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3 1 **Title**
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5 2 Potential of indicators to unveil the hidden side of cropping system classification: differences
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7 3 and similarities in cropping practices between conventional, no-till and organic systems
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61
62 **Abstract**
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64 To compare different cropping systems, it is crucial to describe explicitly the associated
65 cropping practices. A set of 31 indicators, and six composite indexes, addressing farm
66 structure, crop diversification, soil disturbance, organic matter inputs, nitrogen fertilisation,
67 crop protection, and yield was used to describe 59 winter wheat fields belonging to
68 conventional, no-till and organic systems, in Switzerland. The aim of this study was to
69 investigate the complementarity and redundancy of the indicators and their potential to
70 characterise these cropping systems. In general, weak correlations were observed between the
71 studied indicators, showing the importance of using a set of indicators to fully characterise
72 cropping practices. The complex indicators were often correlated with simpler ones, but it
73 cannot be excluded that they can prove to be more useful in different contexts. Retaining a
74 combination of simple and complex indicators to obtain a broad picture of cropping practices
75 is thus recommended. The indicators highlighted differences but also similarities between the
76 three systems. For example, the input of organic matter and crop rotation diversification were
77 similar between the three systems. In contrast, total nitrogen fertilisation (lower for organic
78 systems) and soil disturbance (lower for no-till systems) were different. A high within-system
79 variability was observed for some indicators, suggesting that using quantitative indicators
80 rather than simple classifications based on a general description of the systems allows a better
81 characterisation of these systems. Overall, the use of indicators has the potential to improve
82 our understanding of the influence of cropping practices on the soil and environment.
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107 **Keywords**
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109 field level indicators, composite indexes, crop diversification, organic matter inputs, soil
110 disturbance intensity, on-farm study
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121 **46 1. Introduction**
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123 47 Agriculture is characterised by a wide range of soil management and cropping practices, such
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125 48 as choice of cultivated crop and cultivar, crop rotation, tillage intensity and implements,
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128 49 nutrient management, crop protection and irrigation. As alternatives to what can be called
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130 50 'conventional' cropping practices, different cropping systems have been developed, especially
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132 51 to reduce the impact of agriculture on the environment. Among others, organic farming and
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134 52 no-till agriculture are alternative systems which are increasingly adopted. Organic farming is
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136 53 principally based on the exclusive utilisation of organic fertilisers and treatments: synthetic
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138 54 substances are prohibited but soil tillage and mechanical weeding is allowed (Reganold and
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140 55 Wachter, 2016; Migliorini and Wezel, 2017). No-till farming implies the absence of any
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142 56 tillage interventions prior to seeding and should ensure at least 30% soil cover throughout the
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144 57 year (Soane et al., 2012). No-till systems could fulfil the principles of conservation agriculture
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146 58 if they insure sufficient soil cover (by residues or crops) and a diversified crop sequence
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148 59 (FAO, 2018).

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151 60 Many studies have aimed at comparing these systems to assess if yield can be maintained
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153 61 compared to conventional systems. Based on a meta-analysis, it has been shown that no-till
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155 62 alone tends to reduce yield by about 10%, but this decrease can be mitigated when no-till is
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157 63 associated with crop residue retention and improved crop rotation (Pittelkow et al., 2015a). In
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159 64 organic farming, a yield decline of about 20% compared to conventional systems is typically
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161 65 observed (Mäder et al., 2002; de Ponti et al., 2012; Seufert et al., 2012; Ponisio et al., 2015;
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163 66 Seufert and Ramankutty, 2017). Moreover, a recent meta-analysis has shown that temporal
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165 67 yield stability of conventional fields was higher than that of organic fields (Knapp and van der
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167 68 Heijden, 2018). However, precautions must be taken when comparing these systems as
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169 69 observed differences could be induced by confounding factors (e.g. soil or climatic factors),
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171 70 or fundamental differences in the system design such as differences in crop rotation
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173 71 (Kirchmann et al., 2016). Most often, systems are compared by 'labels' without specifying to
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180 72 which extent these systems actually differ in terms of cropping practices (Armengot et al.,
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182 73 2011; Therond et al., 2017). However, information on cropping practices is crucial when it
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184 74 comes to understand and explain the observed effects on yield, plant performance or soil
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186 75 properties. The amount of organic amendments, the intensity of tillage, the extent of fertiliser
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188 76 inputs, the number and amount of pesticides used, and the crop diversity may vary drastically
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190 77 within a given type of cropping system.

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193 78 Indicators of agricultural practices can be used to achieve such a description. Many sets of
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195 79 indicators aiming at describing farming and cropping systems exist, from simple ones to
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197 80 complex multi-dimensional assessment tools (Bockstaller et al., 1997; Bockstaller et al., 2008;
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199 81 Pelzer et al., 2012). The choice of the indicators depends on the objective of the study. In
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201 82 many studies, indicators are chosen to characterise the sustainability of the system or the
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203 83 intensity of management and practices (i.e. land-use intensity LUI) (e.g. Bechini and Castoldi,
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205 84 2009; Geiger et al., 2010; Gaudino et al., 2014; Smith et al., 2017). These primary indicators
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207 85 can then be combined to obtain secondary composite indexes (Nardo et al., 2005; Castoldi
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209 86 and Bechini, 2010; Blüthgen et al., 2012) to reduce the dimensionality of the data and allow
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211 87 more straightforward interpretations of the results. A drawback of this is obviously the loss of
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213 88 information and the potential concealing of trade-offs between practices. Different methods to
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215 89 build these composite indexes exists (Nardo et al., 2005), the two most common being
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217 90 additive aggregation of indicators after normalisation (e.g. Herzog et al., 2006; Blüthgen et
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219 91 al., 2012) and the use of multivariate analyses such as PCA (e.g. Armengot et al., 2011;
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221 92 Nkurunziza et al., 2017). However, the collection of the data needed to implement such
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223 93 indicators is a daunting task and thus simple and reliable indicators, based on data that is
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225 94 reasonably easy to obtain, are required.

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229 95 Here, we present results from an on-farm study conducted in Switzerland in 2016-2017, on
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231 96 winter wheat fields belonging to three cropping systems, conventional, no-till and organic. A
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233 97 survey was conducted to gather information about management and cropping practices at field

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239 98 and farm scale. Based on these data, 31 indicators of different complexity levels were
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241 99 computed to cover the main characteristics of the cropping systems. For three thematic
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243 100 categories of indicators, composite indexes were computed using the multivariate and additive
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245 101 aggregation methods.
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248 102 The aims of this study were a) to assess the complementarity and redundancy of the 31 chosen
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250 103 indicators and of the composite indexes and b) to evaluate the potential of these indicators to
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252 104 characterise the three cropping systems.
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256 106 **2. Materials and Methods**

258 107 *2.1 Farm and field selection*

260 108 Sixty farms (one field per farm) distributed over the Swiss plateau (Supplementary Material
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262 109 Figure S1 and Table S1) were selected for this on-farm study conducted in 2016-2017. Three
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264 110 different cropping systems were studied, with 20 fields selected for each system. The first
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266 111 group of 20 fields corresponded to 'conventional' system, with soil tillage and potential use of
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268 112 synthetic substances. The second group consisted of 'no-till' fields, i.e. without any soil tillage
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270 113 except for occasional use of strip till (mainly 0-1 time over 5 years, max 2-3 times), and
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272 114 potential use of synthetic substances. The third group contained fields in organic farms, with
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274 115 more or less deep and intense soil tillage, but no use of synthetic substances. All farms had to
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276 116 comply to their specific cropping system for more than five years. All conventional and no-till
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278 117 farms followed the 'Proof of Ecological Performance' guidelines from the Swiss Federal
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280 118 Office for Agriculture, which include a **balanced nutrient budget**, diversified crop distribution
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282 119 (at least four different main crops per year), proper soil protection, targeted selection and use
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284 120 of pesticide treatments and biodiversity promoting surfaces (FOAG, 2018a). Organic farms
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286 121 followed the guidelines of Bio Suisse, which is the federation of Swiss organic farmers.
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288 122 Prerequisites were that the fields should have been seeded with winter wheat in autumn 2015
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290 123 and be larger than 1 ha. Winter wheat fields were targeted as this is the most frequent crop in
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298 124 Switzerland, representing more than 20% of the arable surface (FSO, 2016). The most
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300 125 common crop rotation in the type of farms studied here has a cereal crop every two years; and
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302 126 the most cultivated crops outside from cereals are maize (silage or grain), rapeseed and sugar
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304 127 beet. Fields belonging to Cambisols with minimum 10% to maximum 40% of clay were
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306 128 targeted (Figure S2).

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309 129 In order to check for a potential sampling effect on differences between cropping systems,
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311 130 information about six pedoclimatic variables (clay and silt content (0-20 cm), altitude, mean
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313 131 annual temperature and precipitation) were also gathered. Temperature and precipitation data
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315 132 were taking from the closest available weather station for each field.

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319 134 *2.2 Cropping practice indicators*

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321 135 Cropping practices were characterised according to 31 indicators, grouped into six thematic
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323 136 categories, as described below and summarised in Table 1. The data needed to compute these
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325 137 indicators were gathered from the farmers through a survey. Most questions were closed
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327 138 questions, i.e. several options of pre-defined answers were given. Information about the
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329 139 general farm structure and the specific cropping practices of the selected winter wheat field
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331 140 were collected (Table S2). Two types of time periods were used to collect data on cropping
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333 141 practices of the winter wheat field: detailed information on all cropping practices including
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335 142 dates of treatment for the crop cultivation year (winter wheat 2015-2016, period going from
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337 143 the harvest of the previous crop to the harvest of the winter wheat), and information on the
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339 144 five-year crop rotation, gathered for the wheat year and the four preceding years (2012-2016)
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341 145 (Table 1 and S2). The used indicators were chosen among published indicators or standard
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343 146 farm or field descriptors. These indicators differed in their complexity, i.e. the amount of
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345 147 information needed to compute them.

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357 148 Because survey results could not be obtained from one of the farms, all analyses involving
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359 149 cropping practice indicators were performed on 59 values (19 for the 'conventional' group, 20
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361 150 for the 'no-till' group and 20 for the 'organic' group).
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365 366 152 Farm structure

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368 153 For this category, the indicators concerned the farm scale, whereas the five other categories
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370 154 refer to field scale. Farm structure was described by three indicators: utilised agricultural area,
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372 155 including fallow surface ('UAA', in ha), annual working unit ('AWU', full time equivalent, a
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374 156 value of 1 corresponds to 1 person working full time on the farm the whole year) and
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376 157 livestock unit per hectare of UAA ('LSU', a value of 1 corresponds to 1 dairy cow per hectare)
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378 158 (Table 1). In addition, the diversity at the farm level in the year 2016 including crops, leys and
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380 159 fallows, was assessed ('farmDiv').
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384 385 161 Crop diversification

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387 162 Crop diversification was addressed using five indicators. The number of years in ley
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389 163 ('nbLeys'), the number of legumes ('nbLeg') and cover crops ('nbCC') occurrence during the
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391 164 five-year crop rotation 2012-2016 was quantified. Legumes species count included main
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393 165 crops as well as cover crops. The number of cover crops was also compared to the potential
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395 166 maximum number of cover crops that could have been cultivated given the crop rotation. It
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397 167 was assumed that a cover crop could be cultivated whenever there were more than eight
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399 168 weeks between the harvest of the previous crop and the seeding of the new one, based on
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401 169 standard harvest and seeding dates. Crop diversity ('cropDiv') was then computed as the
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403 170 number of different crops (main and cover) cultivated during the five years. A crop rotation
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405 171 diversification index ('rDiversification') was derived following the Indigo method
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407 172 (Bockstaller and Girardin, 2000), adapted here for a five-year duration. This indicator takes
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416 173 into account crop rotation diversity, identity of the preceding crop and the time to the previous
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423 176 Soil disturbance and protection
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425 177 A total of seven indicators were selected to assess soil disturbance and protection. Field traffic
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427 178 ('traffic') was the number of interventions on the field, all type of interventions included,
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429 179 during the wheat cultivation period 2015-2016. The number of tillage ('nbTill') and
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431 180 mechanical weeding ('nbWeed') operations during that period were also used as indicators.
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433 181 Then, the mean number of tillage and weeding interventions over the five-year crop rotation
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435 182 ('nbTW') was computed. Fifth, a simple soil protection index ('soilP') was derived from the
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437 183 IDEA method (Zahm et al., 2008), based only on the type of soil tillage adopted in the last
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439 184 five years. It consisted in attributing a weight to each type of tillage (plough=0.5, reduced
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441 185 tillage=3, no-till=5) for each year of the crop rotation, and then averaging it. Soil tillage
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443 186 intensity rating ('stir') was computed for the wheat cultivation period, based on the
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445 187 disturbance induced by each tillage implement ('Soil Tillage Intensity Rating STIR' method
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447 188 from the RUSLE2 framework, USDA, 2012). In this method, a tillage intensity coefficient is
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449 189 attributed to each type of tillage implement as a function of tillage depth, area, speed and
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451 190 intensity. A list of such coefficients for different machines and interventions are available
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453 191 from the RUSLE2 method. The total tillage intensity was computed as the sum of these
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455 192 coefficients for all the interventions done during seedbed preparation and weeding. Last, the
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457 193 mean soil cover ('sCover') provided by crop residues or cover crops during the pre-sowing
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459 194 period (from the harvest of the preceding crop to the seeding of the winter wheat in 2015) was
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461 195 assessed using the soil cover indicator described by Büchi et al. (2016). It is based on standard
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463 196 values of soil cover by crop residues after harvest and incorporation rate by tillage
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465 197 implements. A minimal threshold value of 30% cover is generally seen as providing proper
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467 198 soil protection (Armand et al., 2009; Lilley and Moore, 2009; FAO, 2018).
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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')

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225 and total ('rTreat') relative treatment frequency index was computed, based on the index
226 developed in France (Hossard et al., 2017). This index is computed as the sum of the ratio of
227 applied treatment dose over recommended dose, over all treatment applications. The
228 recommended dose of each product was extracted from the website of the Swiss Federal
229 Office for Agriculture (FOAG, 2018b). When a range of doses was indicated, the mean value
230 was used.

231
232 Yield

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

239
240 *2.3 Composite intensity indexes*

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

243 Multivariate approach index I_{PCA}

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

247 Additive aggregation index I_{add}

248 In the second method, the composite index, thereafter called I_{add} , is based on an additive
249 combination of the indicators after normalisation, as in Herzog et al. (2006). For each

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593 250 indicator, normalisation was done following Herzog et al. (2006), to scale the values between
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595 251 0 and 1, 1 representing the highest and more intense value:
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$$597 \quad 252 \quad nI = (y_i - y_{\min}) / (y_{\max} - y_{\min}) \quad (1)$$

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600 253 where nI is the normalised indicator, y_i the individual values, y_{\min} the minimal value and y_{\max}
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602 254 the maximal value. In order to reduce the influence of outliers, we followed the
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604 255 recommendation of Nardo et al. (2005) and replaced the y_i values higher than the 97.5% or
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606 256 lower than the 2.5% percentiles by these threshold values. The composite index I_{add} was then
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608 257 obtained by averaging the normalised indicators, with similar weight for all indicators.

$$610 \quad 258 \quad I_{\text{add}} = \frac{\sum_{i=1}^n nI}{n} \quad (2)$$

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614 259 where n is the number of indicators to aggregate.

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616 260 In contrast to the PCA method, which is ‘neutral’, here a decision about the direction of each
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618 261 indicator must be done prior to the aggregation. ‘Direction’ is meant as a statement about
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620 262 which values (high or low, or sometimes even intermediate) represent the most intense
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622 263 practice. While this could be relatively straightforward for some indicators, as for example for
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624 264 the number of pesticide treatments, it could be more debatable for some others, for example
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626 265 for the input of organic matter. The direction of the intensity gradient could also depend on
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628 266 the intended use of the index: an index to interpret environmental impact could be built
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630 267 differently from an index to interpret soil organic carbon stocks. Thus, in some cases,
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632 268 individual indicators need to be reversed to have all indicators pointing in the same direction.
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634 269 This was done here by using 1-nI rather than nI in the final aggregation (Table 2).

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639 271 These two composite indexes were computed for the three categories Crop diversification,
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641 272 Soil disturbance and protection and Organic matter inputs and nitrogen fertilisation. No
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643 273 composite index was computed for the Crop protection category as the indicators total number
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652 274 of treatments 'nbTreat' and total treatment frequency index 'rTreat' already represented an
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654 275 aggregated information about different pesticide treatment applications.
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656 276 For each category, the indicators included in the composite indexes were chosen in order to
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658 277 exclude highly correlated indicators (Kendall's rank correlation $\tau > 0.7$, see section 2.4) and
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660 278 indicators of high complexity (requiring a lot of information to be computed), in order to
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662 279 study if composite indexes based on simple indicators provide the same type of information as
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664 280 complex indicators. The indexes obtained with each method were compared with each other
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666 281 as well as with the more complex indicators in the same category, if available (Table 2). The
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668 282 indicators used to compute the composite indexes, and their direction for the computation of
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670 283 the additive aggregation index I_{add} , are shown in Table 2.
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675 285 *2.4 Data analyses*

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677 286 Differences between the three cropping systems for pedoclimatic variables, primary cropping
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679 287 practice indicators and composite indexes were analysed using analyses of variance, with
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681 288 cropping system as the main factor. Significant analyses of variance ($p < 0.05$) were followed
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683 289 by Tukey HSD post hoc test for pairwise comparison.
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686 290 For each thematic category, correlation between indicators was assessed with Kendall's rank
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688 291 correlation method. In addition, principal component analyses were performed, after
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690 292 standardisation of the data, using the 'vegan' R package (Oksanen et al., 2017).

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692 293 Following the same method, a principal component analysis was performed using all primary
693
694 294 farm and field indicators.

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696 295 The results obtained for the farm structure indicators were compared to Eurostat data
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698 296 (Eurostat, 2018) to situate the studied farms relative to other European countries. Data from
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700 297 the 2010 Eurostat survey were used as they also included data from Switzerland. The
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702 298 proportion of area under organic farming (%UAA) in 2016 was also shown for comparison
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704 299 purpose.
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711 300 All statistical analyses were performed using R 3.5.1 (R Core Team, 2018).
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715 302 **3. Results**

717 303 *3.1 Field characteristics*

719 304 Of the 60 fields, the most frequent soil texture (ISSS texture triangle) was clay loam (31
720 305 fields), followed by loam (13), light clay (12), silty clay loam (2) and silty clay (1) (Figure
721 306 S2). The proportions of these textures did not differ between cropping systems (Chi-square
722 307 test, $p=0.646$). Altitude ranged between 356 m and 754 m above sea level, mean annual
723 308 temperature (2015-2016) between 9.3 °C and 11.7 °C, and mean annual precipitation (2015-
724 309 2016) between 680 mm and 1322 mm. However, the three cropping systems did not show
725 310 significant differences for these variables ($p>0.05$, based on analyses of variance). Thus, no
726 311 confounding effect of the pedoclimatic variables could be seen here.
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739 313 *3.2 Complementarity versus redundancy of indicators of different complexity*

740 314 Farm structure

741 315 At the farm level, the indicators were generally not correlated, except for utilised agricultural
742 316 area UAA and working units AWU which showed a slight positive correlation (Kendall's rank
743 317 correlation $\tau=0.50$, $p<0.001$), also visible in the PCA (Figure 1A). Farm scale diversity
744 318 farmDiv was also significantly positively correlated with UAA but the correlation was weak
745 319 ($\tau=0.26$, $p<0.007$).
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756 321 Crop diversification

757 322 Overall, the Crop diversification indicators showed some complementarity and were not
758 323 highly correlated with each other (Figure 1B). Compared to the simpler indicators, the
759 324 complex crop rotation diversification indicator rDiversification takes into account different
760 325 type of information (i.e. crop rotation diversity, identity of the preceding crop and the time to
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770 326 the previous wheat crop). It was slightly correlated with crop diversity cropDiv (Kendall's
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772 327 rank correlation $\tau=0.30$, $p<0.004$), but not with all the other indicators presented here (Figure
773
774 328 1B). Crop diversity was positively correlated with the number of cover crops nbCC ($\tau=0.60$,
775
776 $p<0.001$) and negatively correlated with the number of leys nbLeys ($\tau=-0.53$, $p<0.001$). The
777 329 number of leys was also correlated with nbCC ($\tau=-0.54$, $p<0.001$) and the number of legumes
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779 330 nbLeg ($\tau=-0.44$, $p<0.001$).
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781 331 The composite indexes were computed using nbCC, nbLeys, nbLeg and cropDiv. The index
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783 332 based on the PCA I_{PCA} was positively correlated with nbLeys and nbLeg but negatively with
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785 333 nbCC and cropDiv (Figure S3). In contrast, the index based on the additive aggregation I_{add}
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787 334 was, by construction, positively correlated with the four indicators. These two composite
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789 335 indexes I_{PCA} and I_{add} were not correlated with each other, but I_{add} was weakly correlated with
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791 336 the complex crop rotation diversification indicator ($\tau=0.21$, $p=0.027$).
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798 339 Soil disturbance and protection

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800 340 The indicators linked to soil disturbance and protection showed high redundancy, with almost
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802 341 all indicators significantly correlated with each other (Figure 1C). In particular, the complex
803
804 342 soil tillage intensity indicator stir was correlated with all the others, with some correlations
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806 343 higher than 0.6. For example, the simple soil protection indicator soilP, which relies only on
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808 344 the general type of tillage (plough, minimum or no-till) applied each year, was correlated with
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810 345 the stir indicator ($\tau=-0.47$, $p<0.001$), which integrated more specific information about crop
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812 346 management. The other complex indicator linked to soil cover sCover was also correlated
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814 347 with all the other except traffic. The sum of tillage and mechanical weeding interventions in
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816 348 2016 nbTW was highly correlated with the mean number of tillage nbTill and weeding
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818 349 nbWeed interventions over the five-year crop rotation ($\tau=0.73$, $p<0.001$), showing that, in this
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820 350 study, most farmers were consistent through time in terms of interventions (i.e. tillage and
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822 351 weed management).
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829 352 Given these high correlations between indicators, only four basic indicators were used to
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831 353 compute the composite indexes (traffic, nbTill, nbWeed and soilP). The index based on the
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833 354 PCA I_{PCA} was positively correlated with traffic, nbTill and nbWeed but negatively with soilP
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835 355 (Figure S3). A similar result was obtained for the index based on the additive aggregation I_{add} .
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837 356 These two composite indexes I_{PCA} and I_{add} were highly correlated with each other ($\tau=0.91$,
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839 357 $p<0.001$), and with the complex indicators stir ($\tau=0.68$ and 0.64 , $p<0.001$) and sCover ($\tau=-$
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841 358 0.35 and -0.34 , $p<0.001$).
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846 360 Organic matter inputs and nitrogen fertilisation

848 361 Some significant correlations were observed between indicators linked to organic matter and
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850 362 N inputs (Figure 1D). The number of organic amendments nbOrg was not related with the
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852 363 amount of organic matter provided qOrg ($\tau=0.17$, $p=0.124$). The total amount of organic
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854 364 matter input totOrg was highly correlated with qOrg ($\tau=0.72$, $p<0.001$), as the input through
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856 365 crop residues cropOrg was small compared to the total quantity. In turn, the organic matter
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858 366 coming from crop residues cropOrg was correlated with the less complex crop residue
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860 367 exportation indicator resExp ($\tau=-0.37$, $p<0.001$). Total nitrogen fertilisation totN was highly
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862 368 correlated ($\tau=0.72$, $p<0.001$) with mineral fertilisation minN, as the amount provided by
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864 369 organic fertilisation orgN was low. This category thus contained two indicators which were
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866 370 computed as the sum of two others ($totOrg = cropOrg+qOrg$ and $totN = minN+orgN$), and
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868 371 these showed high correlations with one of their components, totOrg with qOrg and totN with
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870 372 minN. They were thus not used to compute the composite indexes. Here, the index based on
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872 373 the PCA I_{PCA} was positively correlated with resExp, nbOrg and orgN, and negatively with
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874 374 qOrg, cropOrg and minN (Figure S3). The index based on the additive aggregation I_{add} was
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876 375 positively correlated with all indicators except cropOrg. These two composite indexes I_{PCA}
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878 376 and I_{add} were slightly correlated with each other ($\tau=0.25$, $p=0.005$), but not with totOrg. I_{PCA} ,
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880 377 but not I_{add} , was significantly correlated with totN ($\tau=-0.45$, $p<0.001$).
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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).

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947 404 Farm structure
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949 405 The farm structure indicators did not generally differ between systems (Table 3). The test for
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951 406 livestock unit LSU gave a significant p-value ($p=0.035$, Table S4), but the post hoc test did
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954 407 not reveal pairwise significant differences at a threshold of 0.05 (Table 3). The tendency was
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956 408 however to a lower livestock value for no-till systems compared to conventional ($p=0.077$)
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958 409 and organic ones ($p=0.053$) (Table S4). Utilised agricultural area UAA, annual work unit
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960 410 AWU and diversity at the farm level in 2015-2016 farmDiv showed no differences between
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962 411 cropping systems (Table S4).
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966 413 Crop diversification
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968 414 The number of leys, legumes and cover crops in the five-year crop rotation differed between
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970 415 the three cropping systems (Table 3). The number of years with leys nbLeys was higher in the
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972 416 organic system than conventional and no-till systems. This pointed to a difference in crop
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974 417 rotation between this system on one side and conventional and no-till systems on the other
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976 418 side (Figure S4). For the number of legumes nbLeg, the lowest value was observed in
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978 419 conventional fields, compared to no-till and organic systems. Finally, no-till systems had
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980 420 more often cover crops (nbCC) than organic systems, while conventional systems were
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982 421 intermediate between no-till and organic, and not significantly different from both (Table 3).
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984 422 Compared to the potential maximum number of cover crop cultivation (computed based on
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986 423 the five-year crop rotation), conventional systems reached 38% of cover crop potential, no-till
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988 424 57% and organic 44%. Organic systems had generally a lower number of potential cover crop
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990 425 cultivation slots compared to conventional and no-till, due to the higher presence of leys,
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992 426 which explained its higher percentage of actual to potential cover crops compared to
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994 427 conventional systems.

998 428 Crop diversity cropDiv and crop rotation diversification rDiversification were not different
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1000 429 among the three cropping systems (Table 3, Figure 2A).
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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

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456 nitrogen coming from organic amendments orgN, with higher value observed for organic
457 systems compared to conventional and no-till systems. In total, conventional and no-till
458 systems, with on average 160 and 147 equivalent kg N/ha, showed higher amount of available
459 N than organic system (61 equivalent kg N/ha on average).

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

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465 Crop protection

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

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474 Yield

475 Overall, mean wheat grain yield in 2016, as reported by the farmers, reached about 4.6 t/ha (at
476 14% humidity). This represented about 80% of the wheat yield usually observed in the same
477 fields, for all three cropping systems. The reduced yield was due to an extremely wet spring in
478 2016. Indeed, the cumulated precipitation in April-May 2016 was 240 mm (Changins, west of
479 Switzerland) and 252 mm (Reckenholz, north-east), whereas the 30-year averages (1981-
480 2010) for April-May at the same stations are 153 mm and 193 mm. Wheat yield in 2016 was
481 higher in the conventional and no-till systems than in organic farming (Table 3). Relative

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1123
1124 482 yields over the crop rotation (2012-2016) differed significantly among all three cropping
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1126 483 systems (Figure 2F): compared to the Swiss reference yields (for conventional practices), the
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1128 484 mean relative yield was 1.05 for the conventional system, 0.93 for no-till and 0.70 for organic
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1131 485 systems. This means that conventional yield in our study were on average 5% higher than
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1133 486 Swiss reference yield for the same crops, for the period 2012-2016. When comparing the
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1135 487 three systems together, taking the conventional system as the reference, no-till yield reached
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1137 488 90% of the conventional yield, while organic yield was at 67% of the conventional one. For
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1139 489 no-till and organic fields, no relationship between relative yield and time since the start of
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1141 490 respectively no-till and organic practice could be observed (Figure S5).

1143 491 1144 1145 492 Multivariate analysis of primary indicators

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1148 493 The principal component analysis performed on all the primary indicators allowed to
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1150 494 distinguish the three cropping systems on the three first components, despite high variability
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1152 495 within each system (Figure 3). The organic system was the most clearly delineated group,
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1154 496 while overlap was observed between conventional and no-till. The first axis (explaining 30%
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1156 497 of variance) placed the conventional system intermediate between no-till and organic, while
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1158 498 the second axis (explaining 11% of variance) rather separated conventional system from no-
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1160 499 till and organic (Figure 3). The three indicators contributing most to the first axis were
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1162 500 mineral nitrogen fertilisation minN, number of herbicide treatments nbHerb and number of
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1164 501 weeding interventions nbWeed. For the second axis, the three most contributing indicators
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1166 502 were number of fungicide treatments nbFung, soil protection soilP and field traffic (Figure 3).

1168 1169 503 1170 1171 504 Composite intensity indexes

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1173 505 Significant differences between the three cropping systems were observed for five out of the
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1175 506 six composite indexes (Figure 4, Table 3). For the Crop diversification category, the two
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1177 507 composite indexes I_{PCA} and I_{add} were different between systems, but the index based on PCA

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1183 508 showed higher values for the organic systems, while the index based on additive aggregation
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1185 509 was lower for the conventional systems (Figure 4). For Soil disturbance and protection, the
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1187 510 two composite indexes I_{PCA} and I_{add} differentiated the three systems, with higher values for
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1189 511 the organic system, followed by conventional, and then by no-till systems (Figure 4). For
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1191 512 Organic matter inputs and nitrogen fertilisation, I_{PCA} showed higher values in the organic
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1193 513 systems, while I_{add} was not different between the three systems (Figure 4).
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1198 515 *3.4 Comparison with other European countries*

1200 516 Figure 5 shows the position of Switzerland and of the studied farms among 31 other European
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1202 517 countries, according to the three farm structure indicators. Unfortunately, it was not possible
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1204 518 to find separated data for conventional, no-till and organic systems, and thus our results are
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1206 519 compared to overall European data. The mean utilised agricultural area in Switzerland is in
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1208 520 the middle of the European distribution, whereas our study included somewhat larger farms.
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1210 521 Annual working units were also similar to what is seen in other European countries. In
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1212 522 comparison with Europe, the area under organic farming (%UAA) in Switzerland in 2016
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1214 523 (13.5%) is at the sixth position, with the highest value recorded in the neighbouring country of
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1216 524 Austria (21.3%).
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1219 525 To compare the cropping practices applied in Switzerland to what is done in Europe, we used
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1221 526 the survey conducted by Herzog et al. (2006) in seven European countries (i.e. Belgium,
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1223 527 Czech Republic, Estonia, France, Germany, Netherlands and Switzerland) to provide relevant
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1225 528 insights. As the indicators used in this survey were not directly comparable to ours, we used
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1227 529 this paper as a reference to give an idea of where Switzerland is situated compared to the
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1229 530 other countries for conventional systems. This showed that, for nitrogen fertilisation on arable
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1231 531 crops [kg N/ha], number of herbicide, fungicide and total treatments, Switzerland ranked in
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1233 532 the middle of the seven studied countries, with ranks between 3.5 and 5. For crop diversity,
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1235 533 Switzerland ranked at the 2nd position, after Germany (Supplementary material Figure S6).
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1246 536 **4. Discussion**

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1249 537 *4.1 Selection, definition and comparison of primary cropping practice indicators and*
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1251 538 *composite intensity indexes*

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1253 539 In this study, the indicators were chosen to cover the main characteristics of cropping
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1255 540 systems, especially at the field level, taking into account the potential availability and
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1257 541 reliability of the data needed to compute the indicators. The topics covered here were similar
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1259 542 to those appearing in other similar studies (e.g. Nkurunziza et al., 2017 and Gaudino et al.,
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1261 543 2014), but included only so called ‘driving forces’ or ‘causal’ indicators (Bockstaller et al.,
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1263 544 2015). Among the topics not addressed here, irrigation indicators were not included as
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1265 545 generally not practiced on winter wheat fields in Switzerland. Indicators linked to P and K
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1267 546 fertilisation, and five-year N fertilisation were not included either, but should be considered in
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1269 547 a further development of this study. In Switzerland, P and K fertilisers are generally not
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1271 548 applied annually but on a larger time scale, according to the duration of crop rotation or to the
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1273 549 frequency of soil analysis. Thus the short term of this study would not have allowed to capture
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1275 550 accurately P and K fertilisation practices.

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1279 552 A crucial question that arises when defining quantitative indicators is also the number of years
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1281 553 which should be taken into account for computation. Indicators based on the studied
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1283 554 cultivation year are easier to compute as they require information that the farmer is likely to
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1285 555 access easily or remember accurately. On the other hand, indicators based on a longer time
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1287 556 scale should better capture the usual practices and are more pertinent for some practices such
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1289 557 as organic amendment inputs, which are often not applied each year. In addition, longer time
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1291 558 scale indicators would be more pertinent to explain slowly changing characteristics such as
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1293 559 soil organic carbon content. They are, however, more difficult to compute because they

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560 require information spread over several years. Therefore, the multiyear indicators presented
561 here were based on less detailed information, likely to be easily retrieved from the farmers. In
562 this study, the utilisation of one year and five-year indicators allowed to show that the wheat
563 cultivation year studied seemed representative of the practices observed at the crop rotation
564 scale. The same approach was adopted by Nkurunziza et al. (2017), with detailed data
565 collected for the year of the study, and more general information collected for the preceding
566 years.

567
568 The studied indicators also differed in their complexity, i.e. the amount of data, reference
569 values and assumptions needed to compute them. In this study, most of the complex
570 indicators integrating several data and reference values were correlated with simpler
571 indicators based on less data. (e.g. soil tillage intensity with the number of tillage and weeding
572 interventions, soil cover with the simple soil protection indicator). The most complex
573 indicators required a lot of reference data (e.g. reference yields, isohumic coefficients, ...) to
574 be computed, which induced a necessary simplification of the complex farm practices, and
575 increased indicator uncertainty. However, the set of indicators was tested here in one specific
576 context, and we cannot exclude that complex indicators could prove to be necessary if tested
577 with other data. For example, here the relative phytosanitary treatment frequency index,
578 taking into account the applied dose and area (% of field treated), was highly redundant with
579 the number of treatments. This shows that in our specific study, most of pesticide applications
580 were done at the full recommended dose and on the whole field. However, in other contexts it
581 is highly likely that the more complex frequency index would provide more detailed
582 information on the practices.

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584 We also tested the potential of composite indexes to provide additional or simplify redundant
585 information compared to the primary indicators. Many studies recommend using simple as

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586 well as composite indicators to best describe cropping systems (Herzog et al., 2006:
587 Bockstaller et al., 2008; Castoldi and Bechini, 2010). Composite indexes have the advantage
588 to sum up different information into one unique variable and so to facilitate overall
589 conclusions and comparison between systems (e.g. Armengot et al., 2011, Blüthgen et al.,
590 2012), while simple indicators remain essential to interpret the results more precisely. Many
591 methods to build composite indexes exist (Nardo et al., 2005; Sadok et al., 2008), and two
592 commonly used methods were investigated in this study.

593 Our results showed that the interpretation of the indexes could depend on the calculation
594 method used. So, care should be taken when using composite indexes, and referring back to
595 the individual components of the composite indexes is necessary to insure the proper
596 interpretation of the results (Herzog et al., 2006). A good example of the problems which can
597 occur when using the PCA method appeared for the Crop diversification category. While all
598 the four individual indicators considered (frequency of leys, legumes, cover crops, and crop
599 diversity) contribute to a higher diversification of the system, the first axis of the PCA
600 composed a gradient with high diversity and cover crop frequency on one side, and high
601 number of leys on the other side. This method here could not take into account the fact that
602 different practices can achieve the same purpose, diversification in this case. Thus, this
603 unconstrained method cannot guarantee that the composite index really shows the intended
604 gradient. The PCA index can nevertheless be often meaningfully interpreted. In this case,
605 cover crops contributed to higher diversity and thus pointed in the same direction, whereas the
606 presence of rotational leys reduced diversity on a given time period by decreasing the number
607 of main crops and cover crops that can be cultivated during this period. However, both can
608 contribute to overall diversification. In contrast, in the additive aggregation method, the
609 direction of interpretation of the individual indicators is *a priori* decided, which allows to
610 construct meaningful gradients, even if the direction of some indicators is sometimes
611 debatable. However, for the Soil disturbance and protection category, both methods produced

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612 similar composite indexes, showing that the PCA method could also be useful, provided that
613 the produced gradient is carefully checked. The PCA method is thus highly dependent on the
614 dataset on which it is based, while the additive aggregation method is mostly dependent on
615 the computation procedure, such as the normalisation or weighing method used. Depending
616 on the utilisation of the composite indexes, one or the other method should be preferred. For
617 example, when the objective is to aggregate further these indexes to produce a unique
618 multifunctionality index, the additive aggregation method is preferable for the first step, as it
619 allows controlling the direction of the indexes, and thus insuring proper interpretation of the
620 overall index. In contrast, the PCA **method is more useful** to explore datasets without
621 preconceived ideas about underlying data structure and relationships between indicators.

622

623 *4.2 Potential of indicators to characterise cropping systems*

624 Farm level indicators

625 Including indicators common to European or international frameworks allowed to situate our
626 study in a broader context, which could help the interpretation of the results. The farms in this
627 study appear larger than the Swiss and European average. This could be partly explained by
628 the fact that only lowland farms were selected for this study, excluding hill and mountain
629 farms, which are generally smaller. This could also explain the lower values of livestock units
630 in our study compared to the Swiss mean, but these values were in the range of what is seen in
631 Europe. In Switzerland, most conventional farms follow the ‘Proof of Ecological
632 Performance’ (PEP) guidance, which ensure, in principle, an equalised nutrient balance,
633 diversified crop rotation and proper soil protection and pesticide treatment use (FOAG,
634 2018a). In this study, all conventional and no-till farms followed these prescriptions. This
635 could explain some similarities between the conventional, no-till and organic systems, for
636 example in terms of organic amendment inputs or crop rotation diversification. The
637 application of these PEP guidelines in Switzerland could perhaps also explain the highest crop

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638 diversity observed by Herzog et al. (2006), whereas Switzerland was in line with the other
639 studied countries for nitrogen inputs and pesticide treatments.

640
641 Primary cropping practice indicators and composite intensity indexes

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

649
650 The three simpler Crop diversification indicators differentiated the three systems, while
651 diversity and rotation diversification were similar between systems, with high within-system
652 variability. However, overall, the indicators pointed to a lower diversification of conventional
653 systems, which was confirmed by the composite index based on additive aggregation. This
654 shows that no-till systems including cover crops as well as organic systems with rotational
655 leys allow to increase diversification, a key factor of sustainable agriculture intensification
656 (Smith et al., 2017).

657 The Soil disturbance and protection category was the one showing the major differences
658 between systems. As expected, no-till systems had higher soil protection values compared to
659 conventional and organic systems. Interestingly, these indicators also separated organic
660 systems, and the composite indexes clearly showed the same pattern. To compensate for the
661 absence of herbicide use, intense mechanical weeding was generally observed in organic
662 fields, which yielded to higher values of soil perturbation indicators compared to conventional
663 fields. This poses the question of the balance of the benefits of reduced pesticide products

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664 utilisation and the potential negative effects of increased soil disturbance in organic farming.

665 Minimum soil tillage in organic farming is a challenge, but the development of more specific
666 and efficient tillage implements and the adoption of cover crop cultivation, which was low in
667 our studied organic farms, will probably allow a reduction of soil tillage intensity in organic
668 farming (Buchanan et al., 2016; Cooper et al., 2016).

669 In contrast, indicators linked to Organic matter inputs, included the composite index based on
670 additive aggregation, were similar between the three cropping systems. This finding is
671 surprising as organic systems are generally thought to provide more organic matter to the soil,
672 through organic amendments or inputs due to the introduction of leys in the rotation. In the
673 organic system, the level of fertilisation was generally low, with an estimated N input to the
674 2016 wheat (61 kgN/ha, from organic source) less than half the Swiss (conventional)
675 reference standard for N fertilisation of winter wheat (140 kgN/ha), while conventional and
676 no-till systems showed similar, higher, values (160 kgN/ha and 147 kgN/ha, from both
677 mineral and organic sources).

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

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689 are generally adopting these practices to reduce the impact of agriculture on the environment,
690 which explain their higher compliance with these extensive farming programs.

691
692 Overall, the organic system was the most homogeneous one in terms of cropping practices,
693 which can be explained by the fact that this system has more specific rules than the no-till or
694 conventional systems and bans several practices, principally mineral fertilisation and chemical
695 crop protection. In contrast, conventional and no-till systems showed higher overlap in their
696 practices, especially in terms of crop diversity, rotation diversification and fertilisation. This
697 showed that, in this study, focusing on the 'no-till' criterion did not implicitly co-select other
698 specific cropping practices.

699
700 Yield and relative yield cannot be considered as cropping practices like the other indicators
701 presented here, but are the main outcomes of these practices and fundamental to interpret their
702 sustainability. The no-till fields showed a mean decrease of yield of 10% compared to
703 conventional ones on the five-year crop rotation, which is similar to what has been previously
704 shown (Pittelkow et al., 2015a). This difference was, however, not significant for the 2016
705 wheat yield, and was partially linked to the compliance of farmers with the extensive farming
706 programs mentioned earlier. Indeed, extensive conventional fields showed lower yield than
707 intensive conventional ones, and thus more similar to no-till yields. In contrast, no difference
708 was observed for extensive and intensive no-till yields. A yield decrease in the initial years of
709 transition to no-till is generally expected, while the yield gap generally fills up after some
710 years (Soane et al., 2012; Pittelkow et al., 2015b). The cover crop frequency tended to be
711 higher in new no-till systems, pointing probably to a growing awareness of the importance of
712 integrating no-till in an ensemble of sustainable practices amongst the younger no-till farmers
713 compared to pioneer ones. A relative mean yield decrease of about 33% was observed in
714 organic fields compared to conventional ones, which is slightly higher than what has been

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715 shown in global meta-analyses (~26% for cereals with high variability, de Ponti et al., 2012;
716 Seufert et al., 2012). The yield difference between organic and conventional systems was
717 even higher when looking only at the 2016 wheat yield, which showed a decrease of 40%.
718 The 2016 spring was very wet and favourable to diseases, which could have been more
719 detrimental for organic fields. Despite the low mean yield in the organic system, it is
720 worthwhile mentioning that the highest organic yields were higher than some of the yields
721 obtained in conventional or no-till systems. This showed that depending on the conditions and
722 on the practices implemented, organic yield could achieve a reasonable productivity.

723
724 *4.3 Conclusions*

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

738 This study has demonstrated that an exhaustive and explicit description of the cropping
739 practices involved in what is generally classified as different cropping systems is crucial to
740 better understand the potential influence of these systems on yield or soil properties. For

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1714 741 example, knowing the tillage intensity applied in organic fields would be of crucial
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1716 742 importance to analyse and predict soil organic matter evolution. While the comparison of
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1718 743 systems in terms of yield, soil properties or their influence on the environment is highly
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1720 744 relevant, this study has shown that it is crucial to describe precisely and quantitatively the
1721
1722 745 cropping practices involved to avoid any misinterpretation based on supposed or non-
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1724 746 acknowledged differences.

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890 **Table and figure legends**

891

892 **Table 1** List of the 31 cropping practice indicators used to describe cropping systems. ‘Time
893 scale’ indicates if the indicator is computed with data coming only from the focal year 2015-
894 2016 ('1 y') or from data collected for the five-year crop rotation ('5 y').

895

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

900

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

905

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

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2188 917 **Figure 2** Differences between cropping systems for six indicators. A. crop rotation
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2190 918 diversification (rDiversification), B. soil tillage intensity (stir), C. quantity of organic
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2192 919 amendment inputs (qOrg) [kg OM/ha], D. total nitrogen fertilisation (totN) [kg N/ha], E.
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2194 920 relative herbicide treatment intensity (rHerb), F. relative yield (relY). 'conv': conventional
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2196 921 systems, 'nt': no-till systems, 'org': organic systems. Different letters above the boxes show
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2198 922 significant ($p < 0.05$) pairwise differences between systems.
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2203 924 **Figure 3** Principal component analysis on the 31 indicators, showing the two first principal
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2205 925 components, explaining respectively 30% and 11%. A. Field projection (scaling 2) on the 1st
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2207 926 and 2nd principal components, B. Indicator projection (scaling 1) on the 1st and 2nd principal
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2209 927 components. Blue points correspond to conventional systems, red points to no-till systems and
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2211 928 green points to organic systems. Correspondence between abbreviations and indicator names
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2213 929 are given in Table 1.
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2218 931 **Figure 4** Differences between cropping systems for the composite indexes. Upper row,
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2220 932 indexes based on the PCA method, lower row indexes based on the additive aggregation. First
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2222 933 column (A and D) shows the Crop diversification category, the middle column (B and E), the
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2224 934 Soil disturbance and protection category, and the last column (C and F), the Organic matter
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2226 935 inputs and nitrogen fertilisation category.
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2231 937 **Figure 5** Comparison of the three farm structure indicators and of area under organic farming
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2233 938 (% UAA) with mean data from Switzerland and European countries. Data were obtained from
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2235 939 the Eurostat website. Blue points correspond to conventional systems, red points to no-till
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2237 940 systems and green points to organic systems. On each box, 'CH' shows the position of
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2239 941 Switzerland in the European dataset.
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2250 944 **Supplementary Material**
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2252 945 **Table S1** List and description of the 60 farms included in the study. 'Mean temperature' and
2253
2254 946 'Rainfall' are given as average values over the two years 2015 and 2016. 'Soil texture' gives
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2256 947 texture classes according to the ISSS system. 'Program' refers to compliance to specific
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2258 948 'integrated' (no pesticides except herbicides) or 'organic' programs in 2016. 'UAA' is for
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2260 949 utilised agricultural area. 'Fertilisation' indicates what kind of fertilisation was used during
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2262 950 the five-year crop rotation: 'min' = mineral only, 'org' = organic only, 'min-org' = mixed
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2264 951 mineral and organic. The conventional farm indicated in light grey was removed from the
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2266 952 analyses due to missing survey data.
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2271 954 **Table S2** Data collected in the questionnaire survey (rows), filled in by the farmers, and used
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2273 955 to compute the 31 cropping practice indicators (columns). The crosses indicate which data has
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2275 956 been used for which indicator.
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2279 958 **Table S3** Isohumic coefficients and nitrogen availability of organic amendments used in the
2280
2281 959 computation of the organic amendment inputs (qOrg), total organic inputs (totOrg), nitrogen
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2283 960 organic fertilisation (orgN) and total nitrogen fertilisation indicators (totN).
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2288 962 **Table S4** Mean values and standard errors of the 31 indicators for the three cropping systems,
2289
2290 963 and p-values from the overall analysis of variance ('global') and from the Tukey HSD post-
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2292 964 hoc pairwise test. 'conv': conventional farming, 'nt': no-till farming, 'org': organic farming.
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2304 966 **Figure S1** Map of Switzerland showing the geographic position of the 60 fields. Blue points
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2306 967 correspond to conventional systems, red points to no-till systems and green points to organic
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2308 968 systems.
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2313 970 **Figure S2** Texture triangle (ISSS system) showing the texture (0-20 cm) of the 60 fields. Blue
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2315 971 points correspond to conventional systems, red points to no-till systems and green points to
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2317 972 organic systems.
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2321 974 **Figure S3** Principal component analyses (field projection, scaling 2) used for the computation
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2323 975 of the composite indexes for A. Crop diversification, B. Soil disturbance and protection, and
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2325 976 C. Organic matter inputs and nitrogen fertilisation. Blue points correspond to conventional
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2327 977 systems, red points to no-till systems and green points to organic systems. Correspondence
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2329 978 between abbreviations and indicator names are given in Table 1.
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2334 980 **Figure S4** A. Crop frequency for the studied fields, for the three cropping systems ('conv':
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2336 981 conventional, 'nt': no till, 'org': organic). Crops are grouped into types. B. Categorisation of
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2338 982 the crop rotation along three main types: 1. rotations with a cereal every two years, 2.
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2340 983 rotations including leys, and 3. other type of rotations.
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2345 985 **Figure S5** Relative yield indicator as a function of time since the beginning of A. no-till
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2347 986 practice and B. organic practice. In panel A, the numbers above the points indicate the
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2349 987 number of cover crops cultivated the past 5 years (number of cover crop 'nbCC' indicator).
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2351 988
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2353 989 **Figure S6** Comparison of Switzerland with six other European countries in terms of crop
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2355 990 diversity, nitrogen fertilisation and pesticide inputs. On each box, 'CH' shows the position of
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2357 991 Switzerland. On the left of each box, the two-letter code of each other country is indicated,
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2363 992 BE: Belgium, CZ: Czech Republic, EE: Estonia, FR: France, DE: Germany, NL: Netherlands.
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2365 993 The data come from Herzog et al. (2006).
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695 **Table 1**

Indicator	Abbreviation	Time scale^a	
<i>Farm structure</i>			
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
<i>Crop diversification</i>			
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
<i>Soil disturbance and protection</i>			
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
<i>Organic matter inputs and nitrogen fertilisation</i>			
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

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total nitrogen fertilisation [kg N/ha]	totN	1 y	
<i>Crop protection</i>			
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
<i>Yield</i>			
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)

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999 **Table 2**

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

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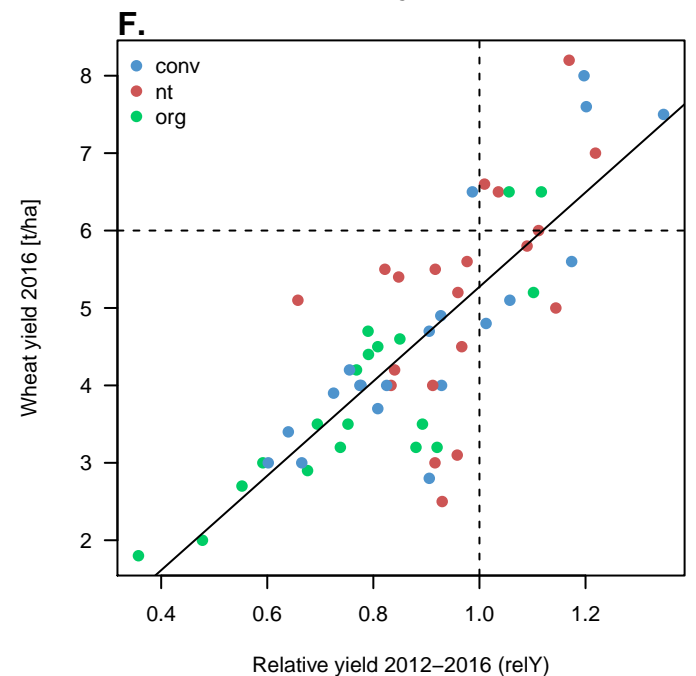
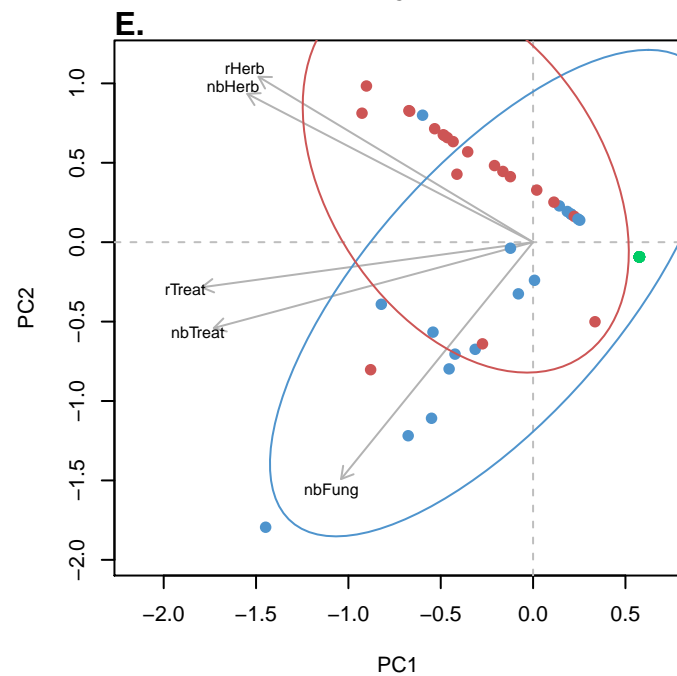
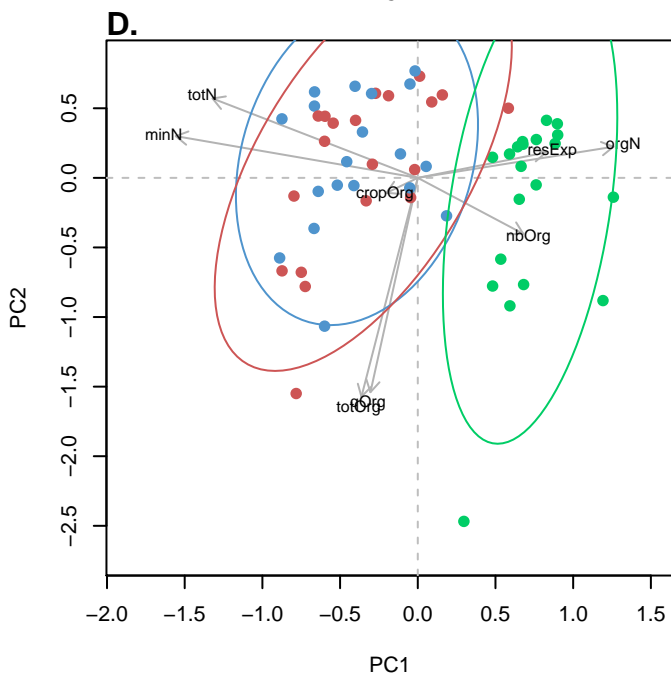
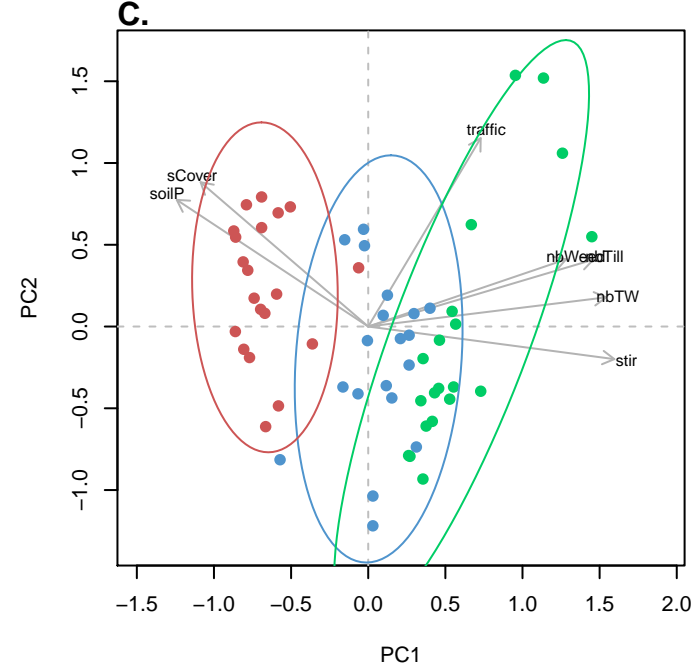
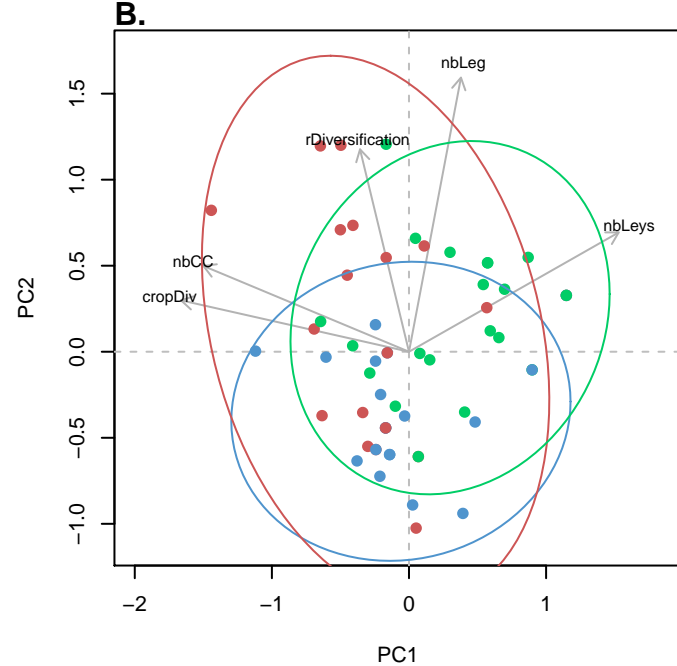
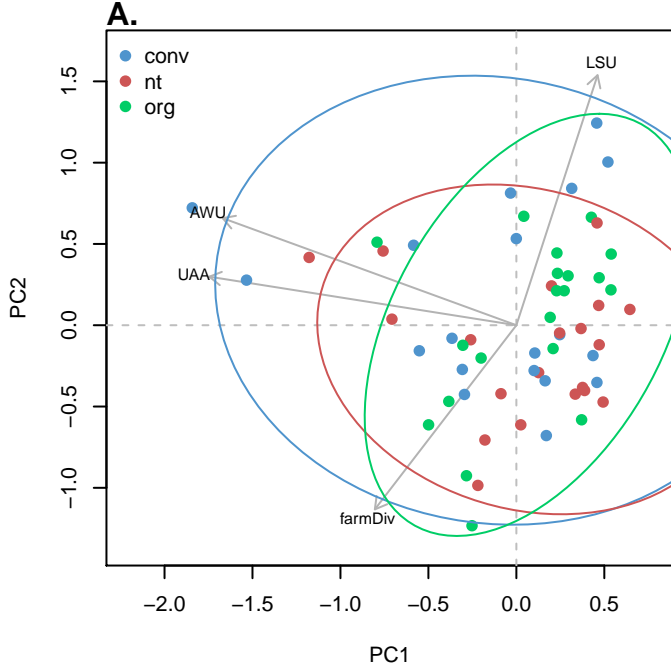
1001 **Table 3**

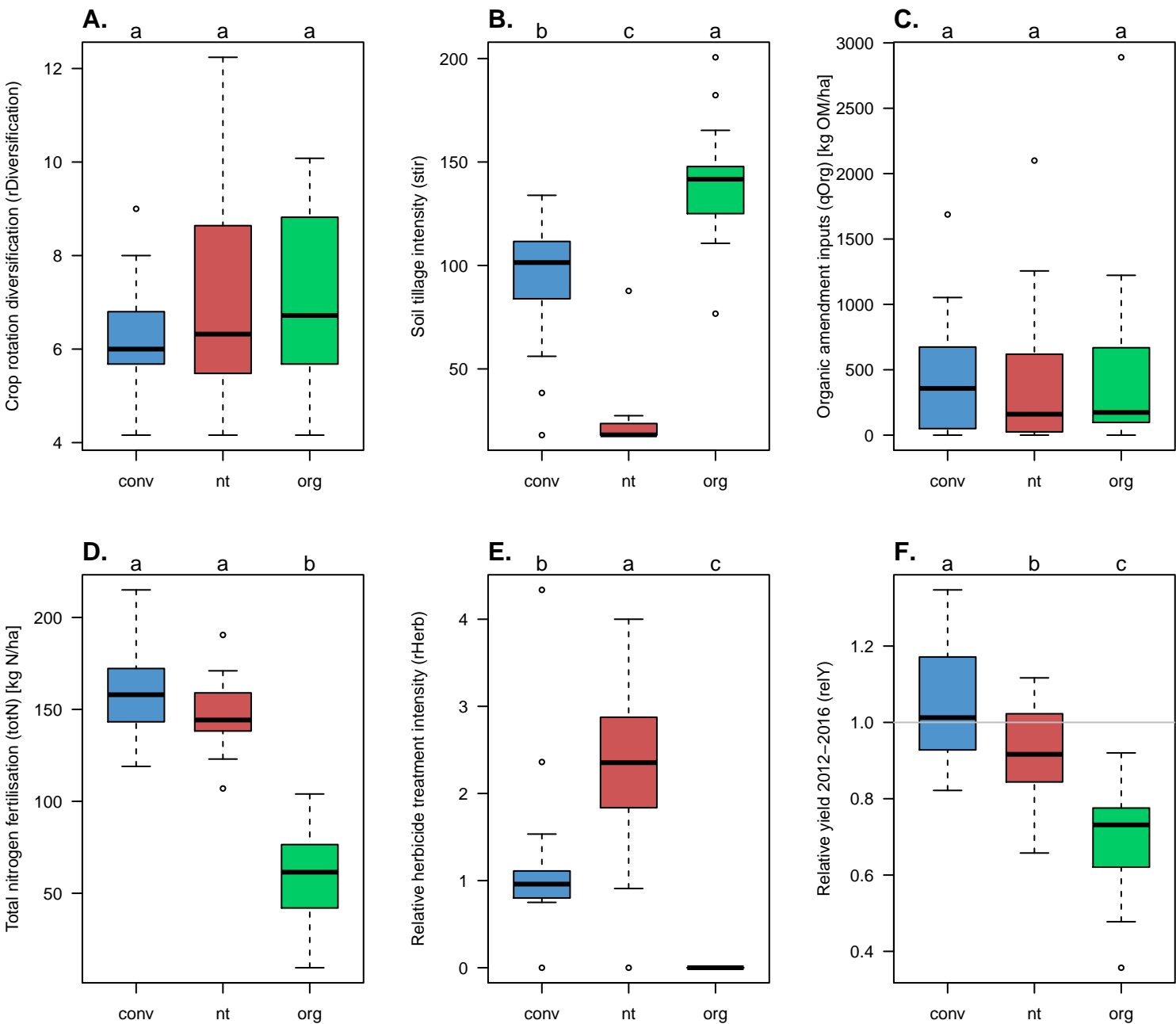
Indicator	Abbreviation	Overall means			Differences between systems				
		conv	nt	org	all different ^a	conv different ^b	nt different ^c	org different ^d	no difference
<i>Farm structure</i>									
utilised agricultural area [ha]	UAA	62	44	41					X
annual working unit	AWU	2.6	1.9	2.0					X
livestock unit	LSU	0.70	0.27	0.73					X
diversity at farm level 2016	farmDiv	6.58	6.25	7.15					X
<i>Crop diversification</i>									
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			
<i>Soil disturbance and protection</i>									
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				
<i>Organic matter inputs and nitrogen fertilisation</i>									
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

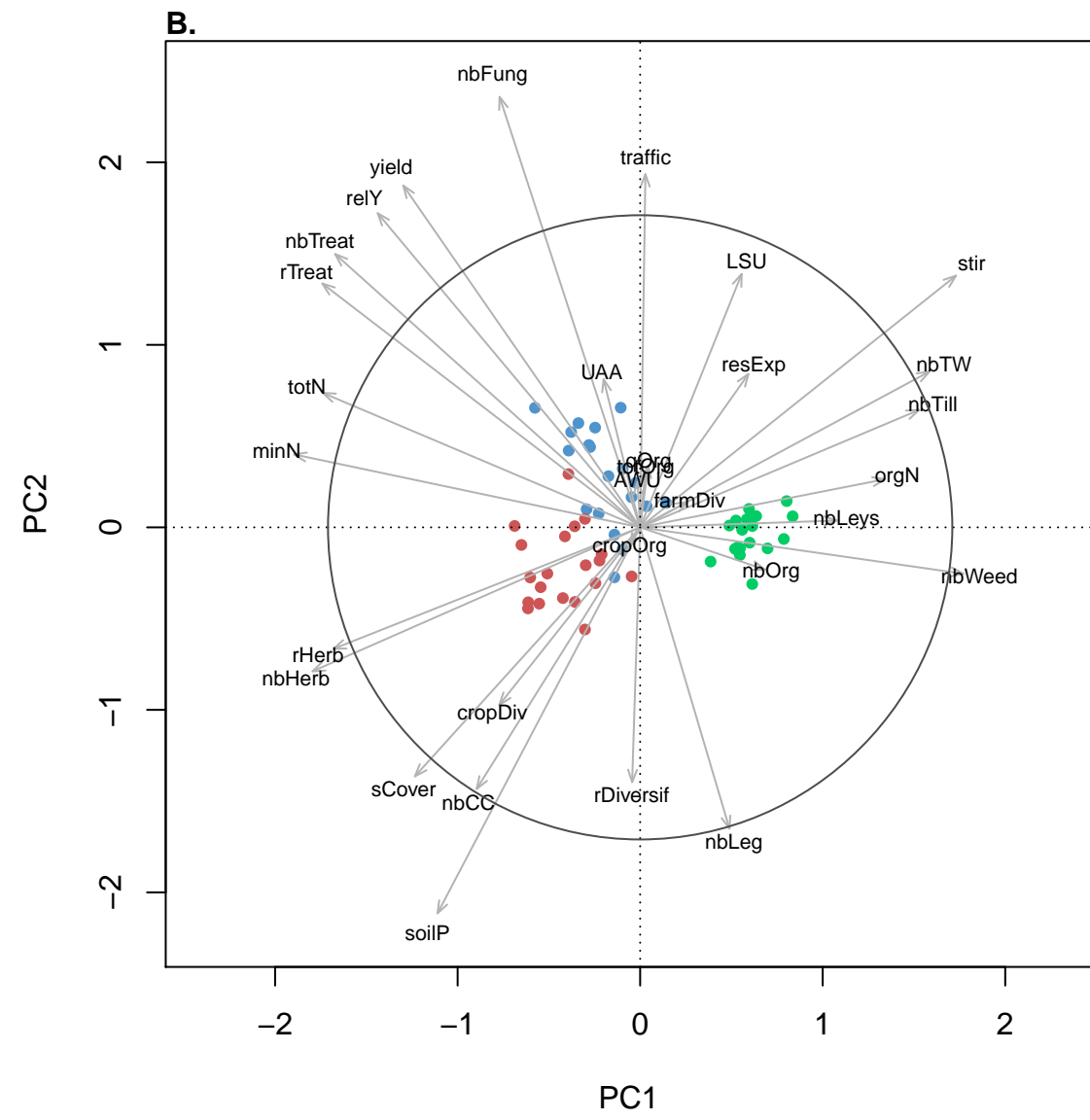
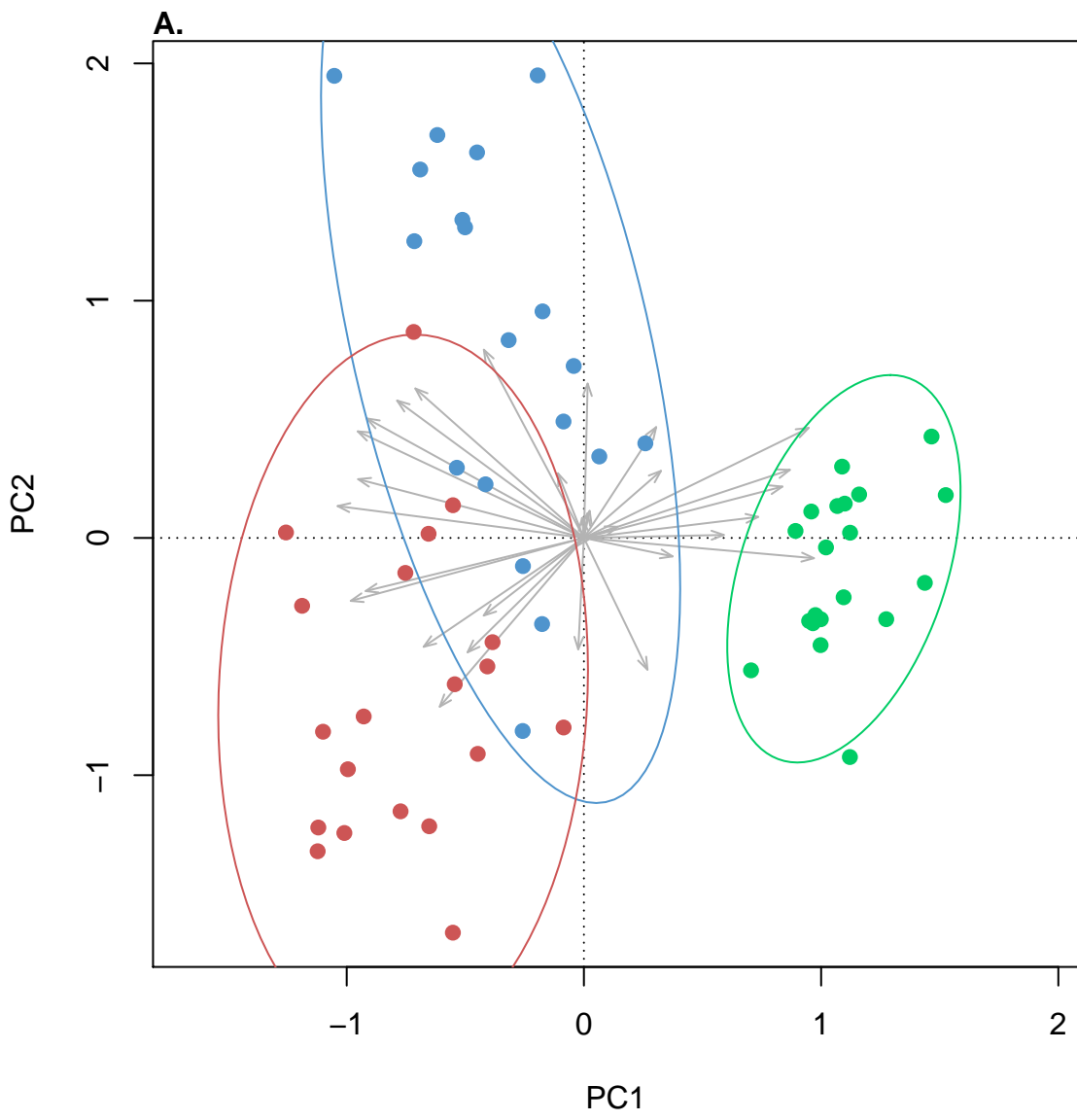
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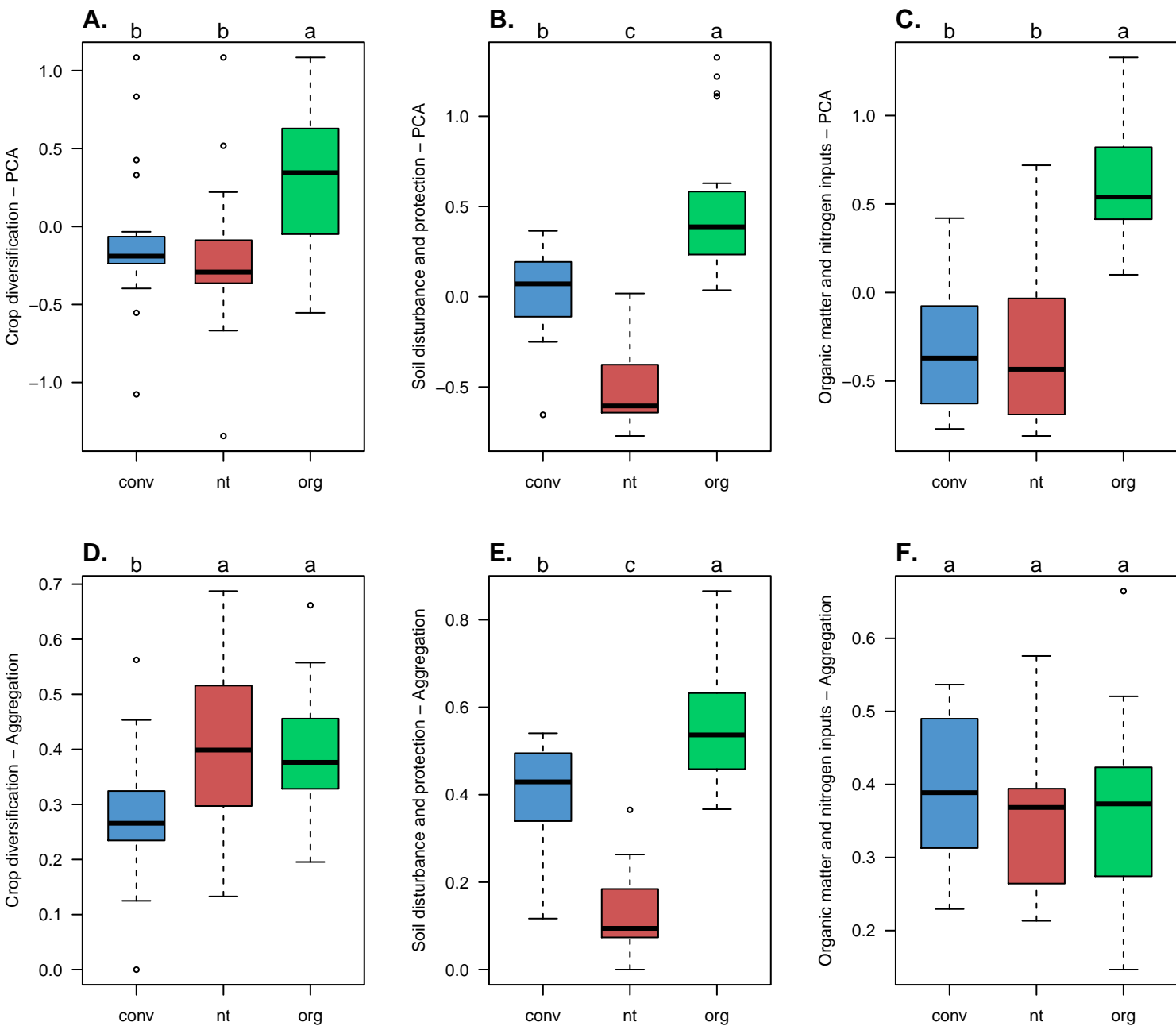
total organic inputs [kg OM/ha]	totOrg	1148	1161	1178						X
mineral nitrogen fertilisation [kg N/ha]	minN	141	127	0					X	
organic nitrogen fertilisation [kg N/ha]	orgN	19	20	61					X	
total nitrogen fertilisation [kg N/ha]	totN	160	147	61					X	
composite index based on PCA		-0.29	-0.32	0.59					X	
composite index based on additive aggregation		0.40	0.35	0.36						X
<i>Crop protection</i>										
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	
<i>Yield</i>										
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









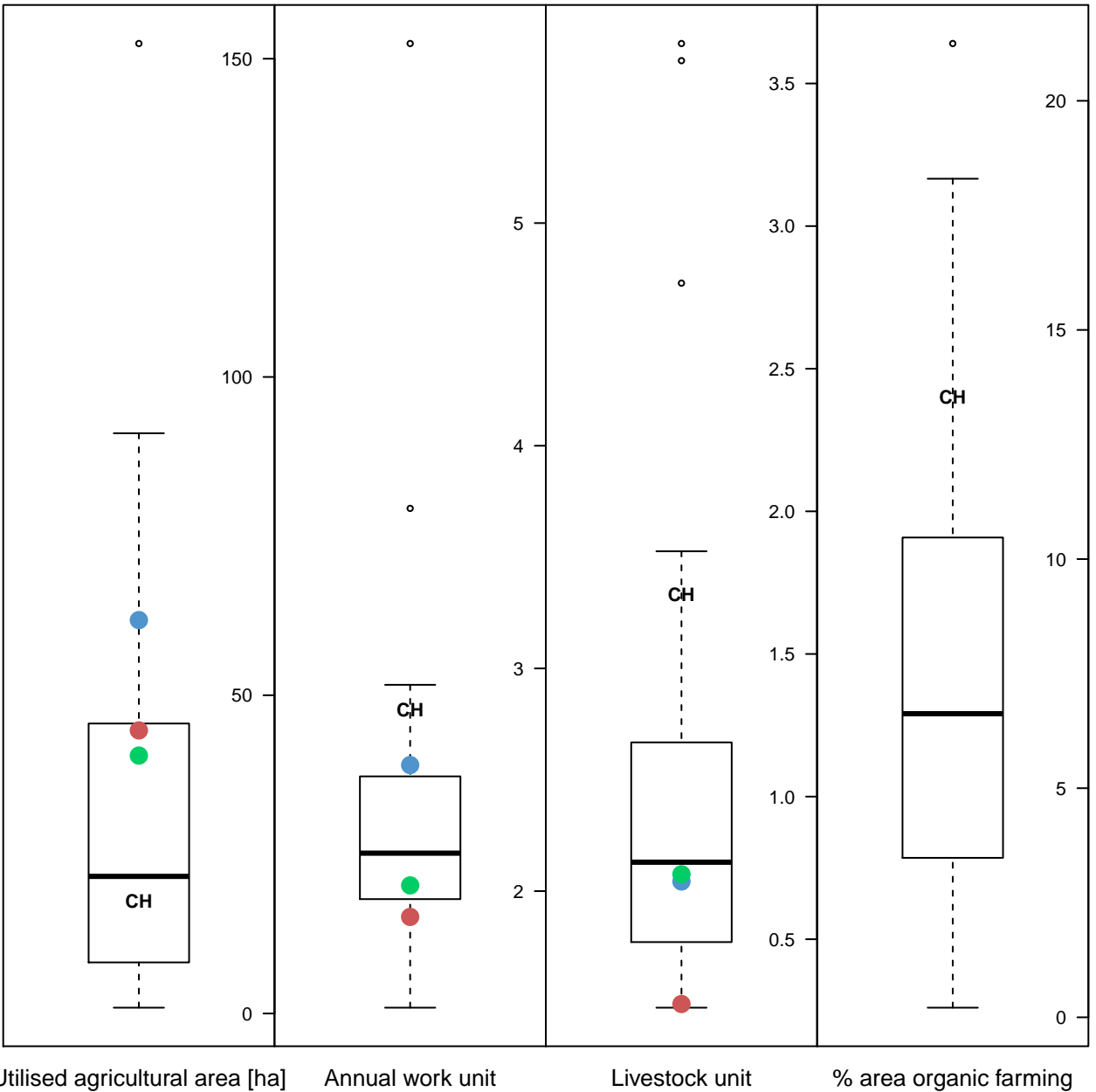


Table S1 List and description of the 60 farms included in the study. ‘Mean temperature’ and ‘Rainfall’ are given as average values over the two years 2015 and 2016. ‘Soil texture’ gives texture classes according to the ISSS system. ‘Program’ refers to compliance to specific ‘integrated’ (no pesticides 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 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

^adry organic matter and total nitrogen are given in kg/t, except for values marked with *, in kg/m3

^bpart 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

- CSICM, 2010. Directive suisse 2010 de la branche sur la qualité du compost et du digestat. Commission suisse de l'inspection du compostage et de la méthanisation, 40 pp.
- 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
<i>Farm structure</i>										
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
<i>Crop diversification</i>										
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
<i>Soil disturbance and protection</i>										
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
<i>Organic matter inputs and nitrogen fertilisation</i>										
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
<i>Crop protection</i>										
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
<i>Yield</i>										
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

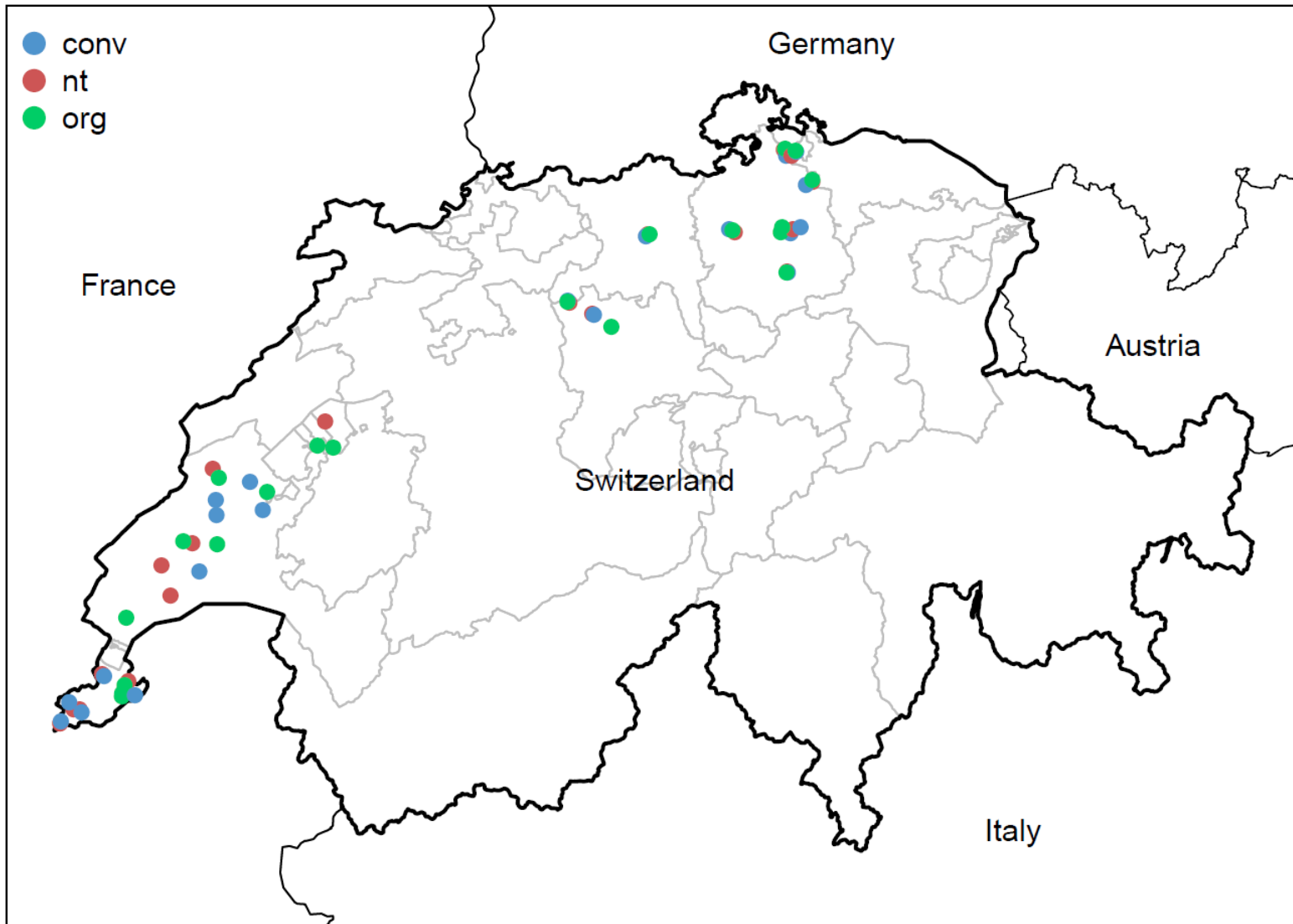


Figure S1 Map of Switzerland showing the geographic position of the 60 fields. Blue points correspond to conventional systems, red points to no till systems and green points to organic systems.

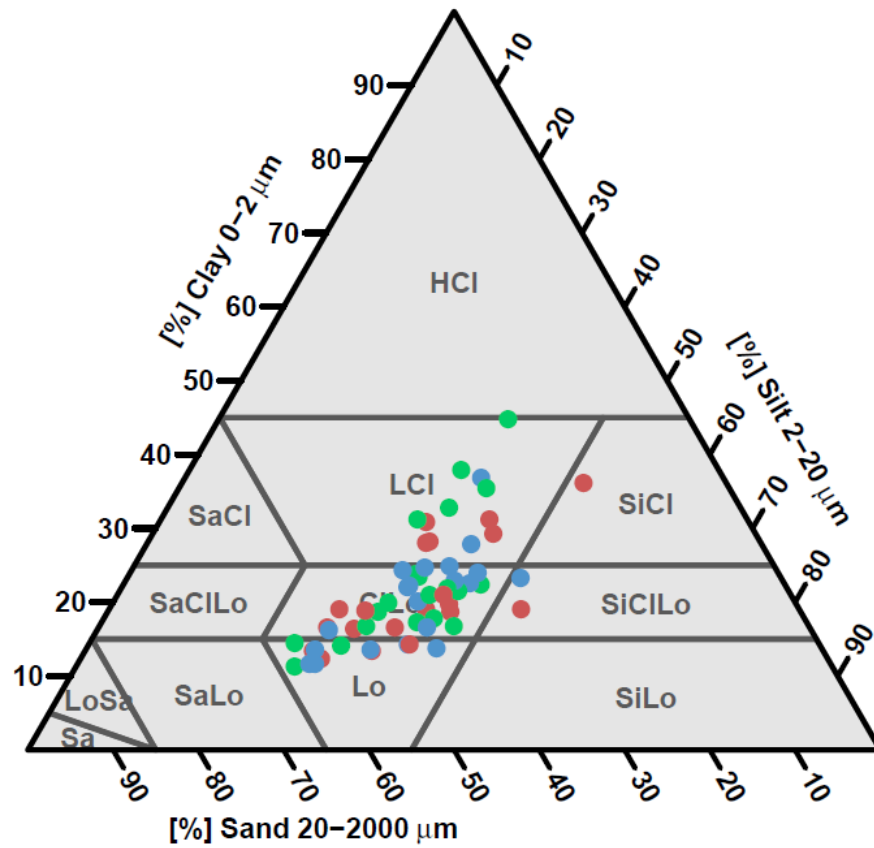


Figure S2 Texture triangle (ISSS system) showing the texture (0-20 cm) of the 60 fields. Blue points correspond to conventional systems, red points to no till systems and green points to organic systems.

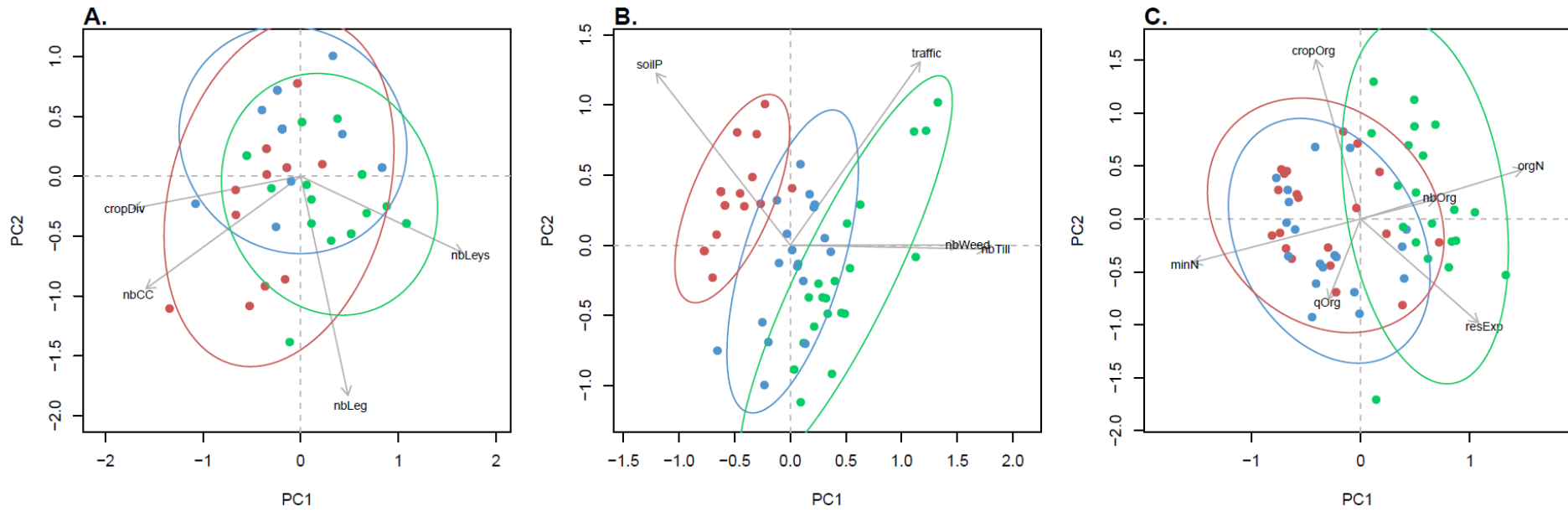


Figure S3 Principal component analyses (field projection, scaling 2) used for the computation of the composite indexes for A. Crop diversification, B. Soil disturbance and protection, and C. Organic matter inputs and nitrogen fertilisation. Blue points correspond to conventional systems, red points to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

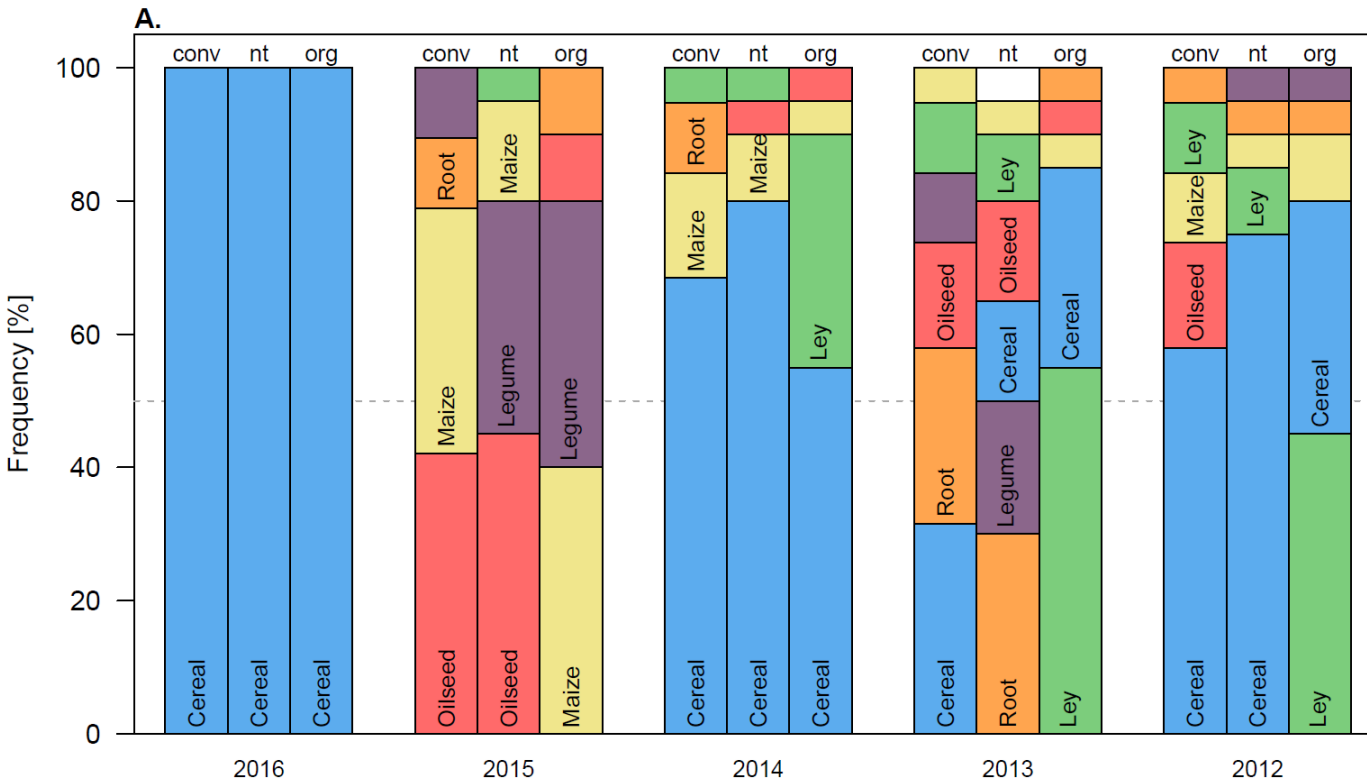
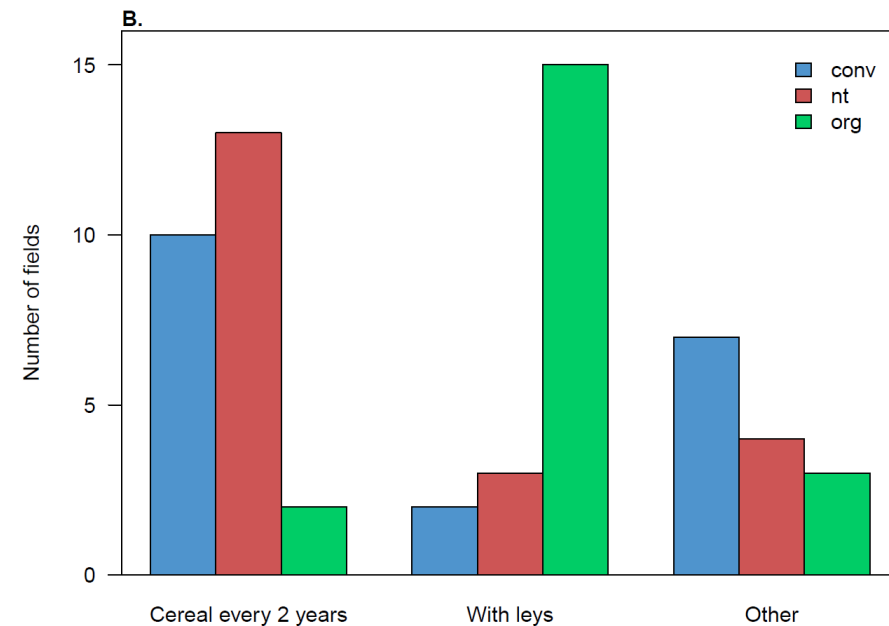


Figure S4 A. Crop frequency for the studied fields, for the three cropping systems ('conv': conventional, 'nt': no till, 'org': organic). Crops are grouped into types. **B.** Categorisation of the crop rotation along three main types: 1. rotations with a cereal every two years, 2. rotations including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



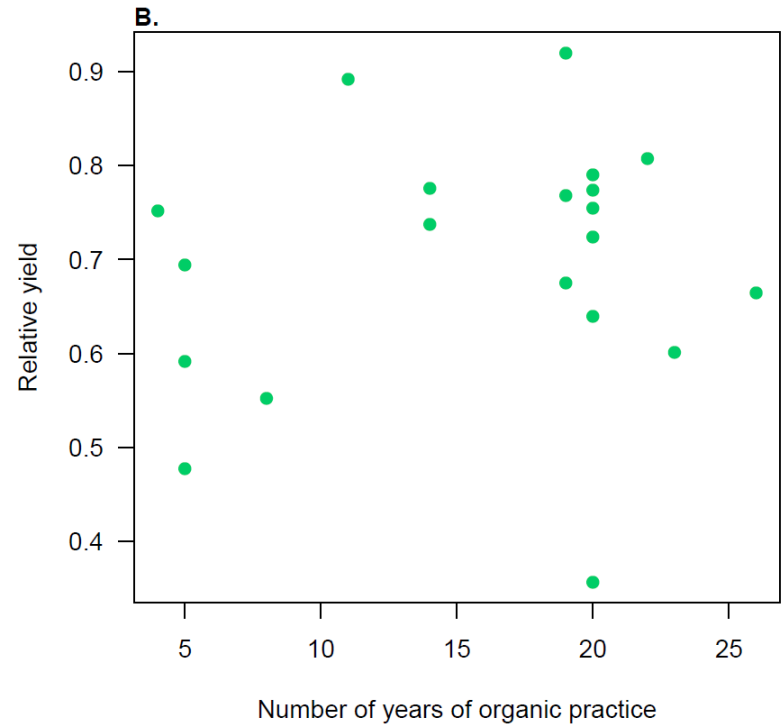
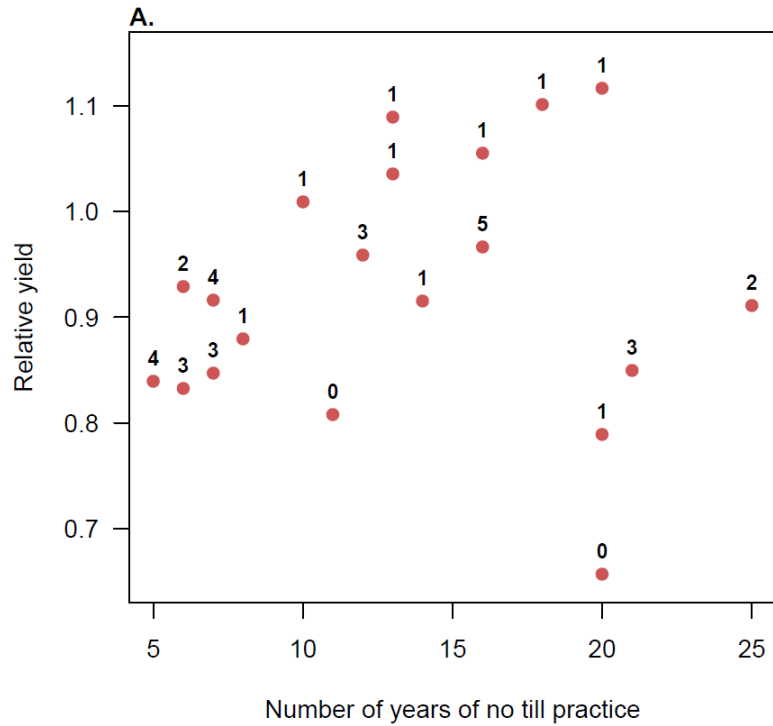


Figure S5 Relative yield indicator as a function of time since the beginning of A. no till practice and B. organic practice. In panel A, the numbers above the points indicate the number of cover crops cultivated the past 5 years (number of cover crop ‘nbCC’ indicator).

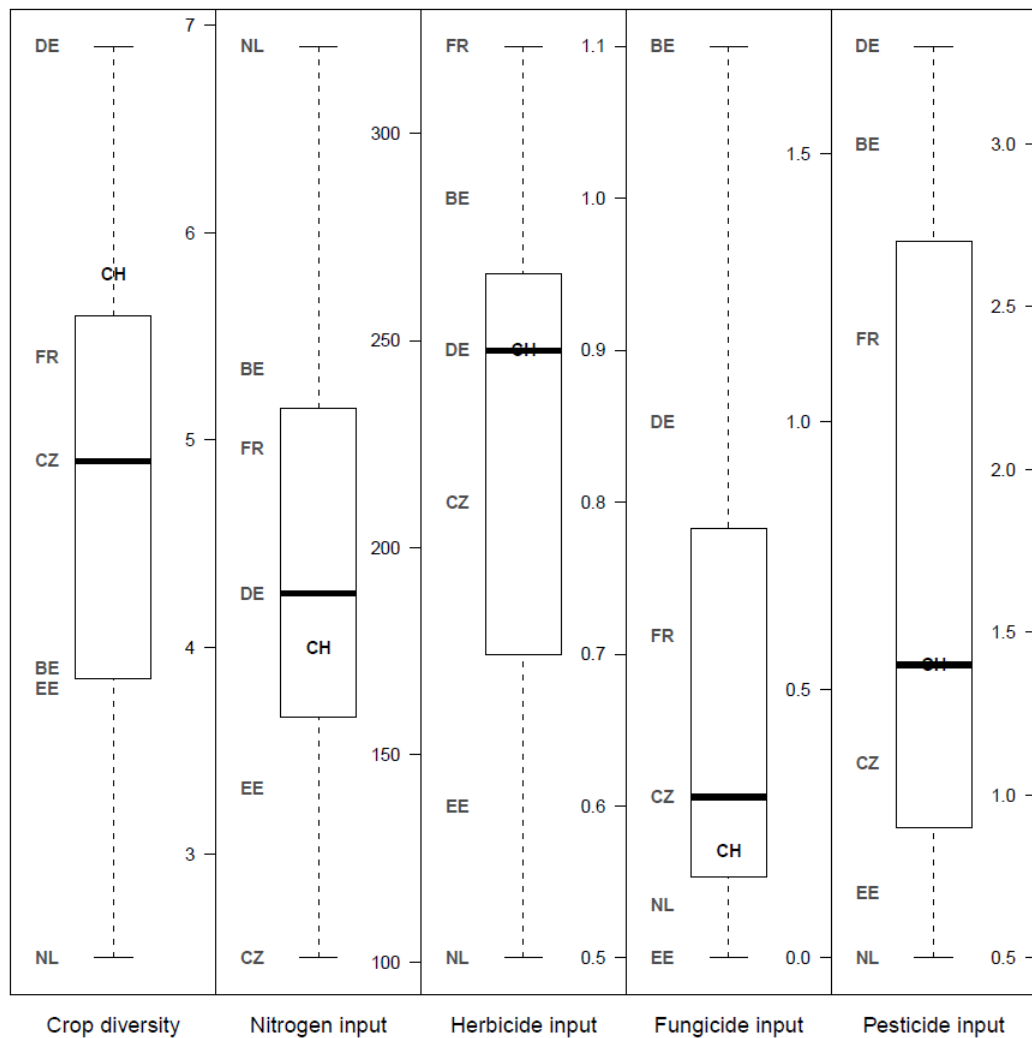


Figure S6 Comparison of Switzerland with six other European countries in terms of crop diversity, nitrogen fertilisation and pesticide inputs. On each box, ‘CH’ shows the position of Switzerland. On the left of each box, the two letter code of each other country is indicated, BE: Belgium, CZ: Czech Republic,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

Reference

Herzog, F., Steiner, B., Bailey, D., Baudry, J., Billeter, R., Bukacek, R., De Blust, G., De Cock, R., Dirksen, J., Dormann, C.F., De Filippi, R., Frossard, E., Liira, J., Schmidt, T., Stöckli, R., Thenail, C., van Wingerden W., Bugter, R. 2006. Assessing the intensity of temperate European agriculture at the landscape scale. *Europ. J. Agron.* 165-181.