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1 A Meta-Analysis of Maize and Wheat Yields in Low-Input vs. Conventional and Organic
2 Systems

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21

22 Abstract

23 Organic and low-input systems are proposed as ways to reduce the environmental impacts of
24 agriculture. Previous studies have shown that yields of organic systems can be ~19-25%
25 lower than conventional systems. An intermediary, low-input system could be less damaging
26 for the environment than conventional systems, while reducing yield losses in comparison
27 with organic systems. In this study, we carried out a meta-analysis to compare low-input
28 systems to both conventional and organic systems. Our analysis is based on data of cropping
29 system experiments conducted in Europe and North America, and focuses on two important
30 crops, maize and soft winter wheat. Pesticide use was greatly reduced for low-input systems
31 as compared with conventional for the two crops (50% for maize, 70% for wheat on average).
32 Mean mineral N use was also reduced by 36% for maize and 28% for wheat in low input
33 relative to conventional. Maize yields in low-input systems were not different from those in
34 conventional systems, and were higher than yields in organic systems (yield ratio of low-input
35 vs. organic = 1.24). Wheat yields in low-input systems were lower than yields in conventional
36 systems (yield ratio of low-input vs. conventional = 0.88), but were substantially higher than
37 yields in organic systems (yield ratio of low input vs. organic = 1.43). This is one of the first
38 meta-analyses to assess performance in terms of pesticide use intensity, and yields, with clear
39 evidence emerging that low-input systems can markedly reduce pesticide application, without
40 strongly reducing crop yields, relative to conventional systems.

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48 Organic and low-input systems have been proposed as two possible alternatives to
49 conventional systems in an effort to reduce the harmful environmental effects of agriculture
50 (International Assessment of Agricultural Knowledge, 2009; Loyce et al., 2012). Organic
51 system aims at food production with minimal harm to humans, animals and ecosystems.
52 Organic agriculture has legal standards (e.g., European Commission (2008) for Europe) and
53 does not rely on the use of synthetic pesticides and fertilizers. Low-input and organic systems
54 make less intensive use of chemical inputs and/or of energy, which may help preserve natural
55 resources in the long term (e.g. soil quality including carbon; water quality; fossil fuel)
56 (Matson et al., 1997). Low-input systems seek to minimize the use of purchased production
57 inputs (e.g., fertilizer and pesticides) by optimizing the management of internal production
58 inputs (i.e. on-farm resources) in order to lower production costs, to avoid pollution of surface
59 and groundwater, to reduce pesticide residues in food, to reduce the farmer's overall risk, and
60 to increase both short- and long-term farm profitability (Parr et al., 1990). Conventional
61 systems are chemically-intensive and biologically simplified (Ponisio et al., 2015).
62 Conventional and low-input system characteristics depend on local conditions, especially on
63 soil fertility and on potential yields. Low-input systems rely on a large variety of strategies to
64 reduce synthetic inputs, especially on crop species diversification to reduce N fertilization
65 (e.g., Colnenne-David and Doré, 2015), integrated weed management with modified soil
66 tillage (e.g., Rasmussen, 2004; Pardo et al., 2010), use of resistant cultivars, and modified
67 sowing dates (e.g., Debaeke et al., 2009). In Europe (EU-15), 2.3% (5.9%) of agricultural
68 lands were managed with organic agriculture in 2012, and less than 1% in Canada and in the
69 U.S. (FAOSTAT, 2015). Currently there is no reliable statistics on areas cultivated with low-
70 input systems in the studied regions.

71 The performance of alternative cropping systems that are locally defined, and more
72 environment-friendly can be assessed with experiments in which different cropping systems

73 are compared in terms of crop yields, income, and/or environmental impacts. These long-term
74 system experiments, where several practices are simultaneously changed in a consistent way,
75 allow agronomists to evaluate promising innovative systems (Drinkwater, 2002; Debaeke et
76 al., 2009), in terms of both yield and environmental performances. However, the results of a
77 cropping system experiment carried out at a particular site can hardly be extrapolated to other
78 pedo-climatic contexts (Debaeke et al., 2009). Meta-analysis (Evans and Foster, 2011) is a
79 useful approach to analyze a large number of data for extrapolating local conclusions to
80 broader contexts.

81 Meta-analyses have been carried out to compare crop yields of organic and
82 conventional systems, showing ratios of organic yield to conventional yield, ranging from
83 0.75 to 0.81, depending on crops and regions (Badgley et al., 2007, de Ponti et al. 2012,
84 Seufert et al. 2012, Ponisio et al., 2015). Based on four experiments carried out in France,
85 Hossard et al. (2014) showed that a 50% reduction of pesticide use led to wheat yield losses
86 of 5 to 12% compared to conventional intensive cropping systems. No meta-analysis has yet
87 been conducted to compare yields of low input systems with those of conventional and
88 organic systems. In this study, we analyzed the data from 15 cropping system experiments
89 that are comparable in terms of experimental objectives and have been conducted over a wide
90 range of conditions in Europe and North America. We compared the yields and cropping
91 practices of low-input versus conventional and organic systems. We focused our analysis on
92 systems including soft winter wheat (*Triticum aestivum* L.) and/or maize (*Zea mays* L.),
93 which are two major crops grown throughout the world. At the global scale, maize is the
94 agricultural commodity with the highest production, while wheat is third, just after rice, which
95 is mostly grown in developing countries (data of 2011 in FAOSTAT, 2015). We chose to
96 limit the geographical scope of this work to Europe and North America, because together they
97 produce about half of the world's maize and wheat (FAOSTAT, 2015). Wheat and maize are

98 grown on about 22% and 6%, respectively, of the arable land in Europe, on about 21% and
99 12%, respectively, of the arable land in the USA, and on about 3% and 20% respectively of
100 the arable land in Canada (data from 2011, calculations based on FAOSTAT, 2015).

101 As low-input systems use less fertilizers and pesticides than conventional systems, our
102 hypotheses were that low-input systems lead to lower yields than conventional systems, but
103 that yield reduction are lower in low-input systems than in organic systems. The first
104 objective of this study was to compare yields in low-input systems to yields in conventional
105 and organic systems for wheat and maize. The second objective was to analyze the main
106 differences between these three types of systems in terms of crop rotation and use of chemical
107 inputs.

108

109 **MATERIALS AND METHODS**

110

Criteria for Data Selection

111 Study Focus

112 We focused on experiments comparing low-input systems with conventional and/or
113 organic systems on the same site (i.e., in the same pedo-climatic conditions). Only papers
114 evaluating at least one low-input system, and one conventional or one organic system were
115 selected for the analysis. We excluded experiments testing a single cropping technique (e.g.
116 tillage; cultivar), or several levels of one type of input, and experiments conducted over less
117 than two years.

118 Our analysis also excludes systems involving grazing animals, systems mainly
119 composed of feed crops, and studies with insufficient information about crop rotations,
120 cropping practices, and yields (Figure 1). We focused on rain-fed systems, and only
121 considered experiments conducted in Europe and North America.

122

123 #Figure 1 approximately here#

124

125 Definitions of Low-Input, Conventional and Organic Systems

126 We identified three types of systems using names or descriptions given in the articles.
127 “Conventional”, “standard”, and “reference” systems were characterized as conventional
128 systems. “Low-input”, “reduced input”, and “integrated” systems were grouped as low-input
129 systems. In the low-input systems, the use of N fertilization and/or pesticides was lower than
130 in the conventional systems tested at the same site; and no chemical input was used in a
131 higher quantity. The organic systems were characterized as such because they have legal
132 standards that define them.

133

134

Data Collection

135 We used two sources of data to conduct this research: 1) a comprehensive literature
136 search of peer-reviewed scientific studies evaluating cropping systems, and 2) direct
137 communication with researchers, who shared data from cropping system experiments that had
138 only been published in reports without peer-review.

139

140 Literature Search

141 The literature search was conducted on the basis of keywords in the ISI Web of
142 Knowledge, with no timeframe limitation. We used the “All Databases” option, limiting our
143 search to the “Article” document types and the “English” language. For “Topics”, we used the
144 following search equation: “Yield* AND crop* AND (system* OR rotation* OR sequence*)
145 AND (low-input* OR reduced-input* OR (low* NEAR input*) OR (reduced NEAR input*)
146 OR integrated OR (environmental* NEAR friend*) OR (environmental* NEAR sound) OR
147 agroecolog* OR agro-ecolog*) AND (maize OR corn OR wheat OR triticum OR zea mays

148 OR arable) AND (experiment* OR trial* OR field stud* OR evalua*) NOT (graz* OR
149 digestibility OR forest* OR tree*)”. Exclusion criteria related to geographical location and
150 research domain were added to this equation in order to refine the literature search (see
151 Appendix A for the complete equation).

152

153 Study Selection

154 This equation resulted in 609 studies. We then excluded studies based on article
155 abstracts (202 studies) or on full texts (395 studies), when they did not match our data
156 selection criteria, e.g. simulated yields, missing data, no change of input levels between low-
157 input and conventional systems, etc. (Figure 1). Based on this selection, we selected a corpus
158 of 12 peer-reviewed papers including results of 12 different experiments. In order to increase
159 the number of European experiments included in our dataset, three partially published
160 experiments were added to our analysis: two experiments located in two different sites
161 (Grignon and Versailles) in France (Colnenne-David and Doré, 2015, and Bertrand et al.,
162 2005) and one experiment located in Alnarp, Southern Sweden (Nilsson, 1994). The total
163 number of studies, making up the global dataset, was thus equal to 15 (Appendix B).

164 When peer-reviewed articles indicated that the experiment corresponded to our criteria
165 regarding the testing of different types of cropping systems (low-input, conventional or
166 organic), missing data were searched and retrieved using other articles presenting the results
167 of the same experiments (Appendix C). The set of data from the experiment published by
168 Posner et al. (2008) (two sites: Elkhorn and Arlington; Wisconsin, USA) was expanded to
169 include details on pesticide use and yields in recent years at the Arlington site (2003-2012).
170 Missing data from the experiment of Pardo et al. (2010) and from the partially published
171 experiments (Colnenne-David and Doré, 2015; Bertrand et al., 2005; Nilsson, 1994) were
172 obtained by contacting the managers of these experiments directly.

173

174 Global Dataset

175 The global dataset of 15 experiments included 55 treatments. Each treatment
176 corresponded to a unique combination of one cropping system tested in one experimental site.
177 Ten treatments corresponded to organic systems, 15 to conventional systems, and 30 to low-
178 input systems (Appendix D). Seven experiments were located in Europe and eight in North
179 America. The 55 treatments were tested on 17 different experimental sites located in six
180 countries (Figure 2; note that one experiment in France and one in the U.S.A. were performed
181 on two different sites, with slight differences in either crop sequence or levels of inputs – see
182 Appendix D).

183

184 #Figure 2 approximately here#

185

186 Data Extraction

187 For each treatment, information on crop rotation, crop management (N fertilization
188 and pesticide use) and yield were extracted (Table 1). For the two focal crops (maize and soft
189 winter wheat), mean yield and its standard deviation over years, for each tested system, were
190 extracted or calculated from the information provided in each article. Since some treatments
191 included data for both wheat and maize, the total number of yield data included in the dataset
192 was higher than the total number of treatments (33 yield data for each of the two focal crops;
193 Table 1).

194

195 #Table 1 approximately here#

196

197

Data Analysis

198 Yield Ratio Estimation

199 Depending on data availability, one or two types of yield ratios were calculated for
200 each experimental site and each crop (i.e., the ratio of low-input yield to conventional yield
201 and/or the ratio of low-input yield to organic yield): $Y_{LI_wheat}/Y_{CONV_wheat}$,
202 $Y_{LI_maize}/Y_{CONV_maize}$, $Y_{LI_wheat}/Y_{ORG_wheat}$ and $Y_{LI_maize}/Y_{ORG_maize}$, where Y is the yield,
203 wheat/corn are the two considered species, and LI, CONV and ORG correspond to low-input,
204 conventional and organic systems (CONV and LI are the control systems). These ratios were
205 calculated for wheat and maize separately. We calculated the mean yield for each focal crop
206 in each system (conventional, low-input, and organic) by averaging yield data over the
207 number of years that experiments were conducted on each site. A ratio of 1 indicated that the
208 low-input system had the same yield as the reference system (either conventional or organic).
209 Yield ratios greater than 1 indicated that the low-input system was performing better than the
210 reference, and yield ratios lower than 1 indicated that the low-input system was less efficient
211 than the reference.

212 Based on the standard deviations derived from annual yield data provided in each
213 study, 95% confidence intervals (CI) were calculated for each site-specific yield ratio using
214 the method presented by Hedges et al. (1999) in which we compared the logarithm of the
215 ratios between low-input and the reference system (conventional or organic). Missing
216 standard deviations were estimated either by the largest or by the average standard deviation
217 reported in our dataset, and results obtained with these two approaches were compared. The
218 mean log yield ratio was estimated using statistical models with and without random effects,
219 and the resulting mean effect size estimates were compared in order to analyze the sensitivity
220 of our conclusions to the model assumption. Each type of log ratio was considered in turn.
221 The models were fitted in two different ways in order to evaluate the sensitivity of the results
222 to the fitting procedure. Models were first fitted to each of the two considered species

223 separately. Then, maize and wheat data were pooled together, and the models were fitted to
224 the whole dataset. In the second approach, a species effect was included in the statistical
225 models.

226 Heterogeneity in effect size was tested by comparing the Akaike Information Criterion
227 (AIC) of the models with and without the random effects, and by computing the Q statistics
228 (Hedges et al., 1999). Models with and without random-effects were fitted using the functions
229 lme of the R package nlme (Pinheiro et al., 2015) and glm, respectively. Back-transformed
230 results were calculated to make interpretations easier; the difference between yields of the
231 low-input and the reference system (conventional or organic) was significant when one was
232 outside of the 95% confidence interval.

233 A funnel plot was drawn for investigating publication bias (Duval and Tweedie, 2000;
234 Sutton et al., 2000). The funnel plot is a scatter plot of the individual effect sizes (here, the log
235 yield ratio) against a measure of their precision (here, the inverse of the standard deviation).
236 Asymmetry in the funnel plot may indicate publication bias in meta-analysis. An absence of
237 publication bias is reflected in a symmetrical funnel shape (Peters et al., 2008). The
238 significance of the relationship between precision and effect size was tested by fitting a linear
239 regression (Sutton et al., 2000).

240

241 Comparison of Crop Rotation, Pesticide Use, and N Fertilizer Use

242 In order to compare the crop rotations of the three types of cropping systems (low-
243 input, conventional and organic), we identified every crop species included in each rotation,
244 and calculated the number of single crop species included in each rotation. Pesticide use in
245 conventional and low-input systems was compared using different indicators. When the
246 pesticide products and doses were available, pesticide use was characterized with the
247 Treatment Frequency Index (TFI), and conventional and low-input systems were compared

248 using the TFI ratio (TFI ratio = TFI in low-input/TFI in conventional). TFI corresponds to the
249 sum, over all pesticide applications, of the ratio of the applied dose of pesticides to the
250 national recommended dose, for all types of pesticides (e.g., herbicide, fungicide, insecticide).
251 This indicator describes pesticide use with a single synthetic variable allowing between-
252 system comparisons. For each crop, and for conventional and low-input systems, TFI was
253 calculated using the following formula: $TFI = \sum_T (AD_T / RD_T)$, where T is the pesticide product,
254 AD is the amount applied per hectare, and RD is the amount recommended per hectare
255 (Organization for Economic Co-operation and Development, 2001; Pingault et al., 2009).
256 Recommended doses were collected from the E-phy database provided by the French
257 Ministry of Agriculture (Ephy website, 2014). When the applied pesticide product was not
258 available in this database, its recommended dose was collected from product user manuals.
259 TFI was calculated for six studies (out of 15) including at least conventional and low-input
260 systems (see online dataset).

261 Only partial information on pesticide use was available in the nine remaining studies.
262 In four of these studies, pesticide use in low-input versus conventional systems was compared
263 by calculating the ratio of total active ingredient doses in low-input to those in conventional
264 systems (indicator AI). In two other studies, pesticide uses in low-input versus conventional
265 systems were compared by calculating the ratio of pesticide costs (one study; indicator Cost
266 ratio) or by using the ratio of pesticide use directly reported in the article, without details on
267 the way the ratio was calculated (one study; indicator Article ratio).

268 Two articles reported results for low-input and organic systems only, so pesticide
269 ratios were not calculated for these two studies. Since no synthetic pesticide is applied in
270 organic systems, TFI were equal to 0 for these systems. For the last study, no quantitative
271 information was available, so the pesticide use ratio was not quantified (see online dataset).
272 Only mineral N fertilization was quantified (Table 1; online dataset), as organic fertilization

273 was not used in the conventional and low-input systems compared in our dataset. We
274 computed the ratios of the rates of mineral N in low-input systems over those in conventional
275 systems. Information on N fertilizer dose from organic amendments (manure, compost) was
276 missing in one article comparing low-input and organic systems (Appendix E).

277

278

RESULTS

279

Yield Comparisons

280 The Q tests were not significant and the AIC of the random-effect models were higher
281 than those obtained for fixed-effect models (Appendix F). There is thus no evidence for
282 presence of between-study heterogeneity in our datasets. However, as mentioned by Sutton et
283 al. (2000), non-significant results of heterogeneity tests should be interpreted with caution
284 because the non-significance of these tests could only mean that we have failed to detect the
285 between-study variability but does not definitely prove that this variability does not exist. For
286 this reason, results obtained with both fixed-effect and random-effect model were displayed in
287 Tables 2 and 3. Based on these results, estimated mean effect sizes were not found sensitive to
288 the model assumptions.

289 Yield ratios (Figure 3) covered a wide range of values: from 0.63 to 1.19 for ratios of
290 low-input to conventional yields, and from 1 to 1.65 for ratios of low-input to organic yields
291 (Table 2). Low-input yields of maize ranged between 82% and 119% of conventional yields.
292 With all models, average maize yields of low-input systems were not significantly different
293 from those of conventional systems (Table 2, Table 3). Depending on the considered model,
294 the estimated mean yield ratio ranged from 0.99 to 1.02, but 1 was included in the 95%
295 confidence interval in all cases (Table 2, Table 3). Low-input yields of maize were always
296 higher, and significantly higher on average, than maize yields of organic systems, with some
297 experiments demonstrating high standard deviations (Figure 3). The average increase in low-

298 input maize production was 22-26 %, depending on the considered statistical model (Table 2,
299 Table 3).

300 Wheat yields of low-input systems, when compared with conventional systems, were
301 mainly lower, with an estimated mean yield loss ranging between 11% and 13%, depending
302 on the models (Table 2, Table 3). They also displayed high standard deviations in some
303 experiments (Figure 3). Wheat yields were always higher in low-input systems than in organic
304 systems, and were on average significantly higher by 42% to 45% (Table 2, Table 3).

305 Ratios of low-input yield to conventional yield were lower for wheat than for maize (Figure
306 3). The between-site variability of the yield ratios was higher for low-input versus organic
307 systems than for low-input versus conventional systems for both focal crops (Figure 3; Table
308 2; Table 3).

309

310 # Figure 3 approximately here #

311 # Table 2 approximately here #

312 # Table 3 approximately here #

313

314 The individual log yield ratios used to compare low input and conventional systems
315 were symmetrically distributed around the mean effect size (Figure 4), and there was no
316 significant evidence for presence of publication bias ($p = 0.961$). We were also not able to
317 detect publication bias in the log yield ratios used to compare low-input and organic systems
318 ($p = 0.260$) (Figure 4).

319

320 # Figure 4 approximately here #

321

322

Crop Rotation Diversity

323 The number of species in rotations ranged from three to six crop species in wheat-
324 based, low-input and conventional systems (Table 1). The average frequency of wheat in low-
325 input system rotations was slightly lower than the frequency in conventional system rotations
326 (29.4% vs. 32.3% respectively in Europe; 33.3% in both systems in North America). In
327 wheat-based organic system rotations the number of single species ranged from three to five,
328 and the frequency of wheat averaged 26.4% in Europe (Table 1).

329 The number of species in maize-based rotations ranged from 1 to 6 crop species in
330 low-input systems and from one to five in conventional systems (Table 1). The average
331 frequency of maize in low-input system rotations was slightly lower than the frequency in
332 conventional system rotations (47.2% vs. 51% respectively in North America; identical
333 frequencies in Europe). In maize-based organic system rotations, the number of single species
334 ranged from one to six, and the frequency of maize averaged 44% (Table 1). The frequency of
335 cover crops was on average higher in low input systems than in conventional systems. The
336 frequency of cover crops was equivalent between low-input and organic systems, except for
337 wheat-based systems where organic cropped more frequently cover crops (Table 1).

338

339

Pesticide Use and N Fertilizer Rate

340 For maize, pesticide use was reduced by 11% to 87% in low-input systems compared
341 to the conventional systems, with a mean decrease of 50%. For wheat, pesticide use was
342 reduced by 22% to 100% in low-input systems compared to conventional systems, with a
343 mean decrease of 70% (see online database). The levels of reduction in mineral N rates in
344 low-input versus conventional systems varied widely across studies. For maize, mineral N
345 rates ranged from 0 to 150 kg N ha⁻¹ in low-input systems, compared with 100 to 231 kg N ha⁻¹
346 ¹ in conventional systems, representing a mean reduction of 36%. For wheat, mineral N rates

347 ranged from 17 to 161 kg N ha⁻¹ in low-input systems, compared with 56 to 198 kg N ha⁻¹ in
348 conventional systems, representing a mean reduction of 28%.

349 Manure or compost organic fertilizers were used in most of the considered organic
350 systems (7 out of 9 studies; see Appendix E). Amendments based on legumes and crop
351 residues were also frequently applied (Appendix E). In average, N inputs in organic systems
352 were higher than N inputs (organic + mineral) in low-input systems for maize (Table 1). For
353 wheat, missing information on N quantities did not allow such comparisons.

354

355

DISCUSSION

356 This study compares maize and wheat-based cropping system carried out in two major
357 agricultural regions with temperate climates: Europe and North America. Our quantitative
358 analysis looks at the differences between conventional, low-input, and organic cropping
359 systems.

360 Our analysis shows that wheat and maize yields produced under a wide range of crop
361 management and rotations were significantly higher in low-input than in organic systems. For
362 maize, our estimated mean yield ratio (low-input vs. organic) was 1.24. For wheat, we found a
363 mean yield ratio (low-input vs. organic) of 1.43. In our study, wheat production in low-input
364 systems with a mean pesticide reduction of 70% experienced an estimated mean yield loss of
365 12% when compared with production in conventional systems. This estimated value is
366 consistent with that of Hossard et al. (2014); for wheat systems with a 50% reduction in TFI,
367 they reported 5 to 12% yield losses in France. Our yield loss estimates were robust to the
368 model assumptions (fixed vs. random effects), to the procedure used to deal with missing SD
369 (use of the maximum vs. average SD), and to the fitting procedure (separate fit for each crop
370 vs. fit using pooled data).

371 There was a slightly lower average frequency of wheat in the crop rotation in low-
372 input systems than in conventional systems (29% vs. 32% in Europe, no difference in North
373 America), with crop sequences including three to six crops in Europe. Three to four-year crop
374 sequences are frequent in Europe (Bio Intelligence, 2010). The combination of yield losses
375 and small rotation changes associated with the adoption of low-input systems could result in a
376 small decrease in wheat production in Europe for systems similar to the ones tested in the
377 experiments included here. The mean yield loss of 12% that we found for wheat in low-input,
378 compared with conventional systems, was associated with a strong decrease in the use of
379 pesticides and mineral N fertilizer (on average by 70% and 28%, respectively). A small yield
380 loss associated with a strong reduction of pesticide and mineral fertilizer use could be due to
381 changes in crop rotations (e.g., crop replacement). Liebman and Davis (2000) showed that
382 multispecies crop rotations have the potential to reduce weed growth, and Ponisio et al.
383 (2015) showed that multi-cropping and crop rotations could reduce the risk of yield loss.
384 However, in the studies selected in this paper, the number of species included in the rotations
385 of low-input and conventional systems was very similar and cannot explain the results.
386 Similarly, the number of species included in maize-based rotations was very close in low-
387 input and conventional systems. For this crop, we found no significant yield difference
388 between low-input and conventional systems, although pesticide use was halved on average
389 and the mineral N rate was reduced on average by 28-36% in low-input versus conventional
390 systems.

391 In our dataset, organic amendments (e.g., manure, compost) were never applied in
392 conventional systems, almost absent in low-input systems, and frequently applied in organic
393 systems. Nitrogen doses were frequently higher in organic than in low-input systems. Applied
394 N doses were higher in organic systems compared to conventional systems due to organic
395 amendments in 27-35% of the situations considered by Seufert et al. (2012). The review of

396 Kirchmann and Bergstrom (2007) showed that organic and conventional systems led to
397 similar levels of nitrate leaching at the same total N doses.

398 Our analysis shows that low-input systems used lower mineral N fertilizer and
399 pesticides, without generating high yield losses for maize and wheat. Low-input systems are
400 less constraining for farmers than organic systems, which have strict legal standards (i.e.,
401 European Commission (2008) for European standards) prohibiting the use of chemicals.
402 However, the adoption of low-input systems can face several challenges. Although small, the
403 yield loss may not be economically compensated by the input cost reduction, or an adjustment
404 in market prices (e.g. on wheat for pesticide use in Hossard et al. (2014)). The adoption of
405 low-input systems may also face economic and technological “lock-in”, as highlighted by
406 Vanloqueren and Baret (2008) in the use of pesticides in wheat cropping systems. This
407 technological “lock-in” is related to the exclusion of competing technologies by a dominant
408 one, even though alternatives may perform better (Vanloqueren and Baret, 2008; Vanloqueren
409 and Baret, 2009). Technical “lock-in” can also exist, and involves the whole system (from
410 farm to market) (Barbier et al., 2010; Jacquet et al., 2011). Moreover, no market premium is
411 applied for low-input systems, like there is for organic products.

412 The number of studies included in our dataset is relatively small. It is uncommon to
413 find data from long-term experiments on several cropping systems, including low-input and
414 conventional ones. Since our dataset did not include any maize data from conventional
415 cropping systems in Europe, our results on this crop could not be extended to European areas.
416 Most of the North America experiments included in our dataset were located on the edges or
417 outside of the U.S. Corn Belt. These areas are generally favorable for wheat production but
418 they do not usually lead to the highest maize yields in the U.S. The European experiments
419 were mainly carried out in Western Europe, where cereal yields are higher than in Eastern
420 Europe (Olesen et al., 2011; FAOSTAT, 2015). It is thus difficult to extrapolate our

421 conclusions to the U.S. Corn-Belt or Eastern Europe, where long-term experiments would be
422 required.

423

424

CONCLUSION

425 Our analysis shows that low-input systems, tested in long-term experiments, allow a
426 substantial reduction of mineral N fertilizer and pesticides uses without generating high yield
427 losses for maize and wheat in several locations in Europe and North America. Low-input
428 systems offer interesting alternative to both conventional and organic systems. Compared to
429 low input systems, conventional systems lead to slightly higher yields but rely on large
430 quantities of chemical inputs, which are harmful to the environment and to farmers' health
431 (Stoate et al., 2001; Inserm, 2013). Organic systems do not use chemical inputs, but may lead
432 to high yield losses and frequently rely on large quantities of organic N that may decrease
433 water quality. Low-input systems thus appear to be a promising way to decrease the negative
434 impact of agriculture on the environment, while limiting yield losses that are associated with
435 organic systems. It will be useful to expand our dataset in the future in order to test whether
436 our conclusions are valid for other wheat and maize growing areas.

437

438

439

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Figure captions

Figure 1. Study selection flow diagram.

¶Total N (organic + mineral fertilizers) was higher in low-input than in conventional system for the focal crop, so the corresponding studies were not included in our dataset.

Figure 2. Location of 16 long-term cropping system experiments (in 18 sites) : USA (8 sites), Canada (2 sites), France (4 sites), Sweden (1 site), Switzerland (2 sites) and Norway (1 site).

The map was realized using R software (R Development Core team, 2013), and the R packages ggplot2 (Wickam, 2009) and maptools (Bivand and Lewin-Koh, 2014).

Figure 3. Yield ratios of low input treatments vs. conventional treatments (A and C) and of low-input treatments vs. organic treatments (B and D) for maize (A and B) and soft winter wheat (C and D). The error bars correspond to the 95% confidence intervals derived from the standard deviations reported in 12 experiments (missing in the three other experiments).

Figure 4. Funnel plot of centered log yield ratios for low-input vs. conventional (A) and for low-input vs. organic systems (B). Only studies reporting standard deviations (SD) were considered (21 ratios out of 28 for A; 12 ratios out of 19 for B). Red lines represent fitted regressions. The levels of significance of the regression slopes are indicated by the p-values.
SD : standard deviation.

Table 1. Main cropping system characteristics for maize and soft winter wheat in Europe and North America for conventional (Conv), low-input and organic systems. Numbers indicate mean values, with minimum and maximum values between brackets. Only one number is indicated when only one value is observed.

Crop	System	Number of Yield data	Number of species in the rotation [§]	Frequency of wheat or maize in the rotation [¶]	Frequency of cover crops in the rotation [⊥]	N fertilization rates		Pesticide use		Dry Matter Yield
						Mineral N	Organic N [°]	TFI [‡]	Active ingredients	
		n		%		kg N ha ⁻¹ #		kg ha ⁻¹	t ha ⁻¹	
<u>Europe</u>										
Maize	Conv	0	-	-	-	-	-	-	-	-
	Low-input	2	5	16.7	33.3	81	NA	-	1.56	10.56 (10.09-11.02)
	Organic	1	5	16.7	33.3	0	NA	0	0	10.08
Wheat	Conv	7	3.9 (3-6)	32.3 (12.5-50)	2.86 (0-20)	163 (83-198)	0	4.22 (1.14-6.31)	-	6.96 (4.99-8.29)
	Low-input	15	4.7 (3-6)	29.4 (12.5-50)	13.33 (0-33)	126 (17-161)	0 [†]	1.61 (0-3.86)	1.97 (1.29-2.66)	5.94 (4.5-7.67)
	Organic	3	4.3 (3-5)	26.4 (12.5-50)	19.33 (0-33)	0	4 (0-25) [†]	0	0	4.15 (3.17-4.64)
<u>North America</u>										
Maize	Conv	8	2.6 (1-5)	51 (25-100)	8.33 (0-33)	149 (100-231) [†]	0	3.36 (1.68-4.81)	3.26 (2-5.37) [†]	6.82 (4.19-9.07) [†]
	Low-input	15	2.8 (1-6)	47.2 (25-100)	35.47 (0-100)	99 (0-150) [†]	0	2.43 (1.49-2.97)	0.99 (0.35-2.29)	6.68 (4.27-9.38) [†]
	Organic	7	3 (1-6)	44 (25-100)	34.43 (0-100)	0	130 (0-292)	0	0	5.11 (3.27-7.48) [†]
Wheat	Conv	3	3	33.3	22 (0-33)	59 (56-62) [†]	0	0	1.8 (1-2.6) [†]	3.43 (3.17-3.68) [†]
	Low-input	4	3 (3-5)	33.3	33.33	32.5 (31-34) [†]	0	0	0.55 (0-1.14) [†]	3.43 (2.81-3.75) [†]
	Organic	1	3 (3-5)	33.3	33.33	0	0	0	0	1.81

[§]Crops grown several times in the same rotation count for only one crop species; cover crops were excluded from these calculations. [¶]Frequency was calculated as the number of occurrences of the considered species (maize or soft winter wheat) over the length of the rotation. [⊥]Frequency of cover crops was calculated as the number of occurrences of cover crop in the rotation divided by the length of the rotation. [†]The numbers displayed here do not include all data used to further analyze the ratios, for studies where these information were incomplete (e.g. when the N fertilization rate was not provided, i.e., when fertilization practices were identical in low-input and conventional systems as seen in two studies); when no detail on pesticide use ratio was provided (one study); when yield moisture content was not available (three studies)). [°]Only fertilization coming from organic amendments (manure, compost) are including here, i.e., credits for legumes are not taken into account. [‡]TFI: Treatment Frequency Index (see definition §2.3.2; expressed in equivalent number of full dose treatments). [#]Mean annual N fertilization rates, for the considered crop, are expressed in kg N ha⁻¹.

1 Table 2. Minimum and maximum individual yield ratios (R), mean effect sizes and their confidence intervals (95%) calculated from the 15
 2 experiments using fixed and random-effect models, with or without data weighting. Weights were calculated from log yield ratio standard
 3 deviations (SD). Missing SD were set equal to either the largest SD (SD_{max}) or to the mean SD (SD_{mean}) reported in the dataset. The models were
 4 fitted to each species separately. Low input treatments were compared to conventional and organic treatments.
 5

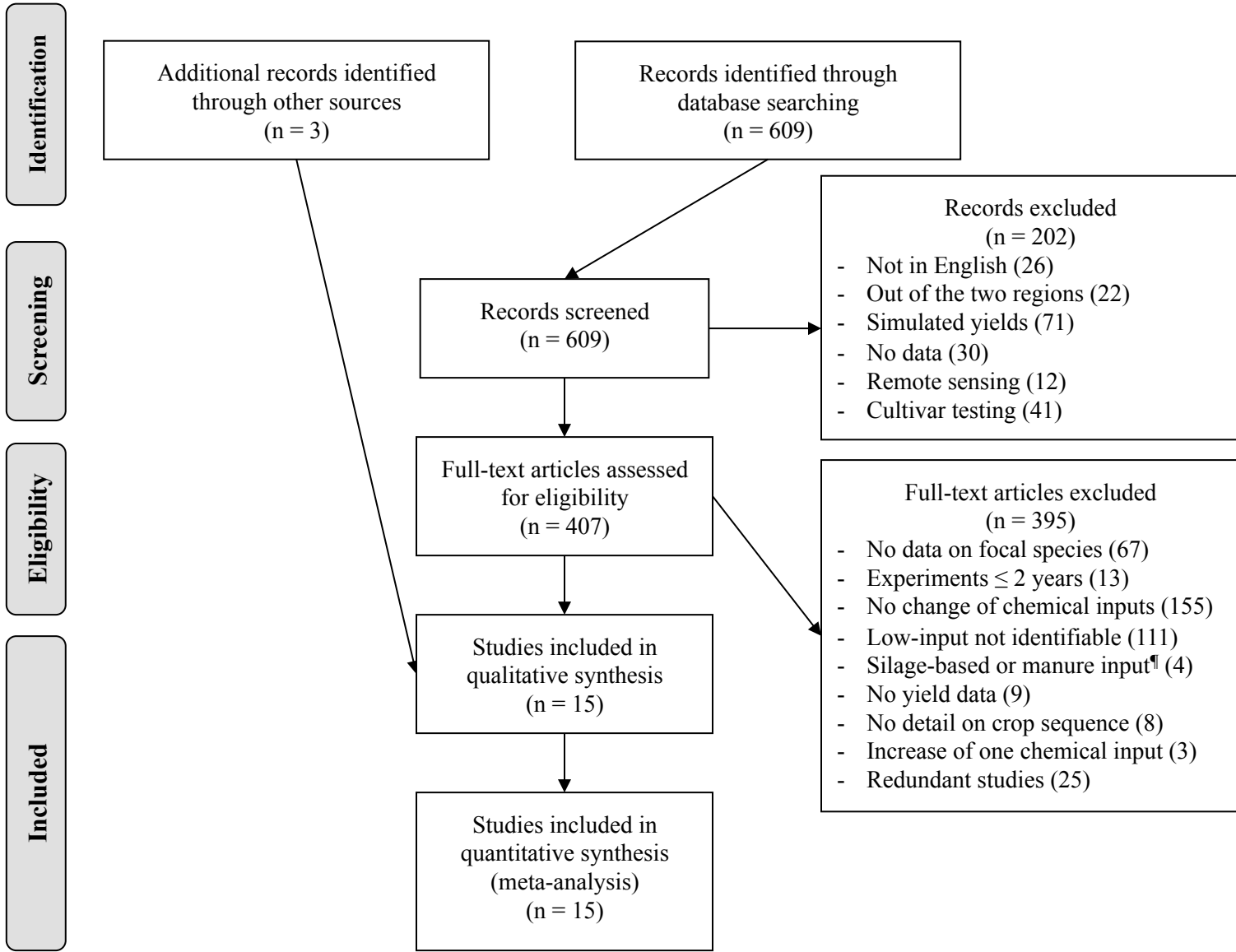
Species	Min R-Max R [¶]	Models without random effects						Models with random effects					
		with SD_{max}			with SD_{mean}			with SD_{max}			with SD_{mean}		
		Estimated mean yield ratio	CI 95%	AIC	Estimated mean yield ratio	CI 95%	AIC	Estimated mean yield ratio	CI 95%	AIC	Estimated mean yield ratio	CI 95%	AIC
<u>Ratio of low-input yield to conventional yield</u>													
All	0.63-1.19	0.90	0.87-0.93	-13.24	0.90	0.87-0.93	-26.25	0.93	0.88-0.99	-26.05	0.93	0.88-0.98	-35.11
Maize	0.82-1.19	1.02	1-1.05	-19.16	1	0.92-1.04	-17.48	1.02	0.97-1.09	-11.29	1	0.95-1.06	-10.19
Wheat [§]	0.63-1.02	0.87	0.84-0.90	-21.13	0.87	0.84-0.90	-23.26	0.88	0.83-0.92	-22.58	0.89	0.84-0.94	-23.89
<u>Ratio of low-input yield to organic yield</u>													
All	1-1.65	1.41	1.37-1.44	-8.98	1.40	1.35-1.44	-10.16	1.31	1.21-1.43	-11.66	1.3	1.20-1.42	-14.10
Maize	1-1.53	1.26	1.20-1.32	-14.122	1.23	1.17-1.30	-16.13	1.24	1.16-1.34	-10.08	1.22	1.14-1.32	-11.69
Wheat [§]	1.06-1.65	1.42	1.39-1.45	-4.803	1.42	1.37-1.47	-4.16	1.45	1.26-1.66	3.86	1.42	1.21-1.66	4.21

6 [¶]R: ratio between low input and considered reference system (i.e. either conventional or organic). [§]Only soft winter wheat was considered. SD:
 7 standard deviation.
 8
 9
 10
 11
 12

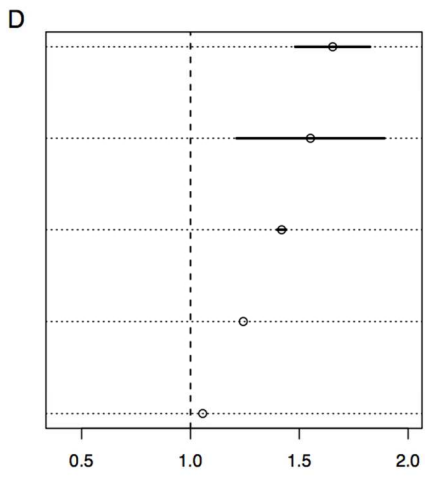
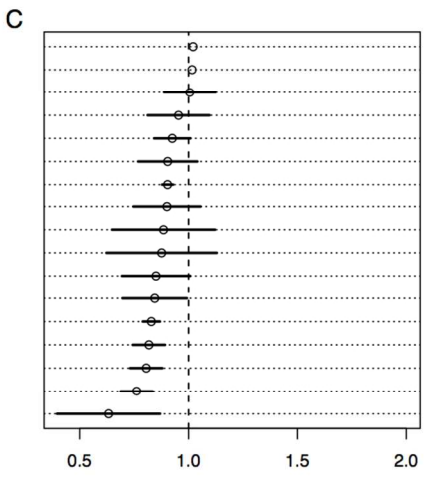
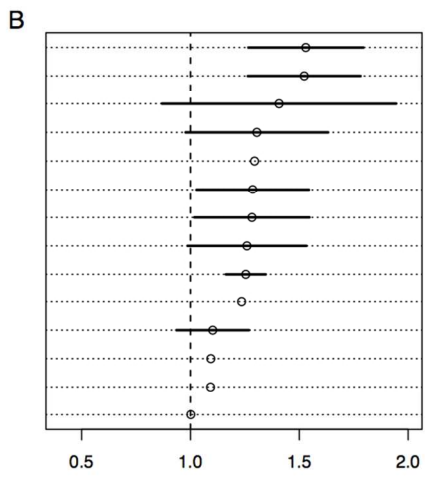
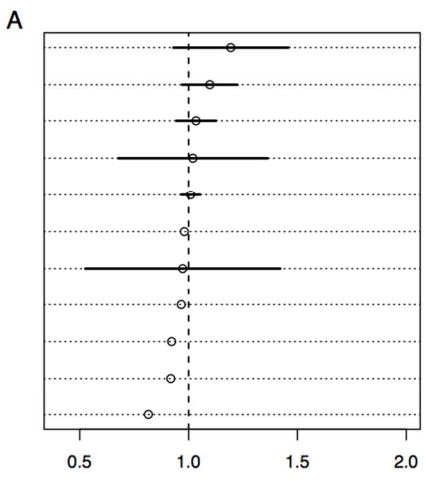
Table 3. Minimum and maximum individual yield ratios (R), mean effect sizes and their confidence intervals (95%) calculated from 15 experiments using fixed and random-effect models, with or without data weighting. Weights were calculated from log yield ratio standard deviations (SD). Missing SD were set equal to either the largest SD (SD_{max}) or to the mean SD (SD_{mean}) reported in the dataset. Maize and wheat data were pooled together and a species effect was included in the models. Low input treatments were compared to conventional and organic treatments.

Species	Models without random effects						Models with random effects					
	with SD_{max}			with SD_{mean}			with SD_{max}			with SD_{mean}		
	Estimated mean yield ratio	CI 95%	AIC	Estimated mean yield ratio	CI 95%	AIC	Estimated mean yield ratio	CI 95%	AIC	Estimated mean yield ratio	CI 95%	AIC
	<u>Ratio of low-input yield to conventional yield</u>											
Maize	1.02	0.97-1.08	31.73	1	0.95-1.06	-39.56	0.99	0.92-1.06	-31.07	0.99	0.92-1.06	-31.07
Wheat [§]	0.87	0.85-0.89		0.87	0.85-0.90		0.89	0.84-0.94		0.89	0.84-0.94	
	<u>Ratio of low-input yield to organic yield</u>											
Maize	1.26	1.19-1.33	-20.48	1.23	1.16-1.32	-20.93	1.26	1.16-1.37	-13.47	1.26	1.16-1.37	-13.47
Wheat [§]	1.42	1.40-1.45		1.42	1.39-1.45		1.43	1.28-1.59		1.43	1.28-1.59	

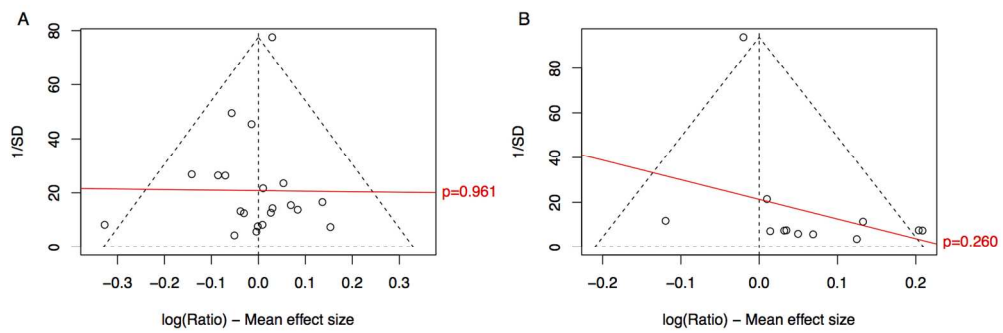
[§]Only soft winter wheat was considered. SD: standard deviation.







203x203mm (150 x 150 DPI)



279x101mm (150 x 150 DPI)

Appendix A. Complete research equation

TOPIC: ((Yield* AND crop* AND (system* OR rotation* OR sequence*) AND (low-input* OR reduced-input* OR (low* NEAR input*) OR (reduced NEAR input*) OR integrated OR (environmental* NEAR friend*) OR (environmental* NEAR sound) OR agroecolog* OR agro-ecolog*) AND (maize OR corn OR wheat OR triticum or zea mays or z mays OR arable) AND (experiment* OR trial* OR field stud* or evalua*) NOT (graz* or digestibility or forest* or tree*) NOT (China OR Chinese OR Nepal OR India* OR tropic* OR Australia* OR Chile* OR Argentina* OR Africa* OR Kenya* OR Zimbabwe OR Nigeria* OR Turkey OR Pakistan* OR Himalaya* OR Benin OR Korea* OR Rwanda* OR Yellow river OR Vietnam OR Syria OR Mexic* OR Asia* OR Iran OR Mozambique OR Mali OR Bengal OR Peru*)))

Refined by: RESEARCH DOMAINS: (SCIENCE TECHNOLOGY) AND **DOCUMENT TYPES:** (ARTICLE) AND **LANGUAGES:** (ENGLISH) AND [excluding] **RESEARCH AREAS:** (FORESTRY OR MICROBIOLOGY OR THERMODYNAMICS OR MEDICAL INFORMATICS OR CHEMISTRY OR GEOLOGY OR GOVERNMENT LAW OR PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH OR UROLOGY NEPHROLOGY OR INSTRUMENTS INSTRUMENTATION OR ZOOLOGY OR PSYCHOLOGY OR PALEONTOLOGY OR METEOROLOGY ATMOSPHERIC SCIENCES OR MEDICAL LABORATORY TECHNOLOGY OR NUTRITION DIETETICS OR MATHEMATICAL COMPUTATIONAL BIOLOGY OR ENTOMOLOGY OR INTERNATIONAL RELATIONS OR MATHEMATICS OR IMMUNOLOGY OR IMAGING SCIENCE PHOTOGRAPHIC TECHNOLOGY OR AUTOMATION CONTROL SYSTEMS OR GEOCHEMISTRY GEOPHYSICS OR VETERINARY SCIENCES OR GASTROENTEROLOGY HEPATOLOGY OR BIOCHEMISTRY MOLECULAR BIOLOGY OR MYCOLOGY OR ELECTROCHEMISTRY OR BIOTECHNOLOGY APPLIED MICROBIOLOGY OR MARINE FRESHWATER BIOLOGY OR REMOTE SENSING OR ASTRONOMY ASTROPHYSICS OR PUBLIC ADMINISTRATION OR PHARMACOLOGY PHARMACY OR ARCHAEOLOGY) AND [excluding] **SOURCE TITLES:** (BIULETYN INSTYTUTU HODOWLI I AKLIMATYZACJI ROSLIN OR INDIAN JOURNAL OF AGRICULTURAL SCIENCES OR INDIAN JOURNAL OF AGRONOMY OR ROSTLINNA VYROBA OR REVISTA BRASILEIRA DE CIENCIAS AGRARIAS OR LUCRARI STIINTIFICE UNIVERSITATEA DE STIINTE AGRICOLE SI MEDICINA VETERINARA ION IONESCU DE LA BRAD IASI SERIA AGRONOMIE OR PHILIPPINE AGRICULTURAL SCIENTIST OR PAKISTAN JOURNAL OF BOTANY OR ANNALI DELL ISTITUTO SPERIMENTALE AGRONOMICOR ZEMDIRBYSTE AGRICULTURE OR TAGUNGSBERICHT AKADEMIE DER LANDWIRTSCHAFTSWISSENSCHAFTEN DER DEUTSCHEN DEMOKRATISCHEN REPUBLIK OR CULTIVOS TROPICALES OR CIENCIA RURAL OR CHILEAN JOURNAL OF AGRICULTURAL RESEARCH OR AUSTRALIAN JOURNAL OF PLANT PHYSIOLOGY OR AGRARFORSCHUNG OR GESUNDE PFLANZEN OR RIVISTA DI AGRONOMIA OR PESQUISA AGROPECUARIA BRASILEIRA) AND [excluding] **COUNTRIES/TERRITORIES:** (BANGLADESH OR VIETNAM OR UZBEKISTAN OR MALAYSIA OR TOGO OR TANZANIA OR SRI LANKA OR SOUTH AFRICA OR INDIA OR SAUDI ARABIA OR NIGER OR ARGENTINA OR NICARAGUA OR PEOPLES R CHINA OR URUGUAY OR NEW ZEALAND OR AUSTRALIA OR TUNISIA OR MOROCCO OR SYRIA OR JAPAN OR IRAN OR PHILIPPINES OR PAKISTAN OR MEXICO OR COSTA RICA OR TURKEY OR KENYA OR GHANA OR BOTSWANA OR ETHIOPIA OR WESTERN SAMOA)

Timespan: All years. Search language=Auto

Appendix B. References included in this study

Bertrand, M., L. Guichard, J.M. Meynard, D. Picard, and P. Saulas. 2005. Design of sustainable and innovative cropping systems for arable crops. The case of the long-term experiment “La Cage” in Versailles, France. (In French.) In: SIFEE, editor, Proceedings of the 10th SIFEE International Symposium. Angers, France. 20-24 Jun. 2005. http://www.sifee.org/static/uploaded/Files/ressources/actes-des-colloques/angers/theme-4/1_Guichard_etal_comm.pdf (accessed, 26 Nov. 2015).

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Appendix C. Sources used to retrieve relevant information about the experiments presented in the articles listed in Appendix B.

Article of Appendix B	Source used to retrieve missing information
Clements <i>et al.</i> , 1995	Swanton <i>et al.</i> , 1996
Coulter <i>et al.</i> , 2011	Coulter <i>et al.</i> , 2013
Eltun <i>et al.</i> , 2002	Lien <i>et al.</i> , 2005 ; Korsæth, 2008
Hiltbrunner <i>et al.</i> , 2008	Nemecek <i>et al.</i> , 2005
Pardo <i>et al.</i> , 2010	Deytieux <i>et al.</i> , 2012 ; Database provided by authors
Posner <i>et al.</i> , 2008	Database provided by authors
Smith <i>et al.</i> , 2007	Website indicated in the article (KBS website)

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Appendix D. Systems tested in each experiment included in our dataset.

Region	Source	Number of sites	Country	Crop [¶]	Conventional system	Low input system	Organic system	Years	
Europe	Bertrand <i>et al.</i> , 2005	1	France	Wheat	1	1	1	1997-2012	
	Colnenne-David <i>et al.</i> , 2010	1	France	Wheat	1	1	0	2008-2012	
	Eltun <i>et al.</i> , 2002	1	Norway	Wheat	1	1	1	1990-1997	
	Hiltbrunner <i>et al.</i> , 2008	Maize	1	Switzerland	Wheat	0	2	1	1991-2008
		Wheat			1991-2008				
	Malitius <i>et al.</i> , 1996	1	Switzerland	Wheat	1	1	0	1989-1993	
	Nilsson, 1994	1	Sweden	Wheat	1	1	0	1993-2006	
Pardo <i>et al.</i> , 2010	2	France	Wheat	2 (1 per site) 8 (4 per site)		0	2000-2006		
North America	Clements <i>et al.</i> , 1995	1	Canada	Maize Wheat	1	1	0	1990-1992	
	Coulter <i>et al.</i> , 2011	1	USA	Maize	1	3	1	1989-2007	
	Posner <i>et al.</i> , 2008 [#]	2	USA	Maize	2 (1 per site) 2 (1 per site)		2 (1 per site)	1989-2002 ; 1989-2012 [§]	
	Poudel <i>et al.</i> , 2002	1	USA	Maize	1	1	1	1994-1998	
	Smith <i>et al.</i> , 2007	Maize	1	USA	Wheat	1	1	1	1993-2004
		Wheat							
	Teasdale <i>et al.</i> , 2007	1	USA	Maize	1	1	1	1993-2002	
Snapp <i>et al.</i> , 2010	1	USA	Maize	0	4	1	1993-2004		
Swanton <i>et al.</i> , 2002	Maize	1	Canada	Wheat	1	2	0	1990-1998	
	Wheat								

[#]Posner et al. (2008) was completed with unpublished data ; [¶]We considered only soft winter wheat (*Triticum aestivum*) ; [§]The experiment duration differed between the two sites included in this experiment.

Appendix E. Organic fertilization in studies comparing low-input and organic systems.

Region	Source	Crop	Low input system ^a	Organic system [#]	Product	Other N source
Europe	Bertrand <i>et al.</i> , 2005	Wheat	-	very rare ; on average 50 uN ha ⁻¹ every 4 years (on wheat or rapeseed)	guano, eather meal	legume cover crop and in the rotation
	Eltun <i>et al.</i> , 2002	Wheat	-	10 to 20 Mg ha ⁻¹ of slurry every 2 years	farmyard manure (slurry)	legume cover-cop
	Hiltbrunner <i>et al.</i> , 2008	Maize Wheat	2 systems: liquid manure for grasslands + solid manure for potatoes and maize; or liquid manure for maize, cereals and grassland + solid manure for potatoes and maize	liquid manure for all arable crops and grassland + solid manure for potatoes and maize	liquid and solid farmyard manure	Leguminous species in the rotation
North America	Coulter <i>et al.</i> , 2011	Maize	-	264 and 11 kN ha ⁻¹ on maize and soybean respectively	liquid swine manure or solid beef manure	Legumes in the rotation
	Posner <i>et al.</i> , 2008 ^a	Maize	-	-	-	Legumes in the rotation
	Poudel <i>et al.</i> , 2002	Maize	-	190 and 292 kg N ha ⁻¹ in tomatoes and maize respectively as composted manure	composted manure	cover crop residue
	Smith <i>et al.</i> , 2007	Maize Wheat	-	-	-	Legumes and green manure in the rotation

Teasdale <i>et al.</i> , 2007	Maize	-	on average 122 and 208 kg N ha ⁻¹ in maize and wheat respectively	dairy solids, fresh solid manure	green manure in the rotation, cover crop residues
Snapp <i>et al.</i> , 2010	Maize	-	88-116 kg N ha ⁻¹ on maize	dairy compost	legume cover crop in the rotation

#Only Nitrogen from organic amendments (manure, compost) is quantified here.

Appendix F. Results of the Q tests.

System	Species	All data, using max(SD) for missing values			All data, using mean(SD) for missing values			Only data with informed SD		
		Q	χ^2	95% p value	Q	χ^2	95% p value	Q	χ^2	95% p value
Conventional	All	5.34	40.11	>0.999	6.05	40.11	>0.999	5.40	31.41	>0.999
	Maize	0.62	18.31	>0.999	1.11	18.31	>0.999	0.250	11.07	0.995
	Wheat	2.62	26.30	>0.999	3.05	26.30	>0.999	2.38	23.69	>0.999
Organic	All	2.65	28.87	>0.999	3.64	28.87	>0.999	1.62	19.68	>0.999
	Maize	1.16	22.36	>0.999	1.54	22.36	>0.999	0.76	15.51	>0.999
	Wheat	0.69	9.488	>0.999	1.13	9.49	0.900	0.27	5.99	0.876

SD : standard deviation

Region	Source	Crop [†]	low input vs. conventional				low input vs. organic		
			log(R) [#]	SE(log(R)) [§]	Mineral N ratio	Pesticide ratio	Pesticide use indicator	log(R) [#]	SE(log(R)) [§]
Europe	Bertrand et al., 2005 [¶]	Wheat	-0.078	0.043	0.724	0.613	TFI	0.503	0.087
	Colnenne-David et al., 2010 [¶]	Wheat	-0.132	0.130	0.210		0 TFI	-	-
	Eltun et al., 2002	Wheat	-0.102	0.013	0.630	0.398	price	0.350	0.011
	Hiltbrunner et al., 2008	Wheat	-	-	-	-	-	0.217	NA
		Wheat	-	-	-	-	-	0.055	NA
		Maize	-	-	-	-	-	0.089	NA
	Pardo et al., 2010	Wheat	0.005	0.060	0.703	0.051	TFI	-	-
		Wheat	-0.101	0.070	0.810	0.438	TFI	-	-
		Wheat	-0.105	0.079	0.592	0.232	TFI	-	-
		Wheat	-0.169	0.076	0.763	0.331	TFI	-	-
		Wheat	-0.202	0.038	0.819	0.059	TFI	-	-
		Wheat	-0.273	0.037	0.749	0.286	TFI	-	-
		Wheat	-0.459	0.121	0.816	0.446	TFI	-	-
		Wheat	-0.217	0.038	0.892	0.227	TFI	-	-
	Malitius et al., 1996	Wheat	-0.188	0.020	0.561	0.333	TFI	-	-
Nilsson, 1994 [¶]	Wheat	-0.048	0.072	0.789	0.781	TFI	-	-	
North America	Clements et al., 1995	Maize	0.009	0.022	0.74	0.4	AI	-	-
		Wheat	-0.162	0.080	0.5		0 AI	-	-
	Coulter et al., 2011	Maize	-0.205	NA	0.733	0.217	AI	0.088	NA
		Maize	-0.034	NA	0.443	0.521	AI	0.258	NA
		Maize	-0.081	NA	0.237	0.131	AI	0.211	NA
	Posner et al., 2008 [¶]	Maize	0.034	0.046	0.926	0.790	TFI	0.227	0.047
		Maize	0.177	0.134	0.910	0.617	TFI	0.231	0.139
Poudel et al., 2002	Maize	0.093	0.064	0.456	0.4	article ratio	0.097	0.085	

Smith et al., 2007	Maize	0.020	0.175		00.887	TFI	0.266	0.167
	Wheat	-0.122	0.121	0.607		0 TFI	0.439	0.174
Snapp et al., 2010		-	-	-	-	-	0.249	0.135
	Maize	-	-	-	-	-	0.251	0.132
		-	-	-	-	-	0.425	0.135
Swanton et al., 2002		-	-	-	-	-	0.420	0.132
	Maize	-0.086	NA		10.367	AI	-	-
		-0.020	NA		10.762	AI	-	-
	Wheat	0.016	NA		10.423	AI	-	-
Teasdale et al., 2007		0.021	NA		10.423	AI	-	-
	Maize	-0.027	0.228	0.642	0.372	AI	0.341	0.275

#Log-yield ratio

§standard error of the log-yield ratio

¶partially published datasets

†only soft winter wheat was considered

NA: data not available

-: not tested in the considered experiment