Supplementary material

Manuscript: Carrascosa, A., Moreno, M.F. Cotrufo, C. Frade, G., Rodrigo, S., Rolo, V. *Improved management increases soil mineral-protected organic carbon storage via plant-microbial-nutrient mediation in semi-arid grasslands*

Table S1. Paddocks management characteristics.

Farm	Management	Paddock size (Ha)	Year of sowing	Days of grazing per year	Periods of grazing	Mean annual stocking rate (LU ha^{-1})
Sa-1	Ab	0.84		0	0	0.00
Sa-1	Ct	7.38		188	1	0.84
Sa-1	Ro	2.68		84	4	0.91
Sa-1	Ct2	55.50		305	1	0.55
Sa-1	Yl	55.50	2019	305	1	0.55
Sa-1	Ol	67.50	2007	305	1	0.55
Sa-2	Ab	0.02		0	0	0.00
Sa-2	Ro	3.50		24	1	0.44
Sa-2	Ct	48.00		335	1	0.62
Sa-2	Yl	8.34	2017	185	2	0.31
Sa-2	Ol	34.00	2011	185	2	0.31
Sa-3	Ab	0.02		0	0	0.00
Sa-3	Ct	45.00		185	1	0.43
Sa-3	Ro	0.98		145	1	0.52
Sa-3	Ct2	18.97		275	1	0.50
Sa-3	Yl	22.76	2019	185	2	0.50
Sa-3	Ol	13.89	2007	185	2	0.50
Ba-1	Ab	1.30		0	0	0.00
Ba-1	Ct	12.20		95	3	0.36
Ba-1	Yl	44.35	2019	260	2	0.49
Ba-1	Ol	52.50	2010	185	2	0.35
Ba-1	Ro	3.70		23	5	0.33
Ba-2	Ab	141.00		0	0	0.00
Ba-2	Ct	77.34		185	1	0.38
Ba-2	Yl	69.95	2020	185	2	0.36
Ba-2	Ol	61.69	2011	185	2	0.36
Ba-2	Ro	10.64		110	2	0.46
Ba-3	Ab	7.00		0	0	0.00
Ba-3	Ct	43.00		150	2	0.50
Ba-3	Yl	30.00	2016	45	3	0.37
Ba-3	Ol	5.00	2006	30	3	0.44
Ba-3	Ro	15.00		7	1	0.36
Cc-1	Ab	0.61		0	0	0.00
Cc-1	Ct	70.00		275	1	0.50
Cc-1	Yl	23.00	2019	180	2	0.64
Cc-1	Ol	65.00	2003	155	4	0.70
Cc-1	Ro	1.19		45	6	0.74
Cc-2	Ab	0.52		0	0	0.00
Cc-2	Ct	35.00		335	1	0.49
Cc-2	Yl	60.00	2016	265	1	0.41
Cc-2	Ol	50.00	2004	265	1	0.49
Cc-2	Ro	5.76		130	1	0.50
Cc-3	Ab	0.88		0	0	0.00

Cc-3	Ct	46.91		265	1	0.52
Cc-3	Yl	14.00	2018	17	2	0.49
Cc-3	Ol	15.49	2009	17	2	0.49
Cc-3	Ro	3.64		15	2	0.50

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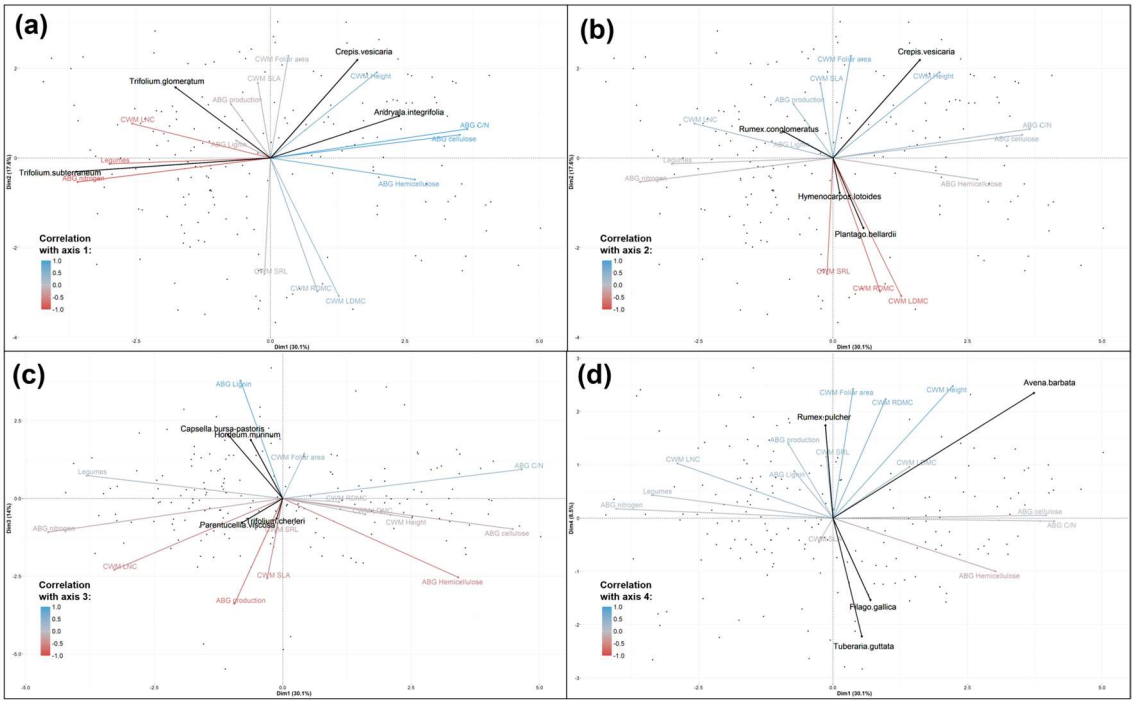

Figure S1. Indicative species of the axis 1 "C/N axis" (a), axis 2 "Plant economic spectrum axis" (b), axis 3 "Lignin axis" (c) and axis 4 "Size axis" (d) of the vegetation attributes principal components analysis (PCA). The correlation between the vegetation attributes included in the PCA and the axis is indicated by the blue-red colour gradient. The direction and magnitude of the black arrows for plant species indicate the correlation of their relative abundance and the values of each axis in the communities.

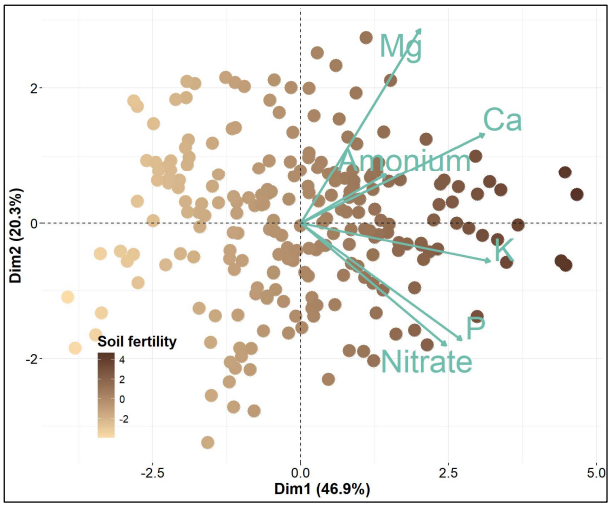

Figure S2. Representation of the 2 first axis of the principal components analysis (PCA) summarizing nutrient (Mg, Ca, K, P, Nitrate and Ammonium) stocks in all sampled soils. The colours of the dots represent the soil fertility index value for each sample.

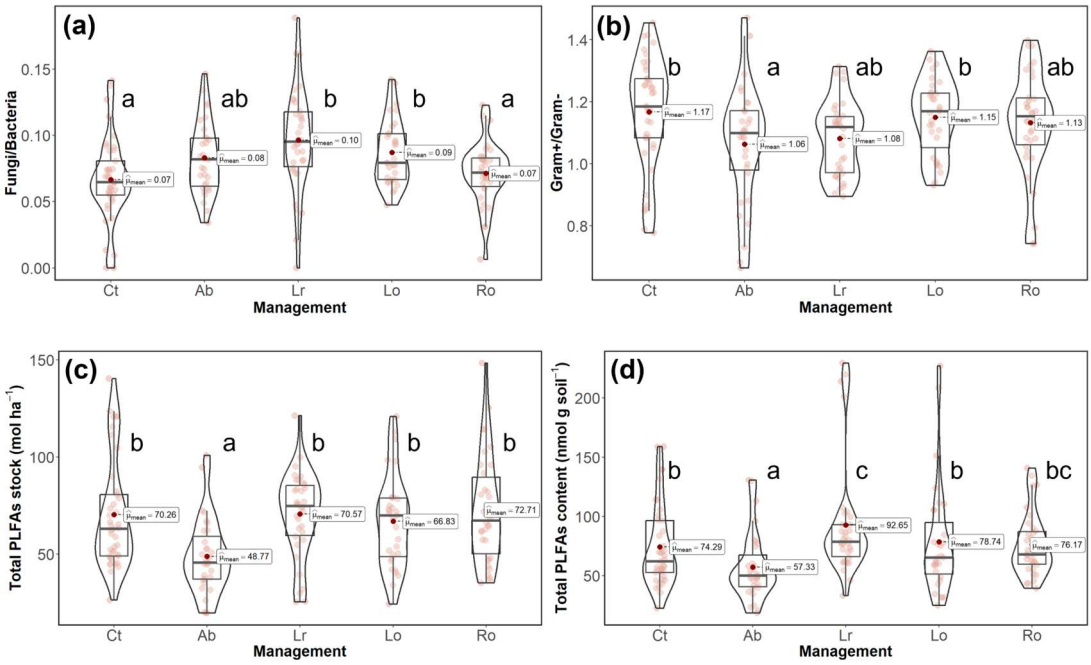

Figure S3. Violin plot and boxplot (with median and quartiles) for the (a) fungi to bacteria phospholipid fatty acids (PLFAs) abundance ratio (Fungi/Bacteria), (b) Gram+ to Gram- PLFAs abundance ratio (Gram+/Gram-), (c) total PLFAs (as an estimate of total microbial biomass) stocks (according Equation 1 in the main text), and (d) total PLFAs content in each management (Ct = Continuous grazing; Ab = grazing abandonment; Lr = Recent legume sowing; Lo = old legume sowing; Ro = Rotational grazing). Labels and red dots indicate mean value. Lower case letters indicate significant differences ($p < 0.05$) between managements according ANOVA testing.

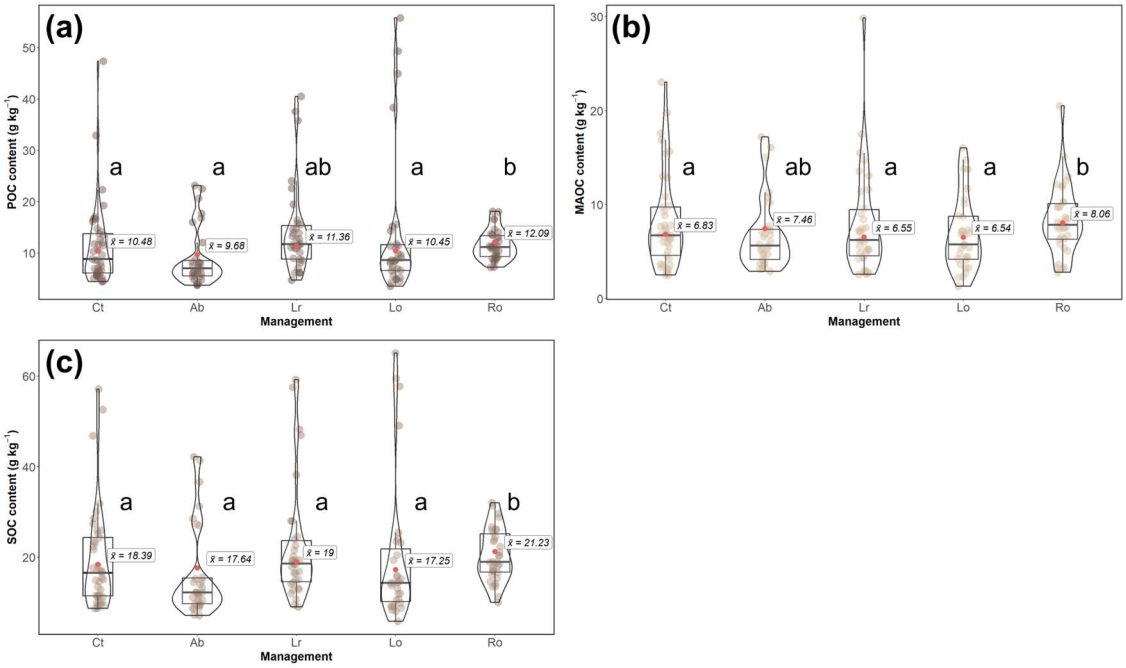

Figure S4. Violin plot and boxplot (with median and quartiles) for the (a) particulate organic carbon (POC), (b) mineral-associated organic carbon (MAOC), and (c) soil organic carbon (SOC) contents (in g of carbon per kg of soil) in each management. Managements acronyms are as in Figure S3. The red point and the label indicate mean values predicted by the structure equation model. Lower case letters indicate significant differences ($p < 0.05$) between managements.

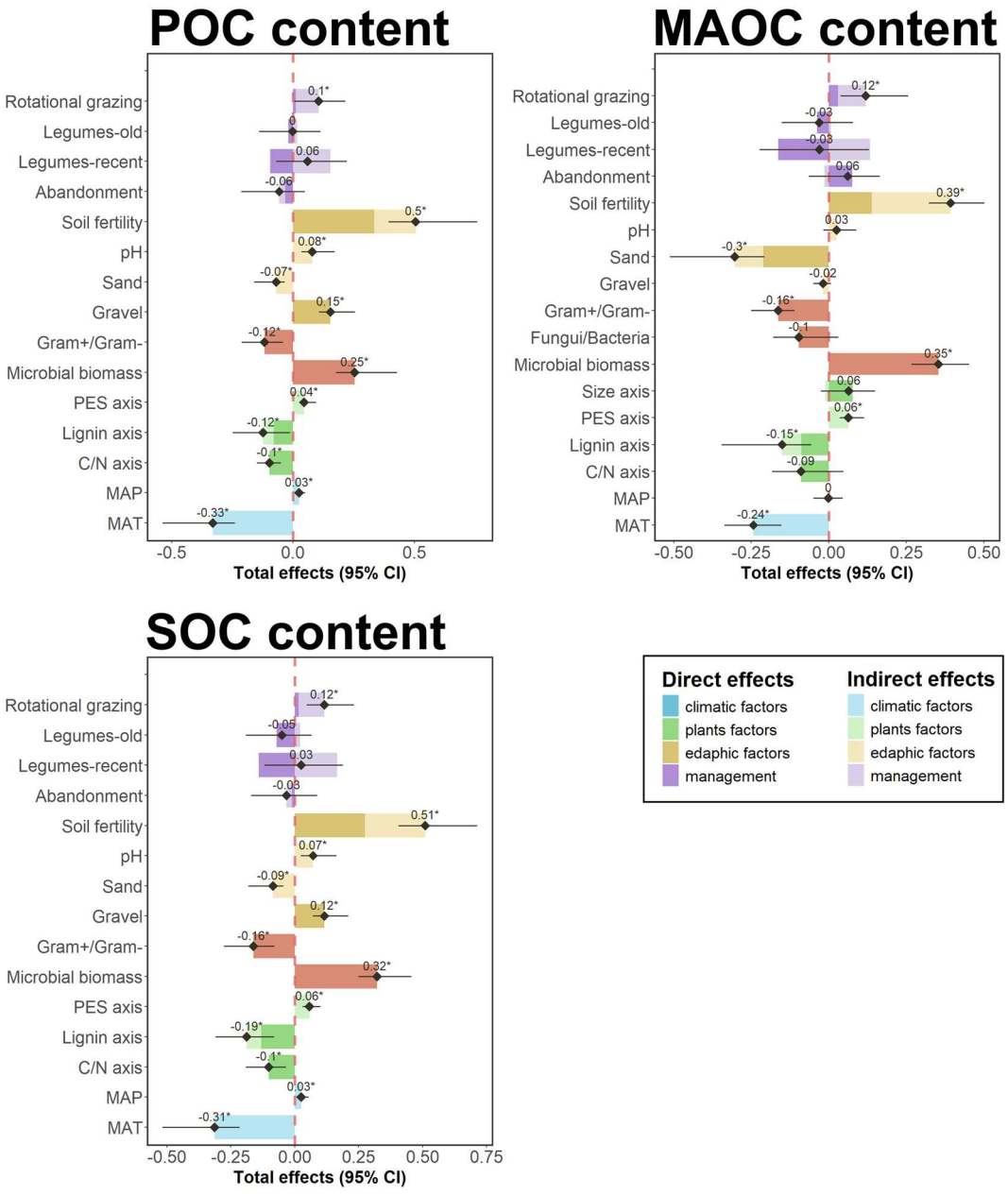

Figure S5. Direct, indirect and total standardized effects of all studied variables included in the structural equation model over the (a) particulate organic carbon (POC), (b) mineral-associated organic carbon (MAOC), and (c) soil organic carbon (SOC) contents. Bars indicate direct (dark colors) and indirect (light colors) effects, and the black points-ranges indicate the total (i.e. direct + indirect) effect (with its 95% confidence interval). Stars over the total effect values indicate significant effects at a level of 0.05.

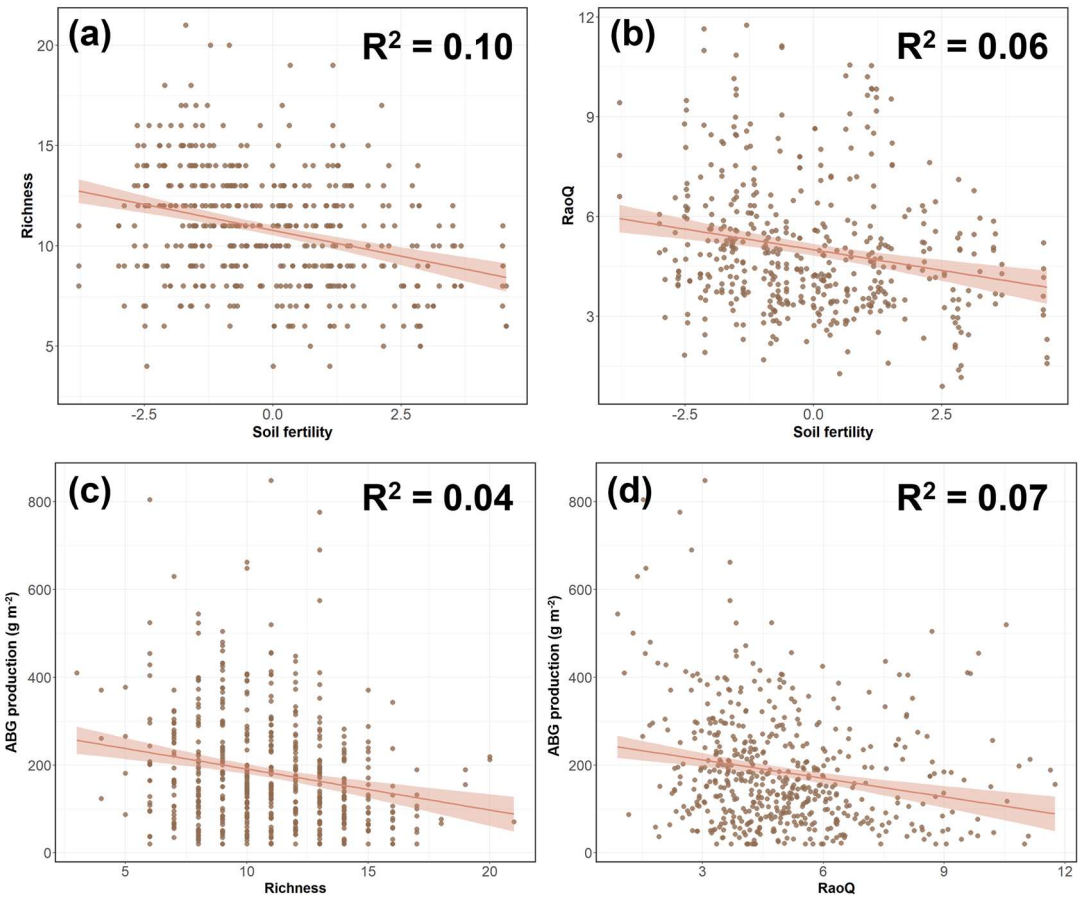

Figure S6. Relations between (a and b) the soil fertility index and the taxonomic (species richness) and functional diversity indicators (RaoQ index), and (c and d) the taxonomic and functional diversity indicators and the above-ground biomass production (ABG production) with data for the entire study period (2021 to 2023). The red lines and ribbons indicate the slopes and confidence intervals fitted by the linear models. The proportion of variance (R2) explained by the models is presented in the upper right corner of each panel.