffs. Orthogonal projection of a point (parcel) on an arrow (ES value) estimates the value or the order of magnitude of this ES within this parcel.

This illustrates well how such analysis will allow answering our research questions. Looking at the green arrows of Figure 5, representing values of the biophysical ES assessment, allows answering our first research question. Among the trends observed, we can notice that ES generally point towards diversified farming systems, indicating that these have a higher potential to provide ES.

This is though not true for the ES biomass production which is pointing towards the points of conventional farming systems. Thus, in our fictive case, biomass production shows tradeoffs with biodiversity protection, and other ES, meaning that when one is increased the other tends to decrease. Hence, diversified farming systems show differing ES synergies and tradeoffs, confirming the hypothesis advanced by Kremen and Miles 2012.

Regarding the second research question, we notice that orange arrows, which represent the social ES valuation, mainly point towards parcels of diversified farming systems. This thus confirms the hypothesis of Bacon *et al.* 2012 that such systems satisfy a greater diversity of stakeholders.

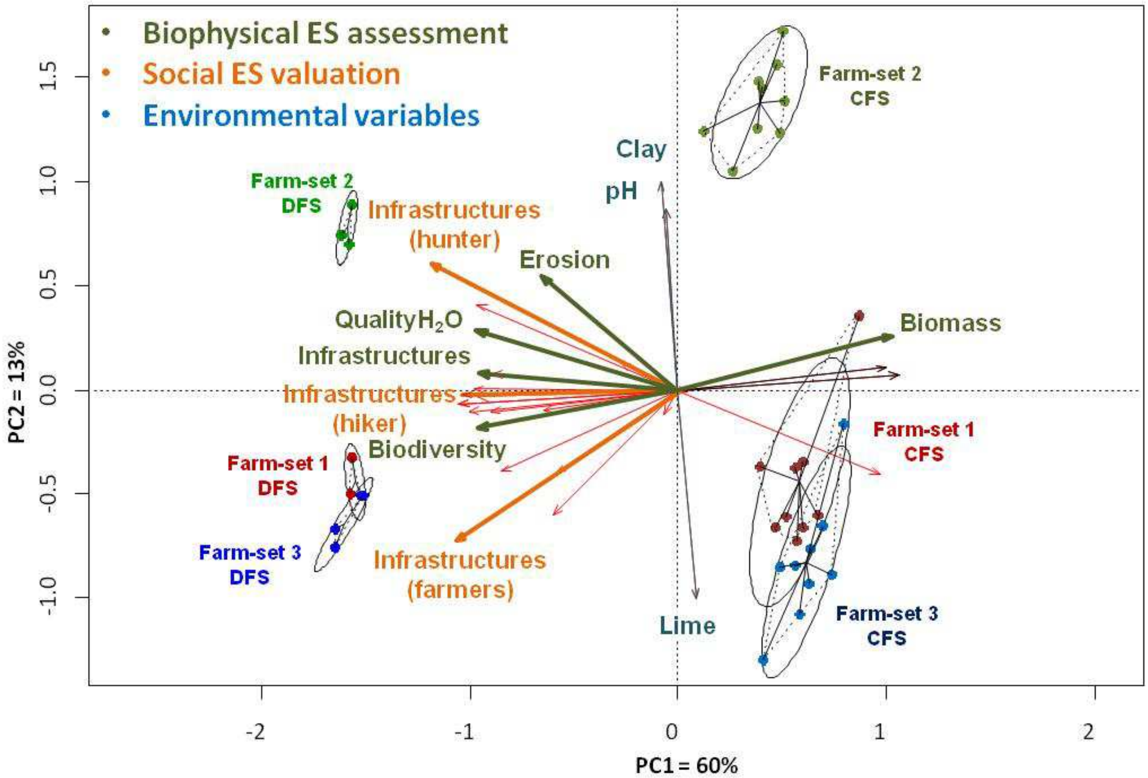

Figure 5 : Results of the Principal Component Analysis carried out on a fictive dataset in order to illustrate how such investigation can answer our two research questions. Green arrows are ES values coming from the biophysical ES assessment. Orange arrows are ES values from the social ES valuation. Blue arrows represent environmental measures. Points represent location of sampling and same colored points come from a same farm-set. DFS: diversified farming system. CFS: conventional farming system.

Conclusions

The contribution of this research within the questioning of scientific approaches in addressing agricultural transition

The transition towards alternative and supposedly more sustainable agricultural systems is hampered by a lack of knowledge on the environmental and social impacts of these innovative practices[8]. However, current scientific practices fail to provide holistic insights on these socio-environmental agroecoesystems. Through standardized protocols, experiments are carried out in laboratories or experimental fields with the aim to produce results which can be applied generally. Such research led to the development of the one-size-fits-all agricultural model we know today. Nonetheless, it is nowadays more and more acknowledged that agricultural transition must go through the adaptation of the agricultural system to its socio-natural environment. Alternative agricultural models thus call for tailor-made solutions rather than recipes[30,31].

In this regard, this research attempts to provide locally relevant knowledge. It focuses on three diversified farming systems all located in the same region. Results emanating from the research are likely to *not* be applicable to other regions with differing environments and social contexts. For this reason, it is of uttermost importance to communicate with local actors throughout the whole research process. For this purpose, a field committee was set up. On the one hand, it aims at considering the gap that could be revealed between theoretical scientists' problem and everyday life stakeholders' problem. On the second hand, it aims at producing responses according to local conditions. In this way, it integrates contextual complexity and its inherent uncertainties to which generic solutions may not be adapted.

Providing locally specific results also implies working in local farms to grasp insights on the field's reality. Indeed, setting measurements in real farm fields provide results closer to reality than those generated from lab and experimental fields. Even if this also means that scientists must deal with a much wider and sometimes inseparable array of factors affecting results. For this reason, conventional scientific research must complement such innovative research practices on the knowledge of interacting and influencing factors.

Since agricultural transition studies complex interactions between the environmental (e.g. physicochemical soil conditions, climate), technical (e.g. tillage depth, fertilization mode, crop rotation) and socio-cultural (e.g. stakeholders' values) elements, studying the topic through an interdisciplinary science would help to understand how complexity can be integrated. The present research suggests relying on the approach of 'integrated ES assessments' in order to combine social and environmental aspects. Such holistic assessments provide good insights on the complex socio-environmental systems of agriculture. Though, for such research to be applicable, scientists must admit a lower level of details in their analysis and aim for a more 'meta' level of investigation.

Using the integrated ES assessment tool can lead to several levels of data integration. Integrated ES assessment is a new scientific topic[9] and there remain much debates on how to integrated data harboring distinct measurement units[37]. This research opts for multivariate analysis in order to get good insights on correlation patterns between variables. Multivariate analysis, though being scarcely applied today in the field of ES assessment is recognized a valuable method when considering more than two ES as it is a relatively flexible method regarding the nature of the indicator (i.e. quantitative or qualitative)[10].

This research project aims at tackling the emerging scientific thematics of sustainable farming systems and integrated ES valuations by adopting an innovative, interdisciplinary, multi-actors approach. Nonetheless, it is to keep in mind that both conventional scientific practices and innovative integrative approaches as the one presented in this paper are complementarity. Holistic research can only be carried out by building on in depth-knowledge of each component which is generated by classical scientific practices. Global, integrated, meta-analysis as presented in the paper ought not to replace in-depth studies focusing on one factor at a time. Rather than saying that research in conventional agriculture and following a biotechnological approach is no longer accurate, agricultural transition calls for exploring the spectrum of methods scientists use.

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