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Abstract

Agriculture is a human activity that receives the most direct benefits from ecosystem services (ES) while it is one of the most influent on their sustainability and is also directly impacted by global changes. One main challenge for future agroecological systems is thus to encourage the co-occurrence of multiple services both *to* agriculture and *from* agriculture. In this article, we questioned through a large-scale study, the ability of conservation agriculture to support not only supporting services related to soils, as it was originally designed for, but also overall biotic potential for multiservice agriculture. We assessed the expression levels of ES from and to agroecosystems (input and output services respectively) within 5 crop management systems, comparing different forms of conservation, organic and conventional agricultures. Fifty winter wheat and fava bean fields in southwestern France were monitored for 17 ES: seven input services (either supporting or regulating) and ten output services (either provisioning or out of direct agricultural income). Observed co-variations and antagonisms between services occurred only for input services and were related to services based on mobile agents or soil properties. Regarding pest regulations, opposite responses were observed between aphids and bruchids, attributed to contrasted responses of the pests to habitat diversity and especially notable in fields under conservation agriculture. As to soil quality, conservation agriculture exhibited significantly higher levels of soil structure stability than conventional and organic systems but slightly lower water infiltration. For output services, our results showed that crop production was not jeopardized by conservation agriculture practices with, for instance, no significant differences in levels of winter wheat yields between systems based on direct seeding or plowing. Organic agriculture however improved crop health regarding diseases but significantly decreased yields. However, high variability in level of expression of output services in conservation agriculture was observed, with both highest and lowest rated fields observed under direct seeding management for provisioning services. These variations can be attributed mainly to system immaturity regarding both ecological processes and farmers' expertise. Finally, one

unexpected outcome of the study was that negative impacts of intensive agricultural practices appeared to be mitigated by elements of production situation such as presence of livestock and clayey soils. Overall, the study provides a detailed illustration of the potential for conservation agriculture to address the apparent antagonism between productivity and environmental performances.

1. Introduction

Agriculture implies risks and costs to ecosystems and the services they support. Modern agriculture is defined by high crop and labor productivities that rely on systematic chemical inputs and ever-improving machine technology (Hazell and Wood, 2008; Tilman et al., 2002). Agriculture that relies solely on large amounts of industrial inputs, in simplified landscapes, to meet greater land and human productivities threatens water quality and availability (Tilman et al., 2002), increases greenhouse gas emissions (Martin and Willaume, 2016) and disturbs natural processes such as pest control by natural enemies or pollination (Dainese et al., 2019; Deguines et al., 2014; Hendrickx et al., 2007). Increasing food production remains a challenge due to population growth and the resulting demand for food. Current food production is even more challenging in the context of increasingly limited resources such as energy, phosphate, land and water (FAO, 2011), and future farming systems must consider decreasing negative externalities to the environment as a priority to ensure their sustainability (Garnett et al., 2013). Future production systems will encounter the challenging task of evolving to systems that ensure productivity, decrease dependence on chemical inputs and non-renewable resources, as well as maintain or improve the supply of ecosystem services (ES) (Wezel et al., 2015). Integrating biological diversity and ecological principles in agronomy and applying them to agriculture can achieve this agroecological intensification (Bommarco et al., 2013; Wezel et al., 2015) and conserve ecosystem functions. Innovative agriculture primarily includes ecological, spatial and temporal diversification as the core of crop management systems (Duru et al., 2015; Kremen and Miles, 2012). Agroecological practices include increasing soil organic matter to improve soil biota and its related nutrient cycling and natural regulation of diseases (Hobbs et al., 2008; Lemanceau et al., 2015; Song et al., 2015) as well as soil structure and structural stability improvement (Bronick and Lal, 2005; Kay et al., 1988), using legume crops to reduce chemical fertilizer applications (Drinkwater and Snapp, 2007). They also include diversifying rotations and conserving semi-natural habitats (SNH) to increase the diversity of pollinators and natural enemies of pests (Crowder and Jabbour, 2014; Kremen et al., 2002; Landis et al., 2005; Rusch et al., 2016) to encourage natural control of pests, diseases and weeds (Crowder et al., 2010; Veres et al., 2013; Witmer et al., 2003).

A systemic approach to evaluate performances is required to assess the sustainability of these agroecological cropping systems. This involves considering system multi-functionality that includes economic, ecological and social aspects (Craheix et al., 2016; Garbach et al., 2016). Moreover, and from a broader perspective, the study of ES “bundles” (*i.e.* groups) in agroecosystems under different management practices and environmental conditions will help to assess the so-called “adaptation services”, as defined by Lavorel et al. (2015). In their case, *i.e.* for the adaptation to climate change, they defined them as “*the benefits to people from increased social ability to respond to change, provided by the capacity of ecosystems to moderate and adapt to […] change and variability”*.

Furthermore, the economic value of non-marketed ES, improved by agroecological practices, could exceeds farm subsidy payments in Europe (Porter et al., 2009) or current global costs of pesticides and fertilizer inputs (Sandhu et al., 2015). Thus, evaluating farming system through a multiservice approach rather than focusing mainly on productivity, allow a more holistic valuation of farming sustainability by including these non-marketed ES (Ghaley et al., 2014).

Among farming systems relying on agroecological practices, organic agriculture was one of the first to address these sustainability challenges. Many studies have assessed organic agriculture and demonstrated its ability to meet the environmental and productive aspects of the challenge (e.g. Badgley et al., 2007; Reganold and Wachter, 2016; Rigby and Caceres, 2001; Sandhu et al., 2015, 2010). In particular, organic farming systems exhibit a much more balanced ES provisioning, even if lightly less productive, than their intensive conventional counterpart (Reganold and Wachter, 2016), crop yields being negatively correlated to many ES in agroecosystems (Röös et al., 2018; Syswerda and Robertson, 2014). Aside from organic farming, another model of agroecological system that has recently received more attention from stakeholders, is conservation agriculture (Farooq and Siddique, 2015). It is based on three fundamental principles: reducing or eliminating tillage (hereafter called "reduced tillage" and "direct seeding" respectively) to decrease soil disturbance ; lengthening and diversifying crop rotations, often by including legume crops; and using crop residues and/or a cover crop for permanent ground cover (Farooq and Siddique, 2015; FAO, 2008). Conservation agriculture is receiving growing interest and support from the scientific community around the world (Hobbs et al., 2008; Pisante et al., 2015; Pittelkow et al., 2015b), especially for its potential to conserve or improve ES (Palm et al., 2014). Its practical adoption is expanding in South America, North America and Australia, among other places (Kassam et al., 2015), but remains controversial (Giller et al., 2009) and is limited in Africa and Western Europe (Kassam et al., 2015; Lahmar, 2010). Unlike for organic farming, conservation agriculture received very few interest regarding its potential to exhibit trade-offs or synergies among ES (Garbach et al., 2016; Palm et al., 2014; Sanderson et al., 2013). More precisely, quantification of ES bundles from simultaneous field experiments, *i.e.* through 'bottom-up' approach (Sandhu et al., 2013), as it is the case for organic farming (Sandhu et al., 2008), are lacking for conservation agriculture. 'Bottom-up' approach of bundles of ES provides a great opportunity to reinforce our knowledge about the state of ES in agroecosystems and their changes in response to human management and field measurements from case studies are necessary to validate current or future models.

The objective of the present study was thus to assess the bundling of ES within agroecological farming systems, taking two contrasted agroecological approach, organic and conservation, and their combination, compared to conventional farming. Seventeen services, either agricultural or ecosystem, were studied. Following Le Roux et al. (2008) and Zhang et al. (2007) operational classification of ES for agroecosystems, we differentiate in this paper input services (*i.e.* services *to* agriculture) from output services (*i.e.* services *from* agriculture). These two categories are themselves subdivided into regulating and supporting services for the former and into provisioning services and services out of direct agricultural income (thereafter referred to as "non-marketed services") for the latter (see table 1 for correspondence to Common International Classification of Ecosystem Services (CICES) v5.1; Haines-Young and Potschin, 2018). We studied four regulating services (pollination, specific parasitism, specific and generalist predation of crop pests) and three supporting services (structural stability of soil aggregates, soil water infiltration, root development); seven provisioning services (yields – *i.e.* primary production – and yields stability in the face of diseases and three pests for a cereal and a legume crop); and three non-marketed services (biodiversity conservation, habitat conservation, greenhouse gas recycling).

We investigated the influence of de-intensification of practices and input use on multiple ES by comparing 5 crop management systems (CM, including conventional, organic and conservation agriculture practices) while taking into account their production situation (PS, *i.e.* landscape, soil characteristics, types of production in the farm). To do so, we studied response profiles of ES for each combination of CM and PS to address the following issues:

- How the four categories of ES are evolving in alternative CM systems compared to more conventional systems?
- What are the occurring combinations and antagonisms of ES and their association to CM systems?
- Do these combinations and their associations to CM systems vary according to production situations?
- Beyond the CM system, does taking into account individual agricultural practices better explain the expression level of ES?

2. Materials and methods

2.1. Study site

The study was conducted in crop fields under several crop management regimes (conventional, organic and conservation agriculture) in southwestern France from September 2014 to April 2016. Fifty winter wheat fields (1ha), 40 of which were paired with a fava bean field (0.5ha), were distributed along a 200 km line intersecting Toulouse (Figure 1, see Chabert and Sarthou, 2017, for further details). Except for crop cultivars and seed origin that was the same for all fields, all other cropping practices were left to the farmer to decide and were monitored by surveys. To standardize disease measurements, half of each winter wheat field did not receive fungicide treatment. All other ES were measured in the treated half.

2.2. Measurement of ecosystem services

In order to study simultaneously 17 ES, we selected measurements simple and quick to implement. Service expression level of each ES was expressed as a score normalized on a 0-5 scale. For all ES except yields, the scale contained six classes (*i.e.* scores) of equal size within values from 0 to the maximum observed value of the ES after removing outliers (*i.e.* values more than 1.5 times the interquartile range from the nearest quartile). Mean regional yields were used to create classes for yields. Fields with a yield over the mean received a score value of 5, and the five remaining classes were set as equal-sized classes from 0 to the regional mean value. Except for biodiversity, root development and greenhouse gas recycling, thorough description of all measurements used to calculate ES scores in this study can be found in Chabert et al. (in press) and matching data are available at https://doi.org/10.15454/KEW1GK.

Regulating services

We chose not to study biocontrol under one sole indicator considering the diversity of processes involved, regarding the pest species, the regulating agents, their respective specialization. We thus chose to limit our study to three examples of pest regulation processes: one specialized parasitism, one specialized predation and one generalist predation. Four regulating services were thus assessed: regulation of a wheat pest by a specific predator and a fava bean pest by a specific parasitoid, generalist regulation by ground predators, and pollination. Pollination being also a key regulation process in and for healthy ecosystems, we added an estimate for the potential of pollination around fields in our set of measurements.

Grain aphid (*Sitobion avenae*) regulation by aerial predators was estimated based on an estimate of the density of an aphidophagous hoverfly population (*Sphaerophoria scripta*, Diptera: Syrphidae) on wheat ears just before harvest (Chabert and Sarthou, 2017).

Bruchid (*Bruchus rufimanus*) regulation by a specialized parasitoid was based on an estimation of the percentage of bruchid parasitism by *Triaspis thoracicus* (Hymenoptera, Braconidea) after harvest.

Potential for generalist regulation was assessed by estimating activity density of opportunistic ground predators, which include ground beetles (Coleoptera, Carabidae), spiders (Araneae) and rove beetles (Coleoptera, Staphylinidae), using modified pitfall traps set in winter wheat fields for 36 hours, simultaneously with slugs' pressure measurements in mid-April. Species of genera *Zabrus* and *Amara*, the only phytophagous genera of Carabid beetles harboring pest species for crops, were excluded from counts.

Given that a positive correlation between pollinator diversity and pollination of plants has already been demonstrated (*e.g.* Albrecht *et al.* 2012, Hoehn *et al.* 2008), potential for pollination was assessed via the abundance of the main pollinators. Insects were sampled using interception "cornet traps" (Sarthou, 2009). These traps are based on the Malaise trap principle but are (i) more resistant to wind, to endure the two years of the study; (ii) lower, to limit trap effectiveness and save sorting time, and (iii) unidirectional, to improve the orientation of traps. Four traps (two pairs of traps facing opposite directions) were set, as much as possible, on two perpendicular edges of each winter wheat field to capture along perpendicular directions in natural corridors. As far as possible, traps were set in order to capture from each of the four cardinal directions. Insects were captured continuously for

50 days, in autumn (from mid-September to early November 2015). We considered only the main pollinator groups that are Lepidoptera: Papilionoidea, Hymenoptera: Anthophila, and Diptera: Syrphidae. We chose as indicator for the potential of pollination the mean number of pollinators in the four traps.

Supporting services

Crop production supporting services included two measures of soil erodibility (structural stability of soil aggregates and water infiltration rate) and a measure of root development. Water infiltration rate was measured as the time needed for the soil to absorb water. Structural stability of soil aggregates was assessed through turbidity of surface water, supposedly due to the detachment of fine particles of soil from the impact of water drops. Root development was assessed for fava bean taproots, which are influenced more by soil compaction than the shallower roots of winter wheat. Five random plants were carefully uprooted, and total length of the taproot (the longest, if more than one) and its apical diameter were measured. The indicator of root development for each field was the mean value of length × diameter of the five taproots. All measurements were performed in April 2016.

Provisioning services

The seven provisioning services were assessed focusing on crop yield and production stability, via crop health and risk of pest damage.

Crop health was assessed by estimating fungal disease infection on leaves for both crops, within part of the field that did not receive fungicide treatment (half of winter wheat field, whole field for fava bean; see Chabert et al., in press). A standardized six-level scale was directly used to assess mean diseases infection within studied fields. Pest risk was assessed as the density (hereafter referred to as pressure) of a winter wheat pest, a fava bean pest and polyphagous pests (*i.e.* grain aphid *Sitobion avenae*, bruchid *Bruchus rufimanus* and slugs *Deroceras reticulatum* and *Arion hortensis*, respectively). For pest and disease pressures, observed values were ranked in a reversed scale so that a score of 5 always represents high level of ES (*i.e.* no diseases or pest) and 0 the complete absence of the ES (*i.e.* highest pressure observed).

Non-marketed services

Conservation of biodiversity was assessed using a Simpson diversity index applied to the entire arthropod community captured in above-mentioned "cornet traps" sorted and counted by orders. Conservation of SNH diversity was also assessed using a Simpson diversity index, which was applied on the number of each SNH type and their relative area on the farm (% of the farm surface) to prevent an overrating of big farms. Farmers identified SNH from photographs in their European Union Common Agricultural Program forms.

Greenhouse gas recycling was estimated for each farm as an index that equaled the amount of carbon sequestered in its soil divided by its greenhouse gas emissions for one year (2014). The index was calculated using the DIALECTE environmental assessment (Solagro, 2000), whose method is based on the computer tool AgriClimateChange (http://www.agriclimatechange.eu/). This indicator includes greenhouse gas emissions from fuel, oil and natural gas consumed on the farm, all greenhouse gas emissions from livestock enteric fermentation, and direct and indirect greenhouse gas emissions from soils. Indirect emissions such as those due to electricity consumption, livestock feed, chemical inputs, plastics and buildings are also included. For carbon sequestration, practices such as no-till, cover crops and grass strips were considered, as were the surface areas of long-term grassland, perennial crops and SNH (hedges, woods, etc.).

2.3. Cropping system survey

Information was recorded for tillage, chemical inputs, intercrop management, plant diversity, soils and the landscape (see Chabert et al., in press). We distinguished information about PS (Aubertot and Robin 2013), which are components and environment of a given field that farmers do not manage directly, from that about CM, which are components directly related to farmers' decisions (Table 2).

CM systems were divided into five categories: plowing under conventional agriculture, plowing under organic agriculture, reduced tillage under conventional agriculture, reduced tillage under organic agriculture and direct seeding under conventional management. In all fields, the considered CM system was applied for more than three consecutive years. Fields were considered under organic agriculture when they were labeled with French Organic Certification.

To better understand the impact of practices underlying those CM, five indicators were used to study effects of certain practices. Organic agriculture is based on banishment of the use of synthetic inputs (pesticides and fertilizers). We thus used the (i) treatment frequency index (TFI) and (ii) total mineral nitrogen input (Nmin), to study effects of reduced synthetic input use (from intensive use in some conventional fields towards suppression of their use in organic fields, Table 3) on the ES studied. Three parameter were used to consider each of the three principles of conservation agriculture (Table 3): (iii) time since last plowing in years, *i.e.* time since conversion to these techniques (Last_plow); (iv) rotation duration (Rotation) and (v) percentage of legume crop area at the farm level (Legum).

2.4. Production situations

In order to compare CM systems in fields with similar agroecological contexts, we used a multiple factorial analysis followed by a hierarchical ascendant classification to identify groups of similar PS. PS were described with 12 variables (Table 2) drawn from Chabert et al. (in press). Six referred to the landscape context and expressed as percentages of the area within a 1.5 km radius around the field covered by woodlands, cultivated fields (crops or temporary grasslands), fallow lands (including natural grasslands), human-modified areas, hedges and water (*e.g.* lakes, ponds, rivers). Five variables described soil properties: soil pH and organic matter, clay, silt and sand contents. An additional variable distinguished farms with or without livestock. Multiple factorial analysis allows to group variables into weighted categories, thereby limiting the degree to which importance is attributed to sets of variables related to the same feature (Escofier and Pagès, 1994). The first three dimensions (28.12%, 15.43% and 15.20% of the observed variation respectively) distinguished respectively: plots in farms without livestock (cos^2 = 0.82), with more alkaline soils (cos^2 = 0.63) and higher clay contents (cos^2 = 0.35, Figure 2a); plots with high percentage of human-modified areas in their vicinity (cos^2 = 0.65, Figure 2a); and plots with higher silt contents (cos^2 = 0.47). Coordinates on the first five dimensions (80.0% of observed variation) were retained to perform the hierarchical ascendant classification, using Ward's method, to identify four homogeneous clusters of PS (Figure 2b). The first group (PS 1) consisted exclusively of the fields from farms without livestock. These fields were mainly associated with clay-loam soils (mean clay content: 34±7%, mean pH: 8.07±0.51). Only two fields were loamy in PS 1 (clay content= 27.1% and 24.8%; pH=7.06 and 6.8 respectively). The second and third groups consisted of fields from farms with livestock and distinguished those with acidic loamy soils (PS 2, mean clay content: 18±5%, mean pH: 6.47±0.52) from clayey soils (PS 3, mean clay content: 40±11%, mean pH: 7.97±0.41). The fourth group (PS 4) contained only four fields that differed from the others due to the urban neighborhood around three of them and a large lake near the fourth. This fourth group was too small to be relevant, and after verifying whether the ES scores of its four fields fell into the interquartile range of similar CM in other PS, we moved them to the nearest PS. The two without livestock, clay content around 30% and alkaline pH were moved to PS 1, while the two with high silt contents and presence of a livestock were moved to PS 2.

2.5. Data analysis

We first chose to select the CM "plowing under conventional agriculture" as the standard system in our study area and determined whether each ES of the other four CM (considered as "alternative") ranked higher than, equal to or less than that in the standard system. We performed ANOVA on proportional odds models, an adaptation of cumulative link models to the study of scores (*i.e.* semi-quantitative data) (Christensen and Brockhoff, 2013) for this comparison. Because significant differences were rarely observed, we set the p-value threshold (α) at 0.10 to include slightly significant trends. To study each ES category individually, we looked for changes in its mean score.

To study the co-occurrence or antagonism of ES, we performed principal component analysis (PCA) of the 17 ES scores of the 50 fields. PCA is better adapted to studying ordered factors such as ranks or scores than are factorial methods, in which the order of the factor's values is ignored (Meulman et al., 2004; Vilela et al., 2015). CM and PS categories were added as supplementary factors to identify corresponding fields in PCA output but were not used to construct PCA dimensions.

We then summarized the scores of the 17 ES with polar area diagrams to visualize co-occurrence of ES among the groups of similar PS and the five CM types. Observed trends were then tested using pairwise likelihood ratio tests on proportional odds models. The CM analysis was supplemented with observations of effects of individual practices on each ES. Influential variables were selected using forward-and-backward proportional odds models selection among the five practice indicators (TFI, Nmin, Last_plow, Rotation, Legum) and the associated PS. We then verified whether the condition number of the models' Hessian matrix was less than 10^4 (Christensen, 2015a); if not, the least significant variable was removed. The most parsimonious model was maintained and analyzed with type-II analysis-of-deviance (*i.e.* ANOVA with likelihood ratio tests). This method was not used to study greenhouse gas recycling because it was the only ES that was estimated from surveys and not from in-field measurements. Thus, by construction, it was correlated with most of the practices studied. Finally, a study of the specific relationships between SNH diversity and mobile-agent based ES was performed, also using ANOVA on proportional odds models.

All statistical analyses were performed with R v3.2.3 software (R Core Team, 2015) and the packages *FactoMineR 1.32* (F. Husson et al., 2016), *ordinal* (Christensen, 2015b), *car* (Fox and Weisberg, 2011), *RVAideMemoire* (Hervé, 2016) and *lsmeans* (Lenth, 2016).

3. Results

3.1. Comparison of ecosystem services under conventional plowing and alternative systems

Each of the four alternative CM systems had at least one regulating service whose score increased compared to that under conventional plowing (Table 4), with both reduced-tillage systems having two. The reduced tillage systems, however, also had two (conventional) to four (organic) provisioning services that decreased, including yields. Organic plowing and direct seeding had two pest pressures (aphids and bruchids) that increased, but their yields were the same as those of conventional plowing, and crop health improved under organic plowing. For supporting services, organic plowing ranked lower than conventional plowing for two ES, and organic reduced-tillage was the only system that did not differ from conventional plowing. Reduced-tillage and direct-seeding systems increased structural stability of soil aggregates, but water infiltration and root development were significantly lower under direct seeding than under conventional plowing. Non-marketed services did not change under organic plowing or reduced-tillage; however, biodiversity conservation increased under organic reduced-tillage, and greenhouse gas recycling increased under direct seeding.

Mean scores per ES categories supported those observations (Figure 3). Mean scores of regulating services increased in the four alternative systems. However, direct seeding exhibited large variability and certain fields of this CM had regulating service scores as low as those of fields under conventional management (Figure 3a). Opposite trends were observed for provisioning services. Alternative CM generally had lower mean scores than conventional plowing, especially organic reduced-tillage ($p = 0.04$). Direct seeding exhibited again a large variability and contained both the lowest and the highest scores of provisioning services (Figure 3c). Conversely, for supporting services, variability decreased from conventional plowing to direct seeding (n.s.). Alternative systems, especially organic ones, had slightly lower mean scores than conventional plowing but similar medians (Figure 3b). Non-marketed services increased in organic systems compared to their conventional counterparts (n.s.), and direct seeding had significantly higher mean score compared to both plowing and reduced tillage systems ($p = 0.01$ for both; Figure 3d).

3.2. Ecosystem service bundles

As to co-occurrence or antagonism among ES on the same plot, the principal component analysis of ES scores highlighted several major trends, with 45.32% of the observed variation explained in the first three dimensions (19.67%, 13.74% and 11.91%, respectively). The first dimension indicated that less aphid pressure often co-occurred in plots with better fava bean health and, to a lesser extent, more ground predator activity, less slug pressure and more bruchid regulation, but displayed antagonism with SNH conservation and aphid regulation and, to a lesser extent, with biodiversity conservation and potential for pollination (Table 5). In addition, CM and PS types were correlated with this first dimension (Table 6). Thus, conventional plowed fields or fields with livestock and silty soils (PS 2) were often associated with low aphid pressure and low fava bean disease, but also low SNH conservation and aphid regulation, while organic reduced-tillage or fields without livestock were associated with the opposite effects on these ES (Table 6; Figure 4).

On the second dimension, plots that ranked highest for fava bean root development were opposed to those with high structural stability of soil aggregates. PS or CM types were not significantly correlated with the second dimension, but the CM type “direct seeding” was negatively associated to it (Table 6), *i.e.* more stable soil aggregates but less root development.

The third dimension opposed fields with high fava bean yields, adequate greenhouse gas recycling and low wheat disease to fields with low water infiltration rate. This third bundle was observed in plowed fields (Table 6) but did not sufficiently explain the overall variation among CM or PS types.

Organic plowed fields were not significantly associated with a dimension, but were mainly distributed in a neutral position in relation to the first bundle, with positive values on the second dimension (Figure 4), *i.e.* adequate root development but low structural stability. Fields under conventional reduced-tillage were homogeneously distributed along the first two dimensions, which precluded generalizing whether these CM types were associated with specific bundles.

3.3. Effects of crop management types on ecosystem services within production situations

Effects of production situation

Belonging to a specific PS appeared as a significant variable for five ES: SNH diversity conservation ($p = 0.004$), ground predator abundance ($p = 0.009$), winter wheat health ($p = 0.016$), aphid pressure ($p = 0.020$) and to a lesser extent biodiversity conservation ($p = 0.064$). In PS 1, *i.e.* fields on farms without livestock and with clayey soils, higher diversity scores for both SNH conservation and biodiversity were observed regardless of the CM considered (Figure 5a); organic fields had significantly more activity density of ground dwelling predators (p-value of the interaction PS:CM = 0.042) and no difference among CM were observed in aphid pressure. In both PS with livestock (PS 2 and 3, Figure 5b and c), wheat health was better in conventional fields, whether plowed or not, than their organic equivalent.

Effects of tillage

Supporting and non-marketed services exhibited the most significant trends regarding tillage (Figure 5). The two soil erodibility parameters had opposite responses. Structural stability of soil aggregates was high under direct seeding in all PS (median score = 5, 4 and 3 for direct seeding, reduced tillage and plowing, respectively; $p = 0.003$), while water infiltration was slightly higher in tilled fields, whether plowed (PS 2) or not (PS 1 and PS 3) (median score = 1, 2 and 2.5 for direct seeding, reduced tillage and plowing, respectively; $p = 0.053$). As to non-marketed services, farms practicing direct seeding recycled a much greater proportion of greenhouse gas than any other CM system (median score = 3, 0.5 and 0 for direct seeding, reduced tillage and plowing, respectively, $p < 0.001$) and SNH diversity was marginally higher under reduced tillage and direct seeding (median score = 4) compared to plowing (median score = 3, $p = 0.090$ and $p = 0.084$ respectively).

Concerning provisioning services, direct seeding and conventional plowing had similar winter wheat yields ($p = 0.786$) while a non-significant decrease was observed under reduced tillage. Reduced-tillage fields had the highest bruchid pressures ($p = 0.028$) and aphids were slightly more abundant under direct seeding ($p = 0.065$), except in PS 1. Overall, variability in aphid and slug pressures increased under reduced tillage and direct seeding. As to regulating services, despite variability among PS, reduced tillage fields had the highest potential for pollination ($p = 0.028$), especially organic reduced-tillage in PS3. Opposite trends were observed for aphid and bruchid regulation under direct seeding (higher and lower than other CM respectively, n.s.).

Effects of organic management

Organic management was associated with significant negative trends for provisioning services and some positive trends for non-marketed and regulating services. Organic fields, whether plowed or not, produced less winter wheat than conventional fields ($p < 0.001$). A slight trend for improved wheat health was observed in organic fields ($p = 0.054$), especially in the absence of livestock (Figure 5a). However, both crops' health was improved in conventional fields in PS 3, *i.e.* when livestock was present on the farm and soils were clayey (p-values of the interaction = 0.015 and 0.002 for wheat and fava bean respectively). For all three pest pressures, conventional plowing had lower pressures in PS 2 and PS 3 (Figure 5b and c), and organic fields, whether plowed or not, generally had higher pressures ($p = 0.017$, 0.132 and 0.071 for slugs, aphids and bruchids respectively). As to non-marketed services, SNH diversity was higher in organic fields, whether plowed or not ($p = 0.006$), and organic farms recycled a slightly greater proportion of their greenhouse gas than their conventional equivalents (n.s., $p = 0.181$). The differences were greater in PS 1, *i.e.* farms producing only crops. All regulating services were greatly variable among PS. For activity density of generalist predators, conventional fields (plowed or not) ranked lower than organic in PS 1 ($p = 0.044$), aphid regulation was slightly higher in organic than conventional fields, whether plowed or not (n.s., clayey fields in PS 1 and PS 3) and, at the opposite, bruchid regulation was generally higher in conventional fields, provided that livestock were present (n.s., Figure 5b and c). Finally, structural stability of soil aggregates was slightly higher in conventional fields than organic fields (median score = 4.5 and 3, respectively; $p = 0.051$), regardless of PS and tillage management type.

3.4. Effects of SNH diversity and individual crop management practices of conservation and organic agriculture on ecosystem services

SNH diversity scores were positively correlated with flying-pest pressure ($p = 0.016$ and <0.001 for bruchids and aphids, respectively) and with the associated aphid regulation ($p = 0.004$) but were negatively correlated with bruchid regulation ($p = 0.009$). For ground pests (slugs) and predators, SNH diversity was associated with a slight increase of slug abundance ($p = 0.053$) and had no effect on activity density of ground-dwelling predators. SNH diversity also had a slight positive correlation with pollinator abundance ($p = 0.076$).

For conservation agriculture practices, extended rotation duration had significant positive effects on bruchid regulation and fava bean yields, while the time since last plowing had negative effects on these ES (Tables 7 and 8). It also had negative effects on water infiltration and root development and a slight negative effect on fava bean health, but had a significant positive effect on soil structural stability (Table 7). Slug pressure slightly decreased in fields with longer rotations but increased as the percentage of legume crop area increased (Table 8). Positive correlation was also observed between SNH conservation and percentage of legume crop area (Table 8).

For organic practices, treatment frequency index was negatively correlated with wheat health, yet not correlated with wheat yield, and slightly correlated with fava bean yield (Table 8). For mineral fertilizer, only slight trends in lesser soil structural stability and aphid pressure were observed with decreasing nitrogen use (Table 7).

Studied practices had no significant effect on pollination, aphid and bruchid regulation and wheat yield.

4. Discussion

Our findings overall supported those of Garbach et al. (2016), whose meta-analysis demonstrated that conservation agriculture generally improved pest control, conservation of biodiversity and habitats, carbon sequestration, control of erosion and water runoff, and water purification. While organic systems improved pollination, biodiversity and habitat diversity, and control of erosion and water runoff, control of pests and weeds was similar to that in the conventional system (Garbach et al., 2016).

High variability of output services response to conservation agriculture practices

One finding that merits greater focus in future studies is the variability in results observed for conservation agriculture systems. For provisioning services in particular, direct seeding and, to a lesser extent, reduced tillage had high variability in yields, winter wheat health and abundance of pests such as aphids and slugs. Particularly, the highest and the lowest scores of the same ES were often found under direct seeding. Similar variability was found for most non-marketed services. However, this was not observed for supporting services (Figure 3), whose variation under direct seeding differed little when compared to plowing. The CM types we chose to study thus encompassed a range of practices with variable agroecological performances. No-plowing systems were found to be more economically productive and beneficial to soil quality when associated with agroecological rather than industrial practices (Virginia et al., 2018). As stressed out by Bender et al. (2016), to fully benefit from natural processes, agroecological systems need to integrate soil ecological engineering, which requires high understanding of soil processes. Yet, farmers involved in conservation agriculture suffer from a lack of specific knowledge and technical support to adapt their technics to local conditions. Furthermore, as evidenced in this study by the significant effect of time since last plowing on several ES, conservation agriculture systems need maturity to express their potential for ES provision, due to gain of farmers’ experience, soil evolutions and ecological equilibrium, which may take a few years (Scopel et al., 2013).

Co-variation and antagonisms between ecosystem services mostly related to mobile agents or soil properties

Several ES that rely on mobile agents and are greatly influenced by field surroundings appeared to display co-occurrence or antagonism in fields. Interestingly, systems combining organic and conservation practices displayed the highest diversity of SNH and associated services, proving that farmers transitioning to agroecological practices seem to extend their management strategies outside the productive zones of their farm. Our observations that both pest pressure and regulation by a given natural enemy increased with habitat diversity and general biodiversity for aphids, was expected (Roschewitz et al., 2005) and the opposite effects on bruchid parasitism concur with recent findings that non-crop habitat diversity does not consistently support higher pest regulation (Karp et al., 2018). Furthermore, for organic agriculture as much as conservation tillage, bruchids and aphids were more abundant compared to conventional plowing, which contradicts results of previous studies (see meta-analysis of Bengtsson et al. 2005). Yet, recent studies support that more complex food web structure in organic farming do not consistently implies an improved pest control (Macfadyen et al., 2009a, 2009b). Despite higher biodiversity (Hole et al., 2005) and richness of potential biocontrol agents (Bengtsson et al., 2005), no differences are sometimes observed in pest damages (Fusaro et al., 2016) or parasitism (Macfadyen et al., 2009b) and as-yet-unknown effects of organic practices on pests and their enemies remain (Lohaus et al., 2013). For instance, it can be supposed that Hymenopteran parasitoids of bruchid larvae are hindered in localizing their host and laying their egg when host plants are mixed with other cultivated plant species or weeds, or are embedded in botanically complex surroundings.

The other ES bundles observed were related to the soil and its sensitivity to erosion. Particularly, both erodibility parameters, water infiltration rate and structural stability, appeared in two orthogonal bundles. These two properties are thus expressed independently in a given field and are not always negatively correlated. Contrary to Garbach et al. (2016) and Reganold and Wachter (2016) meta-analyses, organic agriculture did not improve control of erosion and water run-off. Soil stability was even lower under organic than conventional practices. But our findings confirmed the potential for direct seeding (Bronick and Lal, 2005; D'Haene et al., 2008) to significantly decrease soil loss thanks to more stable soil surface aggregates, which is one of the main advantages of no-till practices

(Puustinen et al., 2005; Soane et al., 2012; Ulén et al., 2010). However, we were unable to confirm the decrease in runoff due to conservation tillage as stated by Soane et al. (2012). Infiltration rate is usually assumed to be higher in conservation agriculture thanks to protection from raindrops and their destructuring 'splash effect' by residues, the greater macropore conductivity, the continuity between soil layers, and the vertically-orientated macroporosity (Sharratt et al., 2006; Soane et al., 2012). Yet, no-till practices are also known to increase soil compaction, especially in the first few years after conversion (Soane et al., 2012) which may hinder the permeability of the first few centimeters or even millimeters of soil. This has been revealed by a decrease in fava bean root development in conservation agriculture because of soil compaction. Furthermore, measurements were performed soon after winter, when the biological activity that could have restored porosity still remains low.

Crop production not jeopardized by conservation agriculture practices and crop health improved in organic agriculture

Worldwide, all crops combined and from experimental plots (what is criticized by some farmers), conservation agriculture is estimated to have yields 2.5% lower than those of conventional plowing (Pittelkow et al., 2015a). Under conservation agriculture, yields are less affected by water stress (Pittelkow et al., 2015a) and are estimated to increase by 20-120% compared to those of conventional plowing in arid countries (Basch et al., 2015; Kesavan and Malarvannan, 2010). No empirical evidence for the overall performance of conservation agriculture exists for France (Lahmar, 2010), but Basch et al. (2015) estimated that yields in Southern Europe (including France) would increase by 13% under conservation agriculture. Yields in our study did not differ significantly between conventional plowing and conservation tillage, including that of direct seeding. Except for reduced tillage in organic systems, crop health was also unchanged by CM type. These findings contradict certain scientific beliefs about conservation agriculture. Indeed, models based on expert knowledge tend to predict an increase in diseases and pests when the soil remains undisturbed and is covered with crop residues (Craheix et al., 2016). Several studies support this, but as mentioned by Scopel et al. (2013), this is observed mainly in young, not-yet-mastered systems, in which the principles of conservation agriculture are not completely or well applied. A large-scale European survey of farmers adopting conservation agriculture revealed that, from their viewpoint, the prevalence of diseases and pests did not change when they changed their practices (Veroz-González et al., 2008). Our study tends to support their claim for diseases, with no trend of deteriorating crop health under direct seeding. Yet, organic reduced-tillage was the CM with the strongest pressure of pathogenic fungi, which indicates that obstacles remain for the development of conservation agriculture in organic systems. As to risk of pests, if aphids and bruchids appeared greater in both alternative agricultures, slugs however significantly increased only under organic agriculture practices. Slugs are considered a major issue hindering the development of conservation agriculture (Basch et al., 2015) but in the winter crops we studied, their abundance was highly variable in fields under reduced tillage or direct seeding, leading to no significant effect of tillage. Thus, our results on pests contradict previous studies showing an improved pest control in conservation agriculture (Basch et al., 2015; Garbach et al., 2016; Kesavan and Malarvannan, 2010), except for regulation of slugs which was poor in conservation agriculture. The differences observed in pest abundance were due more to specific practices and habitat availability in field surroundings rather than CM type (*cf.* below).

Yields and crop health differed greatly between organic and conventional systems. Consequent decrease in wheat yields, but not for fava bean, was expected (Reganold and Wachter, 2016; Seufert et al., 2012), indicating that it was mainly due to lack of mineral nitrogen. As to crop health, the negative correlation between treatment frequency index and crop health proved that organic systems tended to improve wheat health, a trend even greater in the absence of livestock. However, treatment frequency index was not correlated with higher yields, indicating that treatments only allowed fields affected by diseases to have yields similar to those of healthy fields.

Negative impacts of agricultural practices mitigated by elements of production situation such as presence of livestock and clayey soils

We found that presence of a livestock was a major component of production situation and influence several ES responses. Overall, when livestock was present, we observed lower negative effects of conventional practices on several ES, such as soil aggregate stability, crop health, yields, activity density of soil predators and abundance of pests. Presence of livestock on the farm implies availability of organic matter for fertilization, resulting in higher organic matter content in the soils (Figure 2) and potentially more grasslands and longer crop rotations. It seemed that soil quality (physical, chemical and biological) improved in the presence of livestock and mitigated decreases in ES caused by other practices. However, except for fava bean yields, rotation duration was not an explanatory factor for these ES. Livestock presence was negatively correlated with SNH diversity because although it was associated with larger area of grassland (and thus of SNH), grassland dominated the types of SNH, resulting in low SNH diversity at the farm level. In the opposite, livestock presence was logically related to higher greenhouse gas emissions (Gerber et al., 2013). An exception was found for fields under direct seeding which greatly mitigated the impact of livestock on greenhouse gas emissions by sequestering carbon in the soil. Greenhouse gas emissions were not field measured in the present study but estimated and further studies are needed. Yet, our results suggest a high potential for direct seeding to support such a crucial ES by beneficially balancing energy consumption and agroecological practices.

We distinguished two groups of farms with livestock that differed mainly in soil type, *i.e.* loamy or clayey soils, leading to distinct ES responses to CM type. In particular, direct seeding had the highest yields on loamy soils, and plowing had the highest yields on clayey soils. The amount of clay in soils might act as a buffer of prejudicial practices. For instance, practices of reduced tillage often encompass shallow mechanical weed control to limit or supplant herbicide use, especially for organic fields. This repeated shallow disturbance produces fine soil particles that obstruct the biologicallycreated porosity connection between surface and deeper soil layers. As we observed for water infiltration, low infiltration occurred on silty soils and/or soils with low organic matter contents, and both conservation and organic agriculture practices were less detrimental on clayey soils. Additionally, clay in soils buffers the alteration of soil redox potential by mechanical soil management. Loamy soils are indeed more sensitive to oxidation due to soil disturbance or chemical inputs (O. Husson et al., 2016), which provide non-optimal conditions for crops and indirectly decrease the amount of photosynthates directed to grain (Husson, 2013), resulting in lower yields. Soil type in relation to oxidation level might also influence other ES in unexpected ways. Indeed, Chabert and Sarthou (2017) showed that *S. scripta* regulation of aphids might also be influenced by soil and subsequent plant redox potential due to sensitivity of these organisms to electromagnetic fields, as demonstrated for other pollinators (Clarke et al., 2013). It could also be the result of a lesser emission of HIPV (Herbivore Induced Plant Volatiles, molecules used by some natural enemies to find their prey/hosts) by plants (Dicke et al., 2009), eventually because of their high oxidation level.

Ecosystem services better explained by individual practices than categorization by crop management type

Several authors indicate that a set of practices must be considered rather than only one aspect such as soil tillage, especially for conservation agriculture. For example, Craheix et al. (2016) showed that direct seeding with a short rotation was the system favoring the less ES and that conservation agriculture, when completely applied and mastered, resulted in good supply of non-marketed services. Many farmers adopt conservation agriculture practices only partially due to their convictions, objectives or local conditions (Scopel et al., 2013), which greatly undermines the long-term sustainability of their systems. In contrast, some systems based on conventional plowing can have good supply of non-marketed services (Craheix et al., 2016) when, for example, they have long and diversified rotations, reasoned SNH management and moderate pesticide use. Our study was meant to somehow remedy to the lack of case studies that examine multiple ES in agroecosystems at the same time. But because many ES were studied simultaneously, parameters for PS and CM were kept simple to not overweigh the study and we only briefly reviewed several main practices related to conservation and organic agriculture to refine the results. Overall, the assessment of main practices confirmed observations of CM types and provided insight into effects of practices on certain ES that did not significantly differ among CM types. Thus, we confirmed effect of conservation agriculture on soil aggregate stability and water infiltration as an effect long-time non-inverting soil management. The non-significant decrease in bruchid regulation observed in conservation agriculture resulted from an opposite response to time since last plowing, which tends to decrease regulation, and to rotation duration. The opposite effects of these two conservation agriculture principles thus resulted in no definite effects of our CM types because they included fields where the three conservation agriculture principles were not equally applied. Slugs pressure, which varied greatly under conservation agriculture without significant trend, tended to be more important when the percentage of legume crop area and the diversity of SNH on the farm were high, but they were less abundant in fields with a more diversified crop rotation. As to fava bean yields, which were similar among CM types, they were also influenced by time since conversion and rotation duration, as well as pesticide use, which tends to confirm that yields were due mainly to the effectiveness of bruchid control, whether natural or chemical. Despite those examples, only a few cases of prevalence of individual practices over CM or PS categorization appeared in the current study. Indeed, as shown in a previous study in the same dataset (Chabert and Sarthou, 2017), when finer parameters and raw measurement of ES rather than scores are studied, it is possible to show that nitrogen input and time since conversion to conservation agriculture explained aphid regulation more than classification as “organic” or “conservation” agriculture. The relatively coarse assessment of effects of specific practices observed in this study thus initiate future service-specific studies.

5. Conclusion

Overall, this study showed a good performance of conventional agriculture for the expression of provisioning and supporting services but it generally had lower levels of regulating and non-marketed services compared to organic agriculture, which conversely, often had the lowest performance for provisioning and supporting services. In contrast, conservation agriculture showed good potential to sustain agroecological transition in southwestern France. Unlike for organic agriculture, provisioning services did not generally decrease, even though pest risk was sometimes higher. In addition, conservation agriculture can help reduce soil loss by decreasing particle removal caused by water runoff.

Questioning the co-occurrence or antagonisms of ES revealed that the relationship between pests, their natural enemies and habitat diversity was not as straightforward as previously believed. Bruchids for example, did not respond to habitat diversity as expected, and their response was opposite to that of aphids. Drawing general conclusions about multiple pest pressures and regulations for a given type of agriculture system is thus misleading due to high response variability from one species to another.

Interestingly, with this case study, we emphasize the importance of production situation parameters such as inclusion in a livestock-crop farm or soil type on the expression of multiple ES, even if focusing on non-forage crop or non-soil related ecosystem services. Even if determinants remain unclear, livestock on the farm seemed to mitigate negative effects of conventional agriculture, increasing scores of ES such as potential predation by ground-dwelling predators and soil aggregate stability. Similarly, higher soil clay content buffered beneficial effects of alternative systems on soils. Contrary to some authors claim, conservation agriculture did not show increased yields compared to conventional plowing in this study; however, fields on loamy soils had higher yields under conservation agriculture, indicating its potential and the undervalued effect of soil texture on agroecological performances of conservation agriculture. Potential improvements in soil chemical properties under organic or conservation agriculture are understudied and, from our viewpoint, this includes soil redox potential (here again interfering with soil clay content), along with pH and organic matter content.

Finally, a main conclusion of this study concerns the high variability in ES expression under conservation agriculture. Direct seeding had the most variable results, especially for provisioning services, for which it had the highest (higher than conventional systems) and the lowest (lower than organic reduced-tillage) rated fields in the study. Furthermore, time since conversion to these techniques, was often an influential parameter, either because ecological equilibrium was not reach or because of a lack of farmer experience in mastering the required techniques. This study emphasizes that knowledge on how to adapt systems to local conditions and to respond to climate events, remains incomplete and is not easily available to farmers.

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Table 1. List of the studied ecosystem services and correspondence with Common International Classification of Ecosystem Services

Input services (*to* agriculture)			Output services (*from* agriculture)		
	CICES 5.1 group	CICES 5.1 section		CICES 5.1 group	CICES 5.1 section
Regulating Services			**Provisioning Services**		
Potential for pollination	Lifecycle maintenance, habitat and gene pool protection	Regulation & Maintenance	Crop yields (winter wheat, fava bean)	Cultivated terrestrial plants for nutrition, materials or energy	Provisioning
Pest regulation (aphids, bruchids)	Pest and disease control	Regulation & Maintenance	Crop health (winter wheat, fava bean)	Cultivated terrestrial plants for nutrition, materials or energy *	Provisioning
Potential for generalist predation	Lifecycle maintenance, habitat and gene pool protection *	Regulation & Maintenance	Pests pressure (aphids, bruchids, slugs)	Cultivated terrestrial plants for nutrition, materials or energy *	Provisioning
Supporting Services			**Services out of direct agricultural income = Non-Marketed Services**		
Soil aggregate stability	Regulation of soil quality	Regulation & Maintenance	Biodiversity conservation	Lifecycle maintenance, habitat and gene pool protection **	Regulation & Maintenance
Water infiltration rate	Regulation of soil quality	Regulation & Maintenance	Semi-natural habitat conservation	Lifecycle maintenance, habitat and gene pool protection **	Regulation & Maintenance

Root development	Regulation of soil quality	Regulation & Maintenance	Soil greenhouse gas recycling	Atmospheric composition and conditions	Regulation & Maintenance

* can also be classified as 'Regulation & Maintenance' : 'Pest and disease control'

** can also be classified as 'Cultural' : 'Other biotic characteristics that have a non-use value'

Table 2. Description of the variables used in the multiple factor analysis (production situation) and the proportional odds models selection (crop management).

	Subcategory	Variable	Description
Production Situation	Landscape	Wood	% of woodland area within a 1.5 km radius
		Cult	% of cultivated area within a 1.5 km radius
		Fall	% of fallow land area within a 1.5 km radius
		Water	% of water area within a 1.5 km radius
		Hedg	% of hedge area within a 1.5 km radius
		Human	% of human-modified area within a 1.5 km radius
	Soil properties	pH	Soil pH
		OrgMat	Organic matter content
		Clay	% of clay content
		Silt	% of silt content
		Sand	% of sand content
	Farm context	Livestock	Presence or absence of a livestock on the farm
Crop Management	Tillage	Last_plow	Time since last plowing (years)
	Inputs	TFI	Treatment frequency index
		Nmin	Quantity of mineral nitrogen fertilizer applied
	Crop diversity	Legum_area	% of area covered by legume crops at farm level
		Rotation	Mean rotation duration at farm level (years)

Table 3. Mean values (± standard deviation) of CM variables for each CM type studied. Between brackets number of fields concerned.

		Last_plow	Legum_area	Rotation	TFI	Nmin
Conventional agriculture	Plowing (13)	0,54 ±0,88	13,03 ±11,83	3,54 ±1,09	2,05 ±1,25	66,90 ±68,74
	Reduced Tillage (14)	8,36 ±5,26	24,51 ±23,31	3,84 ±1,25	2,18 ±0,79	149,2 ±62,20
	Direct Seeding (10)	15,6 ±6,47	45,55 ±23,15	4,40 ±1,24	2,08 ±1,18	154,7 ±56,54
Organic agriculture	Plowing (5)	0,80 ±0,84	21,67 ±12,62	3,90 ±0,74	0,00 ±0,00	0,00 ±0,00
	Reduced Tillage (8)	7,88 ±6,24	43,97 ±22,47	4,75 ±1,36	0,00 ±0,00	0,00 ±0,00

Table 4. Number of services improved (dark gray), unchanged (light gray) or decreased (no shading) by each crop management practice compared to conventional plowing. Differences are considered significant at $p < 0.10$.

	Organic Plowing			**Reduced Tillage**			**Organic Red. Till.**			**Direct Seeding**		
	↑	↔	↓	↑	↔	↓	↑	↔	↓	↑	↔	↓
Regulating	1	3		2	2		2	2		1	3	
Supporting		1	2	1	2			3		1		2
Provisioning	2	3	2		5	2		3	4		5	2
Non-marketed		3			3		2	1		1	2	

980 **Table 5.** Significant correlations of the 17 ecosystem services studied with the first three principal component analysis dimensions.

	Variable	Corr.	p-value
Dim 1	Aphid pressure	0.74	8.96E-10
	Fava health	0.51	1.68E-04
	Ground predators activity	0.49	2.69E-04
	Slug pressure	0.49	2.98E-04
	Weevil regulation	0.49	3.09E-04
	Fava yield	0.38	6.09E-03
	Weevil pressure	0.37	7.75E-03
	Wheat health	0.36	1.11E-02
	Greenhouse gas recycl.	-0.34	1.71E-02
	Pollination	-0.46	6.93E-04
	Biodiversity	-0.47	6.40E-04
	Aphid regulation	-0.59	7.37E-06
	SNH diversity	-0.69	4.05E-08
Dim 2	Root development	0.81	1.60E-12
	Weevil regulation	0.46	7.20E-04
	Fava health	0.41	3.12E-03
	Weevil pressure	0.33	2.09E-02
	Water infiltration rate	0.32	2.56E-02
	Aphid regulation	0.30	3.52E-02
	Aphid pressure	-0.40	3.72E-03
	Ground predators activity	-0.42	2.27E-03
	Soil aggregate stab.	-0.77	7.59E-11
Dim 3	Fava yield	0.63	8.35E-07
	Greenhouse gas recycl.	0.52	9.25E-05
	Wheat health	0.49	2.90E-04
	Aphid regulation	0.45	1.15E-03

	Water infiltration rate	-0.71	8.97E-09

Table 6. Significant correlations between crop management (CM) type, production situation (PS) group and principal component analysis dimensions.

	Variable	R2	p-value		Estimate	p-value
Dim 1	CM	0.201	3.50E-02	P	1.12	1.57E-02
				RO	-1.20	3.21E-02
	PS	0.295	4.13E-04	PS 2	0.96	2.53E-03
				PS 1	-1.28	8.89E-05
Dim 2	-	-	-	D	-1.05	2.50E-02
Dim 3	-	-	-	P	-0.87	3.30E-02

Table 7. Signs of the estimates of the most parsimonious Proportional Odds Models of crop management practices on regulating and supporting services and p-values of likelihood ratio tests.

	Pollination		**Aphid reg.**		**Weevil reg.**		**Ground pred.**		**Soil ag. stability**		**Water inf.**		**Root dev.**	
	estim.	p-v	estim.	p-v	estim.	p-v	estim.	p-v	estim.	p-v	estim.	p-v	estim.	p-v
Rotation					+	< 0.001 ***					-	0.092 .		
Last plow			+	0.186	-	0.027 *			+	0.004 **	-	0.043 *	-	0.003 **
Legume crop													+	0.066 .
TFI							-	0.168						
mineral N	+	0.164					-	0.404	+	0.074 .			+	0.192

Table 8. Signs of the estimates of the most parsimonious Proportional Odds Models of crop management practices on provisioning and non-marketed services and p-values of likelihood ratio tests.

	Wheat yield		**Fava yield**		**Wheat health**		**Fava health**		**Slug pres.**		**Aphid pres.**		**Weevil pres.**		**Biodiversity**		**SNH diversity**	
	estim.	p-v	estim.	p-v	estim.	p-v	estim.	p-v	estim.	p-v	estim.	p-v	estim.	p-v	estim.	p-v	estim.	p-v
Rotation	-	0.251	+	0.017 *					+	0.062 .								
Last plow			-	0.023 *			-	0.077 .							+	0.368		
Legume crop									-	0.073 .							+	0.017 *
Treat. Freq. Index	+	0.128	+	0.067 .	-	0.006 **	-	0.970					+	0.174				
Mineral N	+	0.322									-	0.067 .						

Figures

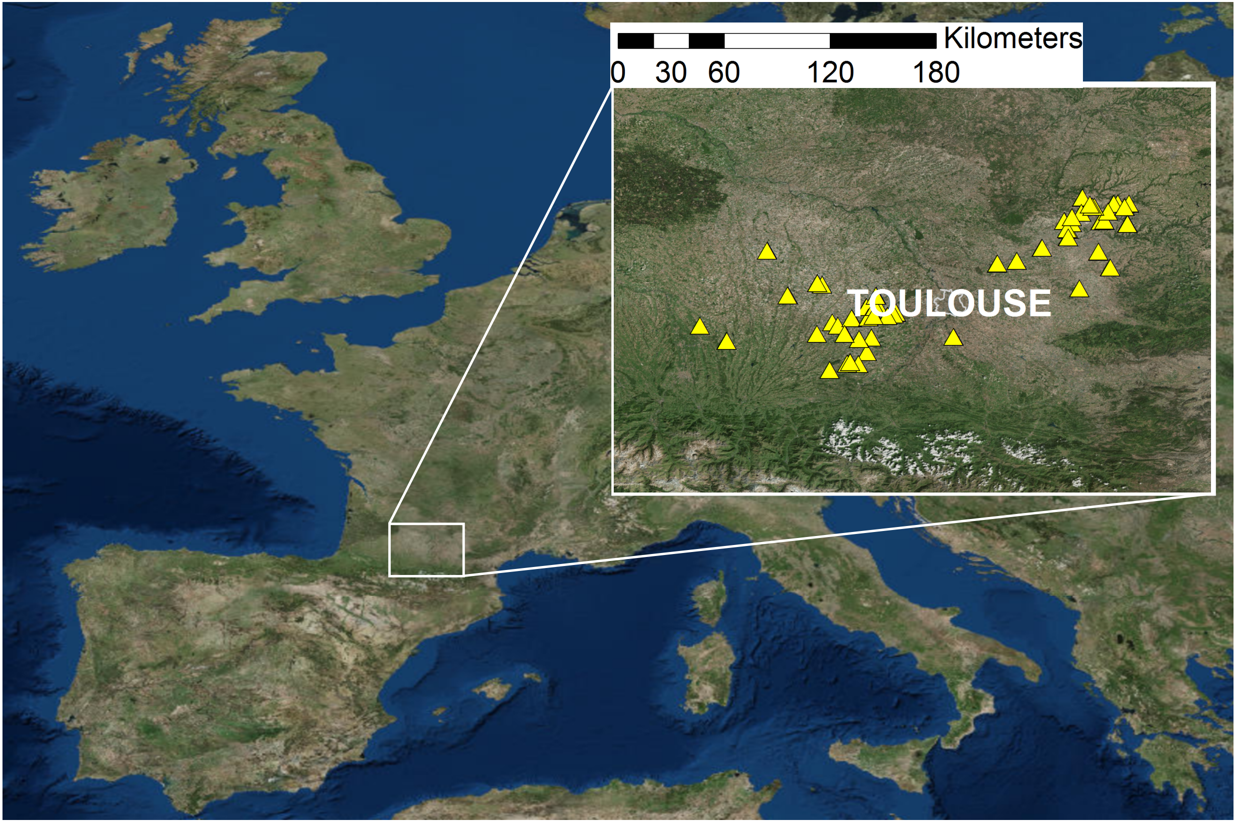
Figure 1. Map showing the location of the 50 fields studied.

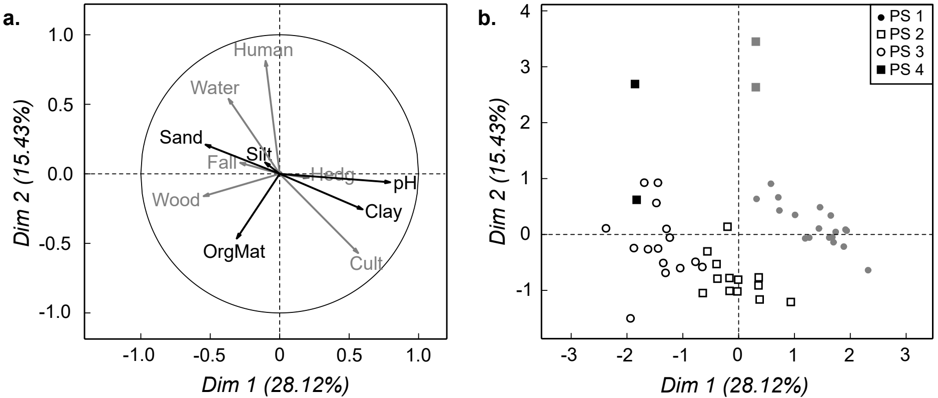
Figure 2. Result plots of the first two dimensions of multiple factor analysis of production situation variables: (a) Correlation circle, with distinction between landscape (lighter labels) and soil parameters (black labels), and (b) individual factor maps with distinction of the four production situation (PS) classified by hierarchical ascendant classification. Black symbols are farms with crops and livestock, while grey symbols are farms with crops only. See Table 2 for abbreviations of variables.

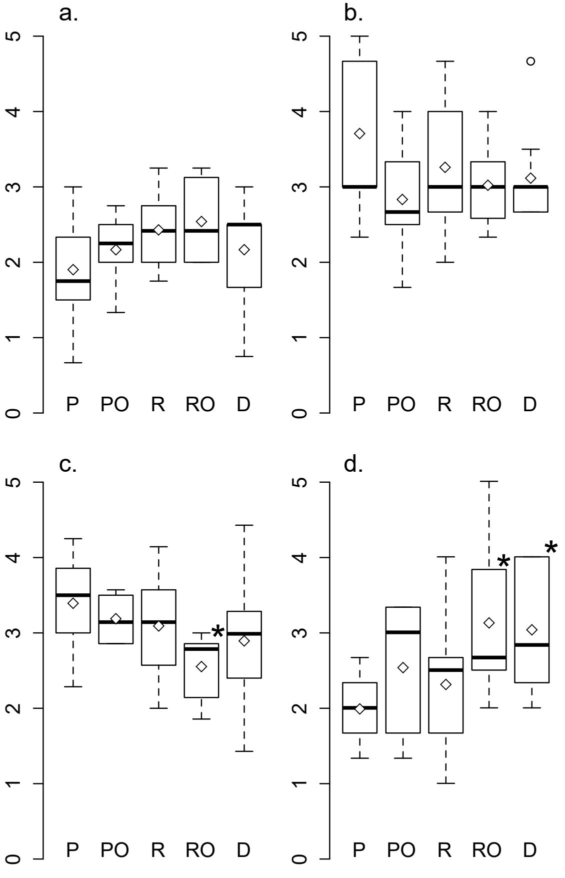
Figure 3. Boxplots by crop management type (P: Plowing, PO: Organic Plowing, R: Reduced tillage, RO: Organic Reduced tillage, D: Direct seeding) of mean ecosystem service (ES) scores for each ES category: (a) regulating services, (b) supporting services, (c) provisioning services and (d) non-marketed services. Solid black lines represent medians, white diamonds represent means, box borders are quartiles and end of whiskers are extremum values. Asterisks identify CM types with means significantly different from that of conventional plowing (P).

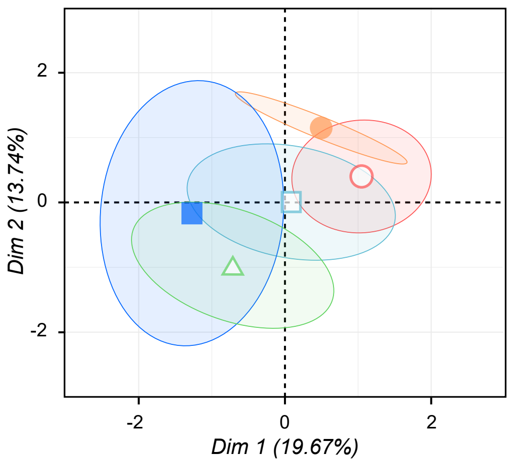
Figure 4. Individual factor map from the principal component analysis of the 17 ecosystem services, grouped by crop management. Circles are plowing systems, squares reduced tillage and triangles direct seeding. Empty symbols are conventional agriculture and full ones, organic agriculture. Only groups centroids and confidence ellipses are shown.

Figure 5. Polar area diagrams of mean scores (range = 0-5) of 17 ecosystem services for each type of crop management in each production situation group (PS): PS1, PS2 and PS3. Services are grouped by color within the four ES categories. Areas with lighter coloring represent standard deviations, hatched areas indicate unavailable data.

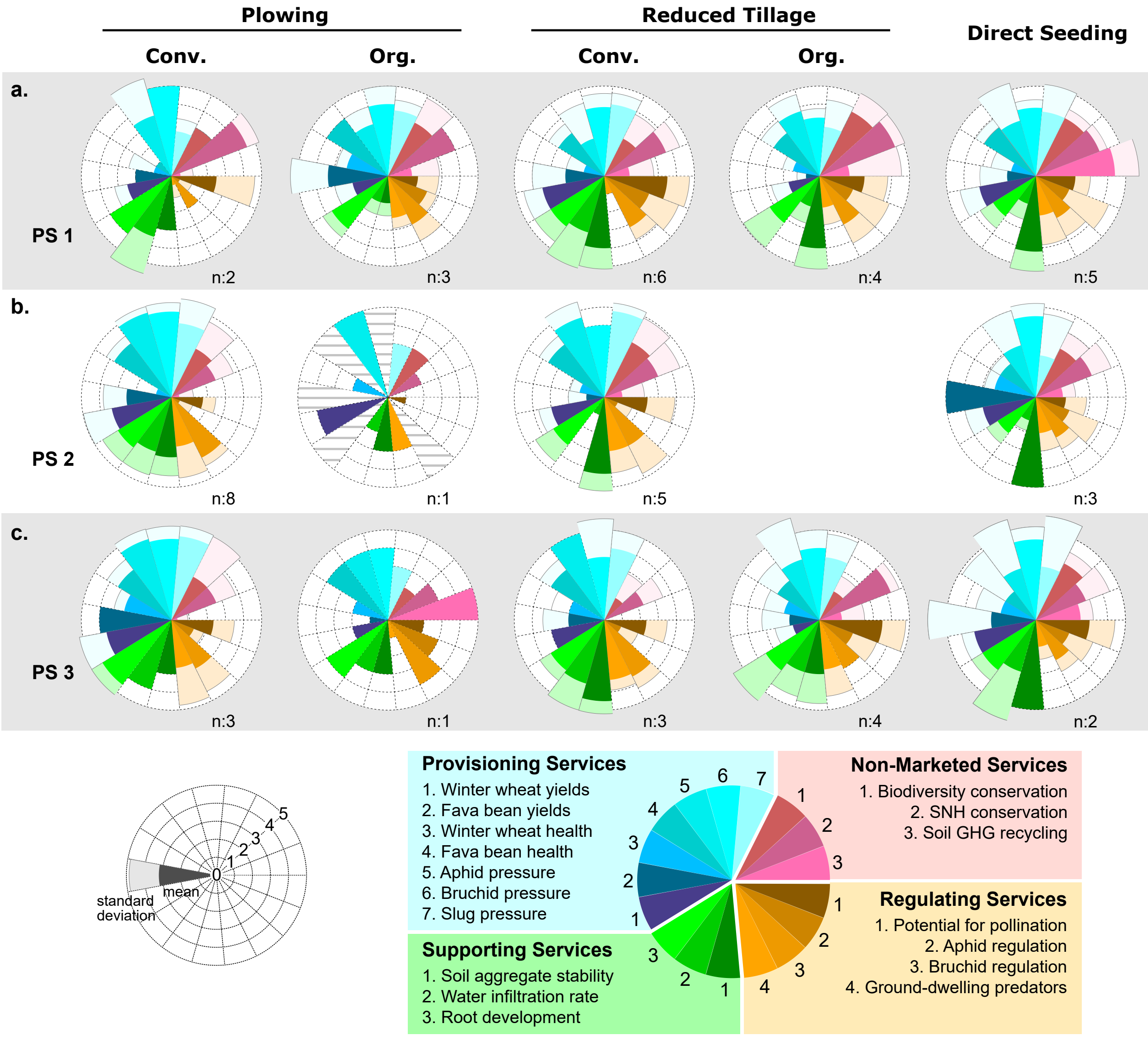

Kilometers
0 30 60 120 180
TOULOUSE


a.
1.0
0.5
0.0
-0.5
-1.0
Dim 2 (15.43%)
Human
Water
Sand
Silt
Fall
Hedg
pH
Wood
Clay
OrgMat
Cult
-1.0
-0.5
0
0.5
1.0
Dim 1 (28.12%)
b.
4
3
2
1
0
-1
Dim 2 (15.43%)
PS 1
PS 2
PS 3
PS 4
-3
-2
-1
0
1
2
3
Dim 1 (28.12%)


a.
b.
c.
d.
0
1
2
3
4
5
P
PO
R
RO
D
*



2
0
-2
-2
0
2
Dim 2 (13.74%)
Dim 1 (19.67%)


Plowing
Reduced Tillage
Direct Seeding
Conv.
Org.
Conv.
Org.
a.
PS 1
n:2
n:3
n:6
n:4
n:5
b.
PS 2
n:8
n:1
n:5
n:3
c.
PS 3
n:3
n:1
n:3
n:4
n:2
0
1
2
3
4
5
standard deviation
mean
Provisioning Services
1. Winter wheat yields
2. Fava bean yields
3. Winter wheat health
4. Fava bean health
5. Aphid pressure
6. Bruchid pressure
7. Slug pressure
Non-Marketed Services
1. Biodiversity conservation
2. SNH conservation
3. Soil GHG recycling
Regulating Services
1. Potential for pollination
2. Aphid regulation
3. Bruchid regulation
4. Ground-dwelling predators
Supporting Services
1. Soil aggregate stability
2. Water infiltration rate
3. Root development