

1 ***Supplementary Information for***

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3 **Above- and belowground biodiversity jointly tighten the P cycle**

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11 Supplementary Table 1: Correlation (Pearson) matrix of variables in the biodiversity experiment. Significant negative and positive relationships in
 12 blue and orange, respectively (hue refers to the closeness of the relationship). Asterisks refer to the level of significance (** $p < 0.01$, **
 13 * $p < 0.05$). The Benjamini & Hochberg correction was applied for the multiple testing (see Methods). PSR = plant species richness; Pi = inorganic
 14 P, PUE = phosphorus use efficiency (inverse of plant P concentrations), C_{org} = organic carbon concentrations in soil, P_{mic} = microbial P, F = fungi,
 15 B = bacteria, PAse = phosphatase activity in soil.

Biodiversity Experiment	(log) PSR	(log) Bioavailable Pi	(log) Plant biomass	(log) Plant P conc	PUE	N:P ratio	Plant P stocks	Plant P exploitation	Grass contribution	Herb contribution	Legume contribution	pH	(log) C _{org} conc	C _{org} stocks	Moderately labile Pi	Mineral P	(log) Microbial P conc	Microbial P stocks	Microbial P exploitation	Total P exploitation	Cmic:Pmic	Fungi	F:B ratio	AMF SR	(log) Relative AMF abundance
(log) Bioavailable Pi	0.22																								
(log) Plant biomass	0.52***	0.27*																							
(log) Plant P conc	0.02	0.31**	-0.06																						
PUE	-0.04	-0.26*	0.06	-0.98***																					
N:P ratio	-0.16	-0.41***	-0.34**	-0.33**	0.29*																				
Plant P stocks	0.55***	0.24*	0.73***	0.08	-0.09	-0.27*																			
Plant P exploitation	0.35**	-0.17	0.64***	-0.08	0.06	-0.13	0.80***																		
Grass contribution	-0.04	0.21	0.17	-0.61***	0.64***	-0.08	-0.05	-0.01																	
Herb contribution	0.13	0.05	0.09	0.57***	-0.56***	-0.42***	0.16	0.06	-0.66***																
Legume contribution	-0.12	-0.30**	-0.31**	0.00	-0.05	0.61***	-0.14	-0.07	-0.34**	-0.48***															
pH	-0.04	-0.34**	-0.23*	-0.12	0.10	0.25*	0.00	0.11	-0.06	-0.10	0.20														
(log) C _{org} conc	0.40***	0.64***	0.30**	0.18	-0.14	-0.23*	0.39***	0.07	0.08	0.04	-0.14	-0.29*													
C _{org} stocks	0.29*	0.68***	0.30*	0.24*	-0.19	-0.28*	0.35**	0.01	0.10	0.03	-0.15	-0.34**	0.96***												
Moderately labile Pi	0.20	0.97***	0.24*	0.30**	-0.26*	-0.38***	0.24*	-0.17	0.18	0.07	-0.31**	-0.38***	0.68***	0.71***											
Mineral P	-0.02	0.57***	0.07	0.14	-0.09	-0.02	0.10	-0.17	0.10	-0.01	-0.10	0.03	0.42***	0.47***	0.58***										
(log) Microbial P conc	0.38***	0.73***	0.28*	0.32**	-0.28*	-0.38***	0.28*	-0.12	0.11	0.06	-0.20	-0.28*	0.68***	0.69***	0.71***	0.38***									
Microbial P stocks	0.26*	0.59***	0.20	0.32**	-0.29**	-0.35**	0.18	-0.16	0.06	0.09	-0.17	-0.27*	0.51***	0.54***	0.58***	0.30**	0.94***								
Microbial P exploitation	0.10	-0.22	-0.12	0.05	-0.05	-0.03	-0.08	-0.10	-0.12	0.05	0.07	0.22	-0.06	-0.07	-0.25*	-0.10	0.42***	0.56***							
Total P exploitation	0.19	-0.24*	0.12	0.04	-0.05	-0.07	0.23	0.24*	-0.16	0.11	0.05	0.26*	-0.04	-0.06	-0.29*	-0.12	0.37**	0.49***	0.94***						
Cmic:Pmic	-0.08	-0.38**	-0.05	-0.13	0.08	0.12	0.16	0.33**	-0.26*	0.24	0.00	0.33**	-0.28*	-0.31*	-0.36**	-0.15	-0.46***	-0.39**	-0.05	0.11					
Fungi	0.18	0.18	0.12	0.10	-0.11	-0.17	0.07	0.02	-0.08	0.24*	-0.21	-0.40***	0.24*	0.24*	0.20	-0.03	0.27*	0.30**	0.03	0.00	-0.08				
F:B ratio	0.01	-0.11	0.07	0.11	-0.13	-0.17	-0.10	-0.02	-0.06	0.27*	-0.27*	-0.32**	-0.31**	-0.25*	-0.12	-0.23*	-0.10	-0.02	0.01	-0.01	-0.08	0.60***			
AMF SR	0.22	0.10	0.11	0.10	-0.09	-0.08	0.06	-0.08	-0.03	0.00	0.04	0.01	0.17	0.18	0.08	0.00	0.18	0.15	0.07	0.08	-0.40**	0.11	0.12		
(log) Relative AMF abundance	0.11	0.06	0.04	0.07	-0.05	-0.04	0.04	-0.11	-0.09	0.04	0.05	0.04	0.09	0.09	0.04	0.03	0.13	0.13	0.11	0.11	-0.29*	0.14	0.13	0.90***	
PAse	0.59***	0.35**	0.40***	0.07	-0.05	-0.15	0.44***	0.23	0.02	0.07	-0.11	-0.23*	0.72***	0.65***	0.39***	0.13	0.56***	0.41***	0.06	0.11	-0.16	0.25*	-0.17	0.17	0.07

16 Supplementary Table 2: Correlation (Pearson) matrix of variables in agricultural grasslands. Significant negative and positive relationships in blue
 17 and orange, respectively (hue refers to the closeness of the relationship). Asterisks refer to the level of significance (** $p < 0.001$, ** $p < 0.01$, * $p <$
 18 0.05). The Benjamini & Hochberg correction was applied for the multiple testing (see Methods). Pi = inorganic P, PUE = phosphorus use efficiency
 19 (inverse of plant P concentrations), C_{org} = organic carbon concentrations in soil, P_{mic} = microbial P, F = fungi, B = bacteria, P_{Ase} = phosphatase
 20 activity in soil, LUI = land use intensity (see Methods).

Agricultural grasslands	LUI	(log) PSR	(log) Bioavailable Pi	(log) Plant biomass	Plant P conc	PUE	N:P ratios	Plant P stocks	Plant P exploitation	Grass contribution	Herb contribution	Legume contribution	pH	(log) Corg conc	Corg stocks	Moderately labile Pi	Mineral P	(log) Microbial P conc	Microbial P stocks	Microbial P exploitation	Total P exploitation	Nmic:	Agricultural grasslands	LUI	(log) PSR	(log) Bioavailable Pi
(log) PSR	-0.66***																									
(log) Bioavailable Pi	0.52***	-0.60***																								
(log) Plant biomass	0.63***	-0.62***	0.62***																							
Plant P conc	0.62***	-0.61***	0.75***	0.61***																						
PUE	-0.56***	0.52***	-0.66***	-0.56***	-0.92***																					
N:P ratios	-0.45***	0.47***	-0.62***	-0.59***	-0.61***	0.53***																				
Plant P stocks	0.60***	-0.59***	0.56***	0.88***	0.57***	-0.47***	-0.53***																			
Plant P exploitation	0.54***	-0.47***	0.38***	0.79***	0.41***	-0.38***	-0.43***	***																		
Grass contribution	0.30**	-0.34***	0.24*	0.34***	0.22*	-0.20*	-0.22*	0.33***	0.44***																	
Herb contribution	-0.29**	0.32**	-0.26**	-0.34***	-0.23*	0.22*	0.25*	-0.29**	-0.35***	-0.90***																
Legume contribution	-0.05	0.05	0.04	-0.02	0.05	-0.05	-0.06	-0.10	-0.27**	-0.42***	-0.02															
pH	-0.04	0.21*	0.01	-0.14	-0.12	0.01	0.21*	-0.19	0.04	-0.11	0.15	-0.08														
(log) Corg conc	0.05	-0.11	0.09	0.00	0.16	-0.02	0.08	0.13	-0.17	-0.04	0.04	0.00	-0.29**													
Corg stocks	0.24*	-0.20	0.20	0.04	0.30**	-0.15	-0.01	0.17	-0.17	-0.10	0.06	0.12	-0.35***	0.93***												
Moderately labile Pi	0.33**	-0.48***	0.64***	0.45***	0.65***	-0.47***	-0.40***	0.49***	0.07	0.08	-0.11	0.09	-0.47***	0.50***	0.57***											
Mineral P	0.37***	-0.21*	0.51***	0.36***	0.39***	-0.36***	-0.35***	0.35***	0.33**	0.16	-0.12	-0.10	0.31**	-0.01	0.03	0.25*										
(log) Microbial P conc	0.08	-0.03	0.01	0.01	0.10	0.01	0.05	-0.04	-0.19	-0.08	0.08	0.02	-0.26**	0.65***	0.61***	0.27**	-0.02									
Microbial P stocks	0.24*	-0.11	0.11	0.06	0.18	-0.09	-0.07	-0.03	-0.15	-0.10	0.07	0.13	-0.26*	0.37***	0.46***	0.23*	0.03	0.89***								
Microbial P exploitation	-0.35***	0.46***	-0.55***	-0.45***	-0.47***	0.41***	0.53***	-0.44***	-0.16	-0.18	0.23*	-0.12	0.35***	-0.07	-0.16	-0.62***	-0.19	0.29**	0.28**							
Total P exploitation	-0.20	0.34**	-0.45***	-0.24*	-0.36***	0.31**	0.41***	-0.21*	0.12	-0.06	0.14	-0.20	0.37***	-0.11	-0.21	-0.60***	-0.10	0.24*	0.24*	0.96***						
Nmic:Pmic	0.18	-0.19	0.36***	0.25*	0.19	-0.21*	-0.14	0.34***	0.30**	0.10	-0.10	-0.02	0.35***	0.05	0.06	0.14	0.37***	-0.52***	-0.57***	-0.44***	-0.36***					
Fungi	-0.26**	0.28**	-0.35***	-0.30**	-0.31**	0.30**	0.41***	-0.24*	-0.27**	-0.29**	0.28**	0.05	-0.03	0.45***	0.34**	-0.12	-0.10	0.32**	0.14	0.32**	0.25*	-0.10				
(log) AMF relative abundance	-0.33***	0.26**	-0.41***	-0.30**	-0.30**	0.26**	0.27**	-0.23*	-0.12	-0.06	0.11	-0.15	0.08	0.05	0.03	-0.24*	-0.36***	0.01	-0.07	0.36***	0.32**	-0.19	0.06			
AMF SR	-0.06	0.17	-0.14	-0.09	-0.13	0.00	0.07	-0.15	0.09	0.06	-0.01	-0.14	0.33***	-0.38***	-0.35***	-0.43***	-0.07	-0.25*	-0.15	0.35***	0.37***	-0.05	-0.19	0.35***		
F:B ratio	-0.43***	0.50***	-0.52***	-0.45***	-0.50***	0.38***	0.46***	-0.47***	-0.24*	-0.26**	0.28**	-0.03	0.33***	-0.41***	-0.48***	-0.57***	-0.15	-0.34***	-0.31**	0.42***	0.35***	-0.13	0.49***	0.15	0.25*	
P _{Ase}	0.17	-0.33***	0.16	0.21*	0.29**	-0.13	-0.17	0.25*	0.01	0.21*	-0.24*	0.03	-0.74***	0.47***	0.49***	0.54***	-0.27**	0.37***	0.31**	-0.30**	-0.30**	-0.27**	-0.06	0.05	-0.32**	-0.52***

Supplementary Table 3: Primers used for the identification of fungi in the biodiversity experiment and the agricultural grasslands

Primer	Sequence	Reference
Biodiversity experiment		
FR 1	5'-AICCATTCAATCGGTAIT -3	Kuramae et al., 2013 ¹
modified version of FF390	5'-CGWTAACGAACGAGACCT-3'	Kuramae et al., 2013 ¹
Agricultural grasslands		
GlomerWT0	GDWTCATTCAAATTTCTGCCCTAT	Wubet et al., 2006 ²
Glomer1536	RTTGCAATGCTCTATCCCCA	Wubet et al., 2006 ²
NS31	TTGGAGGGCAAGTCTGGTGCC	Simon et al., 1992 ³
AML2	GAACCAAACAACACTTTGGTTTCC	Lee et al., 2008 ⁴

Supplementary Table 4: Goodness-of-fit statistics for conceptual and final structural equation models testing the P exploitation in the biodiversity experiment and the agricultural grasslands. Specifically, the table gives the Fisher's C test statistic, the Chi-squared test degrees of freedom (df), the significance derived from a Chi-squared distribution (P-value).

	Model	Fisher's C	<i>df</i>	<i>P</i> -value
Biodiversity experiment (N = 70)	initial	190.4	20	0.000
	final	7.1	14	0.930
Agricultural grasslands (N = 91)	initial	76.9	24	0.000
	final	12.2	12	0.432

1 Supplementary Table 5: The explained variance for each endogenous variable fitted in the final
 2 structural equation models (Table S1) for the biodiversity experiment and the agricultural
 3 grasslands. Marginal (i.e. explained by fixed effects alone) and conditional (i.e. explained by
 4 fixed effects and random effects) pseudo-R-squared values are given⁵.

Response	Biodiversity experiment		Agricultural grasslands	
	R^2_m	R^2_c	R^2_m	R^2_c
Plant species richness			0.41	0.41
C _{org} stocks	0.08	0.57	0.04	0.65
AMF species richness	0.05	0.16	0.01	0.35
Relative AMF abundance	0.02	0.02	0.11	0.11
Plant P stocks	0.37	0.40	0.45	0.48
Microbial P stocks	0.41	0.42	0.26	0.27
Total P exploitation	0.34	0.43	0.32	0.43

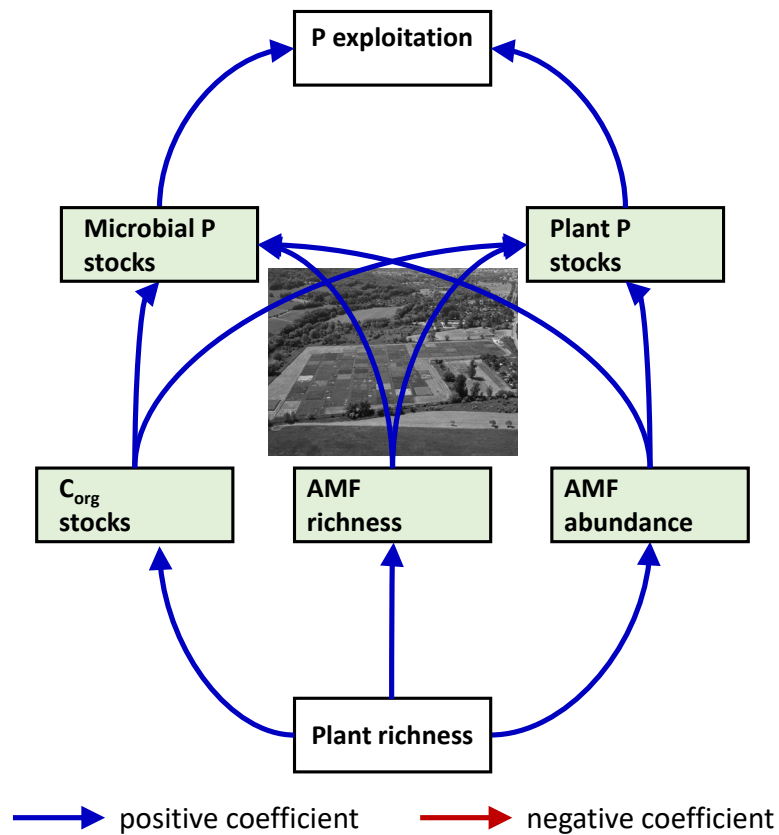
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6 Supplementary Table 6: Standardised estimates (scaled) and their respective *P* values of all
7 relations included in the final structural equation models testing the P exploitation in the
8 biodiversity experiment and in the agricultural grasslands (Fig. 1 in the main manuscript).
9 Numbers in bold indicate a significant relationship between response and predictor variable.
10 Correlated errors between variables are indicated by $\sim\sim$. They indicate that the relationship
11 between the two variables is not presumed to be causal and unidirectional.

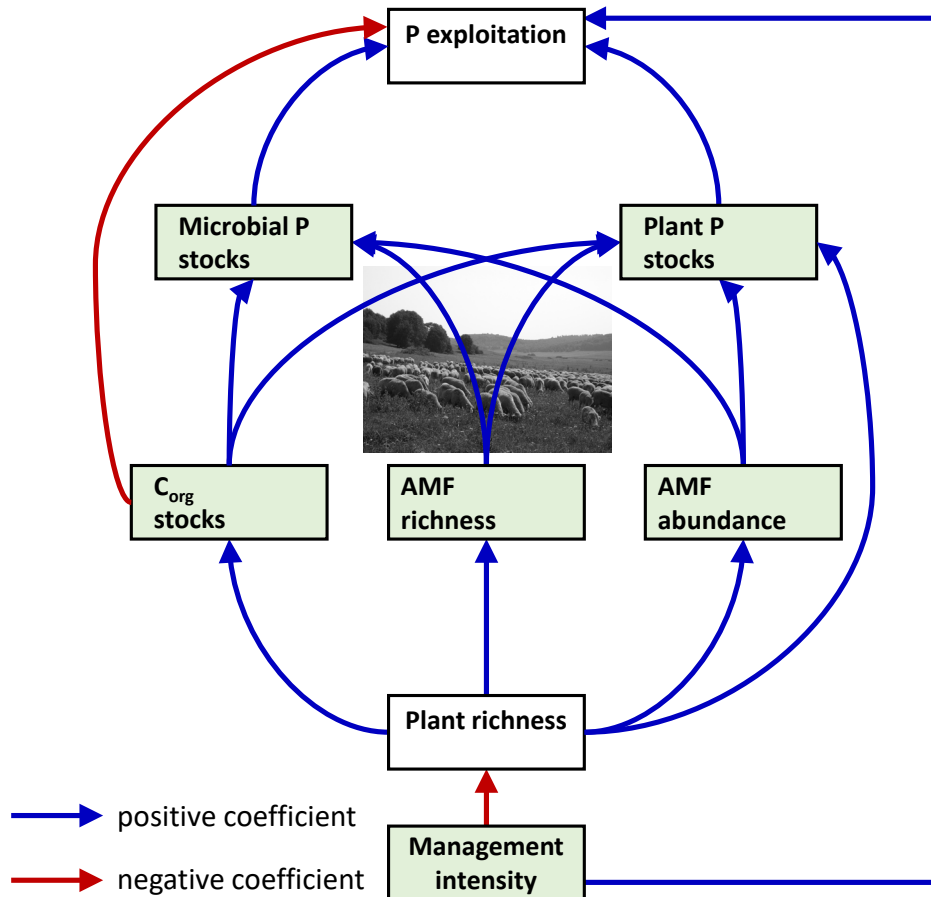
Response	Predictor	Std.estimate	<i>P</i> value
Biodiversity experiment			
(log) C_{org} stocks	(log) Plant species richness	0.293	0.001
AMF species richness	(log) Plant species richness	0.232	0.043
(log) Relative AMF abundance	(log) Plant species richness	0.133	0.272
(log) Plant P stocks	AMF species richness	-0.253	0.325
(log) Plant P stocks	(log) Relative AMF abundance	0.200	0.414
(log) Plant P stocks	(log) C _{org} stocks	0.180	0.120
(log) Plant P stocks	(log) Plant species richness	0.564	< 0.001
(log) Microbial P stocks	AMF species richness	0.023	0.920
(log) Microbial P stocks	(log) Relative AMF abundance	0.073	0.746
(log) Microbial P stocks	(log) C_{org} stocks	0.636	< 0.001
(log) Total P exploitation	(log) Microbial P stocks	0.703	< 0.001
(log) Total P exploitation	(log) Plant P stocks	0.260	0.014
(log) Total P exploitation	(log) C_{org} stocks	-0.564	< 0.001
$\sim\sim$ (log) Relative AMF abundance	$\sim\sim$ AMF species richness	0.934	< 0.001
Agricultural grasslands			
(log) plant species richness	Land use intensity index	-0.640	< 0.001
(log) C _{org} stocks	(log) plant species richness	0.019	0.848
(log) C_{org} stocks	Land use intensity index	0.241	0.017
AMF species richness	(log) plant species richness	0.107	0.259
(log) AMF relative abundance	(log) plant species richness	0.061	0.642
(log) AMF relative abundance	Land use intensity index	-0.291	0.029
Plant P stocks	AMF species richness	-0.061	0.533
Plant P stocks	(log) AMF relative abundance	0.020	0.828
Plant P stocks	(log) C _{org} stocks	0.018	0.873
Plant P stocks	Land use intensity index	0.451	< 0.001
Plant P stocks	(log) Microbial P stocks	-0.205	0.028
Plant P stocks	(log) plant species richness	-0.308	0.004
(log) Microbial P stocks	AMF species richness	0.057	0.603
(log) Microbial P stocks	(log) AMF relative abundance	-0.061	0.547
(log) Microbial P stocks	(log) C_{org} stocks	0.544	< 0.001

(log) Total P exploitation	(log) Microbial P stocks	0.524	< 0.001
(log) Total P exploitation	Plant P stocks	0.107	0.362
(log) Total P exploitation	Land use intensity index	-0.035	0.785
(log) Total P exploitation	(log) AMF relative abundance	0.308	0.001
(log) Total P exploitation	(log) C_{org} stocks	-0.283	0.027
(log) Total P exploitation	(log) plant species richness	0.248	0.035
~~(log) AMF relative abundance	~~AMF species richness	0.452	< 0.001

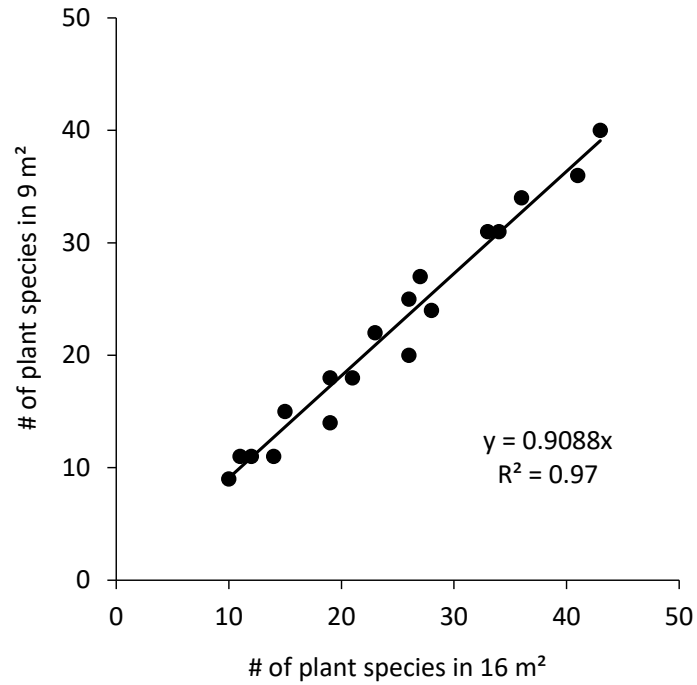
13 Supplementary Figure 1: Hypothesis model biodiversity experiment. Blue arrows display
14 relationships with positive slopes. Expectations according to the hypotheses can be found in
15 Table S1. The SEM did not match with the data: Fisher's C = 190.44, $p = 0$, $df = 20$. P =
16 phosphorus, C_{org} = organic carbon. Photo credit: The Jena Experiment.



17 Supplementary Figure 2: Hypothesis model agricultural grasslands according to the final model
 18 for the biodiversity experiment. Blue and red arrows display relationships with positive and
 19 negative slopes, respectively. Expectations according to the hypotheses can be found in Table
 20 S1. Round-shaped paths refer to the (driving) role of biodiversity while square paths indicate
 21 the role of management. The SEM did not match with the data: Fisher's C = 76.88, $p = 0$, $df =$
 22 24. P = phosphorus, C_{org} = organic carbon. Photo credit: Jörg Hailer.



23 Supplementary Figure 3: Regression of the number of plant species in a 9-m² plot on the
24 number of plant species in a 16-m² plot assessed in a survey of nested subplots of selected
25 plots in agricultural grasslands ($n = 18$). The slope of the regression was used as a factor to
26 downscale plant species richness in agricultural grasslands according to the area used for
27 the assessment of plant species richness in the biodiversity experiment.



Supplementary Reference

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