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Supplement of

Interactions between biogeochemical and management factors explain soil organic carbon in Pyrenean grasslands

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2 Table S1: Variables considered in this study.

Variable	Description
Regional variables	
Climate variables	
MAP	Mean Annual Precipitation, mm.
MSP	Mean Summer Precipitation, mm.
MAT	Mean Annual Temperature, °C.
MST	Mean Summer Temperature, °C.
TSIS	MST-MAT.
Bedrock	3 categories : Basic (marls and calcareous rocks), Acidic (mostly sandstones and slates) or Mixed.
Landscape variables	
Topographical variables	
Slope	Pendent, °.
Aspect	Cos(°)
Macrotopography	Protected; north-facing slopes; Exposed, south-facing slopes.
Microtopography	Flat areas, convexities or mounds, and concavities, convexities or smooth areas.
Soil type variables	
Sand10	Percentage of sands in the 10 cm upper layer (%).
Clay	Percentage of clays in the 10 cm upper layer (%).
Loam	Percentage of loams in the 10 cm upper layer (%).
pH	pH value in soil 10 cm upper layer.
Management variables	
Management	Grazer type : Cattle, Sheep, Mixed
Grazing	Grazing intensity, (units of big grazer (UBG ha-1) low (1; lower than 0.2 UBG ha-1), medium (2; between 0.2-0.4 UBG ha-1) and high (3; up to 0.4 UBG ha-1).

Soil nutrient variables

Soil N	N in soil 20 cm upper layer. (%)
C/N	Soil C/N ratio
P10	Cations of P10 in soil 10 cm upper layer. (ppm).
K10	Cations of K10 in soil 10 cm upper layer. (ppm).

Herbage

Abiom	Aboveground biomass in g/m ²
ADL	Lignin concentration by the acid detergent lignin method (%/DM).
ADF	Fiber concentration by the acid detergent fiber method (%/DM).
NDF	Fiber concentration by the neutro detergent fiber method (%/DM).
NH	Nitrogen in the herbage (%/DM).
CH	Carbon in the herbage (%/DM)
CH/NH	CH/NH
ADL/NH	ADL/NH
NDF/CP	NDF/CP (CP: crude protein)
SOC20	Soil Organic Carbon stocks in the 20 cm upper layer (kg m ⁻²).

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4

5 Table S2: Minimum, maximum, median and mean values of the continuous predictors of this
6 study. Units are shown in Table S1. MAT: mean annual temperature; MST: mean summer
7 temperature; TSIS: mean summer temperature minus mean annual temperature; MAP: mean
8 annual precipitation; MSP: mean summer precipitation; Slope: terrain slope; Aspect:; Sand: sand
9 content; Loam: loam content; Clay: clay content; pH: soil pH; Soil N: soil nitrogen; Soil P: soil
10 phosphorus; Soil C/N: soil carbon to nitrogen ratio; Soil Mg: soil magnesium; Soil K: soil
11 potassium; NDF: neutro-detergent fibre; ADF: acid-detergent fibre; ADL: acid-detergent lignin;
12 NH: nitrogen in the herbage; CH: carbon in the herbage; CH/NH: carbon to nitrogen ratio in the

- 13 herbage; Abiom: aboveground biomass; NDF/CP: neutro-detergent fibre to crude protein ratio;
- 14 ADL/NH: acid-detergent lignin to nitrogen in the herbage ratio.

	Minimum	Maximum	Median	Mean
MAT	1.08	9.90	4.72	4.96
MST	7.88	16.93	12.23	12.47
TSIS	6.80	7.80	7.58	7.51
MAP	964	1586	1252	1242.91
MSP	169.00	258.00	235.00	228.90
Slope	0.00	35.00	16.50	16.88
Aspect	1.00	3.00	1.84	2.05
Sand	3.10	72.20	32.80	32.67
Loam	13.60	73.50	38.60	39.80
Clay	2.90	68.60	27.25	27.53
pH	3.90	7.80	5.47	5.74
Soil N	0.11	1.10	0.46	0.47
Soil P	4.00	54.00	11.00	12.98
Soil C/N	4.13	41.60	12.47	13.39
Soil Mg	2.89	5.99	4.99	4.92
Soil K	3.40	6.84	4.99	5.03
NDF	31.20	78.90	52.45	52.08
ADF	17.70	46.60	29.55	30.07
ADL	1.16	12.72	6.32	6.63
NH	0.48	3.03	1.66	1.63
CH	22.60	49.10	45.15	44.53
CH/NH	13.90	97.20	26.60	31.14

Abiom	64.52	1224	308.32	341.91
NDF/CP	2.15	17.20	4.77	5.71
ADL/NH	0.50	14.02	3.92	4.78

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17 Table S3: Chemical composition of herbage samples used for NIRS calibration. DM: dry matter;
 18 MM: mineral matter or ash content; CP: crude protein; NDF: neutro-detergent fibre; ADF: acid-
 19 detergent fibre; ADL: acid-detergent lignin; NH: nitrogen in the herbage; CH: carbon in the
 20 herbage.

Parameter, %	N	Min.	Max.	Mean	SD
DM	67	91.60	96.73	93.48	1.39
MM (Ash)	67	3.58	19.73	10.10	3.98
CP	67	5.50	14.67	9.29	1.90
NDF	67	36.82	73.11	55.42	9.27
ADF	67	21.95	41.97	30.00	4.70
ADL	67	3.35	12.52	6.18	2.08
NH	55	0.75	2.10	1.44	0.31
CH	55	36.83	51.13	45.10	2.99

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22 Table S4: Calibration and cross validation statistics for predicting the chemical composition
 23 parameters in herbage samples by NIRS analysis. DM: dry matter; MM: mineral matter or ash
 24 content; CP: crude protein; NDF: neutro-detergent fibre; ADF: acid-detergent fibre; ADL: acid-
 25 detergent lignin; NH: nitrogen in the herbage; CH: carbon in the herbage.

Parameter	Math ^a treatment	Scatter ^b correction	R ²	r ²	SEC	SECV	RPD
DM	2,4,4,1	DT	0.92	0.85	0.392	0.539	2.58
Ash	2,4,4,1	MSC	0.83	0.70	1.583	0.830	4.80
CP	2,4,4,1	SNV	0.97	0.94	0.331	0.451	4.21
NDF	2,4,4,1	DT	0.83	0.72	3.756	4.728	1.96

ADF	2,4,4,1	DT	0.81	0.70	2.031	2.548	1.84
ADL	2,4,4,1	MSC	0.80	0.66	0.900	1.178	1.77
N	2,4,4,1	MSC	0.97	0.95	0.055	0.068	4.56
C	2,4,4,1	MSC	0.97	0.95	0.422	0.581	5.15

26 ^aDesignations: derivate order, gap, first smoothing, and second smoothing; ^bStandard Normal
 27 Variance (SNV), Detrend (DT) and Multiplicative Scattering Correction (MSC) transformations.

28 R^2 = coefficient of determination for calibration. r^2 = coefficient of determination for cross
 29 validation. SEC = standard error of calibration. SECV = standard error of cross validation. RPD = ratio
 30 of performance to deviation (RPD=SD/SECV).

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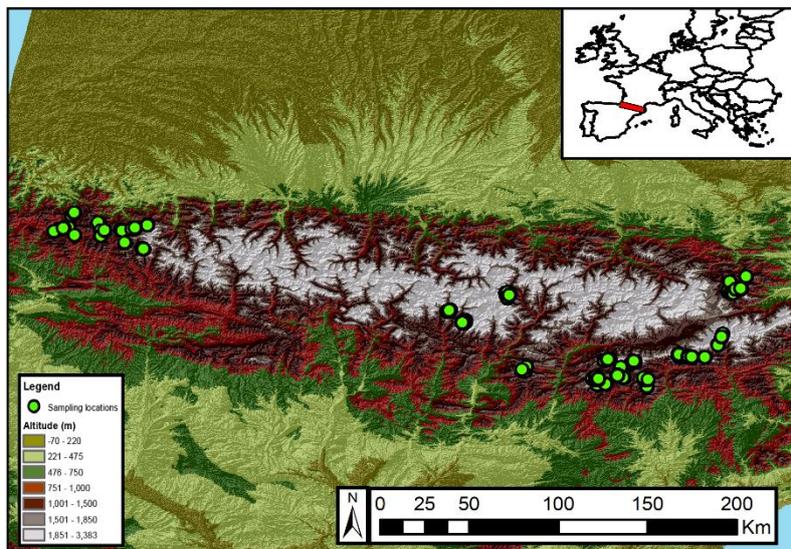
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33 Table S5: Variance inflation values for the continuous predictors included in the GLMs. Values
 34 under 5 are considered non-problematic (Heiberger, 2017). MAP: mean annual precipitation;
 35 TSIS: mean summer temperature minus mean annual temperature; Slope: terrain slope; Clay:
 36 clay content; Soil C/N: soil carbon to nitrogen ratio; soil N: soil nitrogen; NDF: neutro-
 37 detergent fibre; ADL/NH: acid-detergent lignin to nitrogen in the herbage ratio.

Predictor	MAP	MMT	Slope	Clay	Log(soil C/N)	Soil N	NDF	ADL/NH
Geophysical model	1.26	1.16	1.27	1.22	-	-	-	-
Complete model	-	1.26	1.32	-	1.58	1.82	1.32	1.67

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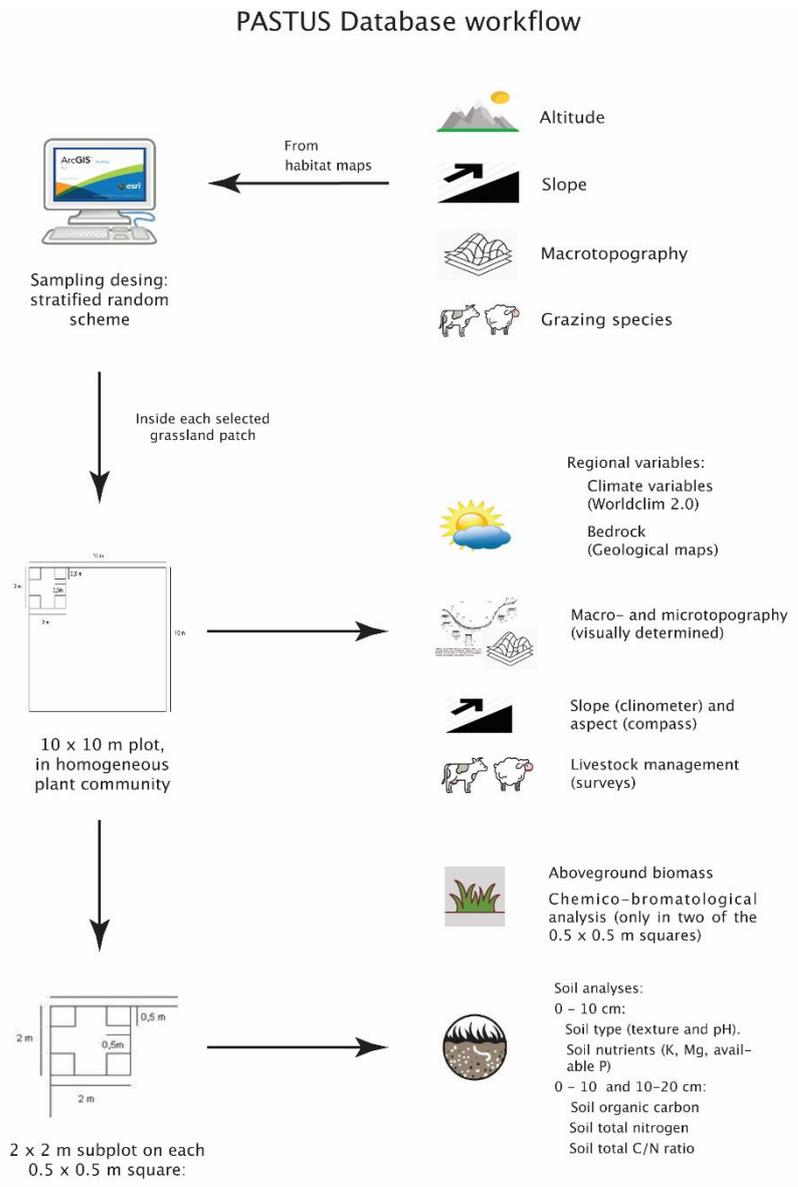


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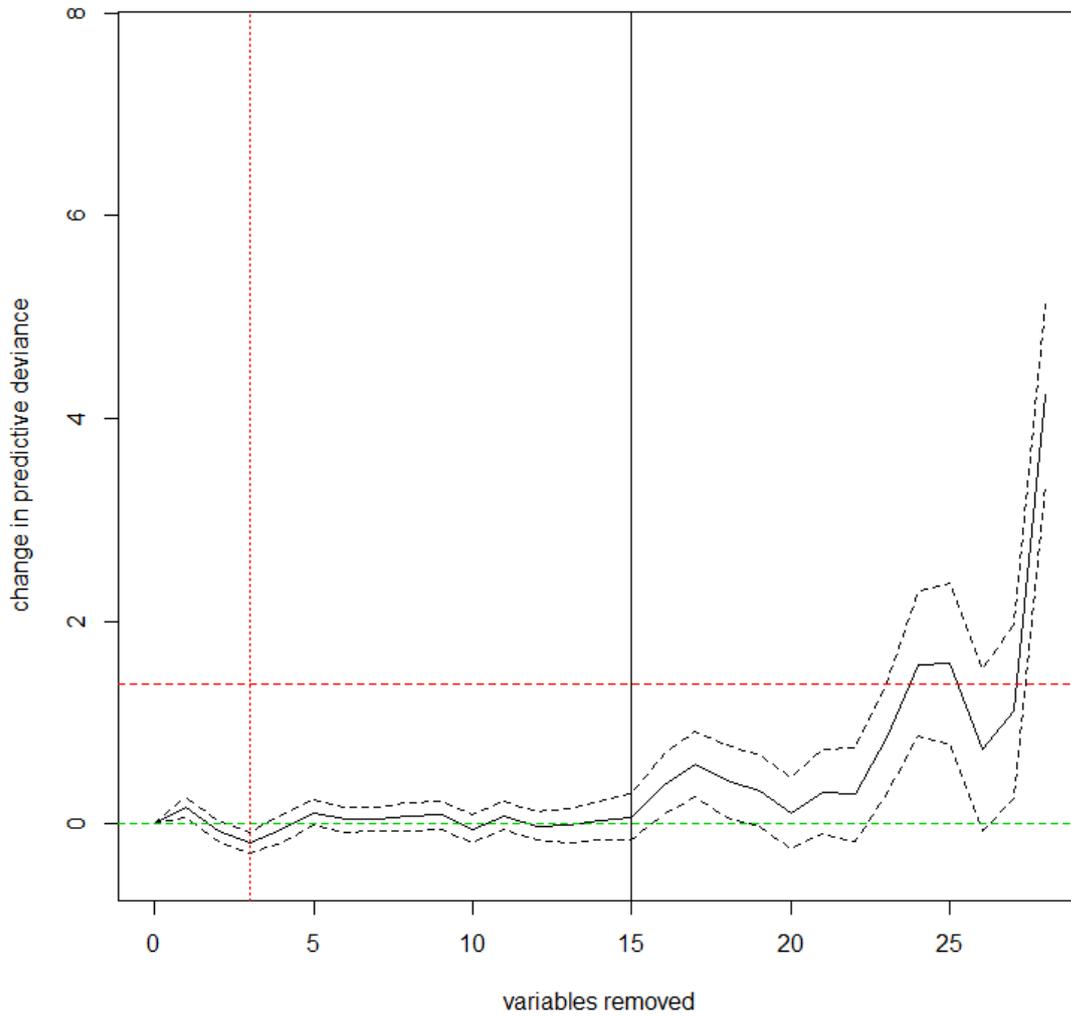
41 Figure S1: Map of the study area. Points indicate sampling locations.

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43 Figure S2: Scheme of the sampling procedure for building the PASTUS database



RFE deviance - SOC20 - folds = 100



44 Figure S3: Changes in the predictive deviance of BRT models by backward removal of its
45 predictors. The solid line indicates the mean change in predictive deviance, and the dotted line
46 the standard error, calculated over the 10 folds of the cross-validation. Solid vertical line
47 indicates the variables removed for the second fit. Dotted vertical line indicates minimum
48 change in predictive deviance. Dotted horizontal line indicates mean change in predictive
49 deviance.

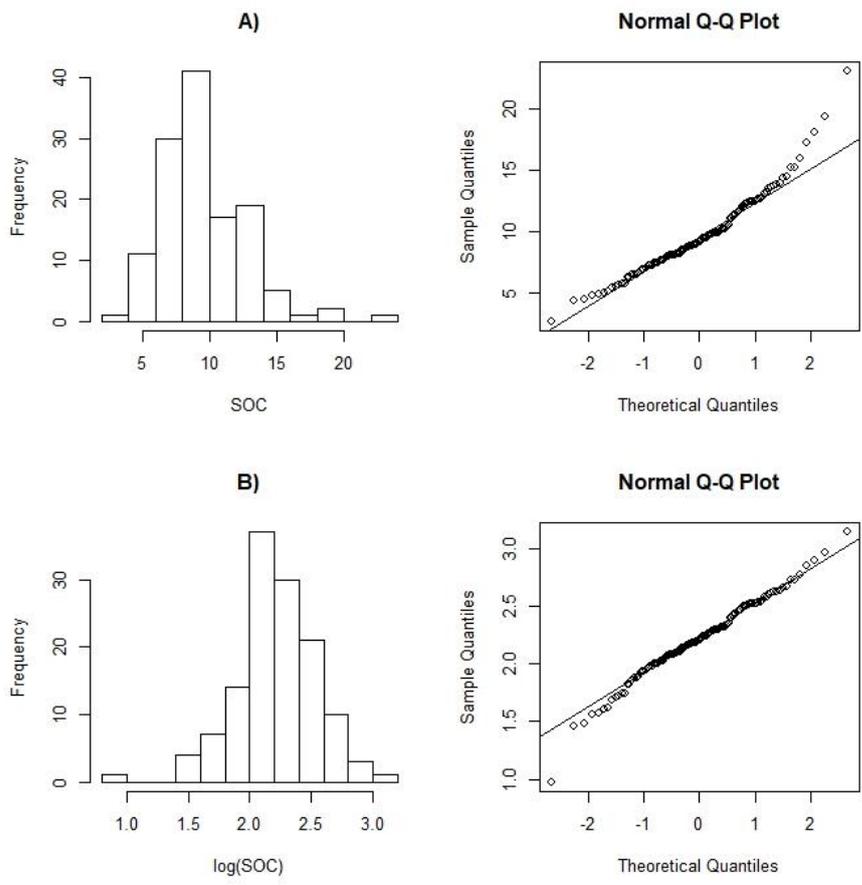
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56 Figure S4: Histogram and normal Q-Q plot of A) SOC and B) log(SOC). Result of Shapiro Wilk W

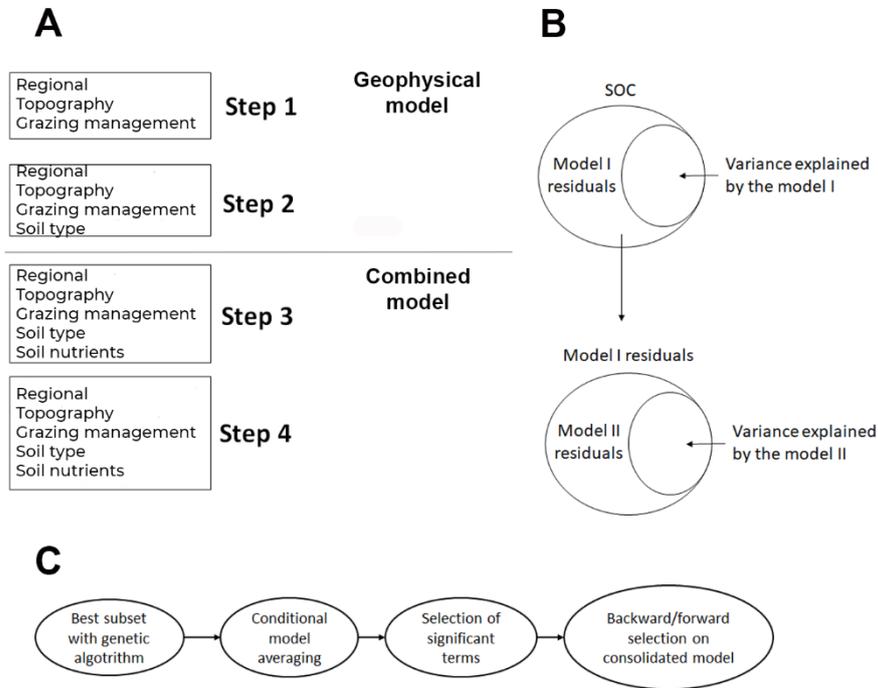
57 test result were $W = 0.948$; $p\text{-value} < 0.001$ and $W = 0.99$; $p\text{-value} = 0.18$ respectively. SOC: soil

58 organic carbon.

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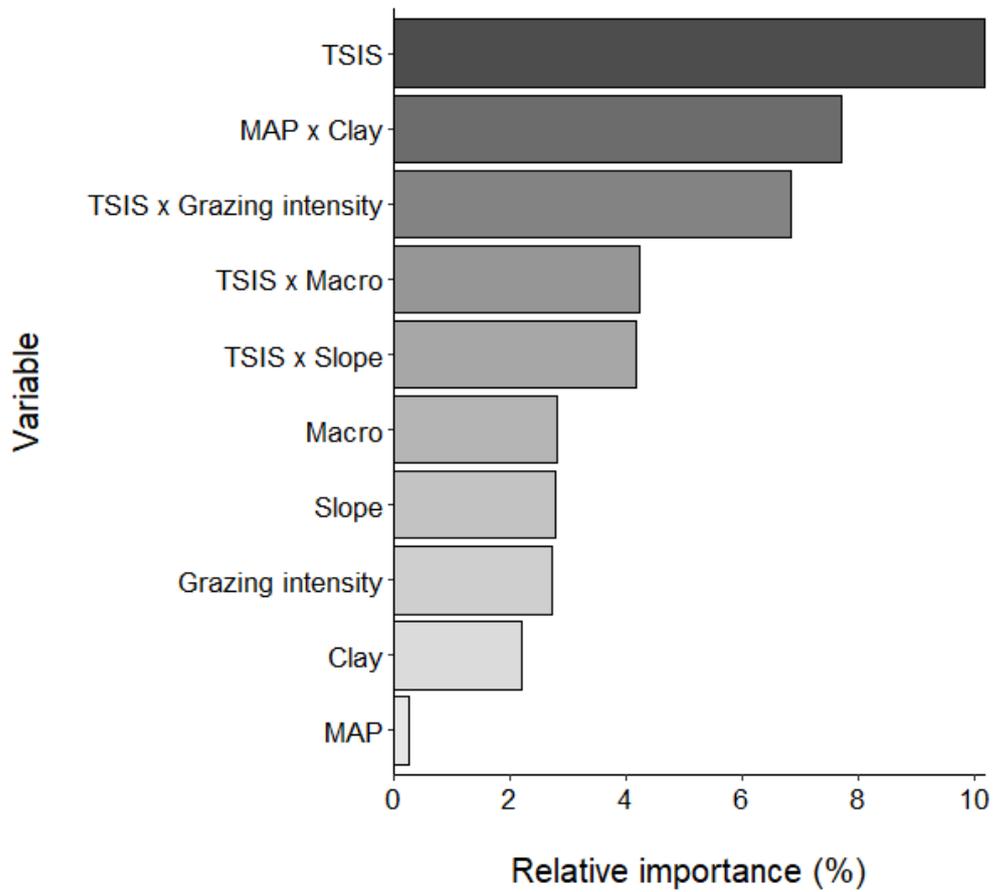


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63 Figure S5: Linear modelling procedure. A) Variables introduced in each step. The first linear
 64 model (Geophysical model) is fitted until Step 2 and the second linear model (Complete
 65 Model) is fitted until Step 4. B) For selecting the candidate predictor terms on each step,
 66 residuals of the model obtained in the previous step are used as response variables in C. C)
 67 Procedure to select candidate terms on each step. First, genetic algorithm was used to obtain a
 68 set of best models. Second, these models were averaged and the significant terms were
 69 selected as candidates for backward forward selection in the main/consolidated model.

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73 Figure S6: Relative contributions of variable groups in the linear model explaining Soil Organic

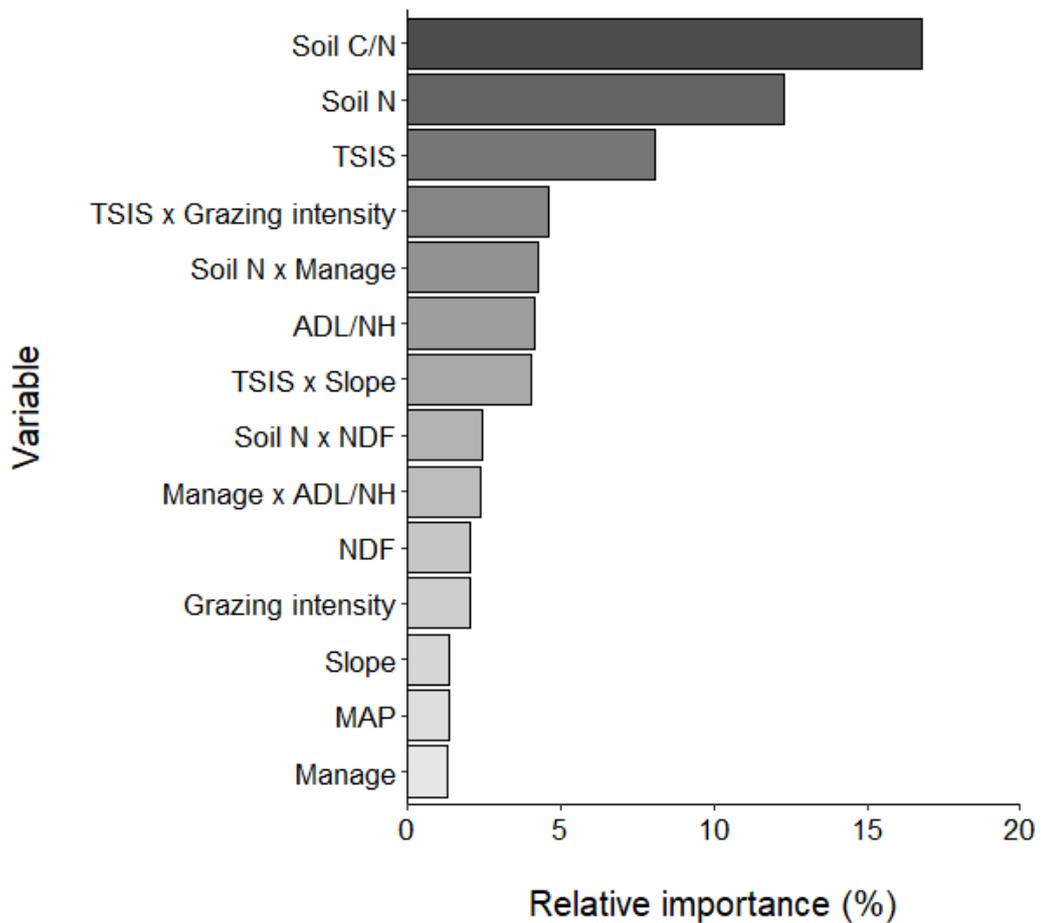
74 Carbon, using regional, landscape and management predictors. MAP: mean annual

75 precipitation; TSIS: mean summer temperature minus mean annual temperature; Slope:

76 terrain slope; Exposed: Exposed position according to Macrotopography; Clay: clay content;

77 Low and medium intensity: Low and medium intensity according to Grazing intensity.

78



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80 Figure S7: Relative contributions of variable groups in the linear model explaining Soil Organic

81 Carbon using regional, landscape, management and biochemical predictors. MAP: mean

82 annual precipitation; TSIS: mean summer temperature minus mean annual temperature;

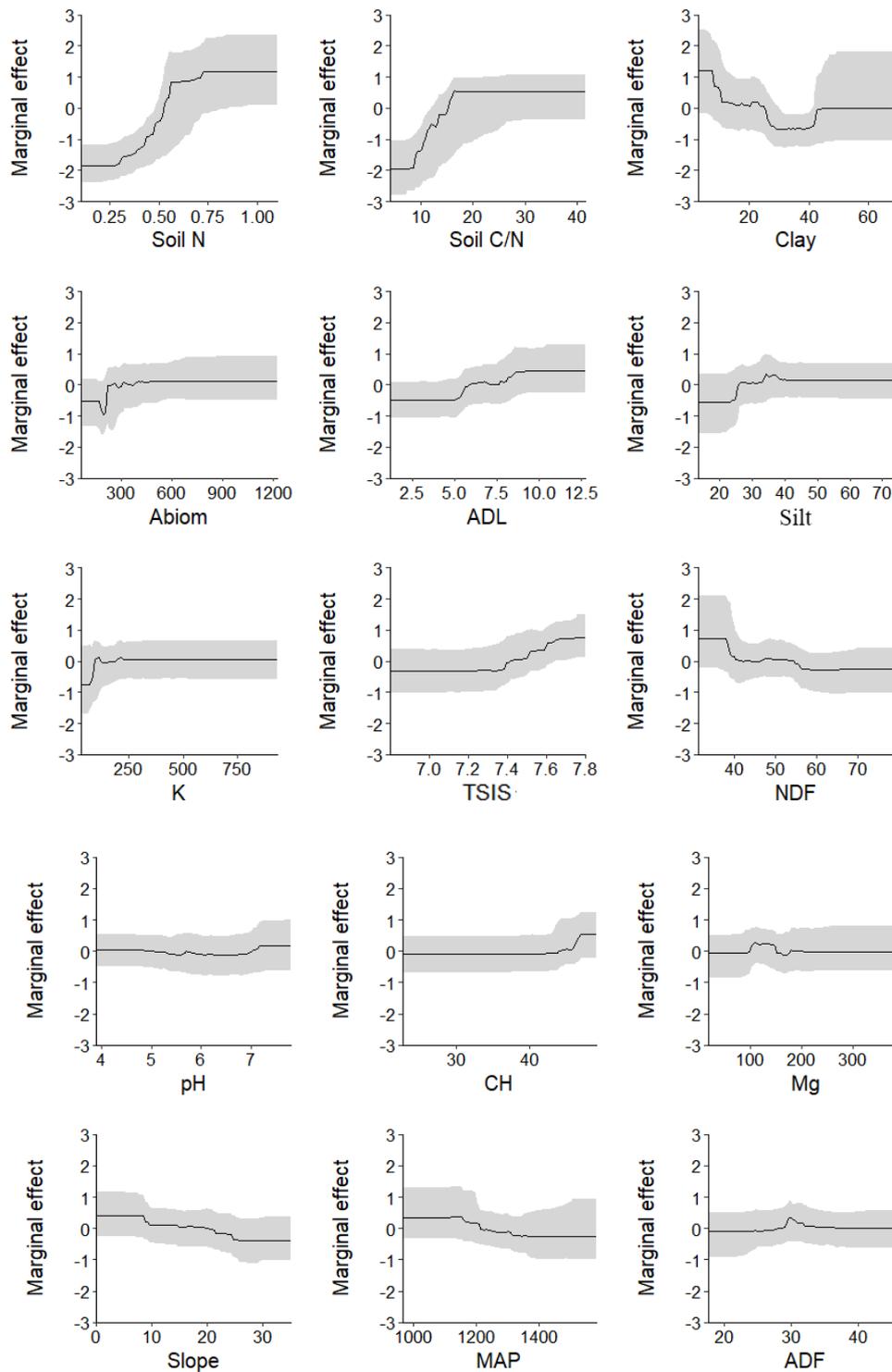
83 Slope: terrain slope; Cattle and Mixed: Cattle and mixed management according to grazing

84 species; Low and medium intensity: Low and medium intensity according to Grazing intensity;

85 Soil C/N: soil carbon to nitrogen ratio; soil N: soil nitrogen; NDF: neutro-detergent fibre;

86 ADL/NH: acid-detergent lignin to nitrogen in the herbage ratio.

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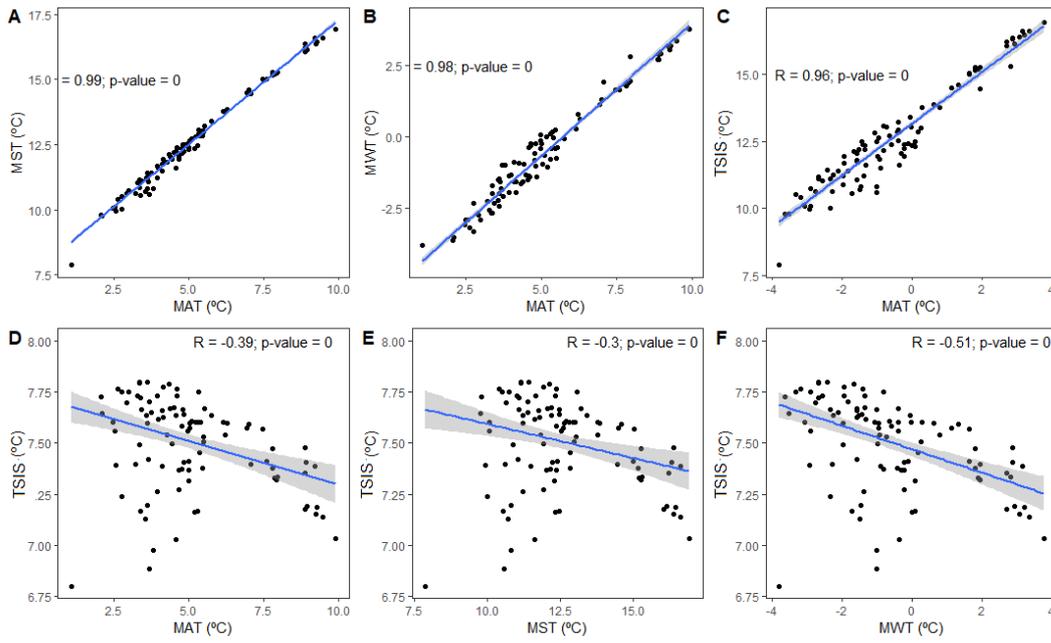


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89 Figure S8: Partial dependence plots for the 15 selected predictors in the BRT model. Y axes are
 90 centred to have zero mean over data distribution. Values (solid lines) are predictions of the
 91 model across the predictor's range maintaining the rest of the predictors at their average
 92 values. Grey areas around prediction lines indicate 95% bootstrap confidence intervals. Soil N:
 93 soil nitrogen; Soil C/N: soil carbon to nitrogen ratio, Clay: clay content; Abiom: aboveground

94 biomass; ADL: acid-detergent lignin; Silt: silt content; K: soil potassium; TSIS: mean summer
95 temperature minus mean annual temperature; NDF: neutro-detergent fibre; pH: soil pH; CH:
96 carbon in the herbage; Mg: soil magnesium; Slope: terrain slope; MAP: mean annual
97 precipitation; ADF: acid detergent fibre. See Table S1 for more details about variables.

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100 Figure S9: Pairwise Pearson's correlations between climate variables. MST: mean summer
 101 temperature; MWT: mean winter temperature; MAT: mean annual temperature; TSIS: inter-
 102 annual seasonality measured as MST-MAT.