Climate change and cropland management compromise soil integrity and multifunctionality

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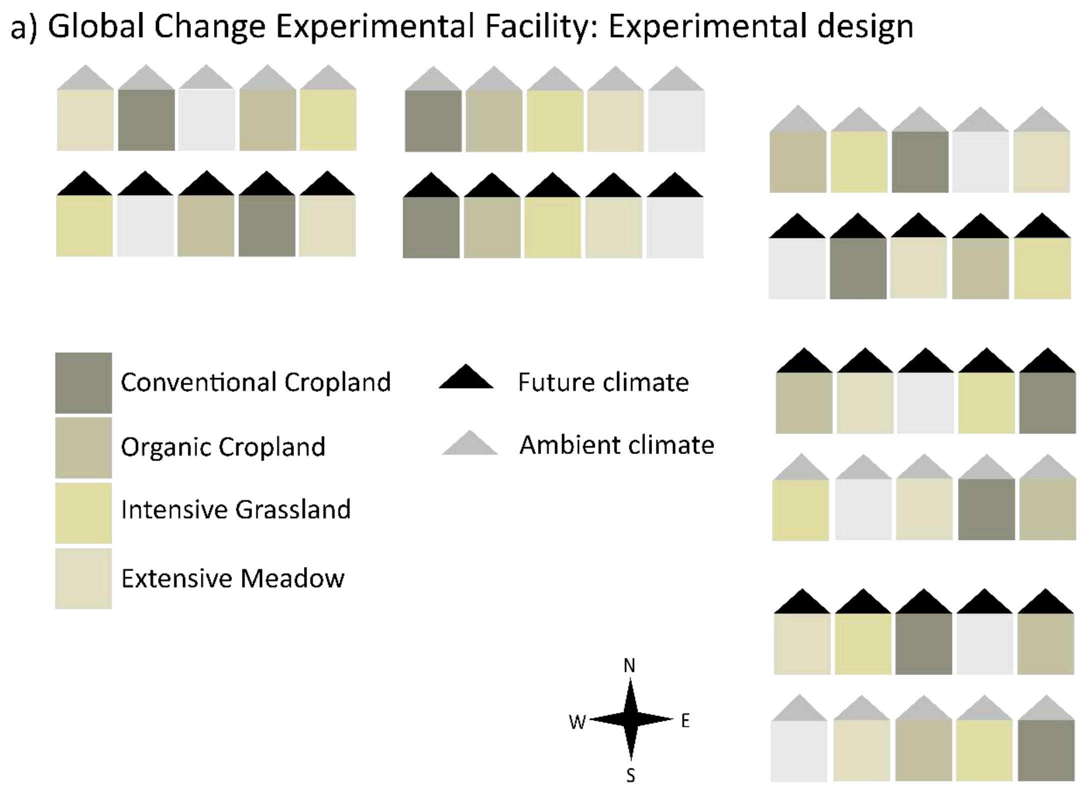
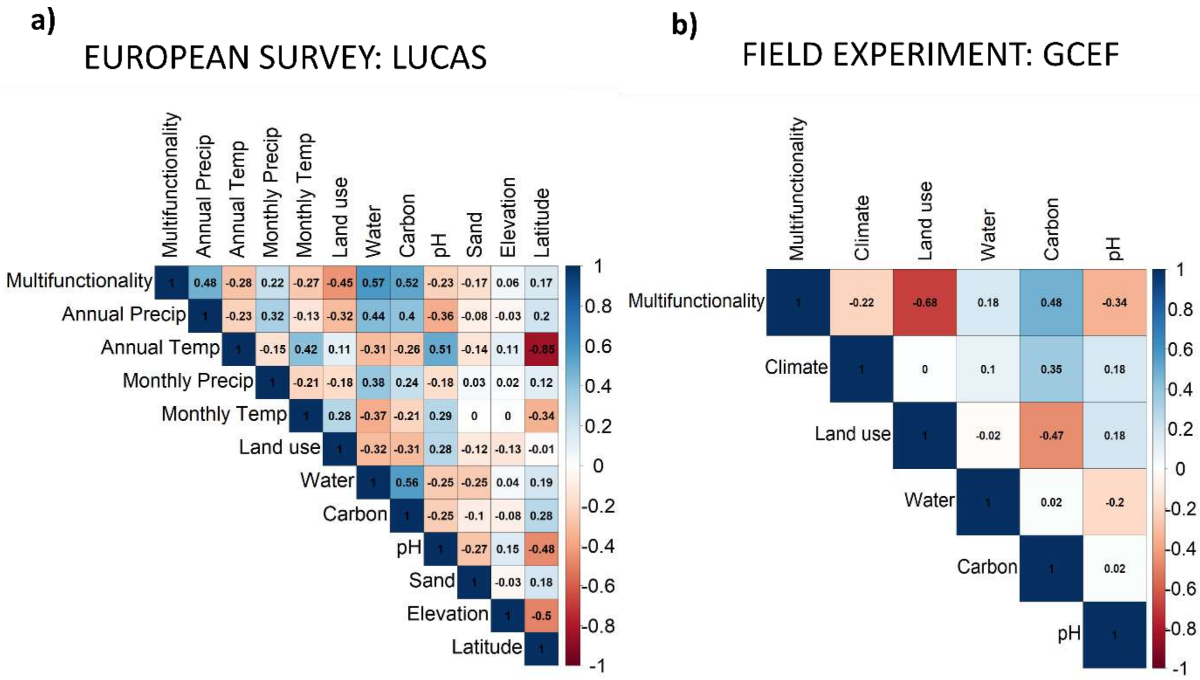


b) Treatments

Conventional Crop	Organic Cropland	Intensive Grassland	Extensive Meadow
3-year crop rotation	6-year crop rotation	5 grass species/cultivars	56 species
2014 Rapeseed	2014 Alfalfa	-Early season *L. perenne*	-Grasses
2015 Wheat	2015 Wheat	-Mid season *L. perenne*	-Forbs
2016 Barley	2016 Barley	-"Festulolium"	-Legumes
2017 Rapeseed	2017 White Clover	-*Dactylis glomerata*	
2018 Wheat	2018 Wheat	-*Poa pratensis*	Mown 2x per year
2019 Barley	2019 Barley		(May/June, August)
		Mown 4x per year	No fertilization
Fertilization with NPK	Fertilization with PK	(May, June, August,	
Herbicides, fungicides,	No herbicides	October)	
Insecticides	Reduced pesticide use	Fertilization with NPK	

Supplementary Figure 1 *a) Layout of the Global Change Experimental Facility in Bad Lauchstädt, Saxony Anhalt, Germany, (b) management practices of land use systems used in the present study. Light grey plots were not sampled for this study.*



Supplementary Figure 2 *a) Correlation matrix of all variables used in the SEM a) in the observational survey (LUCAS) and b) in the field experiment (GCEF).*

Supplementary Methods

Observational Study: LUCAS Soil Multifunctionality - Averaging Approach

Calculated with the averaging approach, which represents the average value of standardized functions.

```
##        LC_4   n
## 1  Cropland 313
## 2 Grassland 143
```

Model structure - without interaction

Annual precipitation is the annual precipitation sum, monthly precipitation is the precipitation sum before sampling. Annual temperature is the mean annual temperature, monthly temperature the mean temperature in the month before sampling.

Here modeled without interaction of climate variables and land use.

```
lucas.sem <- psem(
  lm(Soil.pH ~ Soil.water + Annual.temp + Annual.precip +
       Landuse + Elevation + Latitude + Soil.texture, data = df),
  lm(Soil.water ~ Monthly.temp + Annual.temp + Landuse + Monthly.precip +
       Annual.precip + Elevation + Latitude + Soil.texture, data = df),
  lm(Soil.carbon ~ Soil.water + Monthly.temp + Annual.temp + Monthly.precip +
       Annual.precip + Landuse  + Elevation + Latitude + Soil.texture +
       Soil.pH, data = df),
  lm(Multifunctionality ~ Soil.water + Monthly.temp + Landuse + Annual.temp +
       Monthly.precip + Annual.precip + Elevation + Latitude  + Soil.texture +
       Soil.carbon + Soil.pH, data = df)
)
```

Supplementary Table 1: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality.

Fisher.C	df	P.Value
3.479	4	0.481

Supplementary Table 2: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.0531	0.0585	0.2449
Soil.pH	Annual.temp	0.3760	0.0972	0.0001
Soil.pH	Annual.precip	-0.2269	0.0501	0.0000
Soil.pH	Landuse	0.1348	0.0870	0.0011

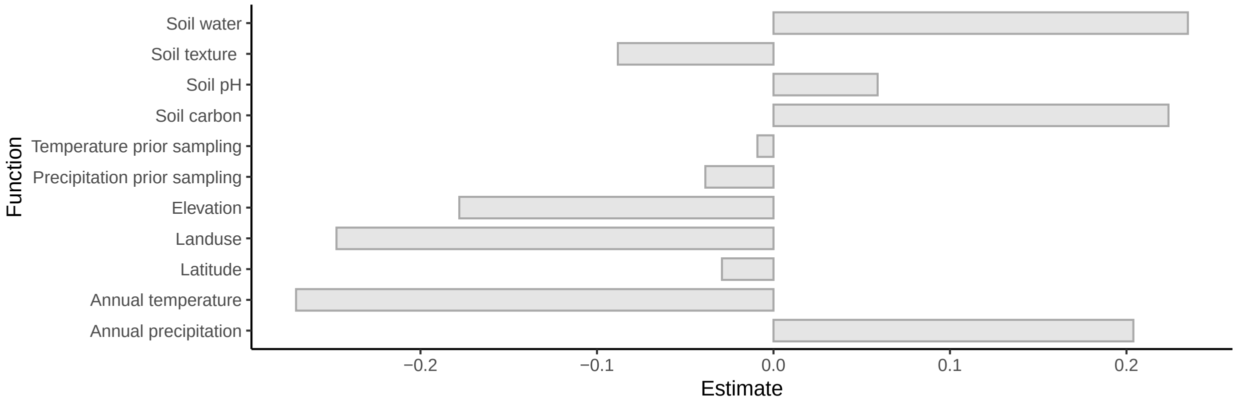
(continued)

Response	Predictor	Estimate	SE	p-value
Soil.pH	Elevation	0.1084	0.0702	0.0583
Soil.pH	Latitude	-0.0042	0.1103	0.9691
Soil.pH	Soil.texture	-0.2301	0.0274	0.0000
Soil.water	Monthly.temp	-0.1747	0.0350	0.0000
Soil.water	Annual.temp	-0.3962	0.0727	0.0000
Soil.water	Landuse	-0.1527	0.0665	0.0002
Soil.water	Monthly.precip	0.2273	0.0347	0.0000
Soil.water	Annual.precip	0.2349	0.0375	0.0000
Soil.water	Elevation	-0.0802	0.0532	0.1498
Soil.water	Latitude	-0.2766	0.0833	0.0093
Soil.water	Soil.texture	-0.2650	0.0199	0.0000
Soil.carbon	Soil.water	0.4780	0.0249	0.0000
Soil.carbon	Monthly.temp	0.0577	0.0188	0.1842
Soil.carbon	Annual.temp	0.3613	0.0396	0.0003
Soil.carbon	Monthly.precip	-0.0229	0.0190	0.5764
Soil.carbon	Annual.precip	0.1279	0.0212	0.0044
Soil.carbon	Landuse	-0.1598	0.0359	0.0002
Soil.carbon	Elevation	0.1222	0.0282	0.0347
Soil.carbon	Latitude	0.5574	0.0442	0.0000
Soil.carbon	Soil.texture	-0.0336	0.0114	0.4258
Soil.carbon	Soil.pH	-0.0023	0.0189	0.9620
Multifunctionality	Soil.water	0.2348	0.0544	0.0000
Multifunctionality	Monthly.temp	-0.0091	0.0373	0.8201
Multifunctionality	Landuse	-0.2476	0.0722	0.0000
Multifunctionality	Annual.temp	-0.2705	0.0796	0.0035
Multifunctionality	Monthly.precip	-0.0386	0.0375	0.3044
Multifunctionality	Annual.precip	0.2039	0.0423	0.0000
Multifunctionality	Elevation	-0.0292	0.0561	0.5830
Multifunctionality	Latitude	-0.1780	0.0900	0.0873
Multifunctionality	Soil.texture	-0.0882	0.0226	0.0233
Multifunctionality	Soil.carbon	0.2238	0.0938	0.0000
Multifunctionality	Soil.pH	0.0590	0.0374	0.1757

Supplementary Table 3: Direct, indirect, and net effect for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality.

Explanatory.variable	Direct.effect	Indirect.effect	Net effect
Climate MAT	-0.20	-0.12	-0.32
Climate Monthly mean temperature	0.00	-0.05	-0.05
Climate MAP	0.22	0.10	0.32
Climate Monthly precipitation	0.00	0.00	0.00
Space	0.00	0.00	0.00
Texture	-0.07	-0.08	-0.15
Land use intensity	-0.24	-0.10	-0.34
pH	0.00	0.00	0.00
Soil water	0.44	0.00	0.44
Soil carbon	0.00	0.00	0.00

Supplementary Figure 3: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on soil multifunctionality.



Model structure - with interaction

With interaction of climate variables and land use. This model was not used in the final analysis, as we observed no interactive effects between climate and land use.

```
lucas.sem.interaction <- psem(
  lm(Soil.pH ~ Soil.water + Annual.temp * Landuse +
       Annual.precip * Landuse + Elevation + Latitude +
       Soil.texture, data = df),
  lm(Soil.water ~ Monthly.temp + Annual.temp * Landuse +
       Monthly.precip + Annual.precip * Landuse + Elevation +
       Latitude + Soil.texture, data = df),
  lm(Soil.carbon ~ Soil.water + Monthly.temp + Annual.temp * Landuse +
       Monthly.precip + Annual.precip * Landuse  + Elevation +
       Latitude + Soil.texture + Soil.pH, data = df),
  lm(Multifunctionality ~ Soil.water + Monthly.temp * Landuse +
       Annual.temp * Landuse + Monthly.precip * Landuse +
       Annual.precip * Landuse + Elevation + Latitude  + Soil.texture +
       Soil.carbon + Soil.pH, data = df)
)
```

Supplementary Table 4: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality.

Fisher.C	df	P.Value
3.833	4	0.429

Supplementary Table 5: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.0439	0.0596	0.3458
Soil.pH	Annual.temp	0.3403	0.1142	0.0029
Soil.pH	Landuse	0.1363	0.0870	0.0009
Soil.pH	Annual.precip	-0.2861	0.0733	0.0000
Soil.pH	Elevation	0.1169	0.0712	0.0444
Soil.pH	Latitude	0.0106	0.1108	0.9234
Soil.pH	Soil.texture	-0.2239	0.0275	0.0000
Soil.pH	Annual.temp:Landuse	0.0636	0.0865	0.3867
Soil.pH	Landuse:Annual.precip	0.0770	0.0965	0.1811
Soil.water	Monthly.temp	-0.1922	0.0340	0.0000
Soil.water	Annual.temp	-0.5381	0.0824	0.0000
Soil.water	Landuse	-0.1384	0.0646	0.0004
Soil.water	Monthly.precip	0.2424	0.0339	0.0000
Soil.water	Annual.precip	0.4196	0.0515	0.0000
Soil.water	Elevation	-0.1313	0.0524	0.0168
Soil.water	Latitude	-0.3046	0.0811	0.0033
Soil.water	Soil.texture	-0.2569	0.0194	0.0000
Soil.water	Annual.temp:Landuse	0.1385	0.0640	0.0473
Soil.water	Landuse:Annual.precip	-0.2540	0.0699	0.0000

(continued)

Response	Predictor	Estimate	SE	p-value
Soil.carbon	Soil.water	0.4502	0.0256	0.0000
Soil.carbon	Monthly.temp	0.0456	0.0188	0.2947
Soil.carbon	Annual.temp	0.3811	0.0461	0.0010
Soil.carbon	Landuse	-0.1610	0.0357	0.0002
Soil.carbon	Monthly.precip	-0.0164	0.0191	0.6899
Soil.carbon	Annual.precip	0.2601	0.0303	0.0001
Soil.carbon	Elevation	0.0968	0.0285	0.0983
Soil.carbon	Latitude	0.5246	0.0441	0.0000
Soil.carbon	Soil.texture	-0.0423	0.0114	0.3148
Soil.carbon	Soil.pH	0.0080	0.0188	0.8663
Soil.carbon	Annual.temp:Landuse	-0.0707	0.0346	0.3391
Soil.carbon	Landuse:Annual.precip	-0.1667	0.0387	0.0042
Multifunctionality	Soil.water	0.2251	0.0554	0.0000
Multifunctionality	Monthly.temp	0.0471	0.0620	0.4780
Multifunctionality	Landuse	-0.2550	0.0728	0.0000
Multifunctionality	Annual.temp	-0.3217	0.0936	0.0032
Multifunctionality	Monthly.precip	0.0449	0.0619	0.4686
Multifunctionality	Annual.precip	0.2065	0.0629	0.0009
Multifunctionality	Elevation	-0.0350	0.0575	0.5216
Multifunctionality	Latitude	-0.1773	0.0903	0.0898
Multifunctionality	Soil.texture	-0.0873	0.0229	0.0263
Multifunctionality	Soil.carbon	0.2223	0.0948	0.0000
Multifunctionality	Soil.pH	0.0583	0.0375	0.1826
Multifunctionality	Monthly.temp:Landuse	-0.0810	0.0763	0.2128
Multifunctionality	Landuse:Annual.temp	0.0590	0.0731	0.4146
Multifunctionality	Landuse:Monthly.precip	-0.1027	0.0761	0.0927
Multifunctionality	Landuse:Annual.precip	-0.0074	0.0806	0.8948

Soil Multifunctionality - Threshold Approach

Calculated with the threshold approach, representing functions that exceed a threshold of 0.6.

```
lucas.sem.thres <- psem(
  lm(Soil.pH ~ Soil.water + Annual.temp + Annual.precip +
       Landuse + Elevation + Latitude + Soil.texture, data = df),
  lm(Soil.water ~ Monthly.temp + Annual.temp + Landuse +
       Monthly.precip + Annual.precip + Elevation + Latitude +
       Soil.texture, data = df),
  lm(Soil.carbon ~ Soil.water + Monthly.temp + Annual.temp +
       Monthly.precip + Annual.precip + Landuse  + Elevation +
       Latitude + Soil.texture + Soil.pH, data = df),
  lm(Multifunc.thres ~ Soil.water + Monthly.temp + Landuse +
       Annual.temp + Monthly.precip + Annual.precip + Elevation +
     Latitude  + Soil.texture + Soil.carbon + Soil.pH, data = df)
)
```

Supplementary Table 6: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality.

Fisher.C	df	P.Value
3.479	4	0.481

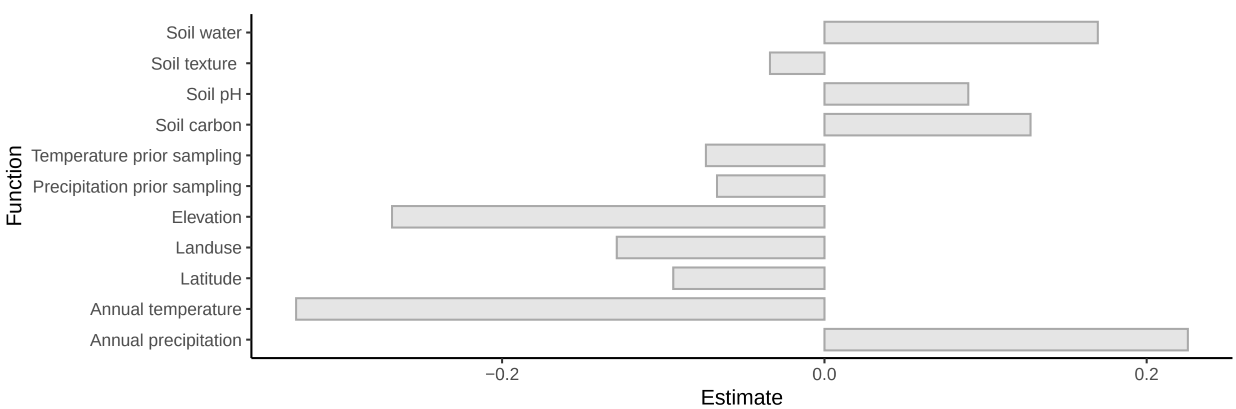
Supplementary Table 7: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.0531	0.0585	0.2449
Soil.pH	Annual.temp	0.3760	0.0972	0.0001
Soil.pH	Annual.precip	-0.2269	0.0501	0.0000
Soil.pH	Landuse	0.1348	0.0870	0.0011
Soil.pH	Elevation	0.1084	0.0702	0.0583
Soil.pH	Latitude	-0.0042	0.1103	0.9691
Soil.pH	Soil.texture	-0.2301	0.0274	0.0000
Soil.water	Monthly.temp	-0.1747	0.0350	0.0000
Soil.water	Annual.temp	-0.3962	0.0727	0.0000
Soil.water	Landuse	-0.1527	0.0665	0.0002
Soil.water	Monthly.precip	0.2273	0.0347	0.0000
Soil.water	Annual.precip	0.2349	0.0375	0.0000
Soil.water	Elevation	-0.0802	0.0532	0.1498
Soil.water	Latitude	-0.2766	0.0833	0.0093
Soil.water	Soil.texture	-0.2650	0.0199	0.0000
Soil.carbon	Soil.water	0.4780	0.0249	0.0000
Soil.carbon	Monthly.temp	0.0577	0.0188	0.1842
Soil.carbon	Annual.temp	0.3613	0.0396	0.0003
Soil.carbon	Monthly.precip	-0.0229	0.0190	0.5764
Soil.carbon	Annual.precip	0.1279	0.0212	0.0044
Soil.carbon	Landuse	-0.1598	0.0359	0.0002
Soil.carbon	Elevation	0.1222	0.0282	0.0347

(continued)

Response	Predictor	Estimate	SE	p-value
Soil.carbon	Latitude	0.5574	0.0442	0.0000
Soil.carbon	Soil.texture	-0.0336	0.0114	0.4258
Soil.carbon	Soil.pH	-0.0023	0.0189	0.9620
Multifunc.thres	Soil.water	0.1697	0.0685	0.0046
Multifunc.thres	Monthly.temp	-0.0737	0.0470	0.1259
Multifunc.thres	Landuse	-0.1290	0.0909	0.0070
Multifunc.thres	Annual.temp	-0.3280	0.1003	0.0033
Multifunc.thres	Monthly.precip	-0.0666	0.0473	0.1419
Multifunc.thres	Annual.precip	0.2256	0.0533	0.0000
Multifunc.thres	Elevation	-0.0938	0.0706	0.1443
Multifunc.thres	Latitude	-0.2685	0.1133	0.0326
Multifunc.thres	Soil.texture	-0.0338	0.0285	0.4696
Multifunc.thres	Soil.carbon	0.1279	0.1182	0.0150
Multifunc.thres	Soil.pH	0.0893	0.0471	0.0894

Supplementary Figure 5: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on soil multifunctionality.



SEM with Soil Microbial Respiration

```
lucas.sem <- psem(
  lm(Soil.pH ~ Soil.water + Annual.temp + Annual.precip +
       Landuse + Elevation + Latitude + Soil.texture, data = df),
  lm(Soil.water ~ Monthly.temp + Annual.temp + Landuse +
       Monthly.precip + Annual.precip + Elevation + Latitude +
       Soil.texture, data = df),
  lm(Soil.carbon ~ Soil.water + Monthly.temp + Annual.temp +
       Monthly.precip + Annual.precip + Landuse  + Elevation +
       Latitude + Soil.texture + Soil.pH, data = df),
  lm(Mic.respi ~ Soil.water + Monthly.temp + Landuse + Annual.temp +
       Monthly.precip + Annual.precip + Elevation + Latitude  +
       Soil.texture + Soil.carbon + Soil.pH, data = df)
)
```

Supplementary Table 8: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil microbial respiration.

Fisher.C	df	P.Value
3.479	4	0.481

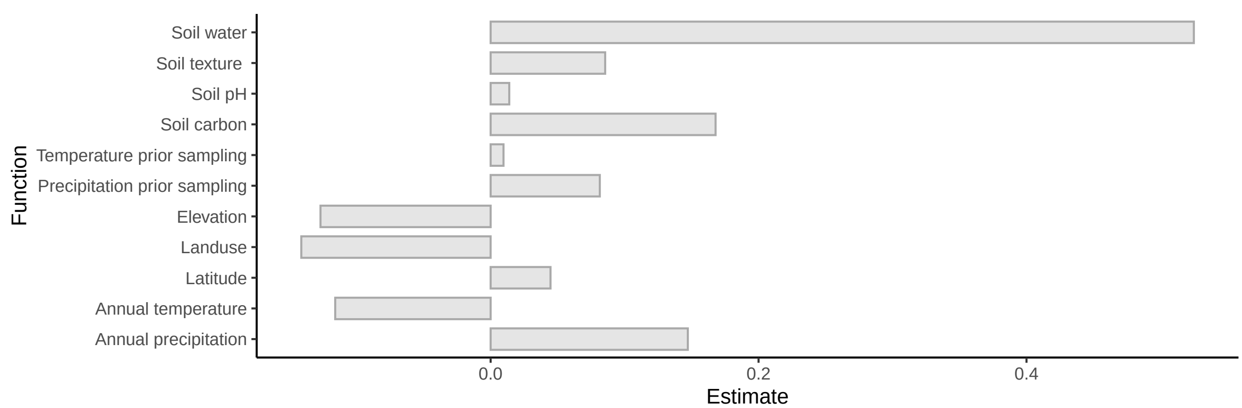
Supplementary Table 9: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil microbial respiration.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.0531	0.0585	0.2449
Soil.pH	Annual.temp	0.3760	0.0972	0.0001
Soil.pH	Annual.precip	-0.2269	0.0501	0.0000
Soil.pH	Landuse	0.1348	0.0870	0.0011
Soil.pH	Elevation	0.1084	0.0702	0.0583
Soil.pH	Latitude	-0.0042	0.1103	0.9691
Soil.pH	Soil.texture	-0.2301	0.0274	0.0000
Soil.water	Monthly.temp	-0.1747	0.0350	0.0000
Soil.water	Annual.temp	-0.3962	0.0727	0.0000
Soil.water	Landuse	-0.1527	0.0665	0.0002
Soil.water	Monthly.precip	0.2273	0.0347	0.0000
Soil.water	Annual.precip	0.2349	0.0375	0.0000
Soil.water	Elevation	-0.0802	0.0532	0.1498
Soil.water	Latitude	-0.2766	0.0833	0.0093
Soil.water	Soil.texture	-0.2650	0.0199	0.0000
Soil.carbon	Soil.water	0.4780	0.0249	0.0000
Soil.carbon	Monthly.temp	0.0577	0.0188	0.1842
Soil.carbon	Annual.temp	0.3613	0.0396	0.0003
Soil.carbon	Monthly.precip	-0.0229	0.0190	0.5764
Soil.carbon	Annual.precip	0.1279	0.0212	0.0044
Soil.carbon	Landuse	-0.1598	0.0359	0.0002
Soil.carbon	Elevation	0.1222	0.0282	0.0347
Soil.carbon	Latitude	0.5574	0.0442	0.0000
Soil.carbon	Soil.texture	-0.0336	0.0114	0.4258

(continued)

Response	Predictor	Estimate	SE	p-value
Soil.carbon	Soil.pH	-0.0023	0.0189	0.9620
Mic.respi	Soil.water	0.5249	0.0351	0.0000
Mic.respi	Monthly.temp	0.0096	0.0241	0.7710
Mic.respi	Landuse	-0.1413	0.0465	0.0000
Mic.respi	Annual.temp	-0.1160	0.0513	0.1281
Mic.respi	Monthly.precip	0.0815	0.0242	0.0088
Mic.respi	Annual.precip	0.1472	0.0273	0.0000
Mic.respi	Elevation	0.0447	0.0362	0.3086
Mic.respi	Latitude	-0.1270	0.0580	0.1391
Mic.respi	Soil.texture	0.0855	0.0146	0.0077
Mic.respi	Soil.carbon	0.1679	0.0605	0.0000
Mic.respi	Soil.pH	0.0139	0.0241	0.6986

Supplementary Figure 6: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on soil microbial respiration.



SEM with Soil Microbial Biomass

```
lucas.sem <- psem(
  lm(Soil.pH ~ Soil.water + Annual.temp + Annual.precip +
       Landuse + Elevation + Latitude + Soil.texture, data = df),
  lm(Soil.water ~ Monthly.temp + Annual.temp + Landuse + Monthly.precip +
       Annual.precip + Elevation + Latitude + Soil.texture, data = df),
  lm(Soil.carbon ~ Soil.water + Monthly.temp + Annual.temp + Monthly.precip +
       Annual.precip + Landuse  + Elevation + Latitude + Soil.texture +
       Soil.pH, data = df),
  lm(Mic.biomass ~ Soil.water + Monthly.temp + Landuse + Annual.temp +
       Monthly.precip + Annual.precip + Elevation + Latitude  +
       Soil.texture + Soil.carbon + Soil.pH, data = df)
)
```

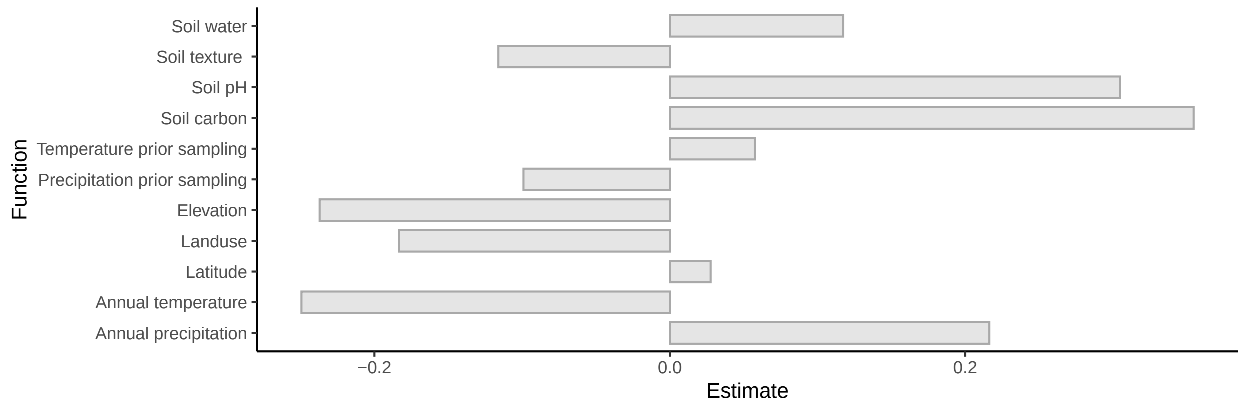
Supplementary Table 10: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil microbial biomass.

Fisher.C	df	P.Value
3.479	4	0.481

Supplementary Table 11: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil microbial biomass.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.0531	0.0585	0.2449
Soil.pH	Annual.temp	0.3760	0.0972	0.0001
Soil.pH	Annual.precip	-0.2269	0.0501	0.0000
Soil.pH	Landuse	0.1348	0.0870	0.0011
Soil.pH	Elevation	0.1084	0.0702	0.0583
Soil.pH	Latitude	-0.0042	0.1103	0.9691
Soil.pH	Soil.texture	-0.2301	0.0274	0.0000
Soil.water	Monthly.temp	-0.1747	0.0350	0.0000
Soil.water	Annual.temp	-0.3962	0.0727	0.0000
Soil.water	Landuse	-0.1527	0.0665	0.0002
Soil.water	Monthly.precip	0.2273	0.0347	0.0000
Soil.water	Annual.precip	0.2349	0.0375	0.0000
Soil.water	Elevation	-0.0802	0.0532	0.1498
Soil.water	Latitude	-0.2766	0.0833	0.0093
Soil.water	Soil.texture	-0.2650	0.0199	0.0000
Soil.carbon	Soil.water	0.4780	0.0249	0.0000
Soil.carbon	Monthly.temp	0.0577	0.0188	0.1842
Soil.carbon	Annual.temp	0.3613	0.0396	0.0003
Soil.carbon	Monthly.precip	-0.0229	0.0190	0.5764
Soil.carbon	Annual.precip	0.1279	0.0212	0.0044
Soil.carbon	Landuse	-0.1598	0.0359	0.0002
Soil.carbon	Elevation	0.1222	0.0282	0.0347
Soil.carbon	Latitude	0.5574	0.0442	0.0000
Soil.carbon	Soil.texture	-0.0336	0.0114	0.4258
Soil.carbon	Soil.pH	-0.0023	0.0189	0.9620
Mic.biomass	Soil.water	0.1174	0.0617	0.0276
Mic.biomass	Monthly.temp	0.0575	0.0423	0.1806
Mic.biomass	Landuse	-0.1833	0.0819	0.0000
Mic.biomass	Annual.temp	-0.2494	0.0903	0.0123
Mic.biomass	Monthly.precip	-0.0991	0.0426	0.0145
Mic.biomass	Annual.precip	0.2163	0.0480	0.0000
Mic.biomass	Elevation	0.0276	0.0636	0.6297
Mic.biomass	Latitude	-0.2371	0.1021	0.0344
Mic.biomass	Soil.texture	-0.1161	0.0257	0.0056
Mic.biomass	Soil.carbon	0.3546	0.1064	0.0000
Mic.biomass	Soil.pH	0.3049	0.0424	0.0000

Supplementary Figure 7: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on soil microbial biomass.



SEM with N-Acetylglucosaminidase Activity

```
lucas.sem <- psem(
  lm(Soil.pH ~ Soil.water + Annual.temp + Annual.precip +
       Landuse + Elevation + Latitude + Soil.texture, data = df),
  lm(Soil.water ~ Monthly.temp + Annual.temp + Landuse + Monthly.precip +
       Annual.precip + Elevation + Latitude + Soil.texture, data = df),
  lm(Soil.carbon ~ Soil.water + Monthly.temp + Annual.temp + Monthly.precip +
       Annual.precip + Landuse  + Elevation + Latitude + Soil.texture + Soil.pH,
    data = df),
  lm(Glucosaminidase ~ Soil.water + Monthly.temp + Landuse + Annual.temp +
       Monthly.precip + Annual.precip + Elevation + Latitude  + Soil.texture +
       Soil.carbon + Soil.pH, data = df)
)
```

Supplementary Table 12: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on N-acetylglucosaminidase activity.

Fisher.C	df	P.Value
3.479	4	0.481

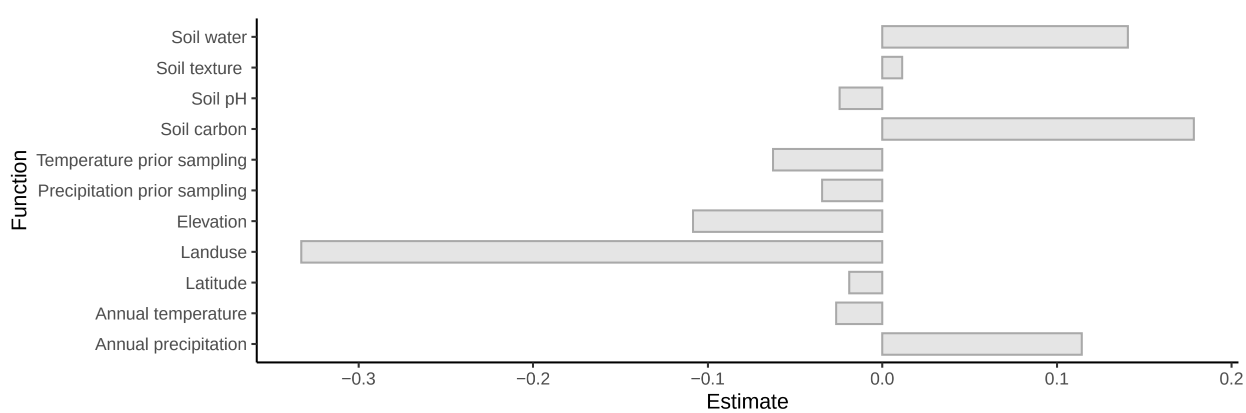
Supplementary Table 13: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on N-acetylglucosaminidase activity.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.0531	0.0585	0.2449
Soil.pH	Annual.temp	0.3760	0.0972	0.0001
Soil.pH	Annual.precip	-0.2269	0.0501	0.0000
Soil.pH	Landuse	0.1348	0.0870	0.0011

(continued)

Response	Predictor	Estimate	SE	p-value
Soil.pH	Elevation	0.1084	0.0702	0.0583
Soil.pH	Latitude	-0.0042	0.1103	0.9691
Soil.pH	Soil.texture	-0.2301	0.0274	0.0000
Soil.water	Monthly.temp	-0.1747	0.0350	0.0000
Soil.water	Annual.temp	-0.3962	0.0727	0.0000
Soil.water	Landuse	-0.1527	0.0665	0.0002
Soil.water	Monthly.precip	0.2273	0.0347	0.0000
Soil.water	Annual.precip	0.2349	0.0375	0.0000
Soil.water	Elevation	-0.0802	0.0532	0.1498
Soil.water	Latitude	-0.2766	0.0833	0.0093
Soil.water	Soil.texture	-0.2650	0.0199	0.0000
Soil.carbon	Soil.water	0.4780	0.0249	0.0000
Soil.carbon	Monthly.temp	0.0577	0.0188	0.1842
Soil.carbon	Annual.temp	0.3613	0.0396	0.0003
Soil.carbon	Monthly.precip	-0.0229	0.0190	0.5764
Soil.carbon	Annual.precip	0.1279	0.0212	0.0044
Soil.carbon	Landuse	-0.1598	0.0359	0.0002
Soil.carbon	Elevation	0.1222	0.0282	0.0347
Soil.carbon	Latitude	0.5574	0.0442	0.0000
Soil.carbon	Soil.texture	-0.0336	0.0114	0.4258
Soil.carbon	Soil.pH	-0.0023	0.0189	0.9620
Glucosaminidase	Soil.water	0.1406	0.0620	0.0139
Glucosaminidase	Monthly.temp	-0.0627	0.0425	0.1730
Glucosaminidase	Landuse	-0.3328	0.0822	0.0000
Glucosaminidase	Annual.temp	-0.0264	0.0907	0.8038
Glucosaminidase	Monthly.precip	-0.0345	0.0428	0.4254
Glucosaminidase	Annual.precip	0.1142	0.0482	0.0169
Glucosaminidase	Elevation	-0.0189	0.0639	0.7575
Glucosaminidase	Latitude	-0.1085	0.1025	0.3649
Glucosaminidase	Soil.texture	0.0114	0.0258	0.7992
Glucosaminidase	Soil.carbon	0.1784	0.1069	0.0004
Glucosaminidase	Soil.pH	-0.0245	0.0426	0.6258

Supplementary Figure 8: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on N-acetylglucosaminidase activity.



SEM with Phosphatase Activity

```r
lucas.sem <- psem(
  lm(Soil.pH ~ Soil.water + Annual.temp + Annual.precip + Landuse + Elevation +
       Latitude + Soil.texture, data = df),
  lm(Soil.water ~ Monthly.temp + Annual.temp + Landuse + Monthly.precip +
       Annual.precip + Elevation + Latitude + Soil.texture, data = df),
  lm(Soil.carbon ~ Soil.water + Monthly.temp + Annual.temp + Monthly.precip +
       Annual.precip + Landuse  + Elevation + Latitude + Soil.texture +
       Soil.pH, data = df),
  lm(Phosphatase ~ Soil.water + Monthly.temp + Landuse + Annual.temp +
       Monthly.precip + Annual.precip + Elevation + Latitude  +
       Soil.texture + Soil.carbon + Soil.pH, data = df)
)
```

Supplementary Table 14: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on phosphatase activity.

Fisher.C	df	P.Value
3.479	4	0.481

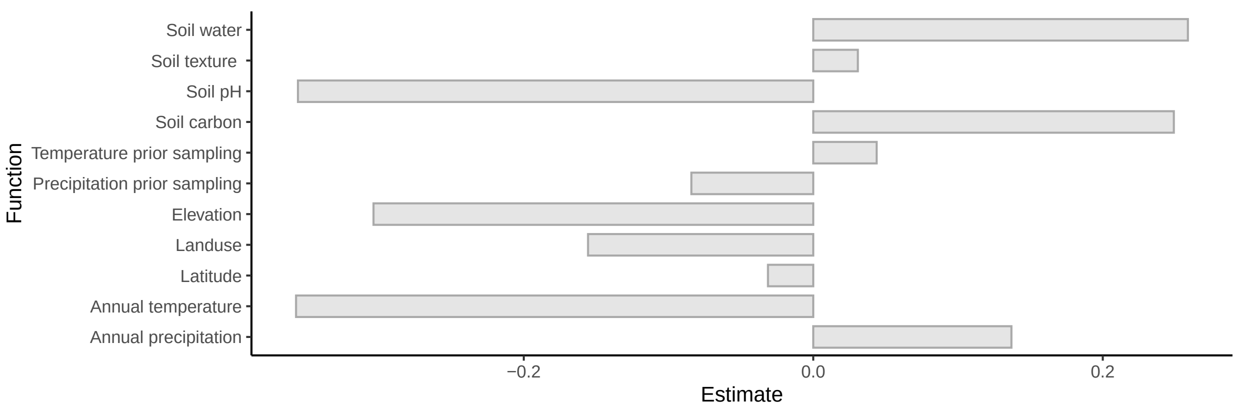
Supplementary Table 15: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on phosphatase activity.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.0531	0.0585	0.2449
Soil.pH	Annual.temp	0.3760	0.0972	0.0001
Soil.pH	Annual.precip	-0.2269	0.0501	0.0000
Soil.pH	Landuse	0.1348	0.0870	0.0011
Soil.pH	Elevation	0.1084	0.0702	0.0583
Soil.pH	Latitude	-0.0042	0.1103	0.9691
Soil.pH	Soil.texture	-0.2301	0.0274	0.0000
Soil.water	Monthly.temp	-0.1747	0.0350	0.0000
Soil.water	Annual.temp	-0.3962	0.0727	0.0000
Soil.water	Landuse	-0.1527	0.0665	0.0002
Soil.water	Monthly.precip	0.2273	0.0347	0.0000
Soil.water	Annual.precip	0.2349	0.0375	0.0000
Soil.water	Elevation	-0.0802	0.0532	0.1498
Soil.water	Latitude	-0.2766	0.0833	0.0093
Soil.water	Soil.texture	-0.2650	0.0199	0.0000
Soil.carbon	Soil.water	0.4780	0.0249	0.0000
Soil.carbon	Monthly.temp	0.0577	0.0188	0.1842
Soil.carbon	Annual.temp	0.3613	0.0396	0.0003
Soil.carbon	Monthly.precip	-0.0229	0.0190	0.5764
Soil.carbon	Annual.precip	0.1279	0.0212	0.0044
Soil.carbon	Landuse	-0.1598	0.0359	0.0002
Soil.carbon	Elevation	0.1222	0.0282	0.0347
Soil.carbon	Latitude	0.5574	0.0442	0.0000
Soil.carbon	Soil.texture	-0.0336	0.0114	0.4258
Soil.carbon	Soil.pH	-0.0023	0.0189	0.9620

(continued)

Response	Predictor	Estimate	SE	p-value
Phosphatase	Soil.water	0.2588	0.0369	0.0000
Phosphatase	Monthly.temp	0.0438	0.0253	0.1668
Phosphatase	Landuse	-0.1556	0.0489	0.0000
Phosphatase	Annual.temp	-0.3573	0.0540	0.0000
Phosphatase	Monthly.precip	-0.0842	0.0255	0.0049
Phosphatase	Annual.precip	0.1369	0.0287	0.0000
Phosphatase	Elevation	-0.0313	0.0380	0.4582
Phosphatase	Latitude	-0.3038	0.0610	0.0003
Phosphatase	Soil.texture	0.0308	0.0153	0.3162
Phosphatase	Soil.carbon	0.2491	0.0636	0.0000
Phosphatase	Soil.pH	-0.3560	0.0253	0.0000

Supplementary Figure 9: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on phosphatase activity.



SEM with Cellulase Activity

```
lucas.sem <- psem(
  lm(Soil.pH ~ Soil.water + Annual.temp + Annual.precip +
       Landuse + Elevation + Latitude + Soil.texture, data = df),
  lm(Soil.water ~ Monthly.temp + Annual.temp + Landuse + Monthly.precip +
       Annual.precip + Elevation + Latitude + Soil.texture, data = df),
  lm(Soil.carbon ~ Soil.water + Monthly.temp + Annual.temp + Monthly.precip +
       Annual.precip + Landuse  + Elevation + Latitude + Soil.texture +
       Soil.pH, data = df),
  lm(Cellulase ~ Soil.water + Monthly.temp + Landuse + Annual.temp +
       Monthly.precip + Annual.precip + Elevation + Latitude  +
       Soil.texture + Soil.carbon + Soil.pH, data = df)
)
```

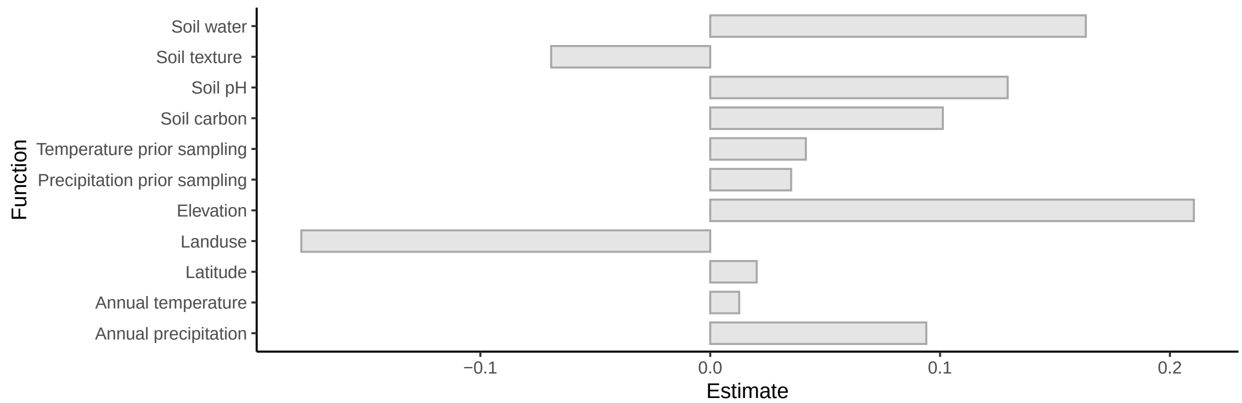
Supplementary Table 16: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on cellulase activity.

Fisher.C	df	P.Value
3.479	4	0.481

Supplementary Table 17: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on cellulase activity.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.0531	0.0585	0.2449
Soil.pH	Annual.temp	0.3760	0.0972	0.0001
Soil.pH	Annual.precip	-0.2269	0.0501	0.0000
Soil.pH	Landuse	0.1348	0.0870	0.0011
Soil.pH	Elevation	0.1084	0.0702	0.0583
Soil.pH	Latitude	-0.0042	0.1103	0.9691
Soil.pH	Soil.texture	-0.2301	0.0274	0.0000
Soil.water	Monthly.temp	-0.1747	0.0350	0.0000
Soil.water	Annual.temp	-0.3962	0.0727	0.0000
Soil.water	Landuse	-0.1527	0.0665	0.0002
Soil.water	Monthly.precip	0.2273	0.0347	0.0000
Soil.water	Annual.precip	0.2349	0.0375	0.0000
Soil.water	Elevation	-0.0802	0.0532	0.1498
Soil.water	Latitude	-0.2766	0.0833	0.0093
Soil.water	Soil.texture	-0.2650	0.0199	0.0000
Soil.carbon	Soil.water	0.4780	0.0249	0.0000
Soil.carbon	Monthly.temp	0.0577	0.0188	0.1842
Soil.carbon	Annual.temp	0.3613	0.0396	0.0003
Soil.carbon	Monthly.precip	-0.0229	0.0190	0.5764
Soil.carbon	Annual.precip	0.1279	0.0212	0.0044
Soil.carbon	Landuse	-0.1598	0.0359	0.0002
Soil.carbon	Elevation	0.1222	0.0282	0.0347
Soil.carbon	Latitude	0.5574	0.0442	0.0000
Soil.carbon	Soil.texture	-0.0336	0.0114	0.4258
Soil.carbon	Soil.pH	-0.0023	0.0189	0.9620
Cellulase	Soil.water	0.1634	0.0760	0.0098
Cellulase	Monthly.temp	0.0416	0.0521	0.4144
Cellulase	Landuse	-0.1779	0.1009	0.0005
Cellulase	Annual.temp	0.0126	0.1113	0.9149
Cellulase	Monthly.precip	0.0352	0.0525	0.4630
Cellulase	Annual.precip	0.0940	0.0591	0.0753
Cellulase	Elevation	0.0202	0.0784	0.7657
Cellulase	Latitude	0.2104	0.1258	0.1132
Cellulase	Soil.texture	-0.0692	0.0316	0.1624
Cellulase	Soil.carbon	0.1012	0.1311	0.0689
Cellulase	Soil.pH	0.1294	0.0522	0.0203

Supplementary Figure 10: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on cellulase activity.



SEM with Xylosidase Activity

```
lucas.sem <- psem(
  lm(Soil.pH ~ Soil.water + Annual.temp + Annual.precip +
       Landuse + Elevation + Latitude + Soil.texture, data = df),
  lm(Soil.water ~ Monthly.temp + Annual.temp + Landuse +
       Monthly.precip + Annual.precip + Elevation + Latitude +
       Soil.texture, data = df),
  lm(Soil.carbon ~ Soil.water + Monthly.temp + Annual.temp + Monthly.precip +
       Annual.precip + Landuse  + Elevation + Latitude + Soil.texture +
       Soil.pH, data = df),
  lm(Xylosidase ~ Soil.water + Monthly.temp + Landuse + Annual.temp +
       Monthly.precip + Annual.precip + Elevation + Latitude  + Soil.texture +
       Soil.carbon + Soil.pH, data = df)
)
```

Supplementary Table 18: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on xylosidase activity.

Fisher.C	df	P.Value
3.479	4	0.481

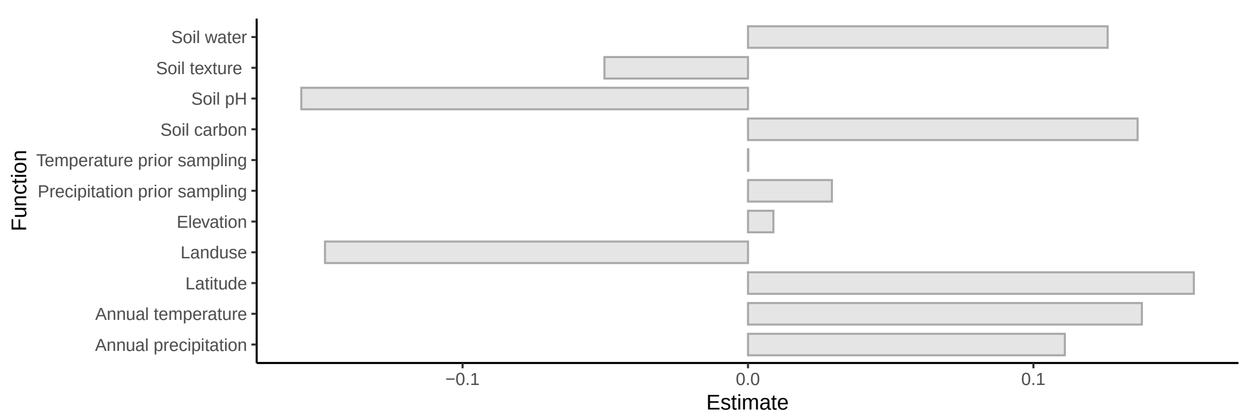
Supplementary Table 19: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on xylosidase activity.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.0531	0.0585	0.2449
Soil.pH	Annual.temp	0.3760	0.0972	0.0001

(continued)

Response	Predictor	Estimate	SE	p-value
Soil.pH	Annual.precip	-0.2269	0.0501	0.0000
Soil.pH	Landuse	0.1348	0.0870	0.0011
Soil.pH	Elevation	0.1084	0.0702	0.0583
Soil.pH	Latitude	-0.0042	0.1103	0.9691
Soil.pH	Soil.texture	-0.2301	0.0274	0.0000
Soil.water	Monthly.temp	-0.1747	0.0350	0.0000
Soil.water	Annual.temp	-0.3962	0.0727	0.0000
Soil.water	Landuse	-0.1527	0.0665	0.0002
Soil.water	Monthly.precip	0.2273	0.0347	0.0000
Soil.water	Annual.precip	0.2349	0.0375	0.0000
Soil.water	Elevation	-0.0802	0.0532	0.1498
Soil.water	Latitude	-0.2766	0.0833	0.0093
Soil.water	Soil.texture	-0.2650	0.0199	0.0000
Soil.carbon	Soil.water	0.4780	0.0249	0.0000
Soil.carbon	Monthly.temp	0.0577	0.0188	0.1842
Soil.carbon	Annual.temp	0.3613	0.0396	0.0003
Soil.carbon	Monthly.precip	-0.0229	0.0190	0.5764
Soil.carbon	Annual.precip	0.1279	0.0212	0.0044
Soil.carbon	Landuse	-0.1598	0.0359	0.0002
Soil.carbon	Elevation	0.1222	0.0282	0.0347
Soil.carbon	Latitude	0.5574	0.0442	0.0000
Soil.carbon	Soil.texture	-0.0336	0.0114	0.4258
Soil.carbon	Soil.pH	-0.0023	0.0189	0.9620
Xylosidase	Soil.water	0.1260	0.0503	0.0416
Xylosidase	Monthly.temp	0.0001	0.0345	0.9983
Xylosidase	Landuse	-0.1482	0.0668	0.0028
Xylosidase	Annual.temp	0.1380	0.0737	0.2317
Xylosidase	Monthly.precip	0.0294	0.0348	0.5305
Xylosidase	Annual.precip	0.1110	0.0391	0.0321
Xylosidase	Elevation	0.1562	0.0519	0.0192
Xylosidase	Latitude	0.0089	0.0833	0.9455
Xylosidase	Soil.texture	-0.0503	0.0209	0.2995
Xylosidase	Soil.carbon	0.1365	0.0869	0.0123
Xylosidase	Soil.pH	-0.1565	0.0346	0.0042

Supplementary Figure 11: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on xylosidase activity.



SEM with Water Stable Aggregates

```
lucas.sem <- psem(
  lm(Soil.pH ~ Soil.water + Annual.temp + Annual.precip +
       Landuse + Elevation + Latitude + Soil.texture, data = df),
  lm(Soil.water ~ Monthly.temp + Annual.temp + Landuse + Monthly.precip +
       Annual.precip + Elevation + Latitude + Soil.texture, data = df),
  lm(Soil.carbon ~ Soil.water + Monthly.temp + Annual.temp + Monthly.precip +
       Annual.precip + Landuse  + Elevation + Latitude + Soil.texture +
       Soil.pH, data = df),
  lm(Soil.aggregates ~ Soil.water + Monthly.temp + Landuse + Annual.temp +
       Monthly.precip + Annual.precip + Elevation + Latitude  + Soil.texture +
       Soil.carbon + Soil.pH, data = df)
)
```

Supplementary Table 20: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on water stable aggregates.

Fisher.C	df	P.Value
3.479	4	0.481

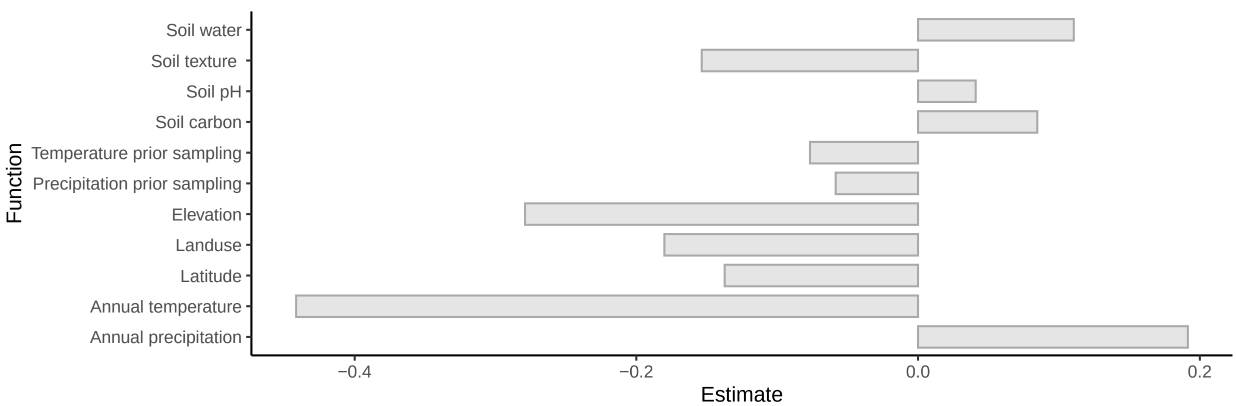
Supplementary Table 21: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on water stable aggregates.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.0531	0.0585	0.2449
Soil.pH	Annual.temp	0.3760	0.0972	0.0001
Soil.pH	Annual.precip	-0.2269	0.0501	0.0000
Soil.pH	Landuse	0.1348	0.0870	0.0011
Soil.pH	Elevation	0.1084	0.0702	0.0583
Soil.pH	Latitude	-0.0042	0.1103	0.9691
Soil.pH	Soil.texture	-0.2301	0.0274	0.0000
Soil.water	Monthly.temp	-0.1747	0.0350	0.0000
Soil.water	Annual.temp	-0.3962	0.0727	0.0000
Soil.water	Landuse	-0.1527	0.0665	0.0002
Soil.water	Monthly.precip	0.2273	0.0347	0.0000
Soil.water	Annual.precip	0.2349	0.0375	0.0000
Soil.water	Elevation	-0.0802	0.0532	0.1498
Soil.water	Latitude	-0.2766	0.0833	0.0093
Soil.water	Soil.texture	-0.2650	0.0199	0.0000
Soil.carbon	Soil.water	0.4780	0.0249	0.0000
Soil.carbon	Monthly.temp	0.0577	0.0188	0.1842
Soil.carbon	Annual.temp	0.3613	0.0396	0.0003
Soil.carbon	Monthly.precip	-0.0229	0.0190	0.5764
Soil.carbon	Annual.precip	0.1279	0.0212	0.0044
Soil.carbon	Landuse	-0.1598	0.0359	0.0002
Soil.carbon	Elevation	0.1222	0.0282	0.0347
Soil.carbon	Latitude	0.5574	0.0442	0.0000
Soil.carbon	Soil.texture	-0.0336	0.0114	0.4258
Soil.carbon	Soil.pH	-0.0023	0.0189	0.9620

(continued)

Response	Predictor	Estimate	SE	p-value
Soil.aggregates	Soil.water	0.1105	1.6716	0.0562
Soil.aggregates	Monthly.temp	-0.0767	1.1469	0.1004
Soil.aggregates	Landuse	-0.1801	2.2189	0.0001
Soil.aggregates	Annual.temp	-0.4416	2.4480	0.0000
Soil.aggregates	Monthly.precip	-0.0586	1.1547	0.1825
Soil.aggregates	Annual.precip	0.1915	1.2998	0.0001
Soil.aggregates	Elevation	-0.1374	1.7239	0.0276
Soil.aggregates	Latitude	-0.2791	2.7664	0.0220
Soil.aggregates	Soil.texture	-0.1537	0.6954	0.0007
Soil.aggregates	Soil.carbon	0.0846	2.8848	0.0965
Soil.aggregates	Soil.pH	0.0408	1.1488	0.4223

Supplementary Figure 12: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on water stable aggregates.



Testing Non-Linearity

"z" stands for z.transformed variable

We conducted tests to explore potential non-linear relationships by comparing the Akaike Information Criterion (AIC) values of linear models with those of polynomial models ranging from degree 2 to 4. The table below presents the difference in AIC (d.AIC) between each model and the best model tested. If the d.AIC for the linear model is lower or equal to 10, we consider the linear model to be the most parsimonious. However, if the d.AIC for the linear model exceeds 10, we compared the best model with the linear model as described below.

Table 11: Supplementary Table 22: Shows the non-linear relationships of the environmental variables used in the SEM

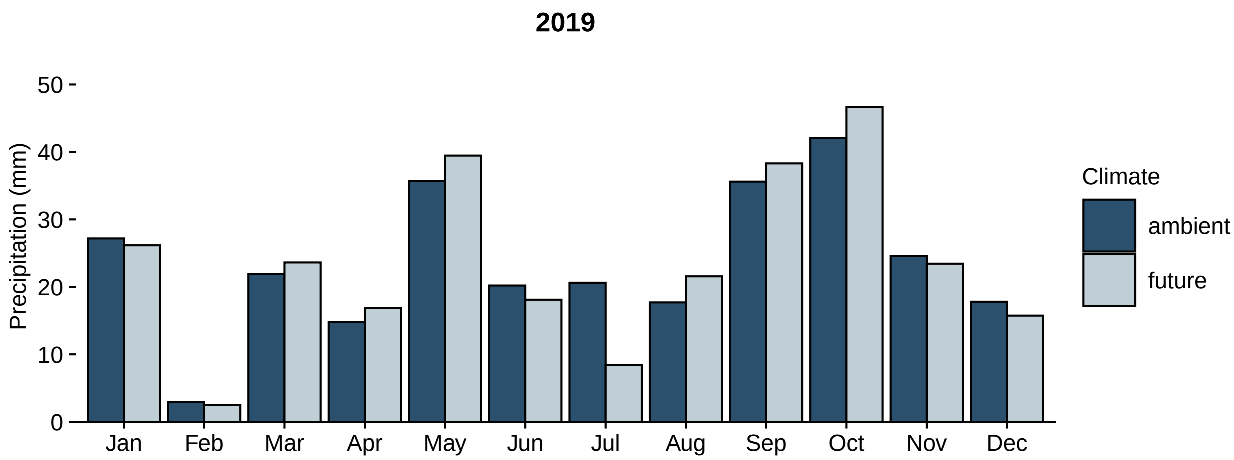
x	y	y ~ x	y ~ poly(x,2)	y ~ poly(x,3)	y ~ poly(x,4)
z.pH	z.water.content	0.0000000	1.7322849	2.9225055	4.8453515
z.pH	z.AnnualTemp	40.6692316	21.7654921	23.7083357	0.0000000
z.pH	z.AnnualPrecip	6.9233993	0.0000000	1.9075813	2.8650869
z.pH	LC_5	2.6553831	1.6579955	0.0000000	1.9808815
z.pH	z.Elevation	7.5899971	4.2427480	6.2321649	0.0000000
z.pH	z.Latitude	32.9293474	18.6492672	20.5593630	0.0000000
z.pH	z.pca.text	7.4935326	3.1467046	2.5703727	0.0000000
z.water.content	z.MonthlyMeanTemp	4.8770849	0.0000000	1.8634167	3.8567990
z.water.content	z.AnnualTemp	0.9157142	1.7843474	0.0000000	1.4759425
z.water.content	LC_5	4.4429724	5.0091744	0.0000000	1.8224011
z.water.content	z.MonthlyPrecipSum	0.6042194	0.4639239	1.2451574	0.0000000
z.water.content	z.AnnualPrecip	2.5998399	4.4294967	3.5390082	0.0000000
z.water.content	z.Latitude	8.5482553	0.0000000	0.5754106	1.5537854
z.water.content	z.pca.text	26.1977554	4.6841996	0.0000000	1.9844681
z.carbon	z.water.content	40.0403910	0.0000000	1.0747962	0.7859147
z.carbon	z.MonthlyMeanTemp	10.6568778	8.2421065	0.0000000	0.3521271
z.carbon	z.AnnualTemp	18.5173423	4.4105849	0.0000000	1.7036917
z.carbon	z.MonthlyPrecipSum	0.0000000	1.9999402	1.7383055	2.8302163
z.carbon	z.AnnualPrecip	47.5887050	0.5802351	0.0000000	0.8859361
z.carbon	LC_5	15.7280786	0.5608720	0.7954063	0.0000000
z.carbon	z.Latitude	16.3895709	6.8548504	0.0000000	1.5641214
z.carbon	z.pca.text	20.2849277	13.4371526	2.9648271	0.0000000
z.carbon	z.pH	2.6781284	0.0000000	1.7087414	0.3825314
z.meanFunction	z.water.content	0.0000000	1.9168582	3.8642349	5.2362627
z.meanFunction	z.MonthlyMeanTemp	5.1888490	0.0000000	0.6538071	2.6359183
z.meanFunction	LC_5	7.7110991	6.1263280	0.0000000	1.9762306

Table 12: Supplementary Table 23: Non-linear relationships of the environmental variables with best AIC scores

x	y	y ~ x	y ~ poly(x,2)	y ~ poly(x,3)	y ~ poly(x,4)
z.pH	z.AnnualTemp	40.66923	21.7654921	23.7083357	0.0000000
z.pH	z.Latitude	32.92935	18.6492672	20.5593630	0.0000000
z.water.content	z.pca.text	26.19776	4.6841996	0.0000000	1.9844681
z.carbon	z.water.content	40.04039	0.0000000	1.0747962	0.7859147
z.carbon	z.MonthlyMeanTemp	10.65688	8.2421065	0.0000000	0.3521271
z.carbon	z.AnnualTemp	18.51734	4.4105849	0.0000000	1.7036917
z.carbon	z.AnnualPrecip	47.58870	0.5802351	0.0000000	0.8859361
z.carbon	LC_5	15.72808	0.5608720	0.7954063	0.0000000
z.carbon	z.Latitude	16.38957	6.8548504	0.0000000	1.5641214
z.carbon	z.pca.text	20.28493	13.4371526	2.9648271	0.0000000

Precipitation in der GLobal Change Experimental Facility

Supplementary Figure 13: Precipitation from January until December in the "Global Change Experimental Facility".



Field Experiment: GCEF - Soil Multifunctionality - Averaging Approach

Calculated with the averaging approach, which represents the average value of standardized functions.

Model structure - without interaction

"Climate" is a categorical variable representing the difference between ambient and future climate conditions. "Land use" is also a categorical variable that represents the difference between grasslands and croplands.

Here modeled without interaction of climate and land use.

```
gcef.sem <- psem(
  lmer(Soil.pH ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df20),
  lmer(Soil.water ~ Landuse + Climate + (1|Mainplot),
       data = df20),
  lmer(Soil.carbon ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df20),
  lmer(Multifunctionality ~ Soil.water + Soil.carbon +
         Soil.pH + Landuse + Climate + (1|Mainplot), data = df20)
)
```

Supplementary Table 24: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality.

Fisher.C	df	P.Value
0.514	2	0.774

Supplementary Table 25: Direct, indirect, and net effect for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality.

Explanatory.variable	Direct.effect	Indirect.effect	Net effect
Climate	-0.30	0.1015	-0.1985
Land use	-0.51	-0.1363	-0.6463
pH	-0.20	0.0000	-0.2000
Soil water	0.15	0.0000	0.1500
Soil carbon	0.29	0.0000	0.2900

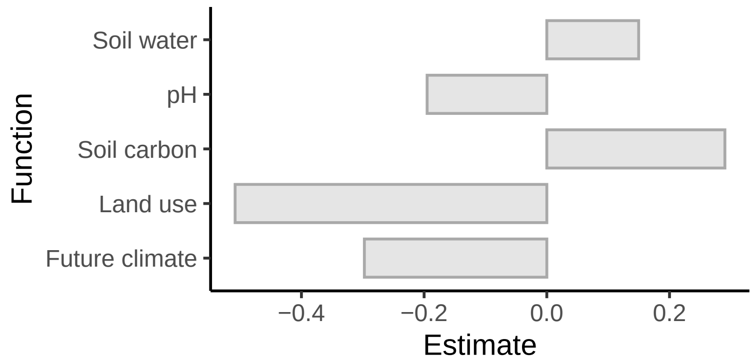
Supplementary Table 26: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.1942	0.0494	0.0002
Soil.pH	Landuse	0.1805	0.0977	0.0005
Soil.pH	Climate	0.1983	0.5980	0.5283

(continued)

Response	Predictor	Estimate	SE	p-value
Soil.water	Landuse	-0.0223	0.2254	0.8446
Soil.water	Climate	0.0958	0.2254	0.4011
Soil.carbon	Soil.water	-0.0298	0.0845	0.7249
Soil.carbon	Landuse	-0.4686	0.1670	0.0000
Soil.carbon	Climate	0.3538	0.2960	0.0447
Multifunctionality	Soil.water	0.1497	0.0659	0.0262
Multifunctionality	Soil.carbon	0.2903	0.0852	0.0011
Multifunctionality	Soil.pH	-0.1951	0.0973	0.0605
Multifunctionality	Landuse	-0.5081	0.1523	0.0000
Multifunctionality	Climate	-0.2974	0.2232	0.0301

Supplementary Figure 14: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on soil multifunctionality.



Model structure - with interaction

With interaction of climate variables and land use. This model was not used in the final analysis, as we observed no interactive effects between climate and land use.

```
gcef.sem <- psem(
  lmer(Soil.pH ~ Soil.water + Landuse * Climate +
         (1|Mainplot), data = df20),
  lmer(Soil.water ~ Landuse * Climate +
         (1|Mainplot), data = df20),
  lmer(Soil.carbon ~ Soil.water + Landuse * Climate +
         (1|Mainplot), data = df20),
  lmer(Multifunctionality ~ Soil.water + Soil.carbon +
         Soil.pH + Landuse * Climate + (1|Mainplot),
      data = df20)
)
```

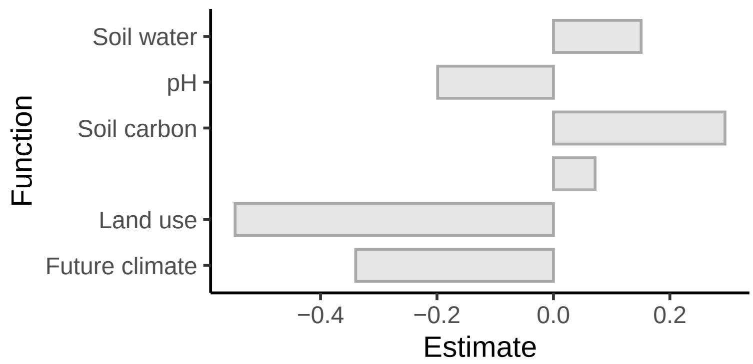
Supplementary Table 27: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality.

Fisher.C	df	P.Value
0.582	2	0.748

Supplementary Table 28: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.1927	0.0496	0.0002
Soil.pH	Landuse	0.1395	0.1385	0.0493
Soil.pH	Climate	0.1571	0.6060	0.6197
Soil.pH	Landuse:Climate	0.0712	0.1959	0.4073
Soil.water	Landuse	0.0146	0.3206	0.9281
Soil.water	Climate	0.1327	0.3206	0.4134
Soil.water	Landuse:Climate	-0.0639	0.4534	0.7472
Soil.carbon	Soil.water	-0.0315	0.0850	0.7120
Soil.carbon	Landuse	-0.4241	0.2375	0.0007
Soil.carbon	Climate	0.3984	0.3407	0.0357
Soil.carbon	Landuse:Climate	-0.0771	0.3360	0.6004
Multifunctionality	Soil.water	0.1506	0.0662	0.0260
Multifunctionality	Soil.carbon	0.2945	0.0857	0.0010
Multifunctionality	Soil.pH	-0.1989	0.0975	0.0571
Multifunctionality	Landuse	-0.5467	0.1933	0.0000
Multifunctionality	Climate	-0.3396	0.2566	0.0202
Multifunctionality	Landuse:Climate	0.0715	0.2512	0.5157

Supplementary Figure 15: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on soil multifunctionality.



Soil Multifunctionality - Threshold Approach

Calculated with the threshold approach, representing functions that exceed a threshold of 0.6.

Model structure

```
gcef.sem.max <- psem(
  lmer(Soil.pH ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df20),
  lmer(Soil.water ~ Landuse + Climate +
         (1|Mainplot), data = df20),
  lmer(Soil.carbon ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df20),
  lmer(Multifunc.thres ~ Soil.water + Soil.carbon +
         Soil.pH + Landuse + Climate + (1|Mainplot), data = df20)
)
```

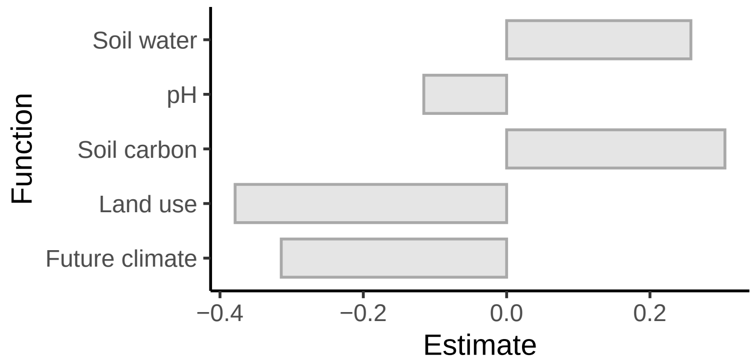
Supplementary Table 29: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality.

Fisher.C	df	P.Value
0.514	2	0.774

Supplementary Table 30: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.1942	0.0494	0.0002
Soil.pH	Landuse	0.1805	0.0977	0.0005
Soil.pH	Climate	0.1983	0.5980	0.5283
Soil.water	Landuse	-0.0223	0.2254	0.8446
Soil.water	Climate	0.0958	0.2254	0.4011
Soil.carbon	Soil.water	-0.0298	0.0845	0.7249
Soil.carbon	Landuse	-0.4686	0.1670	0.0000
Soil.carbon	Climate	0.3538	0.2960	0.0447
Multifunc.thres	Soil.water	0.2571	0.0731	0.0008
Multifunc.thres	Soil.carbon	0.3046	0.0954	0.0021
Multifunc.thres	Soil.pH	-0.1156	0.1222	0.3517
Multifunc.thres	Landuse	-0.3789	0.1691	0.0000
Multifunc.thres	Climate	-0.3145	0.3097	0.0764

Supplementary Figure 16: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on soil multifunctionality.



Soil Multifunctionality - Spring Sampling

Model structure

```
gcef.sem <- psem(
  lmer(Soil.pH ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.water ~ Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.carbon ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Multifunctionality ~ Soil.water + Soil.carbon +
         Soil.pH + Landuse + Climate + (1|Mainplot), data = df2)
)
```

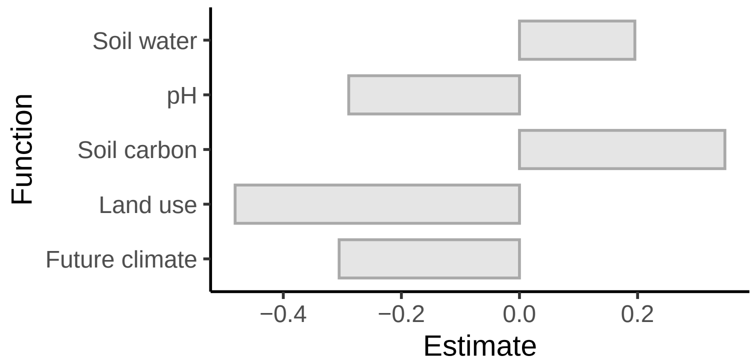
Supplementary Table 31: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality in spring.

Fisher.C	df	P.Value
0.73	2	0.694

Supplementary Table 32: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality in spring.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.0488	0.1967	0.5390
Soil.pH	Landuse	0.3465	0.1081	0.0000
Soil.pH	Climate	0.2150	0.4697	0.4934
Soil.water	Landuse	0.0587	0.0927	0.6953
Soil.water	Climate	0.4232	0.0927	0.0072
Soil.carbon	Soil.water	-0.2872	0.4304	0.0419
Soil.carbon	Landuse	-0.4511	0.2406	0.0009
Soil.carbon	Climate	0.4725	0.3247	0.0158
Multifunctionality	Soil.water	0.1954	0.2744	0.0410
Multifunctionality	Soil.carbon	0.3479	0.1040	0.0035
Multifunctionality	Soil.pH	-0.2892	0.1497	0.0346
Multifunctionality	Landuse	-0.4816	0.1904	0.0000
Multifunctionality	Climate	-0.3054	0.2780	0.0672

Supplementary Figure 17: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on soil multifunctionality in spring.



Soil Multifunctionality - Fall Sampling

Model structure

```
gcef.sem <- psem(
  lmer(Soil.pH ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.water ~ Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.carbon ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Multifunctionality ~ Soil.water + Soil.carbon + Soil.pH +
         Landuse + Climate + (1|Mainplot), data = df2)
)
```

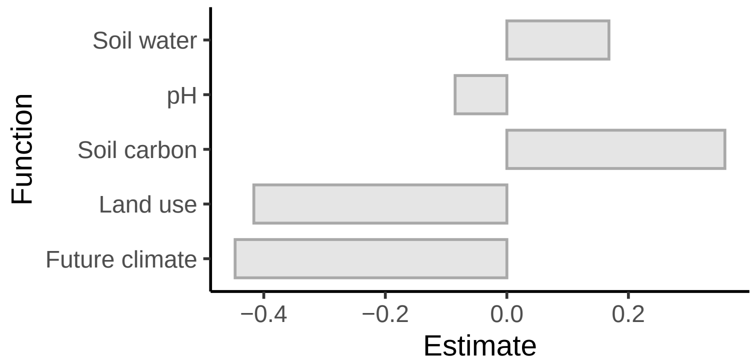
Supplementary Table 33: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality in fall.

Fisher.C	df	P.Value
0.95	2	0.622

Supplementary Table 33: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil multifunctionality in fall.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.0813	0.6079	0.3575
Soil.pH	Landuse	0.0552	0.1598	0.4384
Soil.pH	Climate	0.2094	0.7254	0.5298
Soil.water	Landuse	-0.3853	0.0425	0.0063
Soil.water	Climate	0.3588	0.0547	0.0656
Soil.carbon	Soil.water	0.1256	0.9707	0.4341
Soil.carbon	Landuse	-0.4195	0.2830	0.0061
Soil.carbon	Climate	0.3059	0.3250	0.0927
Multifunctionality	Soil.water	0.1680	0.8409	0.2171
Multifunctionality	Soil.carbon	0.3588	0.1327	0.0087
Multifunctionality	Soil.pH	-0.0852	0.1037	0.4647
Multifunctionality	Landuse	-0.4164	0.2580	0.0023
Multifunctionality	Climate	-0.4472	0.2546	0.0010

Supplementary Figure 18: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on soil multifunctionality in fall.



SEM with Microbial Basal Respiration

Model structure

```
gcef.sem <- psem(
  lmer(Soil.pH ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.water ~ Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.carbon ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Mic.respi ~ Soil.water + Soil.carbon + Soil.pH +
         Landuse + Climate + (1|Mainplot), data = df2)
)
```

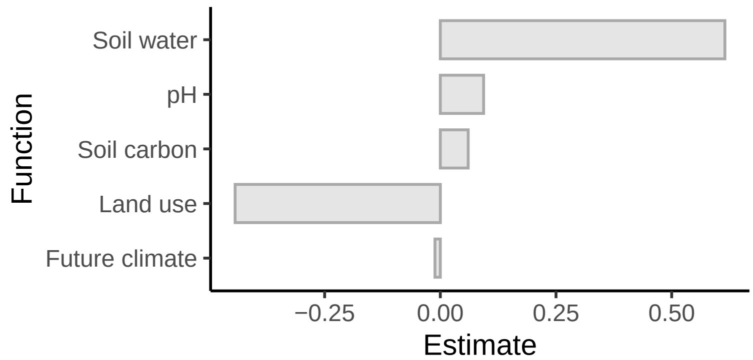
Supplementary Table 35: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil microbial respiration.

Fisher.C	df	P.Value
0.514	2	0.774

Supplementary Table 36: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on soil microbial respiration.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.1942	0.0494	0.0002
Soil.pH	Landuse	0.1805	0.0977	0.0005
Soil.pH	Climate	0.1983	0.5980	0.5283
Soil.water	Landuse	-0.0223	0.2254	0.8446
Soil.water	Climate	0.0958	0.2254	0.4011
Soil.carbon	Soil.water	-0.0298	0.0845	0.7249
Soil.carbon	Landuse	-0.4686	0.1670	0.0000
Soil.carbon	Climate	0.3538	0.2960	0.0447
Mic.respi	Soil.water	0.6150	0.0361	0.0000
Mic.respi	Soil.carbon	0.0602	0.0441	0.5235
Mic.respi	Soil.pH	0.0936	0.0399	0.2983
Mic.respi	Landuse	-0.4435	0.0821	0.0000
Mic.respi	Climate	-0.0116	0.0837	0.9007

Supplementary Figure 19: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on soil microbial activity.



SEM with Phosphatase Activity

Model structure

```
gcef.sem <- psem(
  lmer(Soil.pH ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.water ~ Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.carbon ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Phosphatase ~ Soil.water + Soil.carbon + Soil.pH +
         Landuse + Climate + (1|Mainplot), data = df2)
)
```

Supplementary Table 37: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on phosphatase activity.

Fisher.C	df	P.Value
0.514	2	0.774

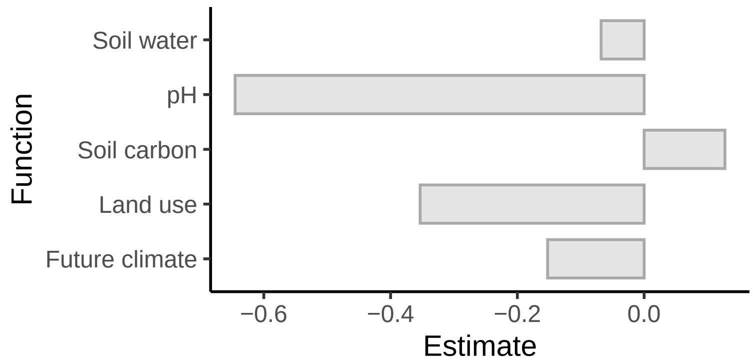
Supplementary Table 38: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on phosphatase activity.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.1942	0.0494	0.0002
Soil.pH	Landuse	0.1805	0.0977	0.0005
Soil.pH	Climate	0.1983	0.5980	0.5283
Soil.water	Landuse	-0.0223	0.2254	0.8446
Soil.water	Climate	0.0958	0.2254	0.4011

(continued)

Response	Predictor	Estimate	SE	p-value
Soil.carbon	Soil.water	-0.0298	0.0845	0.7249
Soil.carbon	Landuse	-0.4686	0.1670	0.0000
Soil.carbon	Climate	0.3538	0.2960	0.0447
Phosphatase	Soil.water	-0.0679	2.6742	0.2930
Phosphatase	Soil.carbon	0.1274	3.2041	0.1016
Phosphatase	Soil.pH	-0.6453	2.7564	0.0000
Phosphatase	Landuse	-0.3534	6.0620	0.0000
Phosphatase	Climate	-0.1523	5.7350	0.0308

Supplementary Figure 20: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on phosphatase activity.



SEM with N-acetylglucosaminidase Activity

Model structure

```
gcef.sem <- psem(
  lmer(Soil.pH ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.water ~ Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.carbon ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Glucosaminidase ~ Soil.water + Soil.carbon + Soil.pH +
         Landuse + Climate + (1|Mainplot), data = df2)
)
```

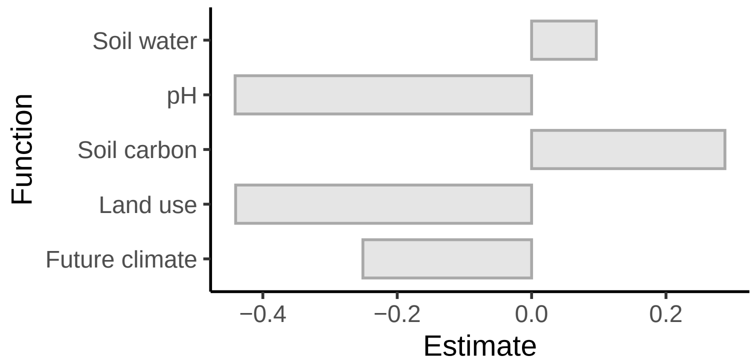
Supplementary Table 39: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on N-acetylglucosaminidase activity.

Fisher.C	df	P.Value
0.514	2	0.774

Supplementary Table 40: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on N-acetylglucosaminidase activity.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.1942	0.0494	0.0002
Soil.pH	Landuse	0.1805	0.0977	0.0005
Soil.pH	Climate	0.1983	0.5980	0.5283
Soil.water	Landuse	-0.0223	0.2254	0.8446
Soil.water	Climate	0.0958	0.2254	0.4011
Soil.carbon	Soil.water	-0.0298	0.0845	0.7249
Soil.carbon	Landuse	-0.4686	0.1670	0.0000
Soil.carbon	Climate	0.3538	0.2960	0.0447
Glucosaminidase	Soil.water	0.0963	1.5185	0.1411
Glucosaminidase	Soil.carbon	0.2877	1.9827	0.0011
Glucosaminidase	Soil.pH	-0.4413	2.5495	0.0008
Glucosaminidase	Landuse	-0.4405	3.5162	0.0000
Glucosaminidase	Climate	-0.2511	6.4901	0.1419

Supplementary Figure 21: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on N-acetylglucosaminidase activity.



SEM with Cellulase Activity

Model structure

```
gcef.sem <- psem(
  lmer(Soil.pH ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.water ~ Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.carbon ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Cellulase ~ Soil.water + Soil.carbon + Soil.pH +
         Landuse + Climate + (1|Mainplot), data = df2)
)
```

Supplementary Table 41: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on cellulase activity.

Fisher.C	df	P.Value
0.514	2	0.774

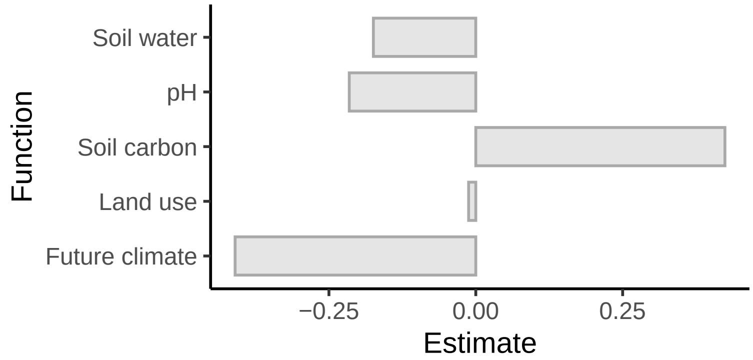
Supplementary Table 42: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on cellulase activity.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.1942	0.0494	0.0002
Soil.pH	Landuse	0.1805	0.0977	0.0005
Soil.pH	Climate	0.1983	0.5980	0.5283
Soil.water	Landuse	-0.0223	0.2254	0.8446
Soil.water	Climate	0.0958	0.2254	0.4011

(continued)

Response	Predictor	Estimate	SE	p-value
Soil.carbon	Soil.water	-0.0298	0.0845	0.7249
Soil.carbon	Landuse	-0.4686	0.1670	0.0000
Soil.carbon	Climate	0.3538	0.2960	0.0447
Cellulase	Soil.water	-0.1743	0.8978	0.0514
Cellulase	Soil.carbon	0.4241	1.1664	0.0004
Cellulase	Soil.pH	-0.2154	1.4031	0.1328
Cellulase	Landuse	-0.0122	2.0767	0.9054
Cellulase	Climate	-0.4097	3.3438	0.0407

Supplementary Figure 22: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on cellulase activity.



SEM with Xylosidase Activity

Model structure

```
gcef.sem <- psem(
  lmer(Soil.pH ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.water ~ Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.carbon ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Xylosidase ~ Soil.water + Soil.carbon + Soil.pH + Landuse +
         Climate + (1|Mainplot), data = df2)
)
```

Supplementary Table 43: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on xylosidase activity.

Fisher.C	df	P.Value
0.514	2	0.774

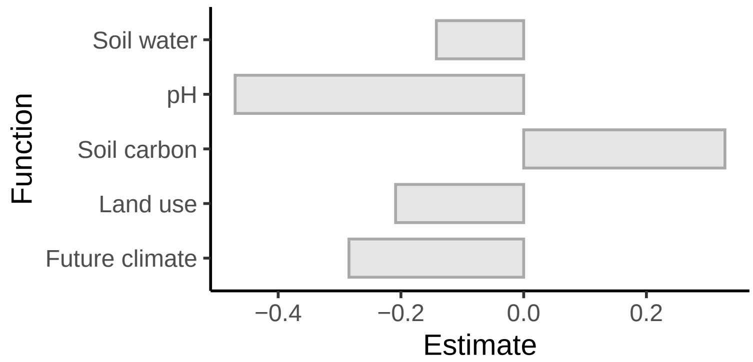
Supplementary Table 44: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on xylosidase activity.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.1942	0.0494	0.0002
Soil.pH	Landuse	0.1805	0.0977	0.0005
Soil.pH	Climate	0.1983	0.5980	0.5283
Soil.water	Landuse	-0.0223	0.2254	0.8446
Soil.water	Climate	0.0958	0.2254	0.4011
Soil.carbon	Soil.water	-0.0298	0.0845	0.7249

(continued)

Response	Predictor	Estimate	SE	p-value
Soil.carbon	Landuse	-0.4686	0.1670	0.0000
Soil.carbon	Climate	0.3538	0.2960	0.0447
Xylosidase	Soil.water	-0.1423	0.3806	0.0877
Xylosidase	Soil.carbon	0.3279	0.4561	0.0014
Xylosidase	Soil.pH	-0.4702	0.3923	0.0000
Xylosidase	Landuse	-0.2087	0.8628	0.0290
Xylosidase	Climate	-0.2847	0.8163	0.0020

Supplementary Figure 23: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on xylosidase activity.



SEM with Water Stable Aggregates

Model structure

```
gcef.sem <- psem(
  lmer(Soil.pH ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.water ~ Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.carbon ~ Soil.water + Landuse + Climate +
         (1|Mainplot), data = df2),
  lmer(Soil.aggregates ~ Soil.water + Soil.carbon + Soil.pH +
         Landuse + Climate + (1|Mainplot), data = df2)
)
```

Supplementary Table 45: Displays the model fit, Fisher's C statistic, degrees of freedom, and p-value for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on water stable aggregates.

Fisher.C	df	P.Value
0.514	2	0.774

Supplementary Table 46: Model summary for the structural equation model that tests the impact of land-use type, climate, and abiotic variables on water stable aggregates.

Response	Predictor	Estimate	SE	p-value
Soil.pH	Soil.water	-0.1942	0.0494	0.0002
Soil.pH	Landuse	0.1805	0.0977	0.0005
Soil.pH	Climate	0.1983	0.5980	0.5283
Soil.water	Landuse	-0.0223	0.2254	0.8446
Soil.water	Climate	0.0958	0.2254	0.4011
Soil.carbon	Soil.water	-0.0298	0.0845	0.7249

(continued)

Response	Predictor	Estimate	SE	p-value
Soil.carbon	Landuse	-0.4686	0.1670	0.0000
Soil.carbon	Climate	0.3538	0.2960	0.0447
Soil.aggregates	Soil.water	-0.2776	1.1530	0.0138
Soil.aggregates	Soil.carbon	0.0380	1.3982	0.7766
Soil.aggregates	Soil.pH	0.0591	1.2386	0.6264
Soil.aggregates	Landuse	-0.2167	2.6213	0.0891
Soil.aggregates	Climate	-0.1244	2.5873	0.3417

Supplementary Figure 24: Plot of the standardized estimate of structural equation model testing the effects of land-use type, climate, and abiotic variables on water stable aggregates.

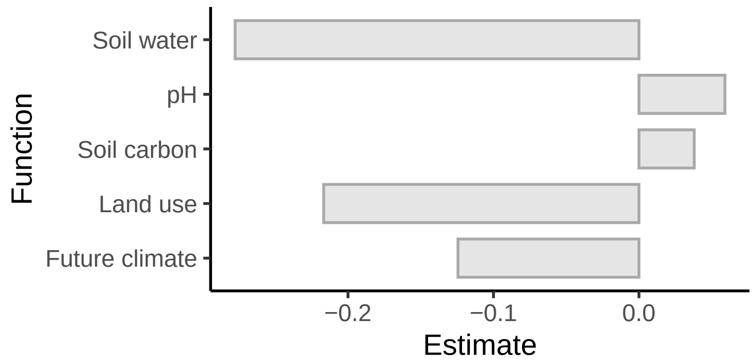


Table 20: Supplementary Table 47: Shows the non-linear relationships of the environmental variables used in the SEM

x	y	y ~ poly(x,2)	y ~ poly(x,3)	y ~ poly(x,4)	y ~ x
z.pH	z.water.content	2.556556	1.545321	0.0000000	NA
z.water.content	Clim	761.779031	0.000000	770.9926386	NA
z.water.content	LC_5	2.613918	3.576881	2.6937069	NA
z.carbon	LC_5	7.581544	8.783190	8.7963890	0.000000
z.meanFunction	z.carbon	NA	NA	NA	13.324636
z.meanFunction	z.pH	0.000000	1.587653	0.6989122	79.598614
z.meanFunction	LC_5	4.331259	0.000000	2.0911245	0.356836

Table 21: Supplementary Table 48: Non-linear relationships of the environmental variables with best AIC scores

x	y	y ~ poly(x,2)	y ~ poly(x,3)	y ~ poly(x,4)	y ~ x
z.meanFunction	z.carbon	NA	NA	NA	13.32464
z.meanFunction	z.pH	0	1.587653	0.6989122	79.59861

Testing Non-Linearity in the GCEF dataset

"z" stands for z.transformed variable

We conducted tests to explore potential non-linear relationships by comparing the Akaike Information Criterion (AIC) values of linear models with those of polynomial models ranging from degree 2 to 4. The table below presents the difference in AIC (d.AIC) between each model and the best model tested. If the d.AIC for the linear model is lower or equal to 10, we consider the linear model to be the most parsimonious. However, if the d.AIC for the linear model exceeds 10, we compared the best model with the linear model as described below.

Supplementary Table 49: Cover Crops of the LUCAS sampling campaign across Europe.

Sample	Country	Cover crop
1	PORTUGAL	Grassland without tree/shrub cover
2	PORTUGAL	Grassland without tree/shrub cover
3	SPAIN	Sunflower
4	SPAIN	Common wheat
5	SPAIN	Barley
6	FRANCE	Temporary grasslands
7	FRANCE	Maize
8	FRANCE	Other fresh vegetables
9	SPAIN	Barley
10	SPAIN	Dry pulses
11	PORTUGAL	Grassland with sparse tree/shrub cover
12	SPAIN	Spontaneously re-vegetated surfaces
13	SPAIN	Vineyards
14	SPAIN	Spontaneously re-vegetated surfaces
15	SPAIN	Durum wheat
16	FRANCE	Grassland without tree/shrub cover
17	UK	Other root crops
18	SPAIN	Grassland with sparse tree/shrub cover
19	UK	Grassland without tree/shrub cover
20	PORTUGAL	Nuts trees
21	SPAIN	Barley
22	FRANCE	Maize
23	SPAIN	Barley
24	FRANCE	Common wheat
25	SPAIN	Durum wheat
26	SPAIN	Common wheat
27	PORTUGAL	Grassland with sparse tree/shrub cover
28	SPAIN	Maize
29	SPAIN	Common wheat
30	SPAIN	Other citrus fruit
31	FRANCE	Grassland without tree/shrub cover
32	FRANCE	Grassland without tree/shrub cover
33	FRANCE	Maize
34	FRANCE	Grassland without tree/shrub cover
35	FRANCE	Grassland without tree/shrub cover
36	PORTUGAL	Vineyards
37	FRANCE	Common wheat
38	SPAIN	Spontaneously re-vegetated surfaces
39	FRANCE	Grassland without tree/shrub cover
40	UK	Grassland without tree/shrub cover
41	SPAIN	Barley
42	FRANCE	Temporary grasslands
43	FRANCE	Grassland without tree/shrub cover
44	SPAIN	Other fruit trees and berries
45	SPAIN	Sunflower
46	FRANCE	Grassland without tree/shrub cover
47	SPAIN	Barley
48	SPAIN	Spontaneously re-vegetated surfaces
49	FRANCE	Grassland without tree/shrub cover

50	FRANCE	Spontaneously re-vegetated surfaces
51	FRANCE	Common wheat
52	SPAIN	Maize
53	UK	Temporary grasslands
54	PORTUGAL	Grassland without tree/shrub cover
55	SPAIN	Other fruit trees and berries
56	UK	Barley
57	SPAIN	Olive groves
58	FRANCE	Vineyards
59	SPAIN	Olive groves
60	UK	Grassland without tree/shrub cover
61	FRANCE	Maize
62	FRANCE	Common wheat
63	FRANCE	Sunflower
64	FRANCE	Maize
65	SPAIN	Durum wheat
66	SPAIN	Pear fruit
67	SPAIN	Barley
68	FRANCE	Maize
69	FRANCE	Lucerne
70	UK	Rape and turnip rape
71	SPAIN	Vineyards
72	FRANCE	Temporary grasslands
73	FRANCE	Common wheat
74	UK	Common wheat
75	SPAIN	Spontaneously re-vegetated surfaces
76	FRANCE	Barley
77	FRANCE	Durum wheat
78	FRANCE	Grassland without tree/shrub cover
79	FRANCE	Common wheat
80	FRANCE	Durum wheat
81	FRANCE	Common wheat
82	UK	Grassland without tree/shrub cover
83	FRANCE	Rape and turnip rape
84	FRANCE	Rape and turnip rape
85	FRANCE	Barley
86	SPAIN	Grassland without tree/shrub cover
87	FRANCE	Grassland without tree/shrub cover
88	FRANCE	Common wheat
89	FRANCE	Grassland without tree/shrub cover
90	FRANCE	Common wheat
91	FRANCE	Maize
92	FRANCE	Grassland without tree/shrub cover
93	FRANCE	Vineyards
94	FRANCE	Temporary grasslands
95	FRANCE	Other fibre and oleaginous crops
96	FRANCE	Temporary grasslands
97	PORTUGAL	Olive groves
98	SPAIN	Grassland without tree/shrub cover
99	FRANCE	Common wheat

100	FRANCE	Barley
101	FRANCE	Durum wheat
102	FRANCE	Grassland without tree/shrub cover
103	FRANCE	Maize
104	FRANCE	Rape and turnip rape
105	FRANCE	Common wheat
106	FRANCE	Vineyards
107	SPAIN	Barley
108	FRANCE	Common wheat
109	FRANCE	Sugar beet
110	FRANCE	Potatoes
111	FRANCE	Grassland without tree/shrub cover
112	FRANCE	Common wheat
113	FRANCE	Sugar beet
114	FRANCE	Rape and turnip rape
115	FRANCE	Vineyards
116	SPAIN	Oats
117	FRANCE	Grassland with sparse tree/shrub cover
118	FRANCE	Grassland without tree/shrub cover
119	FRANCE	Grassland without tree/shrub cover
120	FRANCE	Grassland without tree/shrub cover
121	FRANCE	Barley
122	FRANCE	Barley
123	NETHERLAND	Grassland without tree/shrub cover
124	FRANCE	Barley
125	FRANCE	Lucerne
126	SPAIN	Grassland without tree/shrub cover
127	FRANCE	Sugar beet
128	FRANCE	Common wheat
129	BELGIUM	Common wheat
130	FRANCE	Common wheat
131	BELGIUM	Potatoes
132	FRANCE	Rape and turnip rape
133	FRANCE	Grassland without tree/shrub cover
134	FRANCE	Rape and turnip rape
135	FRANCE	Grassland without tree/shrub cover
136	NETHERLAND	Grassland with sparse tree/shrub cover
137	NETHERLAND	Grassland without tree/shrub cover
138	FRANCE	Common wheat
139	GERMANY	Dry pulses
140	GERMANY	Grassland without tree/shrub cover
141	GERMANY	Common wheat
142	NETHERLAND	Potatoes
143	FRANCE	Apple fruit
144	FRANCE	Grassland without tree/shrub cover
145	GERMANY	Grassland without tree/shrub cover
146	NETHERLAND	Sugar beet
147	NETHERLAND	Common wheat
148	NETHERLAND	Common wheat
149	FRANCE	Vineyards

150	GERMANY	Barley
151	ITALY	Grassland without tree/shrub cover
152	GERMANY	Vineyards
153	SPAIN	Grassland without tree/shrub cover
154	GERMANY	Rape and turnip rape
155	ITALY	Grassland without tree/shrub cover
156	GERMANY	Common wheat
157	ITALY	Vineyards
158	ITALY	Spontaneously re-vegetated surfaces
159	ITALY	Grassland without tree/shrub cover
160	GERMANY	Grassland without tree/shrub cover
161	ITALY	Grassland without tree/shrub cover
162	GERMANY	Triticale
163	SPAIN	Sunflower
164	ITALY	Grassland with sparse tree/shrub cover
165	GERMANY	Triticale
166	GERMANY	Barley
167	GERMANY	Grassland without tree/shrub cover
168	GERMANY	Common wheat
169	GERMANY	Common wheat
170	GERMANY	Grassland without tree/shrub cover
171	germany	Temporary grasslands
172	ITALY	Spontaneously re-vegetated surfaces
173	DENMARK	Maize
174	SPAIN	Durum wheat
175	GERMANY	Maize
176	DENMARK	Common wheat
177	DENMARK	Barley
178	GERMANY	Grassland without tree/shrub cover
179	GERMANY	Common wheat
180	DENMARK	Barley
181	GERMANY	Common wheat
182	AUSTRIA	Grassland without tree/shrub cover
183	GERMANY	Other leguminous and mixtures for fodder
184	SPAIN	Olive groves
185	GERMANY	Grassland without tree/shrub cover
186	GERMANY	Grassland without tree/shrub cover
187	GERMANY	Common wheat
188	ITALY	Grassland without tree/shrub cover
189	DENMARK	Barley
190	GERMANY	Spontaneously re-vegetated surfaces
191	GERMANY	Grassland without tree/shrub cover
192	GERMANY	Barley
193	GERMANY	Grassland without tree/shrub cover
194	PORTUGAL	Olive groves
195	SPAIN	Grassland without tree/shrub cover
196	GERMANY	Common wheat
197	GERMANY	Grassland without tree/shrub cover
198	ITALY	Spontaneously re-vegetated surfaces
199	ITALY	Maize

200	ITALY	Soya
201	DENMARK	Other non-permanent industrial crops
202	ITALY	Apple fruit
203	ITALY	Triticale
204	SPAIN	Oats
205	GERMANY	Grassland without tree/shrub cover
206	SWEDEN	Grassland without tree/shrub cover
207	ITALY	Vineyards
208	SWEDEN	Other leguminous and mixtures for fodder
209	SWEDEN	Oats
210	CZECH REPUBLIC	Common wheat
211	ITALY	Grassland without tree/shrub cover
212	AUSTRIA	Spontaneously re-vegetated surfaces
213	SWEDEN	Rape and turnip rape
214	ITALY	Grassland without tree/shrub cover
215	CZECH REPUBLIC	Common wheat
216	ITALY	Other fresh vegetables
217	SWEDEN	Other leguminous and mixtures for fodder
218	SPAIN	Olive groves
219	AUSTRIA	Grassland without tree/shrub cover
220	POLAND	Common wheat
221	AUSTRIA	Maize
222	AUSTRIA	Grassland without tree/shrub cover
223	POLAND	Common wheat
224	POLAND	Rape and turnip rape
225	CZECH REPUBLIC	Soya
226	CZECH REPUBLIC	Other cereals
227	CZECH REPUBLIC	Grassland without tree/shrub cover
228	SLOVENIA	Temporary grasslands
229	SPAIN	Mixed cereals for fodder
230	CZECH REPUBLIC	Rape and turnip rape
231	SWEDEN	Common wheat
232	AUSTRIA	Triticale
233	POLAND	Rye
234	SLOVENIA	Grassland without tree/shrub cover
235	CZECH REPUBLIC	Grassland without tree/shrub cover
236	SWEDEN	Grassland without tree/shrub cover
237	POLAND	Barley
238	SPAIN	Maize
239	AUSTRIA	Durum wheat
240	AUSTRIA	Maize
241	POLAND	Common wheat
242	ITALY	Other fruit trees and berries
243	ITALY	Durum wheat
244	ITALY	Vineyards
245	POLAND	Grassland without tree/shrub cover
246	AUSTRIA	Dry pulses
247	SPAIN	Sunflower
248	AUSTRIA	Common wheat
249	CZECH REPUBLIC	Rape and turnip rape

250	CZECH REPUBLIC	Other fruit trees and berries
251	POLAND	Maize
252	CZECH REPUBLIC	Maize
253	POLAND	Maize
254	SLOVAKIA	Rape and turnip rape
255	CZECH REPUBLIC	Rape and turnip rape
256	CZECH REPUBLIC	Common wheat
257	CZECH REPUBLIC	Grassland without tree/shrub cover
258	SPAIN	Maize
259	POLAND	Common wheat
260	ITALY	Olive groves
261	POLAND	Maize
262	POLAND	Common wheat
263	POLAND	Common wheat
264	SLOVAKIA	Grassland without tree/shrub cover
265	SLOVAKIA	Common wheat
266	POLAND	Strawberries
267	SPAIN	Durum wheat
268	CZECH REPUBLIC	Soya
269	POLAND	Grassland without tree/shrub cover
270	POLAND	Rape and turnip rape
271	POLAND	Grassland without tree/shrub cover
272	POLAND	Rye
273	POLAND	Sugar beet
274	POLAND	Common wheat
275	POLAND	Common wheat
276	FINLAND	Common wheat
277	FINLAND	Oats
278	SPAIN	Common wheat
279	POLAND	Grassland without tree/shrub cover
280	FINLAND	Oats
281	HUNGARY	Maize
282	SLOVAKIA	Grassland without tree/shrub cover
283	POLAND	Barley
284	LATVIA	Common wheat
285	FINLAND	Grassland without tree/shrub cover
286	PORTUGAL	Olive groves
287	SPAIN	Barley
288	ITALY	Olive groves
289	FINLAND	Common wheat
290	POLAND	Grassland without tree/shrub cover
291	FINLAND	Grassland without tree/shrub cover
292	LITHUANIA	Grassland without tree/shrub cover
293	FINLAND	Oats
294	HUNGARY	Maize
295	POLAND	Grassland without tree/shrub cover
296	POLAND	Barley
297	POLAND	Grassland without tree/shrub cover
298	HUNGARY	Grassland without tree/shrub cover
299	POLAND	Grassland without tree/shrub cover

300	LITHUANIA	Common wheat
301	LITHUANIA	Common wheat
302	POLAND	Rye
303	FINLAND	Dry pulses
304	SPAIN	Barley
305	LATVIA	Common wheat
306	FINLAND	Other leguminous and mixtures for fodder
307	POLAND	Grassland without tree/shrub cover
308	POLAND	Other fruit trees and berries
309	LATVIA	Common wheat
310	LITHUANIA	Rape and turnip rape
311	LITHUANIA	Common wheat
312	FINLAND	Oats
313	POLAND	Grassland without tree/shrub cover
314	LITHUANIA	Rape and turnip rape
315	SPAIN	Rye
316	SLOVAKIA	Rape and turnip rape
317	POLAND	Common wheat
318	POLAND	Grassland without tree/shrub cover
319	POLAND	Maize
320	POLAND	Rye
321	SLOVAKIA	Grassland without tree/shrub cover
322	ROMANIA	Grassland without tree/shrub cover
323	HUNGARY	Maize
324	ESTONIA	Barley
325	ROMANIA	Common wheat
326	POLAND	Maize
327	LATVIA	Other leguminous and mixtures for fodder
328	ESTONIA	Common wheat
329	ROMANIA	Grassland with sparse tree/shrub cover
330	ROMANIA	Grassland without tree/shrub cover
331	ESTONIA	Grassland without tree/shrub cover
332	LITHUANIA	Grassland without tree/shrub cover
333	ESTONIA	Potatoes
334	LITHUANIA	Grassland with sparse tree/shrub cover
335	ESTONIA	Other leguminous and mixtures for fodder
336	SPAIN	Olive groves
337	LITHUANIA	Common wheat
338	LITHUANIA	Grassland with sparse tree/shrub cover
339	ROMANIA	Grassland with sparse tree/shrub cover
340	LATVIA	Barley
341	ROMANIA	Grassland without tree/shrub cover
342	LATVIA	Spontaneously re-vegetated surfaces
343	LATVIA	Oats
344	LATVIA	Grassland without tree/shrub cover
345	ROMANIA	Maize
346	SPAIN	Spontaneously re-vegetated surfaces
347	FINLAND	Barley
348	BULGARIA	Grassland with sparse tree/shrub cover
349	GREECE	Barley

350	LATVIA	Other leguminous and mixtures for fodder
351	BULGARIA	Common wheat
352	ROMANIA	Lucerne
353	GREECE	Durum wheat
354	BULGARIA	Grassland with sparse tree/shrub cover
355	ROMANIA	Common wheat
356	SPAIN	Olive groves
357	BULGARIA	Grassland with sparse tree/shrub cover
358	GREECE	Spontaneously re-vegetated surfaces
359	BULGARIA	Common wheat
360	BULGARIA	Spontaneously re-vegetated surfaces
361	GREECE	Spontaneously re-vegetated surfaces
362	ROMANIA	Maize
363	GREECE	Olive groves
364	ROMANIA	Grassland with sparse tree/shrub cover
365	SPAIN	Grassland without tree/shrub cover
366	BULGARIA	Maize
367	GREECE	Other root crops
368	ROMANIA	Grassland without tree/shrub cover
369	BULGARIA	Sunflower
370	ROMANIA	Grassland without tree/shrub cover
371	ROMANIA	Grassland without tree/shrub cover
372	SPAIN	Durum wheat
373	ROMANIA	Grassland without tree/shrub cover
374	ROMANIA	Sunflower
375	ROMANIA	Grassland without tree/shrub cover
376	ROMANIA	Grassland without tree/shrub cover
377	BULGARIA	Sunflower
378	BULGARIA	Sunflower
379	ROMANIA	Grassland without tree/shrub cover
380	ROMANIA	Grassland without tree/shrub cover
381	ROMANIA	Rape and turnip rape
382	ROMANIA	Common wheat
383	PORTUGAL	Grassland without tree/shrub cover
384	SPAIN	Barley
385	BULGARIA	Sunflower
386	ROMANIA	Grassland without tree/shrub cover
387	ROMANIA	Maize
388	ROMANIA	Spontaneously re-vegetated surfaces
389	ROMANIA	Grassland without tree/shrub cover
390	ROMANIA	Rape and turnip rape
391	BULGARIA	Common wheat
392	ROMANIA	Maize
393	SPAIN	Olive groves
394	BULGARIA	Sunflower
395	BULGARIA	Common wheat
396	ROMANIA	Common wheat
397	ROMANIA	Grassland without tree/shrub cover
398	ROMANIA	Maize
399	GREECE	Cotton

400	BULGARIA	Sunflower
401	ROMANIA	Sunflower
402	BULGARIA	Grassland with sparse tree/shrub cover
403	BULGARIA	Sunflower
404	ROMANIA	Maize
405	ROMANIA	Grassland without tree/shrub cover
406	ROMANIA	Sunflower
407	ROMANIA	Common wheat
408	ROMANIA	Common wheat
409	CYPRUS	Olive groves
410	CYPRUS	Other fruit trees and berries
411	CYPRUS	Common wheat
412	CYPRUS	Common wheat
413	SPAIN	Other leguminous and mixtures for fodder
414	SPAIN	Nuts trees
415	BULGARIA	Grassland with sparse tree/shrub cover
416	ROMANIA	Other fruit trees and berries
417	SPAIN	Barley
418	SPAIN	Spontaneously re-vegetated surfaces
419	IRELAND	Grassland without tree/shrub cover
420	IRELAND	Grassland without tree/shrub cover
421	PORTUGAL	Barley
422	SPAIN	Olive groves
423	SPAIN	Barley
424	SPAIN	Spontaneously re-vegetated surfaces
425	SPAIN	Barley
426	SPAIN	Spontaneously re-vegetated surfaces
427	SPAIN	Oats
428	SPAIN	Sunflower
429	SPAIN	Olive groves
430	SPAIN	Vineyards
431	PORTUGAL	Grassland with sparse tree/shrub cover
432	SPAIN	Barley
433	SPAIN	Lucerne
434	SPAIN	Olive groves
435	SPAIN	Sunflower
436	SPAIN	Barley
437	SPAIN	Common wheat
438	SPAIN	Vineyards
439	SPAIN	Common wheat
440	PORTUGAL	Floriculture and ornamental plants
441	SPAIN	Barley
442	SPAIN	Common wheat
443	SPAIN	Barley
444	SPAIN	Barley
445	SPAIN	Grassland with sparse tree/shrub cover
446	SPAIN	Grassland without tree/shrub cover
447	SPAIN	Durum wheat
448	SPAIN	Rape and turnip rape
449	SPAIN	Barley

450	SPAIN	Grassland without tree/shrub cover
451	SPAIN	Common wheat
452	SPAIN	Barley
453	SPAIN	Vineyards
454	SPAIN	Vineyards
455	SPAIN	Sunflower
456	SPAIN	Dry pulses