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Crop genetic diversity benefits farmland biodiversity in cultivated fields

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1 **Title:** Crop genetic diversity benefits farmland biodiversity in cultivated fields

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4 **Abstract**

5 This study tested whether increasing crop genetic diversity benefited farmland biodiversity in
6 bread wheat (*Triticum aestivum*) fields, using an experimental approach in which arthropod and
7 wild plant diversity were compared in a genetically homogeneous wheat variety vs. a variety
8 mixture. The diversity of wild plant species was not affected by crop genetic diversity. However,
9 we showed for the first time a positive impact of crop genetic diversity on below (Collembolla)
10 and aboveground arthropod (Spiders and predatory Carabids) diversity at field scale in
11 agroecosystems, which may be caused by a wider variety of food resources or more complex
12 crop architecture. Increasing crop genetic diversity could therefore be an easy-to-implement
13 scheme benefiting farmland biodiversity.

15 **Highlights**

- 16 • Plots with higher crop genetic diversity hosted more diverse arthropod communities
- 17 • Crop homogenization may thus contribute to biodiversity loss in agroecosystems

19 **Key words**

20 Carabids; crop management practices; farmland biodiversity; genetic resources; organic farming;
21 spiders; springtails; sustainable farming.

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1 **1. Introduction**

2 Crop genetic diversity has been decreasing steadily in the agricultural landscapes of developed
3 countries since the early 20th century (FAO, 1997; Secretariat of the Convention on Biological
4 Diversity, 2006). This is mostly due the widespread replacement of genetically diverse traditional
5 varieties or landraces by homogeneous modern varieties (Hoisington et al., 1999), leading to
6 decreased genetic diversity in the fields, both within and between varieties. Hence, in spite of an
7 increasing number of registered crop varieties since the sixties, the majority of agricultural land
8 in developed countries is now covered with a few “winning” productive varieties, with generally
9 a single crop per field, so that the actual cultivated diversity is in fact low (e.g. FranceAgriMer
10 and ARVALIS Institut du Végétal, 2009 in France). The resulting crop genetic homogenization is
11 postulated to threaten the sustainability of production systems, and several studies now
12 emphasize the importance of both inter- (e.g. Altieri, 1999; Lin, 2011) and intra-specific crop
13 diversity (e.g. Hajjar et al., 2008; Macfadyen and Bohan, 2010) to increase and stabilize crop
14 yield, via e.g. improved pest control (see e.g. Tooker and Frank, 2012 for a review).

15 Another potential consequence of decreased crop genetic diversity that has received little
16 attention so far is erosion of wild biodiversity in agroecosystems. Previous studies in natural
17 systems (e.g. Whitham et al., 2006) have shown that the phenotype (hence the genotype) of some
18 plant species may affect the composition of the dependent community. These particular species,
19 referred to as foundation species, are abundant in the ecosystem (often, but not always, tree
20 species, Whitham et al., 2006). Because they represent a large fraction of the biomass of an
21 ecosystem, they structure a community by creating locally stable conditions for other species
22 (e.g. habitats and food sources) and by modulating and stabilizing fundamental ecosystem
23 processes (see Ellison et al., 2005 for definitions). The impact of the genotype of a single species
24 on a community is known as a “community phenotype”, i.e. an effect of genes at the community

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4 1 level (“Community genetics”, Whitham et al., 2003). High genetic and phenotypic diversity in
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6 2 foundation species can result in a diversity of local environments, thereby benefiting species
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8 3 diversity in the dependent community and affecting ecosystem processes (Bangert et al., 2005;
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10 4 Whitham et al., 2006; Wimp et al., 2004). Although well documented in natural ecosystems, the
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12 5 influence of genetic diversity on community diversity has never been investigated in
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14 6 agroecosystems. Several lines of evidence nonetheless suggest that crop genetic diversity can
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16 7 greatly affect wild species diversity. First, crops are dominant in terms of biomass in a field and
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18 8 can be considered foundation species. Second, crops are known to be involved in numerous
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20 9 (though altered, Macfadyen and Bohan, 2010) interactions with non-crop species, which may
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22 10 create community phenotypes similar to wild foundation species. These interactions include
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24 11 exploitation and interference competition with weed species (e.g. allelopathy, demonstrated for
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26 12 several cereals: Belz, 2007; Bertholdsson, 2010), trophic interactions with pest or non-pest
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28 13 species (e.g. species that feed on root and leaf secretions or excreta), or mutualistic interactions
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30 14 via the creation of microhabitats for predators by below and aboveground vegetative architecture
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32 15 (e.g. Johnson, 2008). As a result, decreased crop genetic diversity should alter farmland
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34 16 biodiversity within and among fields, via a reduction in the diversity of available ecological
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36 17 niches or food sources (Bangert et al., 2005).

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38 18 The present study assessed the relationship between in-field crop genetic diversity and the
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40 19 species diversity of several taxonomic groups (springtails, ground-dwelling macroarthropods and
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42 20 plants), using an experimental approach in the field. We worked with winter wheat (*Triticum*
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44 21 *aestivum* L.), the main crop in the study region, which also exhibits large phenotypic variation
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46 22 among varieties. Species diversity was compared between plots sown with a pure line variety and
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48 23 plots sown with a combination of several varieties. The following predictions were tested:
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50 24 (1) local (α) diversity at each sampling point should be higher in the variety mixture than in the
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4 1 pure line variety, due to the diversity of genotypes (and therefore phenotypes) surrounding each
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6 2 sampling point; (2) β -diversity (between sampling points) should be low within the pure variety
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9 3 because one wheat genotype should be preferentially associated with one community phenotype,
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11 4 whereas β -diversity in the variety mixture should be higher due to high spatial heterogeneity of
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14 5 wheat genotype associations in the field; (3) consequently, γ -diversity, the sum of α - and β -
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17 6 diversity, should be higher in the variety mixture than the pure line variety. We discuss the most
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19 7 likely underlying mechanisms, as well as possible consequences for ecosystem services and
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22 8 opportunities for agricultural sustainability.
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26 10 **2. Methods**

27 11 The experiment took place in an organic farm in northern France. In winter 2007-2008 ten
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29 12 contiguous square plots (60 m wide) were sown with either a “pure line” bread wheat variety
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32 13 (*Triticum aestivum* “Renan”, INRA, five plots) or a genetically diverse seed mixture including 30
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35 14 landraces and several pure line varieties, among which the “Renan” variety. Pure line varieties
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38 15 are obtained by successive (usually 6-10) self-fertilizations of a few selected plants so that all
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41 16 plants are eventually highly homozygous and genetically identical. These two crop diversity
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44 17 treatments were distributed in a checkerboard-like pattern (see Appendix A). This limited
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47 18 confounding spatial effects but did not fully discard them, owing to the partly unbalanced
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50 19 experimental design that was constrained by field shape. However, these confounding effects
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53 20 appeared to be minor: for example, the only plot not bordered by the surrounding matrix (plot R2,
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56 21 Appendix A) did not exhibit extreme ecological diversities compared to other plots in the same
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59 22 treatment. No mechanical or chemical treatment was applied between sowing and harvest, as is
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4 1 often the case in organic farming; plots were surrounded by a wheat variety not used in the
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6 2 experiment itself.
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10 11 4 *2.1. Community sampling* 12

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14 5 Springtails (Collembola) were sampled at the beginning of May 2008, using five soil cores (5 cm
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16 6 diameter, 12 cm deep) per plot (one in the center of the plot, the other four at the center of each
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18 7 quarter). After ten days of extraction with the Berlese method (Edwards and Fletcher, 1971),
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20 8 individuals were counted and identified to species level. Water content (dry weight / wet weight)
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22 9 and pH (method NF ISO 10390) were also measured in each soil core.
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26 10 Ground-dwelling macroarthropods were sampled twice in May and June 2008, during two-
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28 11 week trapping sessions separated by a two-week interruption. To this end, five pitfall traps
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30 12 (9.5 cm diameter, 11.4 cm deep, filled with ethylene glycol) were located at the corners and
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32 13 center of a 10x10 m square centered in each plot. This distribution reduced the capture of
33
34 14 individuals from neighboring plots, while maintaining enough distance between the five pitfall
35
36 15 traps of a same plot to consider them as relatively independent replicates. The two most abundant
37
38 16 groups, carabids and spiders, were identified to species level. All individuals of small carabid
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40 17 species (≤ 4 mm) without identification were grouped (190 individuals, 6.8% of total carabids)
41
42 18 and six larger individuals could be identified to genus level only. All spider juveniles that could
43
44 19 not be identified to species level were discarded (1674 individuals, 20% of total spiders); the
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46 20 number of discarded individuals was however not significantly different across crop diversity
47
48 21 treatments ($F_{1,8} = 4.41$, $P = 0.07$). Three mature individuals could be identified to genus level
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50 22 only. For aboveground and belowground invertebrates, other taxonomic groups were observed in
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52 23 the samples (including flies, ants, non-carabid Coleoptera and slugs above ground; mites and
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1 earthworms below ground), but these represented a small fraction of total abundance (1 to 5%)
2 and a small number of species.

3 Finally, all wild plants growing in the experimental area were sampled twice, at the
4 beginning of May and June 2008. At each sampling date, all plant species were recorded in 25
5 1 m² quadrats evenly distributed within each plot, i.e. a total of 500 quadrats. All individual
6 plants were identified to species level. The quadrats were divided into 25 20x20 cm squares to
7 estimate abundance as the number of squares where a species was present.

8
9 *2.2. Wheat individual measurements*

10 Morphological and phenological characters that are classically used to describe phenotypes in
11 wheat (e.g. IBPGR Secretariat, 1985; Murphy et al., 2008; UPOV, 1996) were measured to assess
12 wheat phenotypic diversity within each crop diversity treatment: tiller number (five quadrats per
13 plot, 1068 individuals), flowering date (eight quadrats per plot, 2205 individuals), total height at
14 maturity, length, width and position along the stalk of the first leaf, and spike number (four
15 samples of ten individuals per plot). Although these traits were not chosen on the basis of
16 involvement in interspecific interactions, but to provide a general index of phenotypic diversity,
17 some are nonetheless known to influence plant-plant interactions (e.g. plant height and
18 competition for light) or plant-invertebrate interactions (e.g. plant architecture creating
19 microhabitats, Langellotto and Denno, 2004).

20 For each measured character, we checked that wheat diversity was actually different
21 between the two crop diversity treatments with a non-parametric Fligner test for homogeneity of
22 variance. Wheat phenotypic diversity was then summarized within each plot by normalizing and
23 combining the five morphological characters describing vegetation structure (total height, length,
24 width and position of the first leaf, spike number) to calculate Rao's diversity coefficient (Rao,

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1 1982) with the Mahalanobis distance, which removes correlations between morphometric
2 characters measured on the same individual. A permutational test of homogeneity of multivariate
3 dispersion (R, library vegan; Anderson, 2006; Anderson et al., 2006) was used to verify that the
4 diversity measured over these five characters was highest in the variety mixture.

5 Finally wheat density (number of individuals per unit area) was measured in each plot (six
6 quadrats per plot) and we checked that there was no difference in wheat density between crop
7 diversity treatments using a linear model with observer and treatment as fixed variables, and plot
8 as a random variable.

9
10 *2.3. Statistical analyses*

11 For all analyses below, spiders from the family Linyphiidae were analyzed separately to account
12 for differences in the field colonization dynamics between these small late-colonizing, ballooning
13 spiders and spiders from other families. For carabids, all analyses were performed on the full
14 dataset and on predatory and herbivorous species separately.

15 Linear models were analyzed with SAS software (version 9.1, SAS Institute Inc. 2006,
16 Cary; proc GLM and MIXED) and multivariate analyses as well as resampling procedures with R
17 software (version 2.10.1, R Development Core Team 2009, Vienna; library vegan).

18
19 Local community diversity (α -diversity within sampling units: quadrats, soil cores or pitfall
20 traps) was measured using species richness and Shannon Diversity Index. We first tested the
21 effect of wheat diversity treatment on these two dependent variables using linear mixed effects
22 models with the following core structure: crop diversity treatment (pure line variety vs. variety
23 mixture), sampling session and their interaction (dropped if non-significant) were included as

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4 1 fixed effects, and 60x60m plot as a random effect, to account for the spatial clustering of data
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6 2 (replicates clustered within plots). This general model was used a couple of times and is
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8 3 subsequently referred to as “Model 1”. A number of fixed covariates were added to this core
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10 4 structure depending on the taxonomic group but discarded if non-significant: soil pH and water
11
12 5 content for springtails (not retained in the final model: $P > 0.60$ for both, and not influenced by
13
14 6 the crop diversity treatment: $P > 0.10$), distance to field edges for ground-dwelling arthropods to
15
16 7 account for spring recolonization (not retained), and spatial coordinates for all taxa to account for
17
18 8 spatial autocorrelation of data (not retained for springtails only).
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23 9 Second, the relationship between species diversity (richness or Shannon index) and wheat
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25 10 phenotypic diversity was examined to get a more quantitative picture of the effect of wheat
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27 11 diversity on communities. This was done for each above-ground taxon using linear mixed effects
28
29 12 models in which community diversity (richness or Shannon) was explained by Rao’s coefficient
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31 13 of phenotypic diversity (calculated on wheat aerial architecture) and sampling session (fixed
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33 14 effects); plot was included as a random effect.
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41 16 *2.3.1. Local community diversity*

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43 17 We first checked that observed differences in the number of individuals were not a mere
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45 18 by-product of differences in wheat productivity (“more individuals hypothesis”, Srivastava and
46
47 19 Lawton, 1998): a greater biomass offers more resources, hence potentially more individuals.
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49 20 These more abundant resources can be fresh or dead plant tissues for herbivorous carabids
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51 21 (Harvey et al., 2008) and springtails (Hopkin, 1997) or preys for all predatory species owing to
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53 22 cascading effects (Scherber et al., 2010). The relationship between number of individuals and
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55 23 wheat biomass was tested with a linear mixed effects model where abundance was a function of
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57 24 either of two proxies for wheat biomass (mean crop height per plot or mean individual spike
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1 number per plot) and session (fixed effects), as well as plot (random effect). This was done for all
2 taxa except springtails, which were sampled too early for wheat phenotypic measures to be
3 meaningful. We also tested whether the abundance of taxonomic groups differed between wheat
4 diversity treatments using Model 1 with total abundance as a dependent variable.

5 Finally, for all taxa with a significant or marginally significant effect of wheat genetic
6 diversity on species richness or Shannon Index, permutation analyses were performed to separate
7 the effects of abundance vs. diversity. From the original dataset, 1000 rearranged datasets were
8 produced by randomly reallocating each sampled individual to one local community (sampling
9 unit), while keeping the sample size (number of individuals, i.e. abundance) of sampling units
10 constant. Each rearranged dataset was analyzed using Model 1. We then compared the observed
11 F -value for crop diversity treatment (pure line vs. variety mixture) obtained from the original
12 dataset to the distribution of F -values from permuted communities (see Appendix C). When the
13 F -value for the original dataset fell outside of the 95% percentile, the effect of crop diversity on
14 richness or Shannon Index was not explained by differences in abundance.

15
16 *2.3.2. Community similarity*

17 In addition to local biodiversity indices, we examined whether community composition differed
18 between crop diversity treatments. We specifically tested whether individual samples (pitfall
19 traps, soil cores or plant quadrats) were more similar to each other within the pure line treatment
20 than within the variety mixture, using the non-Euclidean Bray-Curtis distance to measure
21 dissimilarity. The significance of the difference in local community dissimilarities between the
22 pure line variety and the variety mixture was then tested with a permutational test of homogeneity
23 of multivariate dispersion (Anderson, 2006 and R library vegan), which permutes model residuals

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1 to generate a permutation distribution of F under the Null hypothesis of no difference in
2 dispersion between groups.

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4 *2.3.3. Total species richness*

5 To test for differences in total richness independently of differences in abundance, we used the
6 resampled communities and we compared the mean γ -diversity in these communities to the
7 observed species richness within each crop diversity treatment using one-tail t-tests. The
8 observed richness was expected to be higher (respectively lower) than the resampled richness in
9 the variety mixture (respectively in the pure line variety).

10

11 **3. Results**

12 Whereas there was no difference in wheat density between crop diversity treatments ($F_{1,8} = 0.00$,
13 $P = 0.97$), the two wheat diversity treatments exhibited contrasting levels of phenotypic diversity:
14 for almost all morphological and phenological measures, individual variance and multivariate
15 dispersion were higher in the variety mixture than in the pure line variety (see Appendix B).
16 There was also a significant difference in biomass between the two crop diversity treatments,
17 with taller (111 ± 23 cm vs. 66 ± 6 cm, $P < 0.001$) and more ramified (4.5 ± 2.4 vs. 3.7 ± 2.0
18 tillers, $P = 0.02$) plants in the variety mixture than in the pure line variety.

19 A total of 48 plant species, 1057 springtail individuals from 19 species, 2781 carabid
20 individuals from 20 species and one group of very small carabids, and 6625 spider individuals
21 from 48 species (linyphiids: 4723 individuals, 15 species; other spiders: 1902 individuals, 33
22 species) were sampled.

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1 *3.1. Local community diversity*

2 There was a significant effect of wheat diversity treatment on α -diversity (Fig. 1), with higher
3 diversity in the variety mixture for springtails (species richness only, $F_{1,8} = 5.38$, $P = 0.049$),
4 linyphiids (species richness only, $F_{1,8} = 7.48$, $P = 0.026$; marginal significance for Shannon
5 Index) and other spiders (Shannon Index only); regardless of statistical significance, diversity
6 was always higher in the variety mixture than in the pure line variety in these taxa. In contrast,
7 plants and carabids were not influenced by wheat diversity ($P > 0.10$), regardless of trophic level
8 for the latter (no difference between predators and herbivores). Community diversity was in
9 general higher during the second sampling session for both crop diversity treatments (non-
10 significant interaction between wheat diversity treatment and session). When the effect of wheat
11 diversity was examined more quantitatively, via a correlation with Rao's diversity coefficient,
12 there were significant positive effects of phenotypic diversity on linyphiid species Shannon Index
13 ($F_{1,8} = 7.85$, $P = 0.023$) and predatory carabid species richness ($F_{1,8} = 5.37$, $P = 0.049$). No effect
14 was found for the other taxa ($P > 0.10$).

15 No effect of wheat biomass ($P > 0.10$) was found on total abundance for all taxa except
16 linyphiids, whose abundance was positively affected by mean crop height ($F_{1,8} = 9.44$,
17 $P = 0.015$). In fact, only linyphiid abundance was positively affected by wheat genetic diversity
18 ($F_{1,8} = 10.52$, $P = 0.012$). For all other taxa, there was no difference in abundance between the
19 variety mixture and the pure line variety ($P > 0.60$). When the effect of abundance was removed
20 by comparing observed communities to randomly assembled communities with the same local
21 abundances, the positive effect of wheat diversity on springtail species richness and spider (other
22 than linyphiids) Shannon Index remained (springtail richness: observed F : 5.38, simulated F
23 (quantile 95%): 3.33; other spider Shannon Index: observed F : 10.67, simulated F : 4.11). In

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1 contrast, the F -values of the ANOVAs on linyphiid species richness and Shannon Index in
2 observed communities were not different from random communities (observed F : 7.48, simulated
3 F : 11.69 and observed F : 4.92, simulated F : 4.93 respectively), suggesting that the positive effect
4 of wheat diversity on linyphiids resulted from an increase in local abundance and not diversity
5 per se.

7 *3.2. Community similarity*

8 The homogeneity of multivariate community dispersion between the pure line variety and the
9 variety mixture was tested for each taxon: for non-linyphiid spiders, community dispersion across
10 sites was higher in the variety mixture compared to the pure line variety ($P = 0.004$, average
11 distance to spatial median in the variety mixture: 0.37; in the pure line variety: 0.30; Fig. 2),
12 indicating that local communities were more similar to one another in the pure line variety. For
13 plants there was a significant but small difference ($P = 0.036$, average distance to spatial median
14 in the variety mixture: 0.45; in the pure line variety: 0.47) with a higher dispersion in the pure
15 line variety, but this effect was mainly caused by inter-plot differences in species composition,
16 consistent with above-mentioned spatial autocorrelation. For other taxa (springtails, linyphiids
17 and carabids), there was no difference in dispersion between the two crop diversity treatments
18 ($P > 0.10$).

20 *3.3. Total species richness*

21 When γ -diversity in the variety mixture and the pure line variety were compared to γ -diversity in
22 randomly permuted communities, total species richness in the pure line variety was lower than
23 expected for all taxa ($P < 0.0001$, Table 1) whereas total species richness in the variety mixture

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1 was almost always higher than expected ($P < 0.0001$ except for predatory carabids and plants).

2 For plants, observed species richness was significantly lower than expected in both crop diversity
3 treatments, reflecting local specific spatial aggregation as commonly observed for weed species
4 (Rew and Cousens, 2001).

6 **4. Discussion**

7 Overall, there was a general positive correlation between wheat diversity and all levels of species
8 diversity (α , β , γ) that was consistent across most studied arthropod taxa. Although the intensity
9 and significance of the effect varied, species richness and/or species diversity of arthropod
10 communities were consistently higher in the variety mixture than in the pure line variety. Plants
11 were the only group to exhibit no difference between the two wheat diversity treatments. This
12 result was however not surprising because most plants were typical annual weed species; the
13 latter generally exhibit patchy distributions caused by environmental heterogeneities or
14 demographic factors (e.g. limited dispersal, Rew and Cousens, 2001). Hence, in comparison to
15 studies that demonstrated an impact of genetic diversity on plant community structure or
16 invasibility (e.g. Booth and Grime, 2003; Crutsinger et al., 2008; Fridley and Grime, 2010), the
17 short time span of the experiment (six months between wheat sowing and the last plant survey)
18 was probably not sufficient for a spatial reorganization of plant communities via seed dispersal
19 and differential growth. In addition, environmental variation is likely to have a much stronger
20 impact than genetic diversity on competition among plant species (Johnson et al., 2008) and
21 theory predicts variable effects of the genetic diversity of a foundation species on the diversity of
22 subordinate species, depending on environmental heterogeneity (Gibson et al., 2012). This
23 homogeneity of weed communities between the two crop genetic diversity treatments also

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4 1 suggests that the observed differences in arthropod diversity were mostly attributable to
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6 2 differences in wheat, not weeds.
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9 3 Our results represent the first experimental evidence that crop genetic diversity can benefit
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11 4 farmland biodiversity in agroecosystems, and one of the rare examples where the effects of the
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13 5 genetic diversity of a foundation species are observed at a relatively large scale under realistic
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15 6 environmental conditions (but see references on *Populus* species, e.g. Wimp et al., 2004; and a
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17 7 number of field studies examining the impact of crop genetic diversity on herbivore abundance,
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19 8 not diversity, e.g. Hamback et al., 2010; reviewed in Tooker and Frank, 2012). The higher local
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21 9 diversity in the variety mixture for most arthropod groups (springtails, spiders, and, to a lesser
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23 10 extent, predatory carabids) is however consistent with comparable small-scale experimental
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25 11 studies on non-crop herbaceous species (Crutsinger et al., 2006; Johnson et al., 2006; Jones et al.,
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27 12 2011) and may involve similar mechanisms. First, differences in diversity may arise as a direct
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29 13 consequence of differences in abundance (“more individuals hypothesis”, Srivastava and Lawton,
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31 14 1998) caused by differences in biomass between diversity treatments (e.g. higher aboveground
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33 15 net primary productivity with higher genotypic diversity of *Solidago altissima* cultures in
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35 16 Crutsinger et al.’s experiment, 2006). Here, this explanation could be rejected for most taxonomic
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37 17 groups: the observed differences in diversity were generally independent of arthropod abundance
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39 18 and wheat productivity, showing that resource quality and not quantity caused higher
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41 19 biodiversity. For linyphiids, however, the higher species richness and Shannon Index in the
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43 20 variety mixture vs. the pure line variety were mainly mediated by an increase in the number of
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45 21 individuals, partly (but not only) due to higher wheat biomass. Hence for this group the relative
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47 22 roles of wheat biomass vs. genetic diversity per se cannot be differentiated. Although it is likely
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49 23 that differences in biomass are the key factor that controls linyphiid species richness by affecting
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51 24 the number of individuals, we cannot exclude that crop genetic diversity also increases
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4 1 productivity of in-field communities via a more efficient use of resources (including web-fixing
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6 2 sites), with consequences on community diversity (Crutsinger et al., 2006; Genung et al., 2010).

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9 3 In the cases where differences in species diversity were not controlled by the number of
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11 4 individual arthropods, at least two alternative mechanisms may explain higher species diversity in
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14 5 the mixture of wheat varieties. First, the taxonomic diversity hypothesis states that higher genetic
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16 6 diversity of the foundation species increases the diversity of resources available to herbivores
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19 7 (e.g. Bukovinszky et al., 2008 in *Brassica* lines; or Crutsinger et al., 2006 in *Solidago altissima*
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21 8 plots). This mechanism may apply to springtails, which may be offered a wider variety or more
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24 9 accessible food resources in the variety mixture, directly through biochemical variation in root
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26 10 systems or indirectly through associated microflora. The taxonomic diversity hypothesis is
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29 11 however a much less likely explanation for differences in aboveground communities, where the
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31 12 only herbivore group (carabids) was unaffected by wheat genetic diversity. Instead, the structural
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34 13 heterogeneity hypothesis states that higher genetic diversity of the foundation species generates
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36 14 more complex vegetation architecture (Brose, 2003; Harvey et al., 2008). Several studies have
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38 15 shown that ground-dwelling arthropods, especially spiders, were sensitive to vegetation structural
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41 16 diversity (Brose, 2003; Hansen, 2000; Jeanneret et al., 2003; Langellotto and Denno, 2004) or
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43 17 that arthropod abundance and richness were higher on structurally complex plant genotypes
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46 18 (Johnson and Agrawal, 2005 in *Oenothera biennis* L.). Here we observed a significant effect of
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48 19 wheat morphological diversity on spiders and predatory (but not herbivorous) carabids, which
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51 20 provides support for a possible role of wheat architectural diversity in increasing species
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53 21 diversity, e.g. by creating multiple micro-habitats, although other mechanisms may be involved.

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55 22 At the crop diversity treatment level, total (γ) species diversity was also higher in the
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58 23 variety mixture than in the pure line variety, which was much more due to the increase in local
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1 (α) species diversity than to among-sampling-unit differences in community composition (β -
2 diversity): heterogeneity between communities was significantly higher in the variety mixture for
3 non-lynyphiid spiders only. This may be caused by the relatively large number of rare species
4 found for all taxa except plants in the variety mixture vs. the pure line variety. These species
5 represented 20 to 57% of species present in the mixture, but accounted for a small number of
6 individuals, reflecting the strong dominance of one or a few species (e.g. *Pardosa agrestis*
7 Westring in spiders) and explaining the high similarity between local communities. For non-
8 linyphiid spiders, this pattern of dominance was found in the pure line variety only, hence the
9 difference in β -diversity.

11 *4.1. Limitations and perspectives*

12 One key limitation of our approach is that two crop diversity treatments only were compared
13 (pure line variety vs. highly diverse mixture), with a single variety in the pure line variety
14 treatment. As a result, we cannot make firm conclusions on the true role of genetic or phenotypic
15 diversity per se vs. a variety effect on the diversity of farmland species. However, several facts
16 and lines of evidence suggest that the difference in species diversity observed between the two
17 treatments is caused by differences in genetic diversity. First, the pure line variety “Renan” was
18 included in the variety mixture, although at a low frequency (<10%), so that a variety effect
19 (repulsion of several species by the pure line variety) can be partly discarded. Second, and most
20 important, wheat morphological diversity correlated positively with species diversity for two
21 taxonomic groups, which cannot be explained by a mere variety effect. An additional limit of
22 incomplete crop diversity treatments is that the actual effect of diversity vs. biomass on
23 community diversity cannot be differentiated for the one taxonomic group (linyphiid spiders) that

1 exhibited differences in abundance between the two treatments. More generally, we cannot
2 distinguish additive from interactive processes, i.e. processes resulting from the simple
3 combination of community phenotypes in monocultures vs. processes that are non predictable
4 from isolated genotypes only, nor can we point out the exact source of wheat variability involved
5 in community diversity (e.g. biochemical and/or architectural).

6 To confirm these results, the next essential step is therefore to consider a larger range of
7 diversity levels and to compare several wheat varieties grown in monocultures vs. plots
8 containing contrasting numbers of wheat varieties, as in similar studies exploring the relationship
9 between a number of genotypes and the diversity of associated communities (Crutsinger et al.,
10 2006; Johnson et al., 2006). Such full experimental design, ideally based on neighbor-balanced
11 latin square designs, is the only way to discriminate additive vs. interactive mechanisms for the
12 effects of genetic diversity (Hughes et al., 2008; Loreau and Hector, 2001). Focusing on the
13 number of genotypes alone may, however, be misleading when studying the influence of
14 intraspecific diversity on communities and ecosystems, because the relationship between the
15 number of genotypes and genetically based variance in phenotypic traits is not straightforward
16 (Hughes et al., 2008). Two genotypes can have very similar or very different phenotypic traits
17 involved in interspecific interactions, so that the genetic variance for these traits can be same on
18 average whether one compares two or many genotypes (Hughes et al., 2008). Hence, there is a
19 need to go beyond the number of genotypes and to quantify phenotypic diversity, as was done in
20 the present study. This quantification is necessary to confirm that genotypic diversity is
21 associated with phenotypic diversity, and to elucidate the underlying genetic and ecological
22 mechanisms.

23 Finally, future work should also investigate whether genetic diversity impacts farmland
24 biodiversity for other crop species and other agricultural systems. The diversity and identity of

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1 plant and invertebrates communities in cultivated fields depend strongly on agricultural practices
2 (e.g. conventional vs. organic farming, Bengtsson et al., 2005) and on crop type (Hawes et al.,
3 2009; Macfadyen and Bohan, 2010; Smith et al., 2008). Hence, our results under organic farming
4 may not apply to conventional farming, because most taxonomic groups (including plants and
5 predatory insects) show decreased species richness under conventional farming (Bengtsson et al.,
6 2005). In contrast, a positive effect of crop genetic diversity on species diversity has already been
7 observed in a wide range of foundation species, from forbs to trees (Whitham et al., 2006), so that
8 such effect is expected in other crop species. Note however that Hambäck et al. (2010) observed
9 no effect of the genetic diversity of *Brassica oleracea* on the abundance of two herbivorous
10 species. Considering a variety of crop species would also broaden the range of phenotypic traits
11 involved in interspecific interactions and may provide useful information to identify some of the
12 mechanisms for the relationship between genetic and specific diversity.

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14 *4.2. Conservation benefits of crop genetic diversity*

15 Genetically heterogeneous crops, which were (and still are) widely used in subsistence
16 agriculture to secure yield (Smithson and Lenne, 1996), have received increasing attention
17 recently, because this practice is believed to improve the sustainability of agriculture. The current
18 genetic homogenization of crops likely decreases their adaptability to environmental change (Lin
19 et al., 2008; Norberg et al., 2001), and creates growing sanitary risks resulting from strong
20 selective pressures on pathogens and herbivores (Hoisington et al., 1999; Villareal and Lannou,
21 2000). In contrast, in-field genetic diversity would help prevent diseases (De Vallavieille-Pope,
22 2004; Zhu et al., 2000) as well as herbivore damage (Andow, 1991; Tooker and Frank, 2012). In
23 addition, when combined to local participatory seed production, a practice that also attracts
24 renewed interest even in developed countries (Dawson et al., 2011; Enjalbert et al., 2011; Osman

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1 and Chable, 2009), in-field genetic diversity would maintain the evolutionary potential of crop
2 varieties, allowing them to adapt to their local environment (including co-evolving flora, fauna
3 and pathogens). Here, we have shown that an increase in crop genetic diversity can also improve
4 biodiversity, which is a general aim of all signatories to the Convention on Biological Diversity,
5 and may help slow down the functional homogenization of agroecosystems. In view of the
6 widespread positive relationship between species diversity and ecosystem functioning (e.g.
7 Cardinale et al., 2012), a higher diversity of taxonomic groups such as soil microarthropods
8 (springtails) and generalist predators (spiders and carabids) may result in better ecosystem
9 services such as soil regeneration or biological control (Hajjar et al., 2008; Whittingham, 2011),
10 but this remains to be demonstrated.

11 Although the impact of crop genetic diversity on farmland communities documented in the
12 present study may appear moderate compared to that of chemical inputs or natural habitat loss,
13 two major causes of biodiversity loss in agroecosystems (Tscharntke et al., 2005), it may
14 nonetheless have significant positive impacts on biodiversity if implemented on a large scale
15 (Macfadyen and Bohan, 2010), which would be easy for farmers. This raises the issue of
16 extrapolating results of small-scale experiments to more natural systems: Hughes et al. (2008),
17 for example, fear that the effects of genetic diversity observed in controlled, small-scale
18 experiments will be masked by other factors in natural situations. However, this experiment was
19 set-up in a real agricultural landscape and met the conditions identified by Hughes et al. (2008) as
20 the requirements for genetic diversity to efficiently drive ecological processes: (1) crops are
21 dominant in fields and therefore can be considered as foundation species; (2) genetic diversity in
22 crop fields is controlled by farmers only and can be stable across time; (3) farmland communities
23 are submitted to repeated anthropogenic disturbance, so that species and genetic diversity may be
24 crucial for disturbance response and stability. Hence, the ecological consequences of increased

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1 crop genetic diversity on farmland communities and its potential contribution to agricultural
2 sustainability deserve further examination.

3
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10 EP).

11
12 **Supplementary data**

13 Supplementary information on the experimental design (Appendix A), on the phenotypic diversity of
14 wheat varieties (Appendix B), and on statistical tests of the difference in species diversity among
15 wheat diversity treatments (Appendix C) can be found in the online version, at <http://...>

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1 **References**

2 Altieri, M., 1999. The ecological role of biodiversity in agroecosystems. *Agric. Ecosyst. Environ.*
3 74, 19–31.

4 Anderson, M., 2006. Distance-based tests for homogeneity of multivariate dispersions.
5 *Biometrics* 62, 245–253.

6 Anderson, M., Ellingsen, K., McArdle, B., 2006. Multivariate dispersion as a measure of beta
7 diversity. *Ecol. Lett.* 9, 683–693.

8 Andow, D., 1991. Vegetational diversity and arthropod population response. *Annu. Rev.*
9 *Entomol.* 36, 561–586.

10 Bangert, R.K., Turek, R.J., Martinsen, G.D., Wimp, G.M., Bailey, J.K., Whitham, T.G., 2005.
11 Benefits of conservation of plant genetic diversity to arthropod diversity. *Conserv. Biol.*
12 19, 379–390.

13 Belz, R., 2007. Allelopathy in crop/weed interactions - an update. *Pest Manag. Sci.* 63, 308–326.

14 Bengtsson, J., Ahnstrom, J., Weibull, A.C., 2005. The effects of organic agriculture on
15 biodiversity and abundance: a meta-analysis. *J. Appl. Ecol.* 42, 261–269.

16 Bertholdsson, N., 2010. Breeding spring wheat for improved allelopathic potential. *Weed Res.*
17 50, 49–57.

18 Booth, R.E., Grime, J.P., 2003. Effects of genetic impoverishment on plant community diversity.
19 *J. Ecol.* 91, 721–730.

20 Brose, U., 2003. Bottom-up control of carabid beetle communities in early successional wetlands:
21 mediated by vegetation structure or plant diversity? *Oecologia* 135, 407–413.

22 Bukovinszky, T., Van Veen, F., Jongema, Y., Dicke, M., 2008. Direct and indirect effects of
23 resource quality on food web structure. *Science* 319, 804–807.

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1 Cardinale, B.J., Duffy, J.E., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P., Narwani, A.,
2 Mace, G.M., Tilman, D., Wardle, D.A., Kinzig, A.P., Daily, G.C., Loreau, M., Grace,
3 J.B., Larigauderie, A., Srivastava, D.S., Naeem, S., 2012. Biodiversity loss and its impact
4 on humanity. *Nature* 486, 59–67.

5 Crutsinger, G., Collins, M., Fordyce, J., Gompert, Z., Nice, C., Sanders, N., 2006. Plant
6 genotypic diversity predicts community structure and governs an ecosystem process.
7 *Science* 313, 966–968.

8 Crutsinger, G.M., Souza, L., Sanders, N.J., 2008. Intraspecific diversity and dominant genotypes
9 resist plant invasions. *Ecol. Lett.* 11, 16–23.

10 Dawson, J.C., Rivière, P., Berthelot, J., Mercier, F., De Kochko, P., Galic, N., Pin, S., Serpoley,
11 E., Thomas, M., Giuliano, S., Goldringer, I., 2011. Collaborative Plant Breeding for
12 Organic Agricultural Systems in Developed Countries. *Sustainability* 3, 1206–1223.

13 De Vallavieille-Pope, C., 2004. Management of disease resistance diversity of cultivars of a
14 species in single fields: controlling epidemics. *C.R. Biol.* 327, 611–620.

15 Edwards, C., Fletcher, K., 1971. A comparison of extraction methods for terrestrial arthropods,
16 in: *Methods of Study in Quantitative Soil Ecology: Population, Production and Energy*
17 *Flow*. Phillipson, J, Oxford, pp. 150–185.

18 Ellison, A.M., Bank, M.S., Clinton, B.D., Colburn, E.A., Elliott, K., Ford, C.R., Foster, D.R.,
19 Kloeppel, B.D., Knoepp, J.D., Lovett, G.M., Mohan, J., Orwig, D.A., Rodenhouse, N.L.,
20 Sobczak, W.V., Stinson, K.A., Stone, J.K., Swan, C.M., Thompson, J., Von Holle, B.,
21 Webster, J.R., 2005. Loss of foundation species: consequences for the structure and
22 dynamics of forested ecosystems. *Front. Ecol. Environ.* 3, 479–486.

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1 Enjalbert, J., Dawson, J.C., Paillard, S., Rhone, B., Rousselle, Y., Thomas, M., Goldringer, I.,
2 2011. Dynamic management of crop diversity: From an experimental approach to on-farm
3 conservation. *C.R. Biol.* 334, 458–468.

4 FAO, 1997. The state of the world’s plant genetic resources for food and agriculture. FAO,
5 Rome.

6 FranceAgriMer and ARVALIS Institut du Végétal, 2009. Qualité des blés tendres français -
7 Récolte 2009.

8 Fridley, J.D., Grime, J.P., 2010. Community and ecosystem effects of intraspecific genetic
9 diversity in grassland microcosms of varying species diversity. *Ecology* 91, 2272–2283.

10 Genung, M., Lessard, J., Brown, C., Bunn, W., Cregger, M., Reynolds, W., Felker-Quinn, E.,
11 Stevenson, M., Hartley, A., Crutsinger, G., Schweitzer, J., Bailey, J., 2010. Non-additive
12 effects of genotypic diversity increase floral abundance and abundance of floral visitors.
13 *PLoS One* 5, e8711.

14 Gibson, D.J., Allstadt, A.J., Baer, S.G., Geisler, M., 2012. Effects of foundation species
15 genotypic diversity on subordinate species richness in an assembling community. *Oikos*
16 121, 496–507.

17 Hajjar, R., Jarvis, D., Gemmill-Herren, B., 2008. The utility of crop genetic diversity in
18 maintaining ecosystem services. *Agric. Ecosyst. Environ.* 123, 261–270.

19 Hamback, P.A., Bjorkman, M., Hopkins, R.J., 2010. Patch size effects are more important than
20 genetic diversity for plant-herbivore interactions in Brassica crops RID A-8194-2008.
21 *Ecol. Entomol.* 35, 299–306.

22 Hansen, R., 2000. Effects of habitat complexity and composition on a diverse litter
23 microarthropod assemblage. *Ecology* 81, 1120–1132.

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1 Harvey, J., Van der Putten, W., Turin, H., Wagenaar, R., Bezemer, T., 2008. Effects of changes
2 in plant species richness and community traits on carabid assemblages and feeding guilds.
3 *Agric. Ecosyst. Environ.* 127, 100–106.

4 Hawes, C., Houghton, A.J., Bohan, D.A., Squire, G.R., 2009. Functional approaches for assessing
5 plant and invertebrate abundance patterns in arable systems. *Basic Appl. Ecol.* 10, 34–
6 42.

7 Hoisington, D., Khairallah, M., Reeves, T., Ribaut, J.V., Skovmand, B., Taba, S., Warburton, M.,
8 1999. Plant genetic resources: What can they contribute toward increased crop
9 productivity? *Proc. Natl. Acad. Sci. U. S. A.* 96, 5937–5943.

10 Hopkin, S., 1997. *Biology of the Springtails (Insecta: Collembola)*. Oxford University Press,
11 Oxford.

12 Hughes, A., Inouye, B., Johnson, M., Underwood, N., Vellend, M., 2008. Ecological
13 consequences of genetic diversity. *Ecol. Lett.* 11, 609–623.

14 IBPGR Secretariat, 1985. *Descriptors for Wheat (revised)*. International Board for Plant Genetic
15 Resources, Commission of European Communities,
16 http://genbank.vurv.cz/ewdb/asp/IPGRI_descr_1985.pdf.

17 Jeanneret, P., Schupbach, B., Luka, H., 2003. Quantifying the impact of landscape and habitat
18 features on biodiversity in cultivated landscapes. *Agric. Ecosyst. Environ.* 98, 311–320.

19 Johnson, M., Agrawal, A., 2005. Plant genotype and environment interact to shape a diverse
20 arthropod community on evening primrose (*Oenothera biennis*). *Ecology* 86, 874–885.

21 Johnson, M., Lajeunesse, M., Agrawal, A., 2006. Additive and interactive effects of plant
22 genotypic diversity on arthropod communities and plant fitness. *Ecol. Lett.* 9, 24–34.

23 Johnson, M.T.J., 2008. Bottom-up effects of plant genotype on aphids, ants, and predators.
24 *Ecology* 89, 145–154.

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1 Johnson, M.T.J., Dinnage, R., Zhou, A.Y., Hunter, M.D., 2008. Environmental variation has
2 stronger effects than plant genotype on competition among plant species. *J. Ecol.* 96,
3 947–955.

4 Jones, T.S., Allan, E., Haerri, S.A., Krauss, J., Mueller, C.B., Van Veen, F.J.F., 2011. Effects of
5 genetic diversity of grass on insect species diversity at higher trophic levels are not due
6 to cascading diversity effects. *Oikos* 120, 1031–1036.

7 Langellotto, G., Denno, R., 2004. Responses of invertebrate natural enemies to complex-
8 structured habitats: a meta-analytical synthesis. *Oecologia* 139, 1–10.

9 Lin, B.B., 2011. Resilience in Agriculture through Crop Diversification: Adaptive Management
10 for Environmental Change. *Bioscience* 61, 183–193.

11 Lin, B.B., Perfecto, I., Vandermeer, J., 2008. Synergies between agricultural intensification and
12 climate change could create surprising vulnerabilities for crops. *Bioscience* 58, 847–854.

13 Loreau, M., Hector, A., 2001. Partitioning selection and complementarity in biodiversity
14 experiments. *Nature* 412, 72–76.

15 Macfadyen, S., Bohan, D., 2010. Crop domestication and the disruption of species interactions.
16 *Basic Appl. Ecol.* 11, 116–125.

17 Murphy, K.M., Dawson, J.C., Jones, S.S., 2008. Relationship among phenotypic growth traits,
18 yield and weed suppression in spring wheat landraces and modern cultivars. *Field Crop.*
19 *Res.* 105, 107–115.

20 Norberg, J., Swaney, D., Dushoff, J., Lin, J., Casagrandi, R., Levin, S., 2001. Phenotypic
21 diversity and ecosystem functioning in changing environments: A theoretical framework.
22 *Proc. Natl. Acad. Sci. U. S. A.* 98, 11376–11381.

23 Osman, A., Chable, V., 2009. Inventory of initiatives on seeds of landraces in Europe. *Journal of*
24 *Agriculture and Environment for International Development* 103, 95–130.

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55
56
57
58
59
60
61
62
63
64
65

1 Rao, C., 1982. Diversity and dissimilarity coefficients - A unified approach. *Theor. Popul. Biol.*
2
3
4 1 Rao, C., 1982. Diversity and dissimilarity coefficients - A unified approach. *Theor. Popul. Biol.*
5
6 2 21, 24–43.
7
8
9 3 Rew, L.J., Cousens, R.D., 2001. Spatial distribution of weeds in arable crops: are current
10
11 sampling and analytical methods appropriate? *Weed Res.* 41, 1–18.
12
13
14 5 Scherber, C., Eisenhauer, N., Weisser, W.W., Schmid, B., Voigt, W., Fischer, M., Schulze, E.-D.,
15
16 6 Roscher, C., Weigelt, A., Allan, E., Bessler, H., Bonkowski, M., Buchmann, N., Buscot,
17
18 F., Clement, L.W., Ebeling, A., Engels, C., Halle, S., Kertscher, I., Klein, A.-M., Koller,
19 7
20 R., Koenig, S., Kowalski, E., Kummer, V., Kuu, A., Lange, M., Lauterbach, D.,
21 8
22
23 9 Middelhoff, C., Migunova, V.D., Milcu, A., Mueller, R., Partsch, S., Petermann, J.S.,
24
25
26 10 Renker, C., Rottstock, T., Sabais, A., Scheu, S., Schumacher, J., Temperton, V.M.,
27
28
29 11 Tschardtke, T., 2010. Bottom-up effects of plant diversity on multitrophic interactions in
30
31 12 a biodiversity experiment. *Nature* 468, 553–556.
32
33
34 13 Secretariat of the Convention on Biological Diversity, 2006. *Global Biodiversity Outlook 2.*
35
36 14 Montreal.
37
38 15 Smith, B., Bohan, D.A., Clark, S.J., Haughton, A.J., Bell, J.R., Heard, M.S., 2008. Weed and
39
40
41 16 invertebrate community compositions in arable farmland. *Arthropod-Plant Interact.* 2, 21–
42
43 17 30.
44
45
46 18 Smithson, J., Lenne, J., 1996. Varietal mixtures: A viable strategy for sustainable productivity in
47
48 19 subsistence agriculture. *Ann. Appl. Biol.* 128, 127–158.
49
50
51 20 Srivastava, D., Lawton, J., 1998. Why more productive sites have more species: An experimental
52
53 21 test of theory using tree-hole communities. *Am. Nat.* 152, 510–529.
54
55
56 22 Tooker, J.F., Frank, S.D., 2012. Genotypically diverse cultivar mixtures for insect pest
57
58 23 management and increased crop yields. *J. Appl. Ecol.* 49, 974–985.
59
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1 Tscharntke, T., Klein, A., Kruess, A., Steffan-Dewenter, I., Thies, C., 2005. Landscape
2 perspectives on agricultural intensification and biodiversity - ecosystem service
3 management. *Ecol. Lett.* 8, 857–874.

4 UPOV, 1996. Guidelines for the conduct of tests for distinctness, homogeneity and stability:
5 Wheat (*Triticum aestivum* L. emend. Fiori et Paol.). International Union for the
6 Protection of New Varieties of Plants, <http://www.upov.int/edocs/tgdocs/en/tg003.pdf>.

7 Villareal, L., Lannou, C., 2000. Selection for increased spore efficacy by host genetic background
8 in a wheat powdery mildew population. *Phytopathology* 90, 1300–1306.

9 Whitham, T., Bailey, J., Schweitzer, J., Shuster, S., Bangert, R., Leroy, C., Lonsdorf, E., Allan,
10 G., DiFazio, S., Potts, B., Fischer, D., Gehring, C., Lindroth, R., Marks, J., Hart, S.,
11 Wimp, G., Wooley, S., 2006. A framework for community and ecosystem genetics: from
12 genes to ecosystems. *Nat. Rev. Genet.* 7, 510–523.

13 Whitham, T., Young, W., Martinsen, G., Gehring, C., Schweitzer, J., Shuster, S., Wimp, G.,
14 Fischer, D., Bailey, J., Lindroth, R., Woolbright, S., Kuske, C., 2003. Community and
15 ecosystem genetics: A consequence of the extended phenotype. *Ecology* 84, 559–573.

16 Whittingham, M.J., 2011. The future of agri-environment schemes: biodiversity gains and
17 ecosystem service delivery? *J. Appl. Ecol.* 48, 509–513.

18 Wimp, G., Young, W., Woolbright, S., Martinsen, G., Keim, P., Whitham, T., 2004. Conserving
19 plant genetic diversity for dependent animal communities. *Ecol. Lett.* 7, 776–780.

20 Zhu, Y., Chen, H., Fan, J., Wang, Y., Li, Y., Chen, J., Fan, J., Yang, S., Hu, L., Leung, H., Mew,
21 T., Teng, P., Wang, Z., Mundt, C., 2000. Genetic diversity and disease control in rice.
22 *Nature* 406, 718–722.

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4 **1 Tables**

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9 **3** Table 1. Comparison of species richness in the variety mixture vs. the pure line variety in each
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11 **4** taxon or trophic group.
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Taxa or trophic group	Number of shared species	Number of species unique to		Total number of species		Mean number of species after randomization ^a	
		Mixture	Pure line	Mixture	Pure line	Mixture	Pure line
Springtails	15	4	0	19	15	16.6 <i>P</i> < 0.001	17.2 <i>P</i> < 0.001
Linyphiids	10	4	1	14	11	13.5 <i>P</i> < 0.001	12.5 <i>P</i> < 0.001
Other spiders	16	11	6	27	22	24.8 <i>P</i> < 0.001	25.8 <i>P</i> < 0.001
Carabids	12	6	3	18	15	16.6 <i>P</i> < 0.001	16.8 <i>P</i> < 0.001
Predators	7	2	1	9	8	8.9 <i>P</i> = 0.22	9.0 <i>P</i> < 0.001
Herbivores	3	4	1	7	4	5.8 <i>P</i> < 0.001	5.2 <i>P</i> < 0.001
Plants	33	8	7	41	40	43.4 <i>P</i> = 1	43.5 <i>P</i> < 0.001

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39 **5** ^aThe total number of species in each crop diversity treatment is compared to the mean number of
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41 **6** species observed in 1000 randomized datasets (see text for details). *P*-values of one-tail t-tests
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43 **7** indicate whether the observed number of species in the variety mixture (respectively in the pure
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46 **8** line variety) is significantly higher (respectively smaller) than expected at random.
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1 **Figure captions**

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4 Figure 1: Shannon Diversity Index for all studied taxonomic groups in the variety mixture (white
5 bars) and in the pure line variety (grey bars).
6 Error bars represent standard errors. *F* and *P*-values for the crop diversity treatment effect in the
7 ANOVA are given (significant effects are in bold).

8 Figure 2: Principal coordinate ordination of the non-lynyphiid spider data, showing assemblages
9 from the variety mixture (circles, solid line) and the pure line variety (triangles, dashed line).

Figure 1

[Click here to download Figure: AGEE9558Figure1Revised.pdf](#)

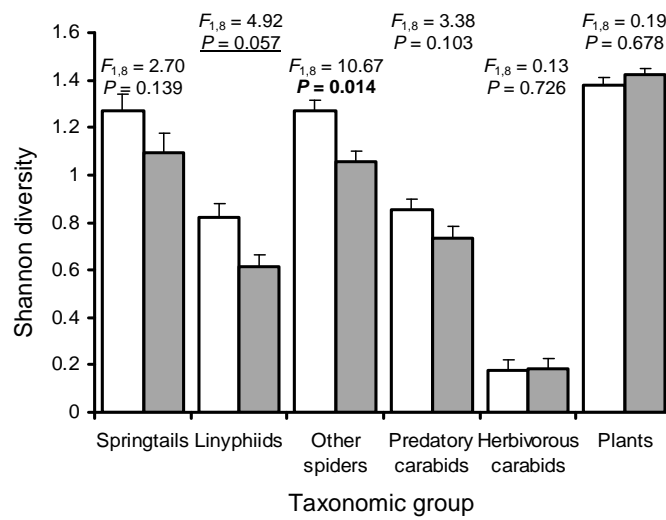


Figure 1

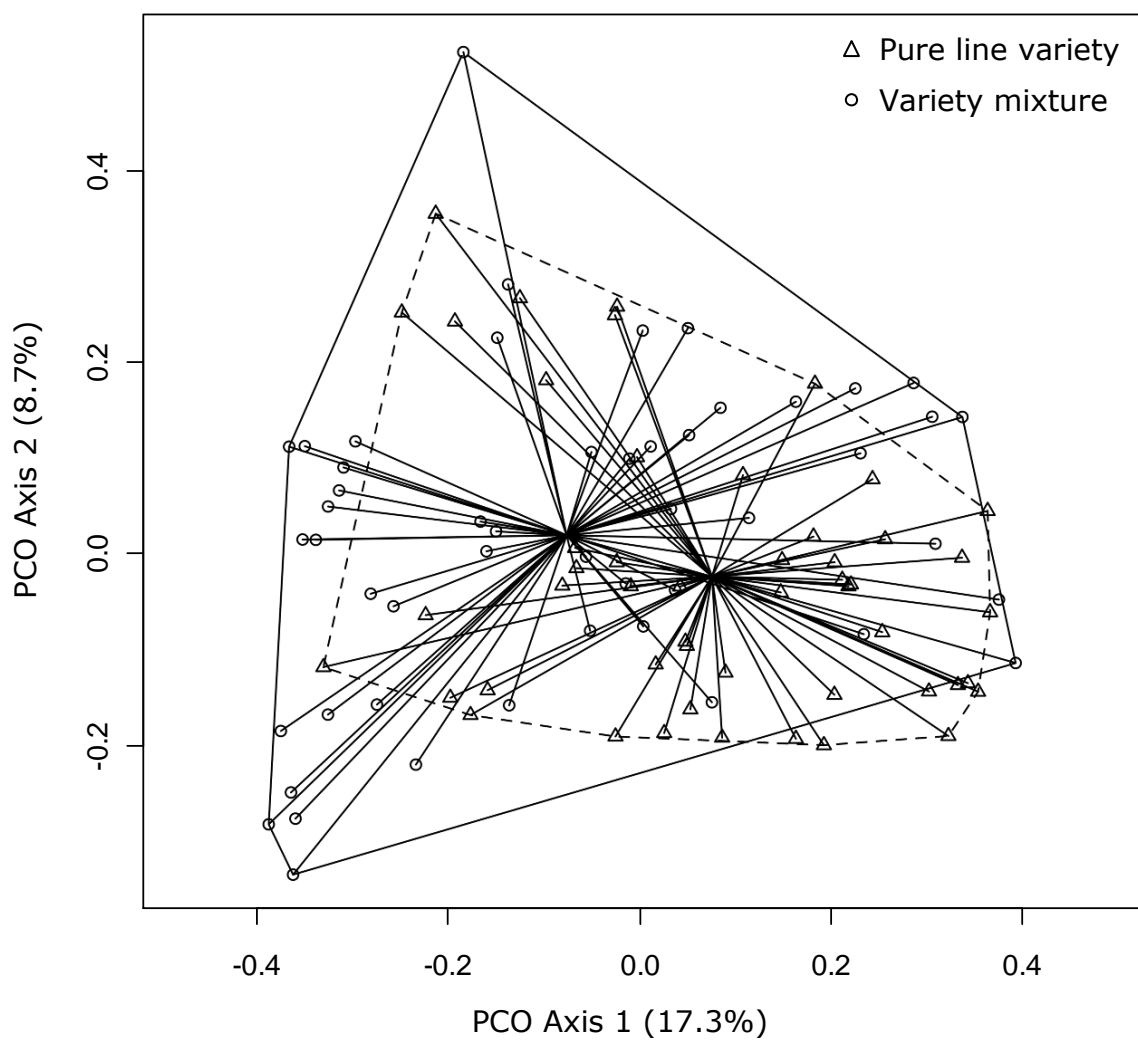


Figure 2

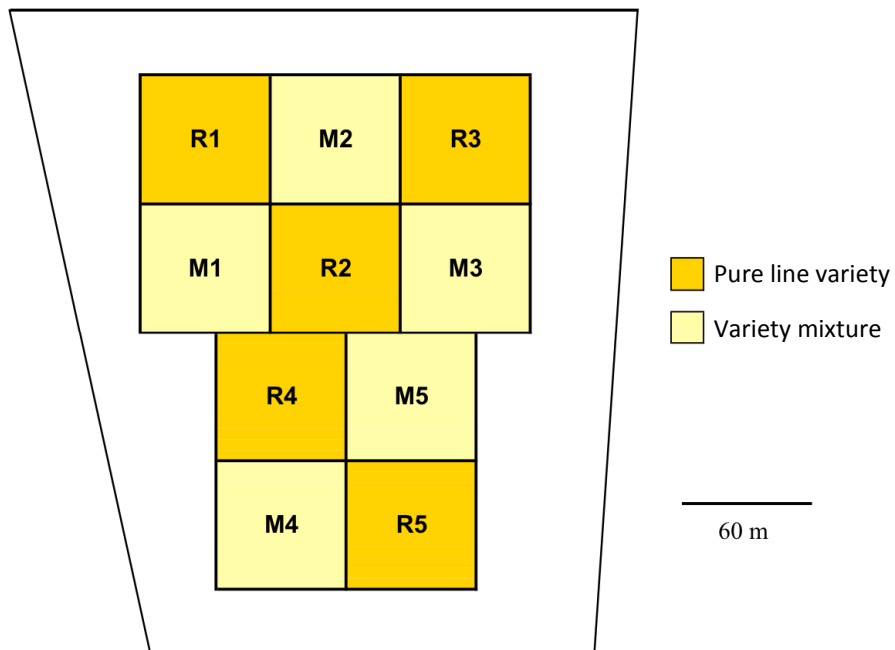
Chateil et al. Supporting Information

Appendix A: Experimental design

(a) Aerial photography of the field



(b) Localization of the pure line vs. variety mixture plots



Appendix B: Wheat phenotypic diversity in the pure line variety vs. variety mixture

Character	Individual variance*		P-value (test for homogeneity of variances†)
	Pure line variety (number of samples)	Variety mixture (number of samples)	
1. Tiller number	3.72 (<i>n</i> = 532)	5.74 (<i>n</i> = 536)	<i>P</i> < 0.0001
2. Flowering date (number of days since flowering)	6.35 (<i>n</i> = 1064)	17.08 (<i>n</i> = 1141)	<i>P</i> < 0.0001
3. Total height at maturity (cm)	52.10 (<i>n</i> = 200)	414.89 (<i>n</i> = 200)	<i>P</i> < 0.0001
4. Length of the first leaf (cm)	11.49 (<i>n</i> = 199)	18.01 (<i>n</i> = 195)	<i>P</i> = 0.11
5. Width of the first leaf (mm)	4.82 (<i>n</i> = 200)	8.92 (<i>n</i> = 195)	<i>P</i> < 0.0001
6. Position along the stalk of the first leaf (cm)	32.63 (<i>n</i> = 200)	217.84 (<i>n</i> = 200)	<i>P</i> < 0.0001
7. Spike number	1.76 (<i>n</i> = 200)	2.56 (<i>n</i> = 200)	<i>P</i> = 0.51
8. Multivariate measure (characters 3 to 7 combined)	1.54 (<i>n</i> = 199)	2.24 (<i>n</i> = 195)	<i>P</i> < 0.0001

* Univariate measures: residual variance obtained in mixed model analyses of variance with the following explanatory variables: observer (fixed effect), plot and quadrat nested within plot (random effects); multivariate measure: group mean distance to spatial median.

† Univariate measures: Fligner test for homogeneity of variances; multivariate measure: distance-based multivariate test for homogeneity of variances (multivariate analogue of Levene's test).

Appendix C: Distribution of F-values in linear mixed effects models testing the effect of wheat diversity treatment on species diversity or Shannon diversity index.

In the model, wheat diversity treatment, sampling session and their interaction were included as fixed effects; plot was included as a random effect. The distribution of F -values obtained from linear mixed effects models on 1000 rearranged datasets is plotted in grey; the 95th percentile of this distribution ($F_{95\%}$) is plotted in red; F -values from linear mixed effects models on original data (F_{obs}) are plotted in blue.

