Title

Potential of indicators to unveil the hidden side of cropping system classification: differences and similarities in cropping practices between conventional, no-till and organic systems

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Abstract

To compare different cropping systems, it is crucial to describe explicitly the associated cropping practices. A set of 31 indicators, and six composite indexes, addressing farm structure, crop diversification, soil disturbance, organic matter inputs, nitrogen fertilisation, crop protection, and yield was used to describe 59 winter wheat fields belonging to conventional, no-till and organic systems, in Switzerland. The aim of this study was to investigate the complementarity and redundancy of the indicators and their potential to characterise these cropping systems. In general, weak correlations were observed between the studied indicators, showing the importance of using a set of indicators to fully characterise cropping practices. The complex indicators were often correlated with simpler ones, but it cannot be excluded that they can prove to be more useful in different contexts. Retaining a combination of simple and complex indicators to obtain a broad picture of cropping practices is thus recommended. The indicators highlighted differences but also similarities between the three systems. For example, the input of organic matter and crop rotation diversification were similar between the three systems. In contrast, total nitrogen fertilisation (lower for organic systems) and soil disturbance (lower for no-till systems) were different. A high within-system variability was observed for some indicators, suggesting that using quantitative indicators rather than simple classifications based on a general description of the systems allows a better characterisation of these systems. Overall, the use of indicators has the potential to improve our understanding of the influence of cropping practices on the soil and environment.

Keywords

field level indicators, composite indexes, crop diversification, organic matter inputs, soil disturbance intensity, on-farm study

1. Introduction

Agriculture is characterised by a wide range of soil management and cropping practices, such as choice of cultivated crop and cultivar, crop rotation, tillage intensity and implements, nutrient management, crop protection and irrigation. As alternatives to what can be called 'conventional' cropping practices, different cropping systems have been developed, especially to reduce the impact of agriculture on the environment. Among others, organic farming and no-till agriculture are alternative systems which are increasingly adopted. Organic farming is principally based on the exclusive utilisation of organic fertilisers and treatments: synthetic substances are prohibited but soil tillage and mechanical weeding is allowed (Reganold and Wachter, 2016; Migliorini and Wezel, 2017). No-till farming implies the absence of any tillage interventions prior to seeding and should ensure at least 30% soil cover throughout the year (Soane et al., 2012). No-till systems could fulfil the principles of conservation agriculture if they insure sufficient soil cover (by residues or crops) and a diversified crop sequence (FAO, 2018).

Many studies have aimed at comparing these systems to assess if yield can be maintained compared to conventional systems. Based on a meta-analysis, it has been shown that no-till alone tends to reduce yield by about 10%, but this decrease can be mitigated when no-till is associated with crop residue retention and improved crop rotation (Pittelkow et al., 2015a). In organic farming, a yield decline of about 20% compared to conventional systems is typically observed (Mäder et al., 2002; de Ponti et al., 2012; Seufert et al., 2012; Ponisio et al., 2015; Seufert and Ramankutty, 2017). Moreover, a recent meta-analysis has shown that temporal yield stability of conventional fields was higher than that of organic fields (Knapp and van der Heijden, 2018). However, precautions must be taken when comparing these systems as observed differences could be induced by confounding factors (e.g. soil or climatic factors), or fundamental differences in the system design such as differences in crop rotation (Kirchmann et al., 2016). Most often, systems are compared by 'labels' without specifying to which extent these systems actually differ in terms of cropping practices (Armengot et al., 2011; Therond et al., 2017). However, information on cropping practices is crucial when it comes to understand and explain the observed effects on yield, plant performance or soil properties. The amount of organic amendments, the intensity of tillage, the extent of fertiliser inputs, the number and amount of pesticides used, and the crop diversity may vary drastically within a given type of cropping system.

Indicators of agricultural practices can be used to achieve such a description. Many sets of indicators aiming at describing farming and cropping systems exist, from simple ones to complex multi-dimensional assessment tools (Bockstaller et al., 1997; Bockstaller et al., 2008; Pelzer et al., 2012). The choice of the indicators depends on the objective of the study. In many studies, indicators are chosen to characterise the sustainability of the system or the intensity of management and practices (i.e. land-use intensity LUI) (e.g. Bechini and Castoldi, 2009; Geiger et al., 2010; Gaudino et al., 2014; Smith et al., 2017). These primary indicators can then be combined to obtain secondary composite indexes (Nardo et al., 2005; Castoldi and Bechini, 2010; Blüthgen et al., 2012) to reduce the dimensionality of the data and allow more straightforward interpretations of the results. A drawback of this is obviously the loss of information and the potential concealing of trade-offs between practices. Different methods to build these composite indexes exists (Nardo et al., 2005), the two most common being additive aggregation of indicators after normalisation (e.g. Herzog et al., 2006; Blüthgen et al., 2012) and the use of multivariate analyses such as PCA (e.g. Armengot et al., 2011; Nkurunziza et al., 2017). However, the collection of the data needed to implement such indicators is a daunting task and thus simple and reliable indicators, based on data that is reasonably easy to obtain, are required.

Here, we present results from an on-farm study conducted in Switzerland in 2016-2017, on winter wheat fields belonging to three cropping systems, conventional, no-till and organic. A survey was conducted to gather information about management and cropping practices at field and farm scale. Based on these data, 31 indicators of different complexity levels were computed to cover the main characteristics of the cropping systems. For three thematic categories of indicators, composite indexes were computed using the multivariate and additive aggregation methods.

The aims of this study were a) to assess the complementarity and redundancy of the 31 chosen indicators and of the composite indexes and b) to evaluate the potential of these indicators to characterise the three cropping systems.

2. Materials and Methods

2.1 Farm and field selection

Sixty farms (one field per farm) distributed over the Swiss plateau (Supplementary Material Figure S1 and Table S1) were selected for this on-farm study conducted in 2016-2017. Three different cropping systems were studied, with 20 fields selected for each system. The first group of 20 fields corresponded to 'conventional' system, with soil tillage and potential use of synthetic substances. The second group consisted of 'no-till' fields, i.e. without any soil tillage except for occasional use of strip till (mainly 0-1 time over 5 years, max 2-3 times), and potential use of synthetic substances. The third group contained fields in organic farms, with more or less deep and intense soil tillage, but no use of synthetic substances. All farms had to comply to their specific cropping system for more than five years. All conventional and no-till farms followed the ‘Proof of Ecological Performance’ guidelines from the Swiss Federal Office for Agriculture, which include a balanced nutrient budget, diversified crop distribution (at least four different main crops per year), proper soil protection, targeted selection and use of pesticide treatments and biodiversity promoting surfaces (FOAG, 2018a). Organic farms followed the guidelines of Bio Suisse, which is the federation of Swiss organic farmers. Prerequisites were that the fields should have been seeded with winter wheat in autumn 2015 and be larger than 1 ha. Winter wheat fields were targeted as this is the most frequent crop in

Switzerland, representing more than 20% of the arable surface (FSO, 2016). The most common crop rotation in the type of farms studied here has a cereal crop every two years; and the most cultivated crops outside from cereals are maize (silage or grain), rapeseed and sugar beet. Fields belonging to Cambisols with minimum 10% to maximum 40% of clay were targeted (Figure S2).

In order to check for a potential sampling effect on differences between cropping systems, information about six pedoclimatic variables (clay and silt content (0-20 cm), altitude, mean annual temperature and precipitation) were also gathered. Temperature and precipitation data were taking from the closest available weather station for each field.

2.2 Cropping practice indicators

Cropping practices were characterised according to 31 indicators, grouped into six thematic categories, as described below and summarised in Table 1. The data needed to compute these indicators were gathered from the farmers through a survey. Most questions were closed questions, i.e. several options of pre-defined answers were given. Information about the general farm structure and the specific cropping practices of the selected winter wheat field were collected (Table S2). Two types of time periods were used to collect data on cropping practices of the winter wheat field: detailed information on all cropping practices including dates of treatment for the crop cultivation year (winter wheat 2015-2016, period going from the harvest of the previous crop to the harvest of the winter wheat), and information on the five-year crop rotation, gathered for the wheat year and the four preceding years (2012-2016) (Table 1 and S2). The used indicators were chosen among published indicators or standard farm or field descriptors. These indicators differed in their complexity, i.e. the amount of information needed to compute them.

Because survey results could not be obtained from one of the farms, all analyses involving cropping practice indicators were performed on 59 values (19 for the 'conventional' group, 20 for the 'no-till' group and 20 for the 'organic' group).

Farm structure

For this category, the indicators concerned the farm scale, whereas the five other categories refer to field scale. Farm structure was described by three indicators: utilised agricultural area, including fallow surface ('UAA', in ha), annual working unit ('AWU', full time equivalent, a value of 1 corresponds to 1 person working full time on the farm the whole year) and livestock unit per hectare of UAA ('LSU', a value of 1 corresponds to 1 dairy cow per hectare) (Table 1). In addition, the diversity at the farm level in the year 2016 including crops, leys and fallows, was assessed (‘farmDiv’).

Crop diversification

Crop diversification was addressed using five indicators. The number of years in ley (‘nbLeys’), the number of legumes (‘nbLeg’) and cover crops (‘nbCC’) occurrence during the five-year crop rotation 2012-2016 was quantified. Legumes species count included main crops as well as cover crops. The number of cover crops was also compared to the potential maximum number of cover crops that could have been cultivated given the crop rotation. It was assumed that a cover crop could be cultivated whenever there were more than eight weeks between the harvest of the previous crop and the seeding of the new one, based on standard harvest and seeding dates. Crop diversity (‘cropDiv’) was then computed as the number of different crops (main and cover) cultivated during the five years. A crop rotation diversification index (‘rDiversification’) was derived following the Indigo method (Bockstaller and Girardin, 2000), adapted here for a five-year duration. This indicator takes into account crop rotation diversity, identity of the preceding crop and the time to the previous wheat crop.

Soil disturbance and protection

A total of seven indicators were selected to assess soil disturbance and protection. Field traffic (‘traffic’) was the number of interventions on the field, all type of interventions included, during the wheat cultivation period 2015-2016. The number of tillage (‘nbTill’) and mechanical weeding (‘nbWeed’) operations during that period were also used as indicators. Then, the mean number of tillage and weeding interventions over the five-year crop rotation (‘nbTW’) was computed. Fifth, a simple soil protection index (‘soilP’) was derived from the IDEA method (Zahm et al., 2008), based only on the type of soil tillage adopted in the last five years. It consisted in attributing a weight to each type of tillage (plough=0.5, reduced tillage=3, no-till=5) for each year of the crop rotation, and then averaging it. Soil tillage intensity rating (‘stir’) was computed for the wheat cultivation period, based on the disturbance induced by each tillage implement ('Soil Tillage Intensity Rating STIR' method from the RUSLE2 framework, USDA, 2012). In this method, a tillage intensity coefficient is attributed to each type of tillage implement as a function of tillage depth, area, speed and intensity. A list of such coefficients for different machines and interventions are available from the RUSLE2 method. The total tillage intensity was computed as the sum of these coefficients for all the interventions done during seedbed preparation and weeding. Last, the mean soil cover (‘sCover’) provided by crop residues or cover crops during the pre-sowing period (from the harvest of the preceding crop to the seeding of the winter wheat in 2015) was assessed using the soil cover indicator described by Büchi et al. (2016). It is based on standard values of soil cover by crop residues after harvest and incorporation rate by tillage implements. A minimal threshold value of 30% cover is generally seen as providing proper soil protection (Armand et al., 2009; Lilley and Moore, 2009; FAO, 2018).

Organic matter inputs and nitrogen fertilisation

The topic of organic matter was represented by five indicators. First, crop residue management (‘resExp’) was evaluated by the frequency of crop residue exportation during the five-year crop rotation. Second, the number of organic amendment inputs (‘nbOrg’) over the crop rotation was counted. Third, an estimation of the corresponding quantity of stable organic matter input (‘qOrg’, kg OM/ha) was computed on a dry matter basis, using isohumic coefficients of each type of amendment (e.g. manure, slurry, compost) (Table S3). Fourth, the amount of organic matter inputs coming from aboveground crop residues (‘cropOrg’, kg OM/ha) were derived from the 'Indigo' method (Bockstaller et al., 1997). Fifth, the total organic matter input (‘totOrg’, kg OM/ha) was estimated, by adding inputs coming from crop residues to inputs coming from amendments.

Nitrogen fertilisation during the wheat cultivation year was described, first, by the amount of nitrogen coming from mineral fertilisers (‘minN’), second by the amount of available nitrogen coming from organic amendments (e.g. manure, slurry, compost) (‘orgN’), and third, by the total amount of available nitrogen (‘totN’), taking into account mineral and organic sources. For organic amendments, the nitrogen available for the crop was extracted from the Swiss principles of agricultural crop fertilisation (Sinaj and Richner, 2017), except for digestate (CSICM, 2010) and ramial chipped wood (CTACF, 2006) (Table S3).

Crop protection

The frequency of pesticide treatments during the cultivation year 2015-2016 was evaluated by five indicators. First, the number of herbicide treatments (‘nbHerb’), number of fungicide treatments (‘nbFung’) and total number of treatments (‘nbTreat’, i.e. herbicide, fungicide, molluscicide, insecticide, growth regulator) were computed. When several products were applied together, each product counted as a separated treatment. Then, an herbicide (‘rHerb’) and total ('rTreat') relative treatment frequency index was computed, based on the index developed in France (Hossard et al., 2017). This index is computed as the sum of the ratio of applied treatment dose over recommended dose, over all treatment applications. The recommended dose of each product was extracted from the website of the Swiss Federal Office for Agriculture (FOAG, 2018b). When a range of doses was indicated, the mean value was used.

Yield

Wheat yield in 2016 as recorded by the farmer was considered ('yield', t/ha), as well as relative yield ('relY') over the five-year crop rotation. The farmers generally estimated yield as the ratio between the total amount of wheat grain sold and the cultivation surface. Relative yield was computed as the mean ratio of effective yield (as recorded by the farmers) over Swiss reference yield of the different crops (Sinaj and Richner, 2017). Each crop has a unique reference yield value for Switzerland, determined for conventional practices.

2.3 Composite intensity indexes

Two composite indexes were computed based on subsets of indicators to characterise the intensity of cropping practices, using two different methods.

Multivariate approach index I_{PCA}

The first method consisted in using as composite index, thereafter called I_{PCA}, the first principal component of a PCA performed on the selected indicators, after standardisation of the variables (e.g. Armengot et al., 2011).

Additive aggregation index I_{add}

In the second method, the composite index, thereafter called I_{add}, is based on an additive combination of the indicators after normalisation, as in Herzog et al. (2006). For each indicator, normalisation was done following Herzog et al. (2006), to scale the values between 0 and 1, 1 representing the highest and more intense value:

$$nI = (y_i - y_{min})/(y_{max} - y_{min}) \quad (1)$$

where nI is the normalised indicator, y_i the individual values, y_{min} the minimal value and y_{max} the maximal value. In order to reduce the influence of outliers, we followed the recommendation of Nardo et al. (2005) and replaced the y_i values higher than the 97.5% or lower than the 2.5% percentiles by these threshold values. The composite index I_{add} was then obtained by averaging the normalised indicators, with similar weight for all indicators.

$$I_{add} = \frac{\sum_{i=1}^{n} nI}{n} \quad (2)$$

where n is the number of indicators to aggregate.

In contrast to the PCA method, which is 'neutral', here a decision about the direction of each indicator must be done prior to the aggregation. 'Direction' is meant as a statement about which values (high or low, or sometimes even intermediate) represent the most intense practice. While this could be relatively straightforward for some indicators, as for example for the number of pesticide treatments, it could be more debatable for some others, for example for the input of organic matter. The direction of the intensity gradient could also depend on the intended use of the index: an index to interpret environmental impact could be built differently from and index to interpret soil organic carbon stocks. Thus, in some cases, individual indicators need to be reversed to have all indicators pointing in the same direction. This was done here by using 1-nI rather than nI in the final aggregation (Table 2).

These two composite indexes were computed for the three categories Crop diversification, Soil disturbance and protection and Organic matter inputs and nitrogen fertilisation. No composite index was computed for the Crop protection category as the indicators total number of treatments ‘nbTreat’ and total treatment frequency index ‘rTreat’ already represented an aggregated information about different pesticide treatment applications.

For each category, the indicators included in the composite indexes were chosen in order to exclude highly correlated indicators (Kendall's rank correlation $\tau>0.7$, see section 2.4) and indicators of high complexity (requiring a lot of information to be computed), in order to study if composite indexes based on simple indicators provide the same type of information as complex indicators. The indexes obtained with each method were compared with each other as well as with the more complex indicators in the same category, if available (Table 2). The indicators used to compute the composite indexes, and their direction for the computation of the additive aggregation index I_{add}, are shown in Table 2.

2.4 Data analyses

Differences between the three cropping systems for pedoclimatic variables, primary cropping practice indicators and composite indexes were analysed using analyses of variance, with cropping system as the main factor. Significant analyses of variance ($p<0.05$) were followed by Tukey HSD post hoc test for pairwise comparison.

For each thematic category, correlation between indicators was assessed with Kendall’s rank correlation method. In addition, principal component analyses were performed, after standardisation of the data, using the 'vegan' R package (Oksanen et al., 2017).

Following the same method, a principal component analysis was performed using all primary farm and field indicators.

The results obtained for the farm structure indicators were compared to Eurostat data (Eurostat, 2018) to situate the studied farms relative to other European countries. Data from the 2010 Eurostat survey were used as they also included data from Switzerland. The proportion of area under organic farming (%UAA) in 2016 was also shown for comparison purpose.

All statistical analyses were performed using R 3.5.1 (R Core Team, 2018).

3. Results

3.1 Field characteristics

Of the 60 fields, the most frequent soil texture (ISSS texture triangle) was clay loam (31 fields), followed by loam (13), light clay (12), silty clay loam (2) and silty clay (1) (Figure S2). The proportions of these textures did not differ between cropping systems (Chi-square test, $p=0.646$). Altitude ranged between 356 m and 754 m above sea level, mean annual temperature (2015-2016) between 9.3 °C and 11.7 °C, and mean annual precipitation (2015-2016) between 680 mm and 1322 mm. However, the three cropping systems did not show significant differences for these variables ($p>0.05$, based on analyses of variance). Thus, no confounding effect of the pedoclimatic variables could be seen here.

3.2 Complementarity versus redundancy of indicators of different complexity

Farm structure

At the farm level, the indicators were generally not correlated, except for utilised agricultural area UAA and working units AWU which showed a slight positive correlation (Kendall's rank correlation $\tau=0.50$, $p<0.001$), also visible in the PCA (Figure 1A). Farm scale diversity farmDiv was also significantly positively correlated with UAA but the correlation was weak ($\tau=0.26$, $p<0.007$).

Crop diversification

Overall, the Crop diversification indicators showed some complementarity and were not highly correlated with each other (Figure 1B). Compared to the simpler indicators, the complex crop rotation diversification indicator rDiversification takes into account different type of information (i.e. crop rotation diversity, identity of the preceding crop and the time to the previous wheat crop). It was slightly correlated with crop diversity cropDiv (Kendall's rank correlation τ=0.30, $p<0.004$), but not with all the other indicators presented here (Figure 1B). Crop diversity was positively correlated with the number of cover crops nbCC (τ=0.60, $p<0.001$) and negatively correlated with the number of leys nbLeys (τ=-0.53, $p<0.001$). The number of leys was also correlated with nbCC (τ=-0.54, $p<0.001$) and the number of legumes nbLeg (τ=-0.44, $p<0.001$).

The composite indexes were computed using nbCC, nbLeys, nbLeg and cropDiv. The index based on the PCA I_{PCA} was positively correlated with nbLeys and nbLeg but negatively with nbCC and cropDiv (Figure S3). In contrast, the index based on the additive aggregation I_{add} was, by construction, positively correlated with the four indicators. These two composite indexes I_{PCA} and I_{add} were not correlated with each other, but I_{add} was weakly correlated with the complex crop rotation diversification indicator (τ=0.21, p=0.027).

Soil disturbance and protection

The indicators linked to soil disturbance and protection showed high redundancy, with almost all indicators significantly correlated with each other (Figure 1C). In particular, the complex soil tillage intensity indicator stir was correlated with all the others, with some correlations higher than 0.6. For example, the simple soil protection indicator soilP, which relies only on the general type of tillage (plough, minimum or no-till) applied each year, was correlated with the stir indicator (τ=-0.47, $p<0.001$), which integrated more specific information about crop management. The other complex indicator linked to soil cover sCover was also correlated with all the other except traffic. The sum of tillage and mechanical weeding interventions in 2016 nbTW was highly correlated with the mean number of tillage nbTill and weeding nbWeed interventions over the five-year crop rotation (τ=0.73, $p<0.001$), showing that, in this study, most farmers were consistent through time in terms of interventions (i.e. tillage and weed management).

Given these high correlations between indicators, only four basic indicators were used to compute the composite indexes (traffic, nbTill, nbWeed and soilP). The index based on the PCA I_{PCA} was positively correlated with traffic, nbTill and nbWeed but negatively with soilP (Figure S3). A similar result was obtained for the index based on the additive aggregation I_{add}. These two composite indexes I_{PCA} and I_{add} were highly correlated with each other ($\tau=0.91$, $p<0.001$), and with the complex indicators stir ($\tau=0.68$ and 0.64, $p<0.001$) and sCover ($\tau=-0.35$ and -0.34, $p<0.001$).

Organic matter inputs and nitrogen fertilisation

Some significant correlations were observed between indicators linked to organic matter and N inputs (Figure 1D). The number of organic amendments nbOrg was not related with the amount of organic matter provided qOrg ($\tau=0.17$, $p=0.124$). The total amount of organic matter input totOrg was highly correlated with qOrg ($\tau=0.72$, $p<0.001$), as the input through crop residues cropOrg was small compared to the total quantity. In turn, the organic matter coming from crop residues cropOrg was correlated with the less complex crop residue exportation indicator resExp ($\tau=-0.37$, $p<0.001$). Total nitrogen fertilisation totN was highly correlated ($\tau=0.72$, $p<0.001$) with mineral fertilisation minN, as the amount provided by organic fertilisation orgN was low. This category thus contained two indicators which were computed as the sum of two others (totOrg = cropOrg+qOrg and totN = minN+orgN), and these showed high correlations with one of their components, totOrg with qOrg and totN with minN. They were thus not used to compute the composite indexes. Here, the index based on the PCA I_{PCA} was positively correlated with resExp, nbOrg and orgN, and negatively with qOrg, cropOrg and minN (Figure S3). The index based on the additive aggregation I_{add} was positively correlated with all indicators except cropOrg. These two composite indexes I_{PCA} and I_{add} were slightly correlated with each other ($\tau=0.25$, $p=0.005$), but not with totOrg. I_{PCA}, but not I_{add}, was significantly correlated with totN ($\tau=-0.45$, $p<0.001$).

Crop protection

Crop protection indicators were highly correlated to each other (Figure 1E). The total number of treatments nbTreat was correlated with its two main components, the number of herbicides nbHerb ($\tau=0.72$, $p<0.001$) and of fungicides nbFung ($\tau=0.55$, $p<0.001$).

In this study, adding a level of complexity to the crop protection indicators, by passing from the number of pesticide treatments to an integration of applied doses did not bring new insights (Figure 1E). The number of herbicide treatments nbHerb was highly correlated to the relative frequency index rHerb ($\tau=0.90$, $p<0.001$), a similar result was observed for the total number of treatments nbTreat and its relative frequency index rTreat ($\tau=0.90$, $p<0.001$).

Yield

Overall, wheat grain yield in 2016 was positively correlated with the relative yield indicator obtained over the five-year crop rotation relY ($\tau=0.58$, $p<0.001$) (Figure 1F). However, the correlation coefficient for the no-till systems ($\tau=0.28$, non-significant, $p=0.08$) was much lower than for the conventional ($\tau=0.54$, $p=0.001$) and organic systems ($\tau=0.58$, $p<0.001$). This was probably due to the high variability in fungicide use among no-till systems, which had a strong impact on 2016 wheat yield given the high disease pressure induced by the wet spring.

3.3 Potential of indicators to characterise cropping systems

Of the 31 primary indicators, 20 showed significant differences between the three cropping systems ($p<0.05$, Supplementary Material Table S4). Looking at the pairwise difference tests showed that the pattern of difference between systems (*i.e.* which systems are significantly different from the other(s)) varied widely depending on the indicators (Table 3).

Farm structure

The farm structure indicators did not generally differ between systems (Table 3). The test for livestock unit LSU gave a significant p-value (p=0.035, Table S4), but the post hoc test did not reveal pairwise significant differences at a threshold of 0.05 (Table 3). The tendency was however to a lower livestock value for no-till systems compared to conventional (p=0.077) and organic ones (p=0.053) (Table S4). Utilised agricultural area UAA, annual work unit AWU and diversity at the farm level in 2015-2016 farmDiv showed no differences between cropping systems (Table S4).

Crop diversification

The number of leys, legumes and cover crops in the five-year crop rotation differed between the three cropping systems (Table 3). The number of years with leys nbLeys was higher in the organic system than conventional and no-till systems. This pointed to a difference in crop rotation between this system on one side and conventional and no-till systems on the other side (Figure S4). For the number of legumes nbLeg, the lowest value was observed in conventional fields, compared to no-till and organic systems. Finally, no-till systems had more often cover crops (nbCC) than organic systems, while conventional systems were intermediate between no-till and organic, and not significantly different from both (Table 3). Compared to the potential maximum number of cover crop cultivation (computed based on the five-year crop rotation), conventional systems reached 38% of cover crop potential, no-till 57% and organic 44%. Organic systems had generally a lower number of potential cover crop cultivation slots compared to conventional and no-till, due to the higher presence of leys, which explained its higher percentage of actual to potential cover crops compared to conventional systems.

Crop diversity cropDiv and crop rotation diversification rDiversification were not different among the three cropping systems (Table 3, Figure 2A).

Soil disturbance and protection

All Soil disturbance and protection indicators except field traffic showed differences between systems (Table 3). The number of tillage nbTill and mechanical weeding nbWeed intervention during the period 2015-2016 differed between systems, with higher number of tillage operations in the organic than conventional systems. Only the organic systems included mechanical weeding. For the mean number of tillage and weeding interventions over the five-year crop rotation nbTW, and for the tillage intensity rating stir (Figure 2B), the highest values were observed for the organic system, followed by conventional, and then by no-till systems. The soil protection index soilP and soil cover sCover had higher values in the no-till systems compared to the conventional and organic ones. The estimated soil cover during the post-harvest, pre-sowing, period was significantly higher in no-till systems, with a mean value of 56%, than in conventional and organic systems (28% and 18% respectively).

No differences between cropping systems were observed regarding total field traffic during the wheat cultivation period 2015-2016, with around 10 interventions on average.

In addition, the use of these Soil disturbance and protection indicators allowed to identify an outlier in the no-till farms, corresponding to the misclassification of one of the farms. For this farm, the actual cropping practices adopted by the farmer did not match the 'no-till' classification the farmer announced during the initial selection, as he practiced some minimum tillage.

Organic matter inputs and nitrogen fertilisation

The indicators linked to nitrogen all differentiated the organic systems compared to conventional and no-till systems (Table 3). As expected, no mineral nitrogen fertilisation was reported in organic system, while no-till and conventional systems showed similar values of mineral fertiliser minN (Table 3, Figure 2D). The opposite was observed for available nitrogen coming from organic amendments orgN, with higher value observed for organic systems compared to conventional and no-till systems. In total, conventional and no-till systems, with on average 160 and 147 equivalent kg N/ha, showed higher amount of available N than organic system (61 equivalent kg N/ha on average).

None of the five indicators linked to organic matter showed significant differences between cropping systems at $p<0.05$ (Table 3, Figure 2C). However, the p-value for the number of organic amendments nbOrg was at 0.055, indicating a tendency of organic systems to have a larger number of inputs (but not higher quantity).

Crop protection

All Crop protection indicators varied between cropping systems (Table 3). As expected, no treatment was recorded in the organic system. No-till systems showed significantly more herbicide treatments than the conventional ones. The highest number of fungicide treatments was in conventional system. In total, conventional and no-till had comparable number of pesticide treatments (3 in average), higher than in organic system. The two relative treatment frequency indexes (rHerb and rTreat) showed similar tendency as the corresponding number-based indicators (nbHerb and nbTreat) (Figure 2E, Table 3).

Yield

Overall, mean wheat grain yield in 2016, as reported by the farmers, reached about 4.6 t/ha (at 14% humidity). This represented about 80% of the wheat yield usually observed in the same fields, for all three cropping systems. The reduced yield was due to an extremely wet spring in 2016. Indeed, the cumulated precipitation in April-May 2016 was 240 mm (Changins, west of Switzerland) and 252 mm (Reckenholz, north-east), whereas the 30-year averages (1981-2010) for April-May at the same stations are 153 mm and 193 mm. Wheat yield in 2016 was higher in the conventional and no-till systems than in organic farming (Table 3). Relative yields over the crop rotation (2012-2016) differed significantly among all three cropping systems (Figure 2F): compared to the Swiss reference yields (for conventional practices), the mean relative yield was 1.05 for the conventional system, 0.93 for no-till and 0.70 for organic systems. This means that conventional yield in our study were on average 5% higher than Swiss reference yield for the same crops, for the period 2012-2016. When comparing the three systems together, taking the conventional system as the reference, no-till yield reached 90% of the conventional yield, while organic yield was at 67% of the conventional one. For no-till and organic fields, no relationship between relative yield and time since the start of respectively no-till and organic practice could be observed (Figure S5).

<u>Multivariate analysis of primary indicators</u>

The principal component analysis performed on all the primary indicators allowed to distinguish the three cropping systems on the three first components, despite high variability within each system (Figure 3). The organic system was the most clearly delineated group, while overlap was observed between conventional and no-till. The first axis (explaining 30% of variance) placed the conventional system intermediate between no-till and organic, while the second axis (explaining 11% of variance) rather separated conventional system from no-till and organic (Figure 3). The three indicators contributing most to the first axis were mineral nitrogen fertilisation minN, number of herbicide treatments nbHerb and number of weeding interventions nbWeed. For the second axis, the three most contributing indicators were number of fungicide treatments nbFung, soil protection soilP and field traffic (Figure 3).

<u>Composite intensity indexes</u>

Significant differences between the three cropping systems were observed for five out of the six composite indexes (Figure 4, Table 3). For the Crop diversification category, the two composite indexes I_{PCA} and I_{add} were different between systems, but the index based on PCA showed higher values for the organic systems, while the index based on additive aggregation was lower for the conventional systems (Figure 4). For Soil disturbance and protection, the two composite indexes I_{PCA} and I_{add} differentiated the three systems, with higher values for the organic system, followed by conventional, and then by no-till systems (Figure 4). For Organic matter inputs and nitrogen fertilisation, I_{PCA} showed higher values in the organic systems, while I_{add} was not different between the three systems (Figure 4).

3.4 Comparison with other European countries

Figure 5 shows the position of Switzerland and of the studied farms among 31 other European countries, according to the three farm structure indicators. Unfortunately, it was not possible to find separated data for conventional, no-till and organic systems, and thus our results are compared to overall European data. The mean utilised agricultural area in Switzerland is in the middle of the European distribution, whereas our study included somewhat larger farms. Annual working units were also similar to what is seen in other European countries. In comparison with Europe, the area under organic farming (%UAA) in Switzerland in 2016 (13.5%) is at the sixth position, with the highest value recorded in the neighbouring country of Austria (21.3%).

To compare the cropping practices applied in Switzerland to what is done in Europe, we used the survey conducted by Herzog et al. (2006) in seven European countries (i.e. Belgium, Czech Republic, Estonia, France, Germany, Netherlands and Switzerland) to provide relevant insights. As the indicators used in this survey were not directly comparable to ours, we used this paper as a reference to give an idea of where Switzerland is situated compared to the other countries for conventional systems. This showed that, for nitrogen fertilisation on arable crops [kg N/ha], number of herbicide, fungicide and total treatments, Switzerland ranked in the middle of the seven studied countries, with ranks between 3.5 and 5. For crop diversity, Switzerland ranked at the 2nd position, after Germany (Supplementary material Figure S6).

4. Discussion

4.1 Selection, definition and comparison of primary cropping practice indicators and composite intensity indexes

In this study, the indicators were chosen to cover the main characteristics of cropping systems, especially at the field level, taking into account the potential availability and reliability of the data needed to compute the indicators. The topics covered here were similar to those appearing in other similar studies (e.g. Nkurunziza et al., 2017 and Gaudino et al., 2014), but included only so called ‘driving forces’ or ‘causal’ indicators (Bockstaller et al., 2015). Among the topics not addressed here, irrigation indicators were not included as generally not practiced on winter wheat fields in Switzerland. Indicators linked to P and K fertilisation, and five-year N fertilisation were not included either, but should be considered in a further development of this study. In Switzerland, P and K fertilisers are generally not applied annually but on a larger time scale, according to the duration of crop rotation or to the frequency of soil analysis. Thus the short term of this study would not have allowed to capture accurately P and K fertilisation practices.

A crucial question that arises when defining quantitative indicators is also the number of years which should be taken into account for computation. Indicators based on the studied cultivation year are easier to compute as they require information that the farmer is likely to access easily or remember accurately. On the other hand, indicators based on a longer time scale should better capture the usual practices and are more pertinent for some practices such as organic amendment inputs, which are often not applied each year. In addition, longer time scale indicators would be more pertinent to explain slowly changing characteristics such as soil organic carbon content. They are, however, more difficult to compute because they require information spread over several years. Therefore, the multiyear indicators presented here were based on less detailed information, likely to be easily retrieved from the farmers. In this study, the utilisation of one year and five-year indicators allowed to show that the wheat cultivation year studied seemed representative of the practices observed at the crop rotation scale. The same approach was adopted by Nkurunziza et al. (2017), with detailed data collected for the year of the study, and more general information collected for the preceding years.

The studied indicators also differed in their complexity, i.e. the amount of data, reference values and assumptions needed to compute them. In this study, most of the complex indicators integrating several data and reference values were correlated with simpler indicators based on less data. (e.g. soil tillage intensity with the number of tillage and weeding interventions, soil cover with the simple soil protection indicator). The most complex indicators required a lot of reference data (e.g. reference yields, isohumic coefficients, …) to be computed, which induced a necessary simplification of the complex farm practices, and increased indicator uncertainty. However, the set of indicators was tested here in one specific context, and we cannot exclude that complex indicators could prove to be necessary if tested with other data. For example, here the relative phytosanitary treatment frequency index, taking into account the applied dose and area (% of field treated), was highly redundant with the number of treatments. This shows that in our specific study, most of pesticide applications were done at the full recommended dose and on the whole field. However, in other contexts it is highly likely that the more complex frequency index would provide more detailed information on the practices.

We also tested the potential of composite indexes to provide additional or simplify redundant information compared to the primary indicators. Many studies recommend using simple as well as composite indicators to best describe cropping systems (Herzog et al., 2006: Bockstaller et al., 2008: Castoldi and Bechini, 2010). Composite indexes have the advantage to sum up different information into one unique variable and so to facilitate overall conclusions and comparison between systems (e.g. Armengot et al., 2011, Blüthgen et al., 2012), while simple indicators remain essential to interpret the results more precisely. Many methods to build composite indexes exist (Nardo et al., 2005; Sadok et al., 2008), and two commonly used methods were investigated in this study.

Our results showed that the interpretation of the indexes could depend on the calculation method used. So, care should be taken when using composite indexes, and referring back to the individual components of the composite indexes is necessary to insure the proper interpretation of the results (Herzog et al., 2006). A good example of the problems which can occur when using the PCA method appeared for the Crop diversification category. While all the four individual indicators considered (frequency of leys, legumes, cover crops, and crop diversity) contribute to a higher diversification of the system, the first axis of the PCA composed a gradient with high diversity and cover crop frequency on one side, and high number of leys on the other side. This method here could not take into account the fact that different practices can achieve the same purpose, diversification in this case. Thus, this unconstrained method cannot guarantee that the composite index really shows the intended gradient. The PCA index can nevertheless be often meaningfully interpreted. In this case, cover crops contributed to higher diversity and thus pointed in the same direction, whereas the presence of rotational leys reduced diversity on a given time period by decreasing the number of main crops and cover crops that can be cultivated during this period. However, both can contribute to overall diversification. In contrast, in the additive aggregation method, the direction of interpretation of the individual indicators is *a priori* decided, which allows to construct meaningful gradients, even if the direction of some indicators is sometimes debatable. However, for the Soil disturbance and protection category, both methods produced similar composite indexes, showing that the PCA method could also be useful, provided that the produced gradient is carefully checked. The PCA method is thus highly dependent on the dataset on which it is based, while the additive aggregation method is mostly dependent on the computation procedure, such as the normalisation or weighing method used. Depending on the utilisation of the composite indexes, one or the other method should be preferred. For example, when the objective is to aggregate further these indexes to produce a unique multifunctionality index, the additive aggregation method is preferable for the first step, as it allows controlling the direction of the indexes, and thus insuring proper interpretation of the overall index. In contrast, the PCA method is more useful to explore datasets without preconceived ideas about underlying data structure and relationships between indicators.

4.2 Potential of indicators to characterise cropping systems

Farm level indicators

Including indicators common to European or international frameworks allowed to situate our study in a broader context, which could help the interpretation of the results. The farms in this study appear larger than the Swiss and European average. This could be partly explained by the fact that only lowland farms were selected for this study, excluding hill and mountain farms, which are generally smaller. This could also explain the lower values of livestock units in our study compared to the Swiss mean, but these values were in the range of what is seen in Europe. In Switzerland, most conventional farms follow the 'Proof of Ecological Performance' (PEP) guidance, which ensure, in principle, an equalised nutrient balance, diversified crop rotation and proper soil protection and pesticide treatment use (FOAG, 2018a). In this study, all conventional and no-till farms followed these prescriptions. This could explain some similarities between the conventional, no-till and organic systems, for example in terms of organic amendment inputs or crop rotation diversification. The application of these PEP guidelines in Switzerland could perhaps also explain the highest crop diversity observed by Herzog et al. (2006), whereas Switzerland was in line with the other studied countries for nitrogen inputs and pesticide treatments.

Primary cropping practice indicators and composite intensity indexes

The set of the 31 indicators used here allowed to characterise the three cropping systems studied. Around one third of them did not show differences between systems, while the others showed a variety of patterns of differences between systems. An important intra-system variability was also observed for most of the indicators. This demonstrates the importance of using cropping practice indicators rather than cropping system classification to assess and understand the impact of practices, particularly in broadly defined cropping systems (Armengot et al., 2011; Nkurunziza et al., 2017; Therond et al., 2017).

The three simpler Crop diversification indicators differentiated the three systems, while diversity and rotation diversification were similar between systems, with high within-system variability. However, overall, the indicators pointed to a lower diversification of conventional systems, which was confirmed by the composite index based on additive aggregation. This shows that no-till systems including cover crops as well as organic systems with rotational leys allow to increase diversification, a key factor of sustainable agriculture intensification (Smith et al., 2017).

The Soil disturbance and protection category was the one showing the major differences between systems. As expected, no-till systems had higher soil protection values compared to conventional and organic systems. Interestingly, these indicators also separated organic systems, and the composite indexes clearly showed the same pattern. To compensate for the absence of herbicide use, intense mechanical weeding was generally observed in organic fields, which yielded to higher values of soil perturbation indicators compared to conventional fields. This poses the question of the balance of the benefits of reduced pesticide products utilisation and the potential negative effects of increased soil disturbance in organic farming. Minimum soil tillage in organic farming is a challenge, but the development of more specific and efficient tillage implements and the adoption of cover crop cultivation, which was low in our studied organic farms, will probably allow a reduction of soil tillage intensity in organic farming (Buchanan et al., 2016; Cooper et al., 2016).

In contrast, indicators linked to Organic matter inputs, included the composite index based on additive aggregation, were similar between the three cropping systems. This finding is surprising as organic systems are generally thought to provide more organic matter to the soil, through organic amendments or inputs due to the introduction of leys in the rotation. In the organic system, the level of fertilisation was generally low, with an estimated N input to the 2016 wheat (61 kgN/ha, from organic source) less than half the Swiss (conventional) reference standard for N fertilisation of winter wheat (140 kgN/ha), while conventional and no-till systems showed similar, higher, values (160 kgN/ha and 147 kgN/ha, from both mineral and organic sources).

Crop protection indicators also allowed the differentiation of both no-till and organic systems compared to conventional ones. As expected, no pesticide treatments were used in the organic fields which were thus easily identified. The frequency of herbicide treatments was higher in no-till compared to conventional systems. The higher reliance on total herbicides in no-till system has been documented (Melander et al., 2013), and remains the principal environmental challenge with no-till. Minimum tillage, such as shallow tillage (5 cm) or strip till, along with the intensification of cover crop utilisation, could be a way of reducing herbicide use while preserving soil, which is a solution currently considered by some farmers. Less fungicide treatments were applied in no-till fields, reflecting the fact that they were more often managed according to so called extensive farming programs that forbids the use of pesticides other than herbicides. Except from farmers adopting no-till practices to save labour time, no-till farmers are generally adopting these practices to reduce the impact of agriculture on the environment, which explain their higher compliance with these extensive farming programs.

Overall, the organic system was the most homogeneous one in terms of cropping practices, which can be explained by the fact that this system has more specific rules than the no-till or conventional systems and bans several practices, principally mineral fertilisation and chemical crop protection. In contrast, conventional and no-till systems showed higher overlap in their practices, especially in terms of crop diversity, rotation diversification and fertilisation. This showed that, in this study, focusing on the 'no-till' criterion did not implicitly co-select other specific cropping practices.

Yield and relative yield cannot be considered as cropping practices like the other indicators presented here, but are the main outcomes of these practices and fundamental to interpret their sustainability. The no-till fields showed a mean decrease of yield of 10% compared to conventional ones on the five-year crop rotation, which is similar to what has been previously shown (Pittelkow et al., 2015a). This difference was, however, not significant for the 2016 wheat yield, and was partially linked to the compliance of farmers with the extensive farming programs mentioned earlier. Indeed, extensive conventional fields showed lower yield than intensive conventional ones, and thus more similar to no-till yields. In contrast, no difference was observed for extensive and intensive no-till yields. A yield decrease in the initial years of transition to no-till is generally expected, while the yield gap generally fills up after some years (Soane et al., 2012; Pittelkow et al., 2015b). The cover crop frequency tended to be higher in new no-till systems, pointing probably to a growing awareness of the importance of integrating no-till in an ensemble of sustainable practices amongst the younger no-till farmers compared to pioneer ones. A relative mean yield decrease of about 33% was observed in organic fields compared to conventional ones, which is slightly higher than what has been shown in global meta-analyses (~26% for cereals with high variability, de Ponti et al., 2012; Seufert et al., 2012). The yield difference between organic and conventional systems was even higher when looking only at the 2016 wheat yield, which showed a decrease of 40%. The 2016 spring was very wet and favourable to diseases, which could have been more detrimental for organic fields. Despite the low mean yield in the organic system, it is worthwhile mentioning that the highest organic yields were higher than some of the yields obtained in conventional or no-till systems. This showed that depending on the conditions and on the practices implemented, organic yield could achieve a reasonable productivity.

4.3 Conclusions

In this study, we employed 31 quantitative primary indicators and six composite indexes to describe the cropping practices in three different systems, i.e. conventional, no-till and organic systems. The set of indicators presented here integrates indicators of different complexity and time scale. It allows to characterise the three cropping systems and highlight differences as well as similarity within systems and within system variability. The composite indexes, based on simple primary indicators, proved to be useful to synthesise information of different indicators and delineate the systems. However, the method used to compute the indexes has an influence on their interpretation and should be carefully chosen. Here, the more complex primary indicators were often correlated with simpler ones or with the composite indexes, challenging their usefulness, but it cannot be excluded that they can prove to be more useful for different datasets or contexts. Retaining a combination of simple and more complex indicators to obtain a broad picture of the cropping practices adopted is thus recommended.

This study has demonstrated that an exhaustive and explicit description of the cropping practices involved in what is generally classified as different cropping systems is crucial to better understand the potential influence of these systems on yield or soil properties. For example, knowing the tillage intensity applied in organic fields would be of crucial importance to analyse and predict soil organic matter evolution. While the comparison of systems in terms of yield, soil properties or their influence on the environment is highly relevant, this study has shown that it is crucial to describe precisely and quantitatively the cropping practices involved to avoid any misinterpretation based on supposed or non-acknowledged differences.

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Table and figure legends

Table 1 List of the 31 cropping practice indicators used to describe cropping systems. 'Time scale' indicates if the indicator is computed with data coming only from the focal year 2015-2016 ('1 y') or from data collected for the five-year crop rotation ('5 y').

Table 2 List of primary indicators selected for the computation of the two composite indexes, for each thematic category, and complex or compound primary indicators used for comparison. Indicators preceded by a '-' were reversed for the computation of the additive aggregation index I_{add}. See Table 1 for the meaning of the indicator abbreviations.

Table 3 Mean values of the 31 primary indicators and six composite indexes for the three cropping systems, and patterns of differences between systems as indicated by the Tukey HSD post-hoc pairwise tests. 'conv': conventional farming, 'nt': no-till farming, 'org': organic farming.

Figure 1 Principal component analyses (field projection, scaling 2) on the indicator subsets, A. Farm structure, B. Crop diversification, C. Soil disturbance and protection, D. Organic matter inputs and nitrogen fertilisation, E. Crop protection. As for yield only two indicators were used, F. shows the pairwise relationship between wheat yield 2016 [t/ha] and relative yield over the five-year crop rotation. The plain line shows the linear regression between these two variables. The dashed horizontal line shows the Swiss reference yield for winter wheat (6 t/ha) and the dashed vertical line a relative yield which is equal to reference yields on average. Blue points correspond to conventional systems, red points to no-till systems and green points to organic systems. Correspondence between abbreviations and indicator names are given in Table 1.

Figure 2 Differences between cropping systems for six indicators. A. crop rotation diversification (rDiversification), B. soil tillage intensity (stir), C. quantity of organic amendment inputs (qOrg) [kg OM/ha], D. total nitrogen fertilisation (totN) [kg N/ha], E. relative herbicide treatment intensity (rHerb), F. relative yield (relY). 'conv': conventional systems, 'nt': no-till systems, 'org': organic systems. Different letters above the boxes show significant ($p<0.05$) pairwise differences between systems.

Figure 3 Principal component analysis on the 31 indicators, showing the two first principal components, explaining respectively 30% and 11%. A. Field projection (scaling 2) on the 1^{st} and 2^{nd} principal components, B. Indicator projection (scaling 1) on the 1^{st} and 2^{nd} principal components. Blue points correspond to conventional systems, red points to no-till systems and green points to organic systems. Correspondence between abbreviations and indicator names are given in Table 1.

Figure 4 Differences between cropping systems for the composite indexes. Upper row, indexes based on the PCA method, lower row indexes based on the additive aggregation. First column (A and D) shows the Crop diversification category, the middle column (B and E), the Soil disturbance and protection category, and the last column (C and F), the Organic matter inputs and nitrogen fertilisation category.

Figure 5 Comparison of the three farm structure indicators and of area under organic farming (% UAA) with mean data from Switzerland and European countries. Data were obtained from the Eurostat website. Blue points correspond to conventional systems, red points to no-till systems and green points to organic systems. On each box, ‘CH’ shows the position of Switzerland in the European dataset.

Supplementary Material

Table S1 List and description of the 60 farms included in the study. ‘Mean temperature’ and ‘Rainfall’ are given as average values over the two years 2015 and 2016. ‘Soil texture’ gives texture classes according to the ISSS system. ‘Program’ refers to compliance to specific ‘integrated’ (no pesticides except herbicides) or ‘organic’ programs in 2016. ‘UAA’ is for utilised agricultural area. ‘Fertilisation’ indicates what kind of fertilisation was used during the five-year crop rotation: ‘min’ = mineral only, ‘org’ = organic only, ‘min-org’ = mixed mineral and organic. The conventional farm indicated in light grey was removed from the analyses due to missing survey data.

Table S2 Data collected in the questionnaire survey (rows), filled in by the farmers, and used to compute the 31 cropping practice indicators (columns). The crosses indicate which data has been used for which indicator.

Table S3 Isohumic coefficients and nitrogen availability of organic amendments used in the computation of the organic amendment inputs (qOrg), total organic inputs (totOrg), nitrogen organic fertilisation (orgN) and total nitrogen fertilisation indicators (totN).

Table S4 Mean values and standard errors of the 31 indicators for the three cropping systems, and p-values from the overall analysis of variance ('global') and from the Tukey HSD post-hoc pairwise test. 'conv': conventional farming, 'nt': no-till farming, 'org': organic farming.

Figure S1 Map of Switzerland showing the geographic position of the 60 fields. Blue points correspond to conventional systems, red points to no-till systems and green points to organic systems.

Figure S2 Texture triangle (ISSS system) showing the texture (0-20 cm) of the 60 fields. Blue points correspond to conventional systems, red points to no-till systems and green points to organic systems.

Figure S3 Principal component analyses (field projection, scaling 2) used for the computation of the composite indexes for A. Crop diversification, B. Soil disturbance and protection, and C. Organic matter inputs and nitrogen fertilisation. Blue points correspond to conventional systems, red points to no-till systems and green points to organic systems. Correspondence between abbreviations and indicator names are given in Table 1.

Figure S4 A. Crop frequency for the studied fields, for the three cropping systems ('conv': conventional, 'nt': no till, 'org': organic). Crops are grouped into types. B. Categorisation of the crop rotation along three main types: 1. rotations with a cereal every two years, 2. rotations including leys, and 3. other type of rotations.

Figure S5 Relative yield indicator as a function of time since the beginning of A. no-till practice and B. organic practice. In panel A, the numbers above the points indicate the number of cover crops cultivated the past 5 years (number of cover crop ‘nbCC’ indicator).

Figure S6 Comparison of Switzerland with six other European countries in terms of crop diversity, nitrogen fertilisation and pesticide inputs. On each box, ‘CH’ shows the position of Switzerland. On the left of each box, the two-letter code of each other country is indicated, BE: Belgium, CZ: Czech Republic, EE: Estonia, FR: France, DE: Germany, NL: Netherlands.

The data come from Herzog et al. (2006).

Table 1

Indicator	Abbreviation	Time scale[a]	
Farm structure			
utilised agricultural area [ha]	UAA	-	
annual working unit	AWU	-	a value of 1 corresponds to 1 person working full time on the farm
livestock unit	LSU	-	a value of 1 corresponds to 1 dairy cow per hectare
diversity at farm level 2016	farmDiv	1 y	nb of crops, meadows or fallows at the farm level in 2016
Crop diversification			
number of years with ley	nbLeys	5 y	nb of years with ley in the 5 year rotation
number of legume crops	nbLeg	5 y	nb of legume cultivation (main and cover crop) in the 5 year rotation
number of cover crops	nbCC	5 y	nb of cover crop cultivation in the 5 year rotation
crop diversity at field level (rotation)	cropDiv	5 y	nb of crops in the 5 year rotation
crop rotation diversification	rDiversification	5 y	index taking into account crop diversity, preceding crop and time to previous wheat
Soil disturbance and protection			
field traffic	traffic	1 y	nb of machinery passages (tillage, seeding, weeding, treatments, fertilisation)
number of tillage 2015-2016	nbTill	1 y	
number of weeding 2015-2016	nbWeed	1 y	
number of tillage and weeding interventions 2012-2016	nbTW	5 y	mean number of tillage and weeding interventions over the crop rotation
soil protection index	soilP	5 y	index linked to the type of tillage (plough, minimum, no till)
soil tillage intensity	stir	1 y	index based on the soil disturbance intensity of each implement (e.g plough=81)
soil cover	sCover	1 y	mean soil cover during the period preceding wheat seeding
Organic matter inputs and nitrogen fertilisation			
crop residue exportation	resExp	5 y	nb of time residues were exported during the 5 year crop rotation
number of organic amendments	nbOrg	5 y	nb of organic amendements
organic amendment inputs [kg OM/ha]	qOrg	5 y	quantity of organic matter inputs through amendements
organic input from crops [kg OM/ha]	cropOrg	5 y	quantity of organic matter inputs through crop residues
total organic inputs (amendment + crop residues) [kg OM/ha]	totOrg	5 y	total quantity of organic inputs
mineral nitrogen fertilisation [kg N/ha]	minN	1 y	quantity of mineral nitrogen fertilisers
organic nitrogen fertilisation [kg N/ha]	orgN	1 y	quantity of available nitrogen through organic fertilisation

total nitrogen fertilisation [kg N/ha]	totN	1 y	
Crop protection			
number of herbicide treatment	nbHerb	1 y	nb of herbicide treatments
number of fungicide treatment	nbFung	1 y	nb of fungicide treatments
total number of treatments	nbTreat	1 y	total number of treatments (herbicide, fungicide, molluscicide, growth regulator)
herbicide treatment frequency index	rHerb	1 y	sum of the ratios of applied herbicide dose over recommended dose
total treatment frequency index	rTreat	1 y	sum of the ratios of applied treatment dose over recommended dose
Yield			
wheat yield 2016 [t/ha]	yield	1 y	
relative yield 2012-2016	relY	5 y	mean of the ratios of effective yield over Swiss reference yield

[a] 1 or 5 y: 1 year (from the harvest of the preceding crop to the wheat harvest) or 5 years (crop rotation)

Table 2

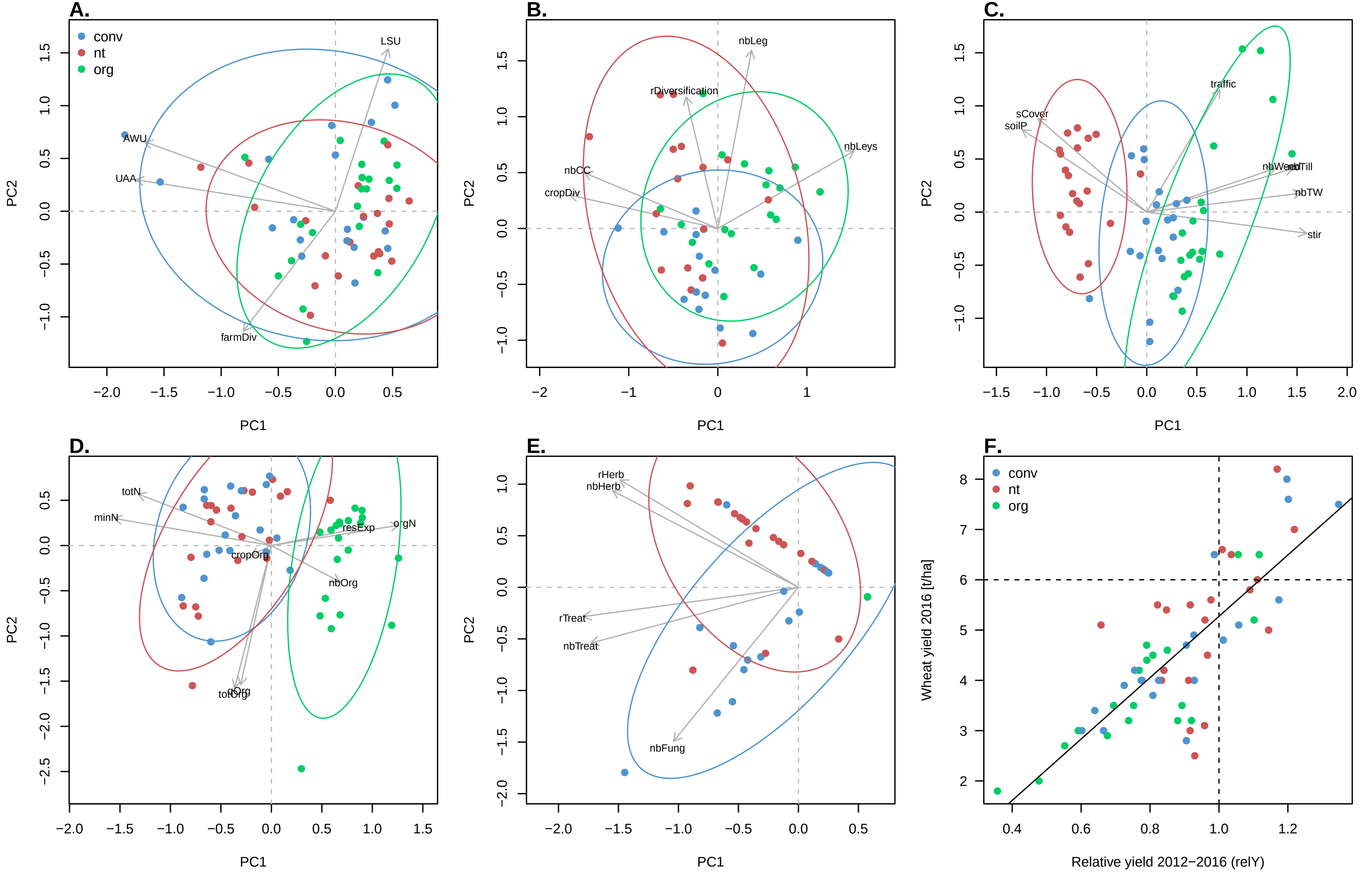
Thematic category	Primary indicators used for composite intensity indexes						Complex primary indicators	
Crop diversification	+nbLeys	+nbLeg	+nbCC	+cropDiv			rDiversification	
Soil disturbance and protection	+traffic	+nbTill	+nbWeed	-soilP			stir	sCover
Organic matter inputs and nitrogen fertilisation	+resExp	+nbOrg	+qOrg	-cropOrg	+minN	+orgN	totOrg	totN
Crop protection	-						rTreat	
Yield	-						relY	

Table 3

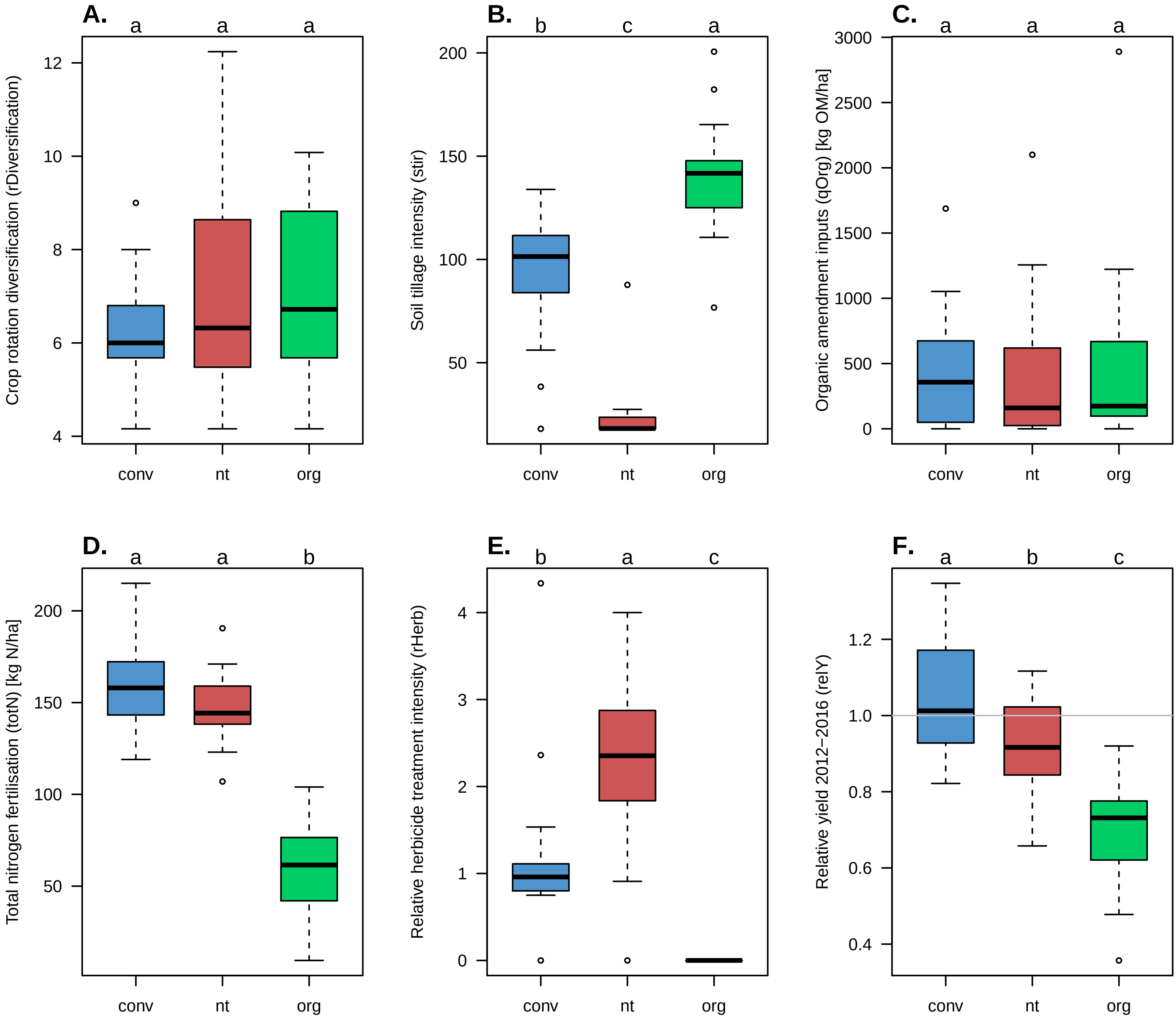
Indicator	Abbreviation	Overall means			Differences between systems				
		conv	nt	org	all different [a]	conv different [b]	nt different [c]	org different [d]	no difference
Farm structure									
utilised agricultural area [ha]	UAA	62	44	41					X
annual working unit	AWU	2.6	1.9	2.0					X
livestock unit	LSU	0.70	0.27	0.73					X
diversity at farm level 2016	farmDiv	6.58	6.25	7.15					X
Crop diversification									
nb years with ley	nbLeys	0.26	0.30	1.25				X	
nb legume crops	nbLeg	1.16	2.05	2.35		X			
nb cover crops	nbCC	1.16	1.90	0.85			X *	X *	
crop diversity at field level (rotation)	cropDiv	4.63	5.00	4.30					X
crop rotation diversification	rDiversification	6.17	7.18	7.00					X
composite index based on PCA		-0.08	-0.22	0.30				X	
composite index based on additive aggregation		0.28	0.40	0.39		X			
Soil disturbance and protection									
field traffic	traffic	10.5	9.1	9.8					X
nb tillage 2015-2016	nbTill	1.32	0.40	2.55	X				
nb weeding 2015-2016	nbWeed	0.00	0.00	2.35				X	
nb tillage and weeding interventions 2012-2016	nbTW	2.32	0.18	4.06	X				
soil protection index	soilP	1.63	4.72	1.82			X		
soil tillage intensity	stir	94	24	139	X				
soil cover	sCover	0.28	0.56	0.18			X		
composite index based on PCA		0.02	-0.52	0.50	X				
composite index based on additive aggregation		0.41	0.13	0.57	X				
Organic matter inputs and nitrogen fertilisation									
crop residue exportation	resExp	2.37	1.60	2.75					X
nb organic amendments	nbOrg	5.05	5.05	5.40					X
organic amendment inputs [kg OM/ha]	qOrg	465	435	470					X
organic input from crops [kg OM/ha]	cropOrg	683	726	708					X

total organic inputs [kg OM/ha]	totOrg	1148	1161	1178					X
mineral nitrogen fertilisation [kg N/ha]	minN	141	127	0				X	
organic nitrogen fertilisation [kg N/ha]	orgN	19	20	61				X	
total nitrogen fertilisation [kg N/ha]	totN	160	147	61				X	
composite index based on PCA		-0.29	-0.32	0.59				X	
composite index based on additive aggregation		0.40	0.35	0.36					X
Crop protection									
nb herbicide treatment	nbHerb	1.11	2.30	0.00	X				
nb fungicide treatment	nbFung	1.16	0.30	0.00		X			
total number of treatments	nbTreat	3.11	2.70	0.00				X	
herbicide treatment frequency index	rHerb	1.18	2.32	0.00	X				
total treatment frequency index	rTreat	2.77	2.71	0.00				X	
Yield									
wheat yield 2016 [t/ha]	yield	5.6	4.9	3.4				X	
relative yield 2012-2016	relY	1.05	0.93	0.70	X				

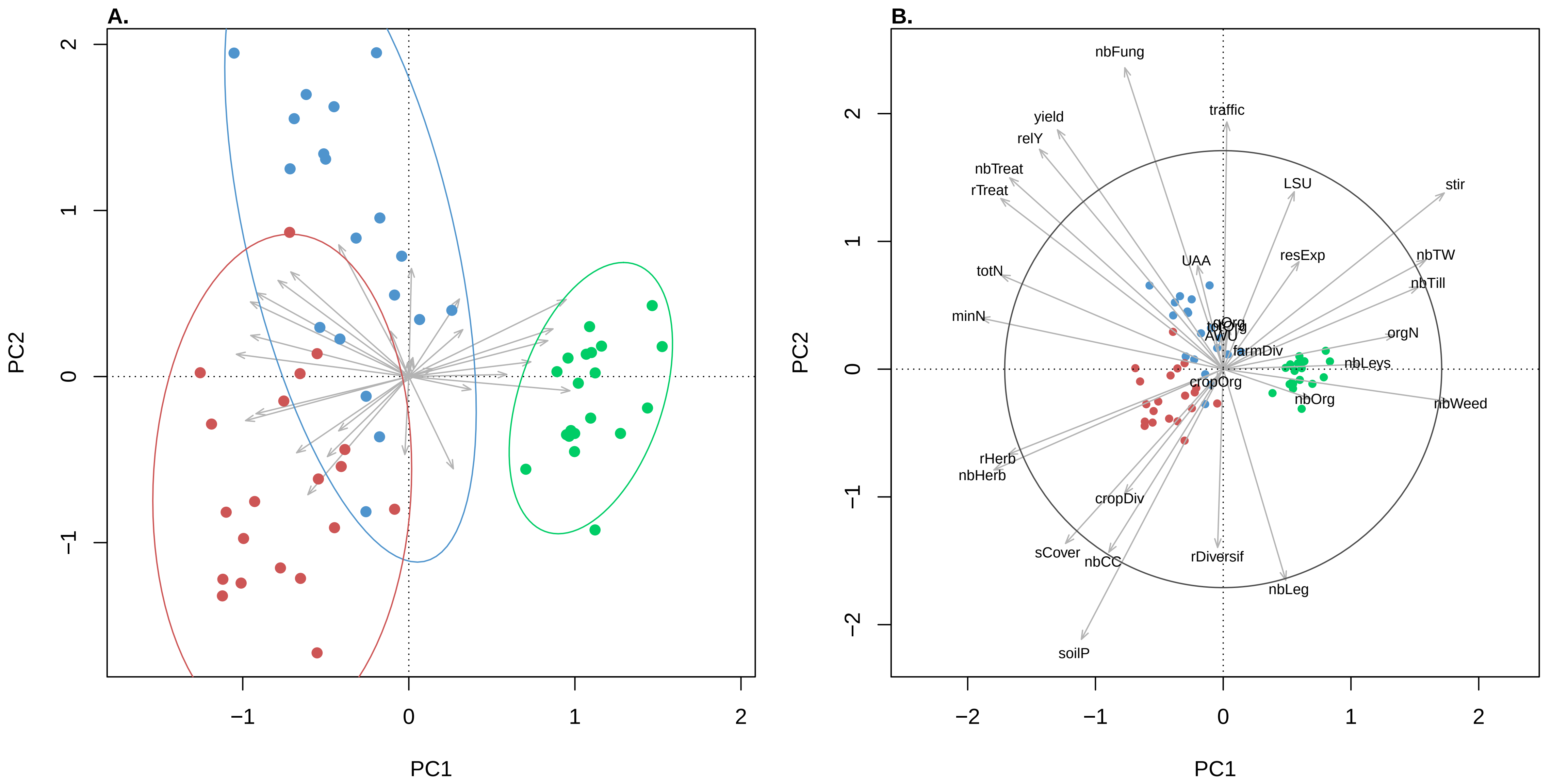
[a] significant differences between the three groups
[b] significant differences between conv-nt and conv-org, but not nt-org
[c] significant differences between nt-conv and nt-org, but not conv-org
[d] significant differences between org-conv and org-nt, but not conv-nt
* significant difference between nt-org, but not between conv-nt and conv-org

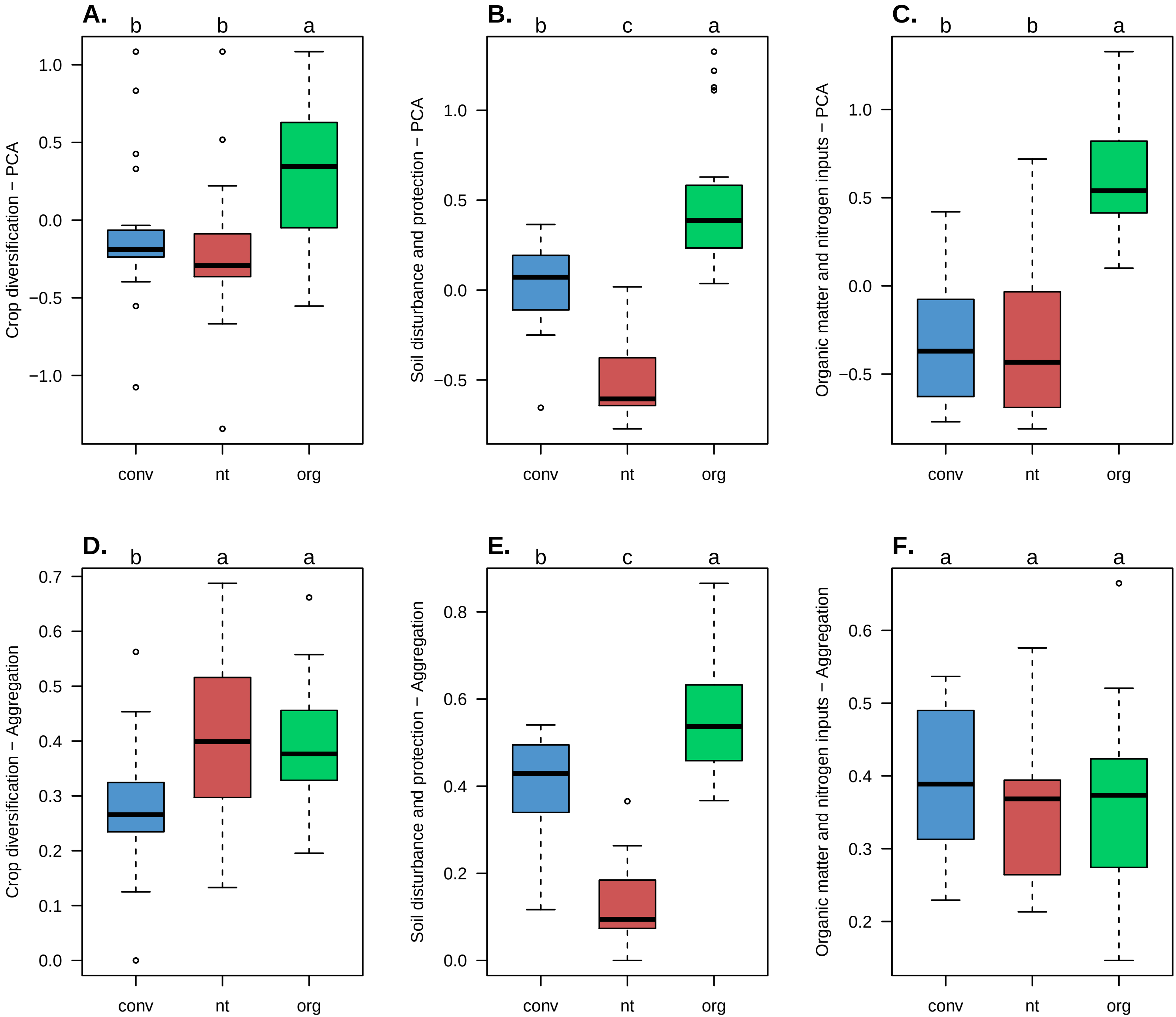


A.
conv
nt
org
LSU
AWU
UAA
farmDiv
PC1
PC2
B.
nbLeg
rDiversification
nbLeys
nbCC
cropDiv
PC1
PC2
C.
traffic
sCover
soilP
nbWeedTill
nbTW
stir
PC1
PC2
D.
totN
minN
orgN
resExp
cropOrg
nbOrg
qOrg
totOrg
PC1
PC2
E.
rHerb
nbHerb
rTreat
nbTreat
nbFung
PC1
PC2
F.
conv
nt
org
Wheat yield 2016 [t/ha]
Relative yield 2012−2016 (relY)



A.
a a a
Crop rotation diversification (rDiversification)
4
6
8
10
12
conv nt org
B.
b c a
Soil tillage intensity (stir)
50
100
150
200
conv nt org
C.
a a a
Organic amendment inputs (qOrg) [kg OM/ha]
0
500
1000
1500
2000
2500
3000
conv nt org
D.
a a b
Total nitrogen fertilisation (totN) [kg N/ha]
50
100
150
200
conv nt org
E.
b a c
Relative herbicide treatment intensity (rHerb)
0
1
2
3
4
conv nt org
F.
a b c
Relative yield 2012−2016 (relY)
0.4
0.6
0.8
1.0
1.2
conv nt org


A.
B.
PC1
PC2
nbFung
traffic
yield
relY
nbTreat
rTreat
LSU
stir
UAA
resExp
nbTW
totN
nbTill
minN
AWU
farmDiv
orgN
nbLeys
cropOrg
nbOrg
nbWeed
rHerb
nbHerb
cropDiv
sCover
nbCC
rDiversif
nbLeg
soilP



A.
b b a
Crop diversification – PCA
1.0
0.5
0.0
−0.5
−1.0
conv nt org
B.
b c a
Soil disturbance and protection – PCA
1.0
0.5
0.0
−0.5
conv nt org
C.
b b a
Organic matter and nitrogen inputs – PCA
1.0
0.5
0.0
−0.5
conv nt org
D.
b a a
Crop diversification – Aggregation
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
conv nt org
E.
b c a
Soil disturbance and protection – Aggregation
0.8
0.6
0.4
0.2
0.0
conv nt org
F.
a a a
Organic matter and nitrogen inputs – Aggregation
0.6
0.5
0.4
0.3
0.2
conv nt org

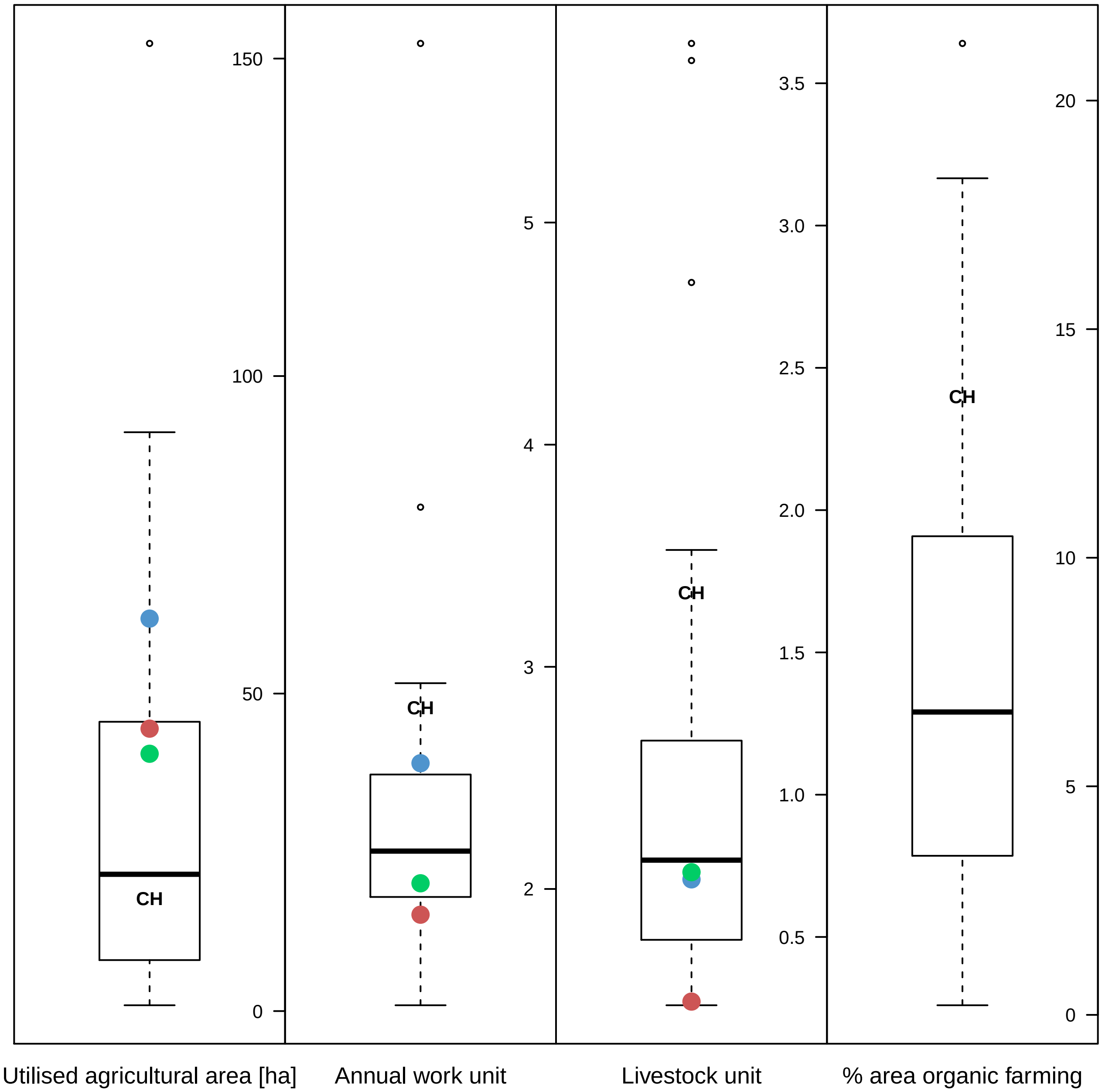

150
100
50
0
5
4
3
2
3.5
3.0
2.5
2.0
1.5
1.0
0.5
20
15
10
5
0
CH
CH
CH
CH
Utilised agricultural area [ha]
Annual work unit
Livestock unit
% area organic farming

Table S1 List and description of the 60 farms included in the study. 'Mean temperature' and 'Rainfall' are given as average values over the two years 2015 and 2016. 'Soil texture' gives texture classes according to the ISSS system. 'Program' refers to compliance to specific 'integrated' (no pesticides except herbicides) or 'organic' programs in 2016. 'UAA' is for utilised agricultural area. 'Fertilisation' indicates what kind of fertilisation was used during the five-year crop rotation: 'min' = mineral only, 'org' = organic only, 'min-org' = mixed mineral and organic. The conventional farm indicated in light grey was removed from the analyses due to missing survey data.

Cropping system	Canton	Altitude [m]	Mean temp [°C]	Rainfall [mm]	Soil texture	Program	UAA [ha]	Fertilisation	Livestock unit
conv	GE	476	11.3	879	light clay	integrated	102	min-org	0.5<>1
conv	GE	427	10.8	793	silty clay loam	integrated	84	min	0<>0.5
conv	GE	361	11.7	680	loam	integrated	110	min	0<>0.5
conv	GE	423	11.3	786	loam	none	190	min-org	0.5<>1
conv	GE	427	11.7	680	clay loam	integrated	63	min	0
conv	VD	485	10.6	743	clay loam	none	106	min	0<>0.5
conv	VD	457	11.5	1035	clay loam	none	63	min-org	>1
conv	VD	754	9.9	1002	loam	integrated	33	min-org	0.5<>1
conv	VD	437	10.4	778	clay loam	none	45	min	0<>0.5
conv	VD	554	10.1	805	loam	none	43	min-org	0<>0.5
conv	AG	383	10.2	934	loam	integrated	25	min-org	0<>0.5
conv	LU	479	9.3	1080	loam	none	30	min-org	>1
conv	*LU*	*506*	*9.3*	*1080*	*clay loam*	-	-	-	-
conv	ZH	408	10.4	967	clay loam	none	18	min-org	0<>0.5
conv	ZH	518	10.4	1322	clay loam	none	33	min-org	>1
conv	ZH	435	10.6	982	clay loam	integrated	41	min-org	0
conv	ZH	429	10.6	982	clay loam	none	23	min-org	0<>0.5
conv	ZH	576	10.4	1322	clay loam	none	31	min-org	>1
conv	ZH	390	10.0	1007	clay loam	none	73	min-org	>1
conv	ZH	442	10.3	1181	light clay	none	62	min-org	0.5<>1
nt	GE	441	11.4	793	clay loam	integrated	57	min-org	0<>0.5
nt	GE	403	11.7	680	silty clay	integrated	48	min-org	0
nt	GE	361	11.7	680	silty clay loam	none	107	min-org	0
nt	GE	356	11.7	680	loam	none	76	min-org	0
nt	GE	427	11.3	786	clay loam	none	25	min	0<>0.5
nt	VD	429	11.3	1109	clay loam	integrated	66	min	0<>0.5
nt	VD	686	9.7	1013	light clay	integrated	144	min-org	0.5<>1
nt	VD	486	10.9	839	loam	integrated	17	min-org	0<>0.5
nt	VD	590	10.3	792	loam	integrated	68	min	0
nt	VD	584	10.4	778	light clay	integrated	31	min-org	0
nt	AG	383	10.2	934	loam	integrated	29	min-org	0.5<>1
nt	LU	504	9.3	1080	clay loam	integrated	13	min-org	0<>0.5
nt	LU	506	9.3	1080	clay loam	none	30	min-org	0<>0.5
nt	ZH	408	10.4	967	clay loam	none	26	min-org	0<>0.5
nt	ZH	518	10.4	1322	clay loam	integrated	35	min-org	0.5<>1
nt	ZH	457	10.6	982	clay loam	integrated	13	min-org	0
nt	ZH	429	10.6	982	light clay	none	31	min	0
nt	ZH	576	10.4	1322	light clay	integrated	29	min-org	>1
nt	ZH	390	10.0	1007	clay loam	none	34	min-org	0<>0.5
nt	ZH	442	10.3	1181	light clay	integrated	12	min-org	0
org	GE	437	11.3	879	clay loam	organic	87	org	0<>0.5
org	GE	437	11.3	879	light clay	organic	71	org	0
org	GE	435	11.4	793	clay loam	organic	20	org	0
org	VD	733	10.1	805	loam	organic	28	org	0.5<>1
org	VD	613	10.3	792	clay loam	organic	46	org	0<>0.5
org	VD	443	10.9	839	clay loam	organic	27	org	0
org	VD	456	11.6	1063	clay loam	organic	47	org	0
org	VD	618	10.3	792	clay loam	organic	76	org	0
org	VD	442	10.4	778	clay loam	organic	46	org	0.5<>1
org	FR	449	10.9	839	loam	organic	40	org	0.5<>1
org	AG	425	10.2	934	clay loam	organic	20	org	>1
org	LU	554	9.3	1080	loam	organic	119	org	0.5<>1
org	LU	506	9.3	1080	clay loam	organic	15	org	0.5<>1
org	ZH	408	10.4	967	clay loam	organic	36	org	>1
org	ZH	518	10.4	1322	light clay	organic	22	org	>1
org	ZH	465	10.6	982	clay loam	organic	18	org	0
org	ZH	429	10.6	982	clay loam	organic	18	org	>1
org	ZH	576	10.4	1322	light clay	organic	25	org	>1
org	ZH	442	10.3	1181	light clay	organic	29	org	0.5<>1
org	TG	416	10.0	1007	light clay	organic	21	org	>1

Table S2 Data collected in the questionnaire survey (rows), filled in by the farmers, and used to compute the 32 cropping practice indicators (columns). The crosses indicate which data has been used for which indicator.

	farm structure	utilised agricultural area	annual working unit	livestock unit	diversity at farm level 2016	*crop diversification*	nb years with ley	nb legumes	nb cover crop	crop diversity at field level (rotation)	crop rotation diversification	*soil disturbance and protection*	field traffic	nb tillage 2015-2016	nb weeding 2015-2016	nb tillage and weeding interventions 2012-2016	soil protection index	soil tillage intensity	soil cover	*organic matter inputs and nitrogen fertilisation*	crop residue exportation	nb organic amendments	organic amendment inputs	organic input from crops	total organic inputs	mineral nitrogen fertilisation	organic nitrogen fertilisation	total nitrogen fertilisation	*crop protection*	nb herbicide treatment	nb fungicide treatment	total number of treatments	herbicide treatment frequency index	total treatment frequency index	*yield*	wheat yield 2016	relative yield 2012-2016		
General information at farm level																																							
utilised agricultural area [ha]		X																																					
annual working unit			X																																				
livestock unit				X																																			
all main crops present on the farm in 2015-2016					X																																		
Detailed management practices for the wheat cultivation year (2015-2016)																																							
=> for each intervention:																																							
date																			X																				
intervention type (tillage, weeding, seeding, treatment, fertilisation)													X	X	X			X	X							X	X	X		X	X	X	X	X					
implement																		X	X																				
product (type, quantity)																										X	X	X					X	X					
Historical data on the 5 year rotation (2012-2016), at field level																																							
=> for each year:																																							
main crop							X	X		X	X													X	X												X		
estimated yield [t/ha]																																				X	X		
organic fertilisation (type, quantity)																						X	X		X														
cover crop (presence or not, species)									X	X	X																												
type of soil tillage (no till, reduced, plough)																	X																						
estimated number of tillage and weeding interventions																X																							
management of crop residue (exported or left on the field)																					X			X	X														

Table S3 Isohumic coefficients and nitrogen availability of organic amendments used in the computation of the organic amendment inputs (qOrg), total organic inputs (totOrg), nitrogen organic fertilisation (orgN) and total nitrogen fertilisation indicators (totN).

source of organic matter	dry organic matter[a] [kg/t or *kg/m3]	isohumic coefficient	total nitrogen[a] [kg/t or *kg/m3]	part of available nitrogen[b]
cow slurry	50*	0.10	4.3*	0.45
cow manure	150	0.50	4.9	0.15
fattening cow slurry	65*	0.10	4.3*	0.45
fattening cow manure	155	0.35	5.4	0.20
pig slurry	33*	0.10	4.7*	0.50
pig manure	40	0.35	7.8	0.35
poultry manure	330	0.25	27.0	0.35
horse manure	270	0.40	5.6	0.10
compost	214	0.25	7.0	0.05
composted manure	200	0.65	4.9	0.15
liquid digestate	50*	0.28	4.0	0.50
ramial chipped wood (BRF)	422	0.50	1.6*	0.00

[a]dry organic matter and total nitrogen are given in kg/t, except for values marked with *, in kg/m3

[b]part of total nitrogen available for the crop the year of application

Most coefficients were extracted from the Swiss principles of agricultural crop fertilisation (Sinaj and Richner, 2017) or extrapolated from similar products, except for digestate isohumic coefficient (CSICM, 2010) and for the ramial chipped wood coefficients (CTACF, 2006)

References

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CTACF, 2006. Mise en oeuvre de la technique du Bois Raméal Fragmenté (BRF) en agriculture wallonne. Centre des Technologies Agronomiques Communauté Française, 168 pp.

Sinaj, S., Richner, W., 2017. Principes de fertilisation des cultures agricoles en Suisse (PRIF 2017). Recherche Agronomique Suisse 8(6).

Table S4 Mean values and standard errors of the 31 indicators for the three cropping systems, and p-values from the overall analysis of variance ('global') and from the Tukey HSD post-hoc pairwise test. 'conv': conventional farming, 'nt': no-till farming, 'org': organic farming.

Indicator	conv		nt		org		p-values			
	mean	se	mean	se	mean	se	anova	nt-conv	org-conv	org-nt
Farm structure										
utilised agricultural area [ha]	62	10	44	8	41	6	0.142	0.278	0.149	0.932
annual working unit	2.6	0.5	1.9	0.4	2.0	0.2	0.464	0.466	0.617	0.966
livestock unit	0.70	0.17	0.27	0.09	0.73	0.14	**0.035**	0.077	0.991	0.053
diversity at farm level 2016	6.58	0.34	6.25	0.45	7.15	0.55	0.376	0.870	0.659	0.350
Crop diversification										
nb years with ley	0.26	0.18	0.30	0.18	1.25	0.22	**0.001**	0.990	**0.002**	**0.003**
nb legume crops	1.16	0.22	2.05	0.29	2.35	0.22	**0.004**	**0.038**	**0.004**	0.667
nb cover crops	1.16	0.22	1.90	0.32	0.85	0.20	**0.013**	0.101	0.663	**0.011**
crop diversity at field level (rotation)	4.63	0.24	5.00	0.23	4.30	0.18	0.082	0.466	0.538	0.066
crop rotation diversification	6.17	0.27	7.18	0.55	7.00	0.41	0.218	0.228	0.364	0.952
Soil disturbance and protection										
field traffic	10.5	0.5	9.1	0.3	9.8	0.5	0.081	0.065	0.503	0.468
nb tillage 2015-2016	1.32	0.15	0.40	0.13	2.55	0.27	**0.000**	**0.005**	**0.000**	**0.000**
nb weeding 2015-2016	0.00	0.00	0.00	0.00	2.35	0.26	**0.000**	1.000	**0.000**	**0.000**
nb tillage and weeding interventions 2012-2016	2.32	0.20	0.18	0.08	4.06	0.46	**0.000**	**0.000**	**0.000**	**0.000**
soil protection index	1.63	0.15	4.72	0.10	1.82	0.23	**0.000**	**0.000**	0.713	**0.000**
soil tillage intensity	94	7	24	3	139	6	**0.000**	**0.000**	**0.000**	**0.000**
soil cover	0.28	0.05	0.56	0.05	0.18	0.03	**0.000**	**0.000**	0.244	**0.000**
Organic matter inputs and nitrogen fertilisation										
crop residue exportation	2.37	0.32	1.60	0.37	2.75	0.38	0.072	0.288	0.731	0.063
nb organic amendments	5.05	0.05	5.05	0.05	5.40	0.18	0.055	1.000	0.096	0.087
organic amendment inputs [kg OM/ha]	465	105	435	130	470	150	0.979	0.986	1.000	0.980
organic input from crops [kg OM/ha]	683	37	726	32	708	41	0.712	0.690	0.880	0.936
total organic inputs [kg OM/ha]	1148	113	1161	134	1178	140	0.986	0.997	0.985	0.995
mineral nitrogen fertilisation [kg N/ha]	141	7	127	8	0	0	**0.000**	0.217	**0.000**	**0.000**
organic nitrogen fertilisation [kg N/ha]	19	7	20	6	61	5	**0.000**	0.978	**0.000**	**0.000**
total nitrogen fertilisation [kg N/ha]	160	6	147	4	61	5	**0.000**	0.201	**0.000**	**0.000**
Crop protection										
nb herbicide treatment	1.11	0.11	2.30	0.24	0.00	0.00	**0.000**	**0.000**	**0.000**	**0.000**
nb fungicide treatment	1.16	0.33	0.30	0.18	0.00	0.00	**0.001**	**0.016**	**0.001**	0.569
total number of treatments	3.11	0.54	2.70	0.26	0.00	0.00	**0.000**	0.678	**0.000**	**0.000**
herbicide treatment frequency index	1.18	0.20	2.32	0.23	0.00	0.00	**0.000**	**0.000**	**0.000**	**0.000**
total treatment frequency index	2.77	0.43	2.71	0.24	0.00	0.00	**0.000**	0.988	**0.000**	**0.000**
Yield										
wheat yield 2016 [t/ha]	5.6	0.4	4.9	0.3	3.4	0.2	**0.000**	0.174	**0.000**	**0.001**
relative yield 2012-2016	1.05	0.03	0.93	0.03	0.70	0.03	**0.000**	**0.020**	**0.000**	**0.000**

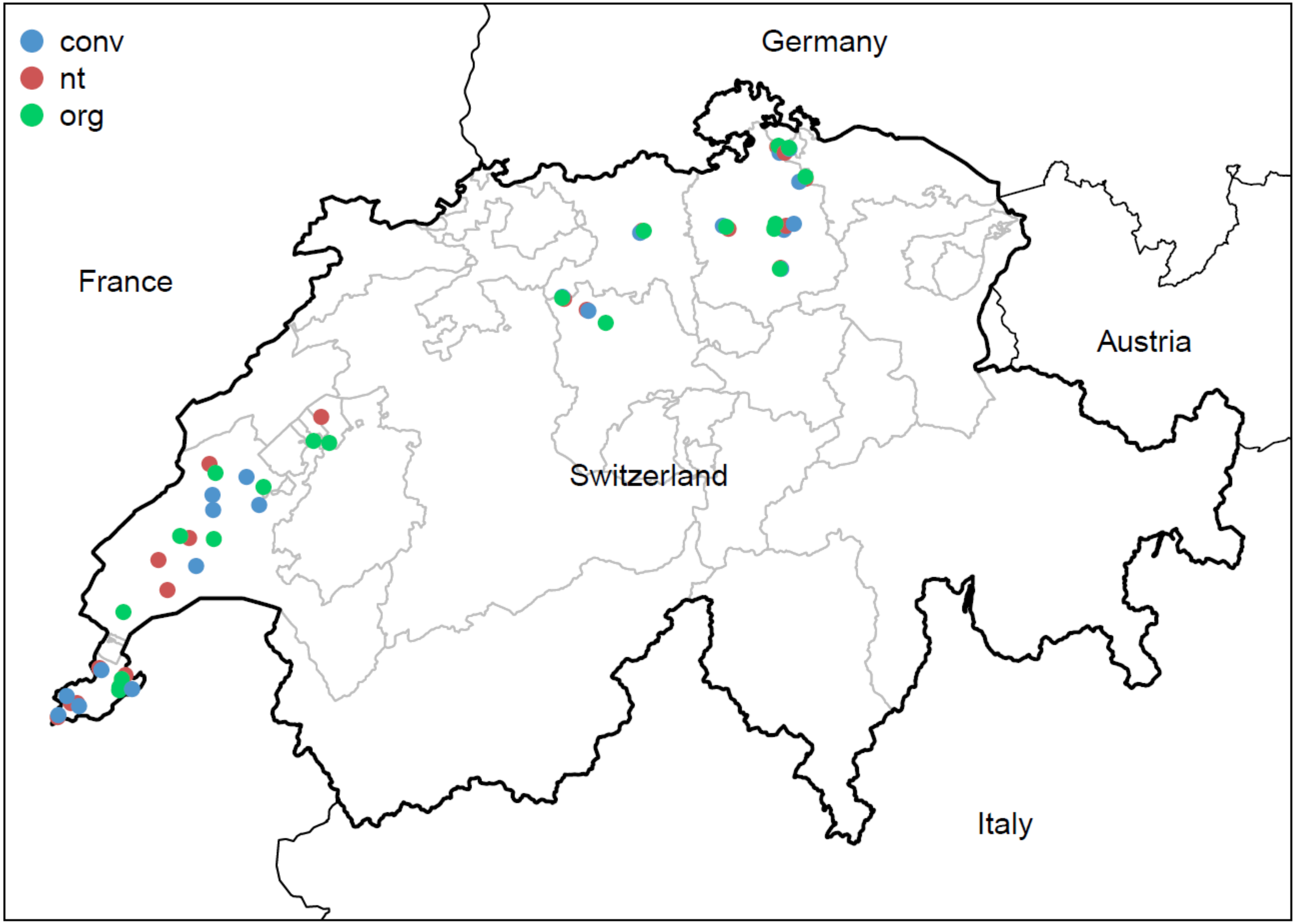


Figure S1 Map of Switzerland showing the geographic position of the 60 fields. Blue points correspond to conventional systems, red points to no till systems and green points to organic systems.

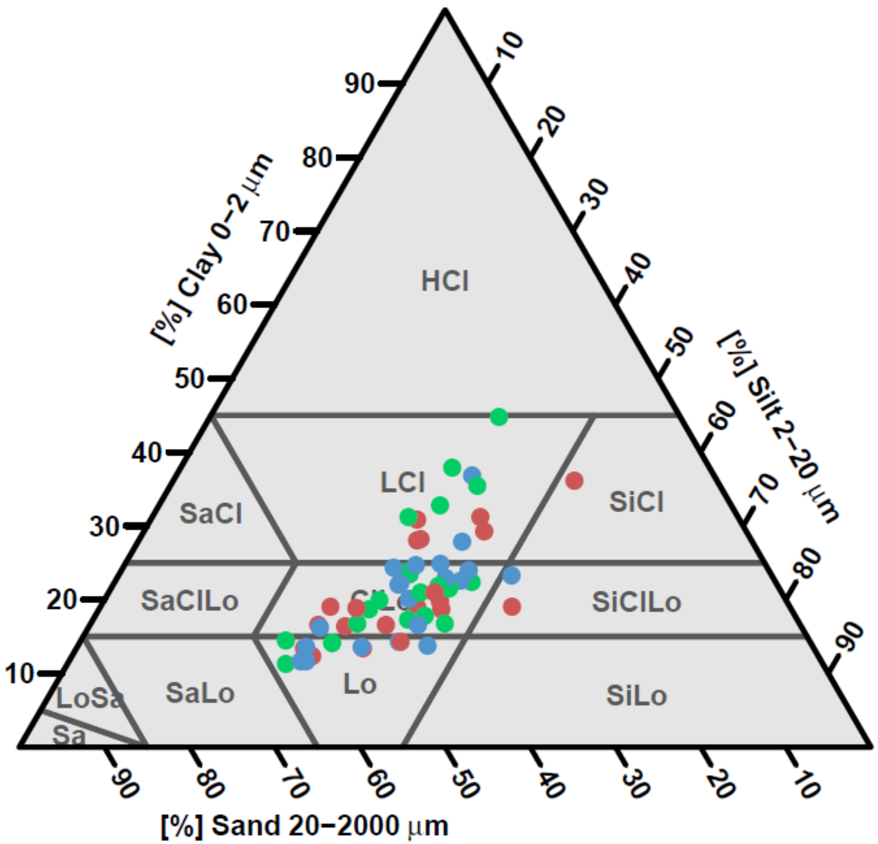


Figure S2 Texture triangle (ISSS system) showing the texture (0-20 cm) of the 60 fields. Blue points correspond to conventional systems, red points to no till systems and green points to organic systems.

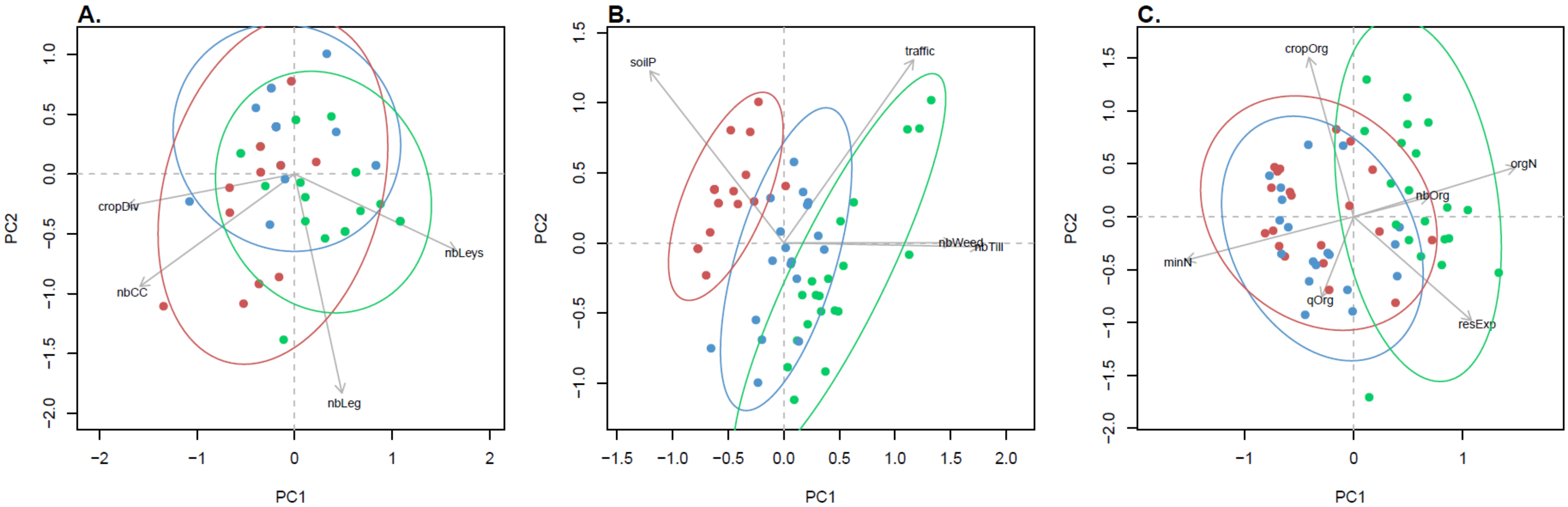
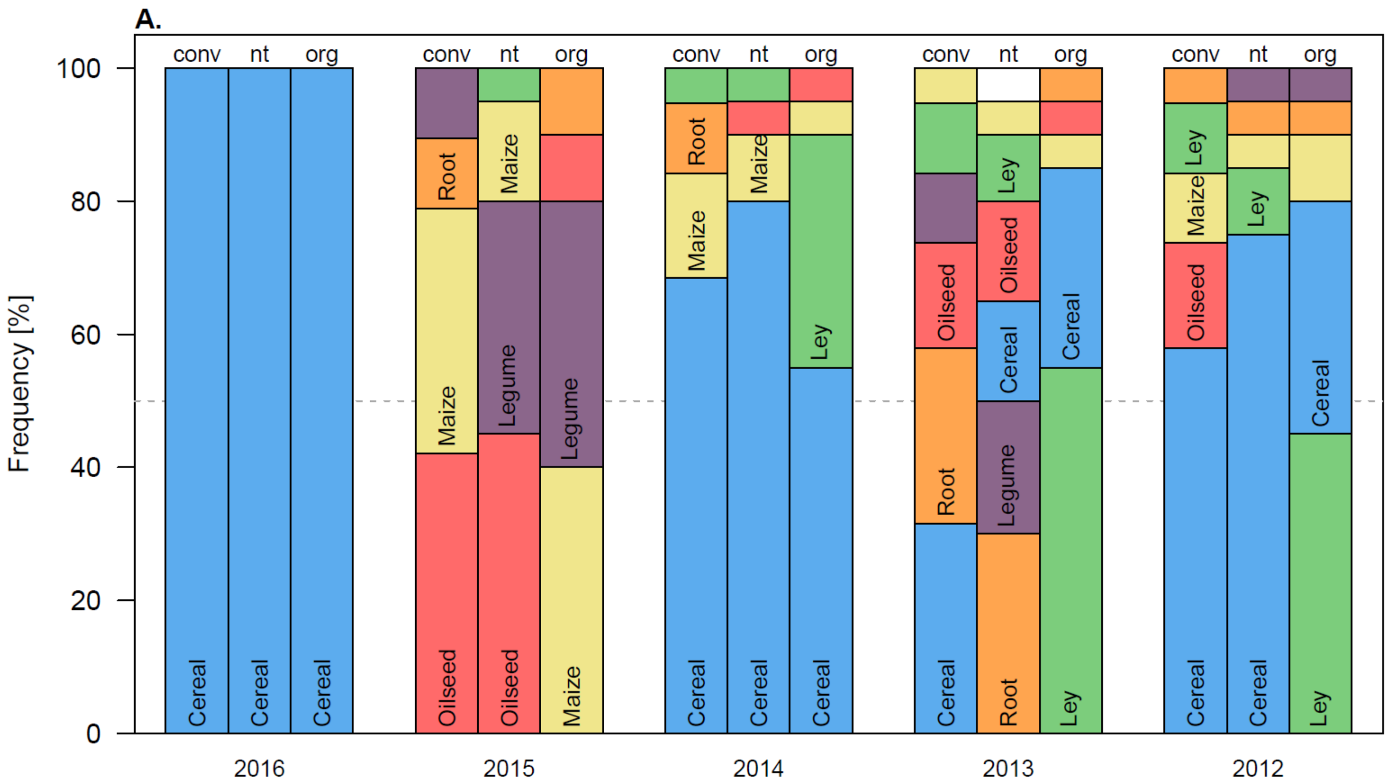


Figure S3 Principal component analyses (field projection, scaling 2) used for the computation of the composite indexes for A. Crop diversification, B. Soil disturbance and protection, and C. Organic matter inputs and nitrogen fertilisation. Blue points correspond to conventional systems, red points to no-till systems and green points to organic systems. Correspondence between abbreviations and indicator names are given in Table 1.



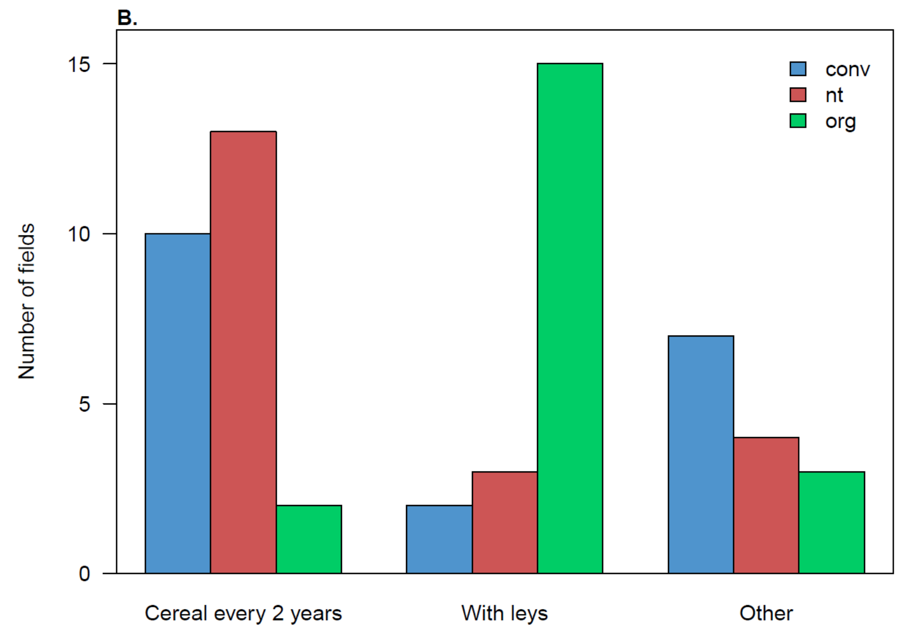


Figure S4 A. Crop frequency for the studied fields, for the three cropping systems ('conv': conventional, 'nt': no till, 'org': organic). Crops are grouped into types. B. Categorisation of the crop rotation along three main types: 1. rotations with a cereal every two years, 2. rotations including leys, and 3. other type of rotations.

Cereal: winter or spring wheat, barley, oat, spelt, rye, triticale
Oilseed: rapeseed, sunflower, flax
Maize: grain maize, silage maize, sorghum
Root: potato, sugarbeet
Legume: soybean, peas, faba bean, lentil, bean, clover

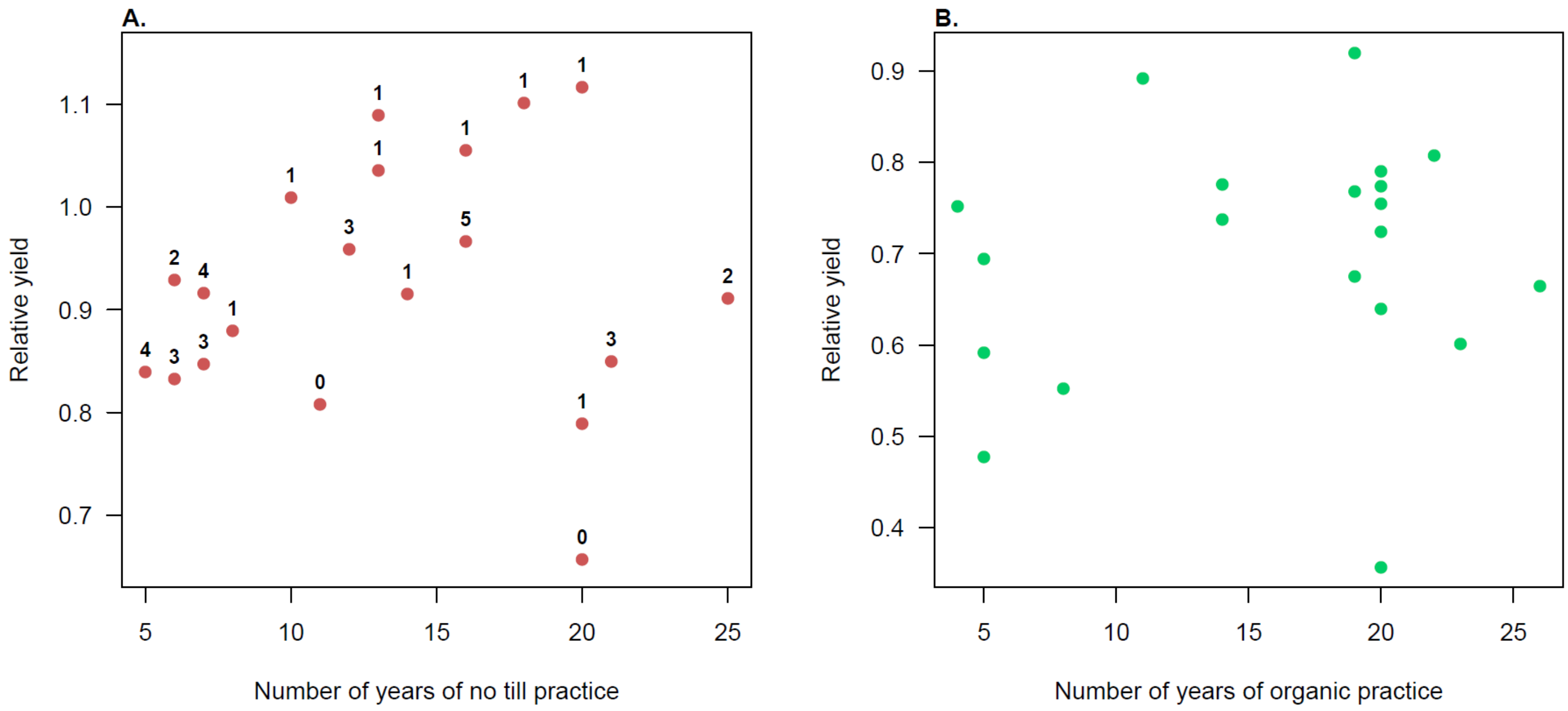


Figure S5 Relative yield indicator as a function of time since the beginning of A. no till practice and B. organic practice. In panel A, the numbers above the points indicate the number of cover crops cultivated the past 5 years (number of cover crop 'nbCC' indicator).

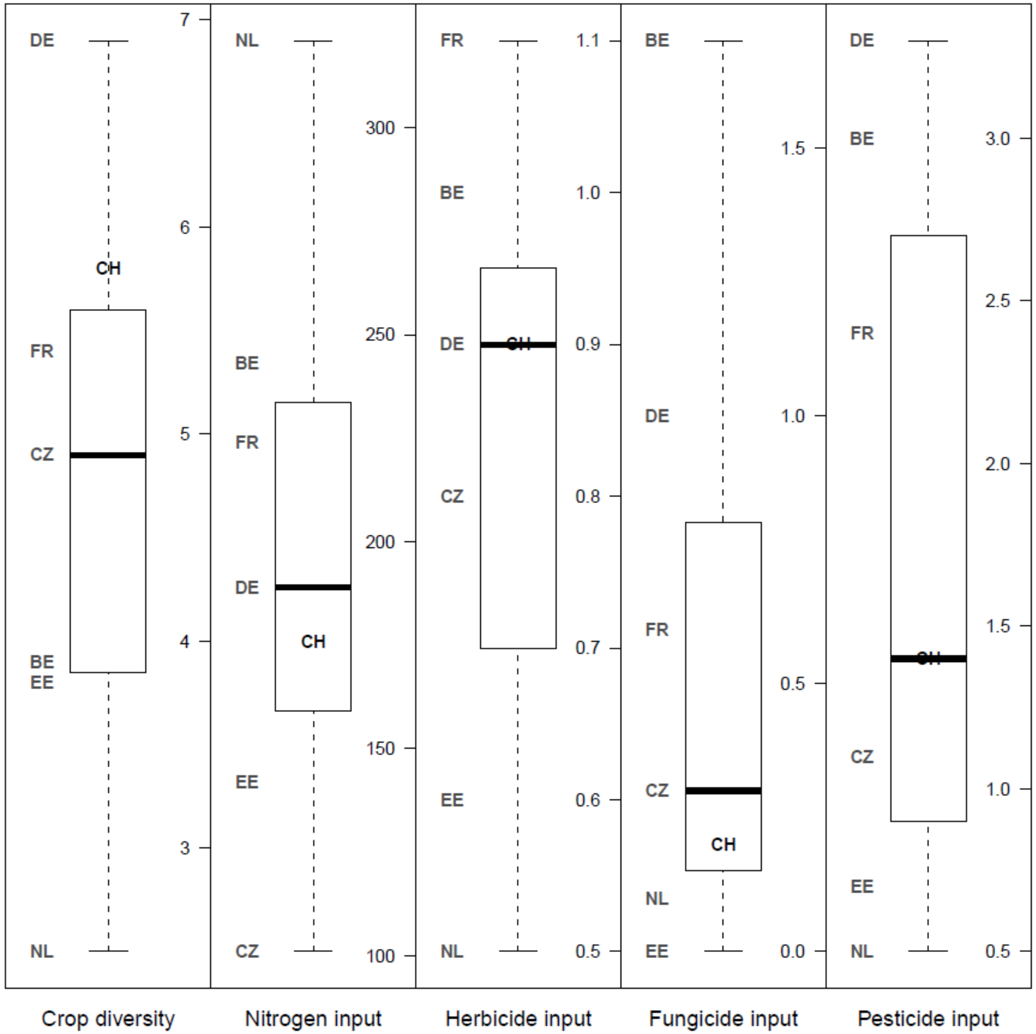


Figure S6 Comparison of Switzerland with six other European countries in terms of crop diversity, nitrogen fertilisation and pesticide inputs. On each box, 'CH' shows the position of Switzerland. On the left of each box, the two letter code of each other country is indicated, BE: Belgium, CZ: Czech Republic, EE: Estonia, FR: France, DE: Germany, NL: Netherlands. The data come from Herzog et al. (2006).

Reference

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