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RUSTICA
Demonstration of circular bio-based fertilisers and implementation of optimized fertiliser strategies and value chains in rural communities

Evaluating the impact of novel biobased fertilisers on soil carbon sequestration integrating laboratory short-term mineralization and modeling

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Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria

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INTRODUCTION

The shift toward circular food economies and sustainable agriculture promotes the recycling of exogenous organic matter (EOM) into **biobased fertilisers (BBFs)**, reducing reliance on synthetic fertilisers. However, **the long-term impacts of BBFs** on soil organic matter are unclear. This study models the impact of novel BBFs (e.g., microbial and insect biomass, frass, biochar, and derived blends, Fig. 1) produced in the framework of H2020 project RUSTICA on soil carbon storage using a **modified RothC model** with kinetic paramenters calibrated from **laboratory cumulative respiration of amended soil.**

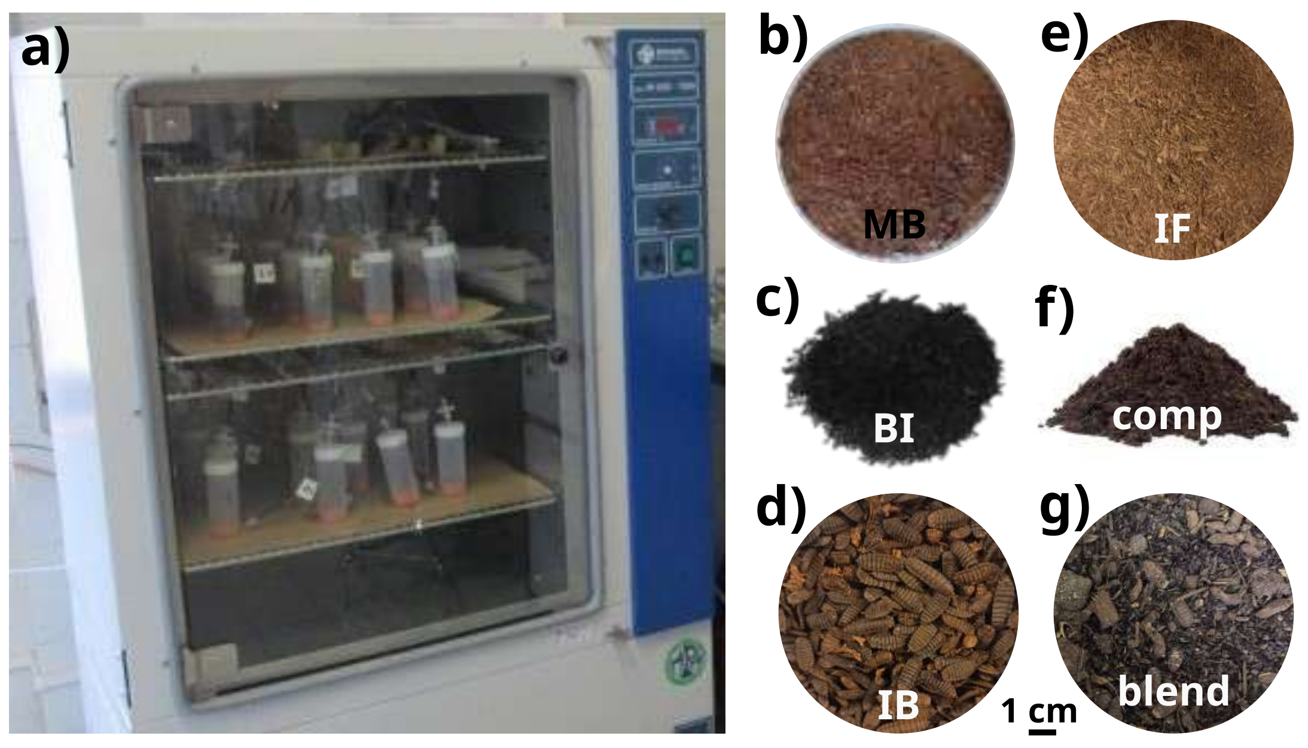


Figure 1 *(a) Thermostat with the incubation jars of the automated GC system. (b - g) BBFs before drying, grinding, and sieving at 1 mm.*

METHODS: Incubation and respiration modeling

50 g (oven-dry basis) **loam soil** from vine farm density of 1.41 t/m^3, 11.83% clay, 3 mm coarse, 40% WHC, preconditioned (4 days at 20°C)

+

0.5% (w:w) novel BBFs (Fig. 1b-e): microbial biomass (MB), biochar (BI), insect biomass (IB), insect frass (IF), or ***variable amount of blends*** (Fig. 1g and Fig. 3b) of BBFs with compost (Fig. 1f)

Soil triplicates were **incubated aerobically in sealed jars** for 30 days at 40% WHC and 20°C, with continuous aeration (15 ml/min) and measuring CO_2 every 4 hours.

Modeling: calibration of EOMs' kinetic parameters
The kinetic parameters of BBFs' and blends' EOM pools were determined using a modified Rothamsted carbon model (RothC)(Mondini et al. 2017), fitted to cumulative respiration data. This model includes three C pools: decomposable (DEOM), resistant (REOM), and humidified (HEOM), each with specific size and decomposition rate (fixed rate of 0.02 y^{-1} only for HEOM). The R package "DREAM" (Guillaume and Andrews, 2012) applied an MCMC approach to estimate the optimal kinetic parameters by inferring their probability density functions. Parameter ranges were informed by literature and refined for robustness, reducing the search to four key variables: DEOM size, repartition factor, and two decomposition rates (Fig. 3a, b).

NEW function for ROTHC model with EOM

DREAM DiffeRential Adaptive Metropolis

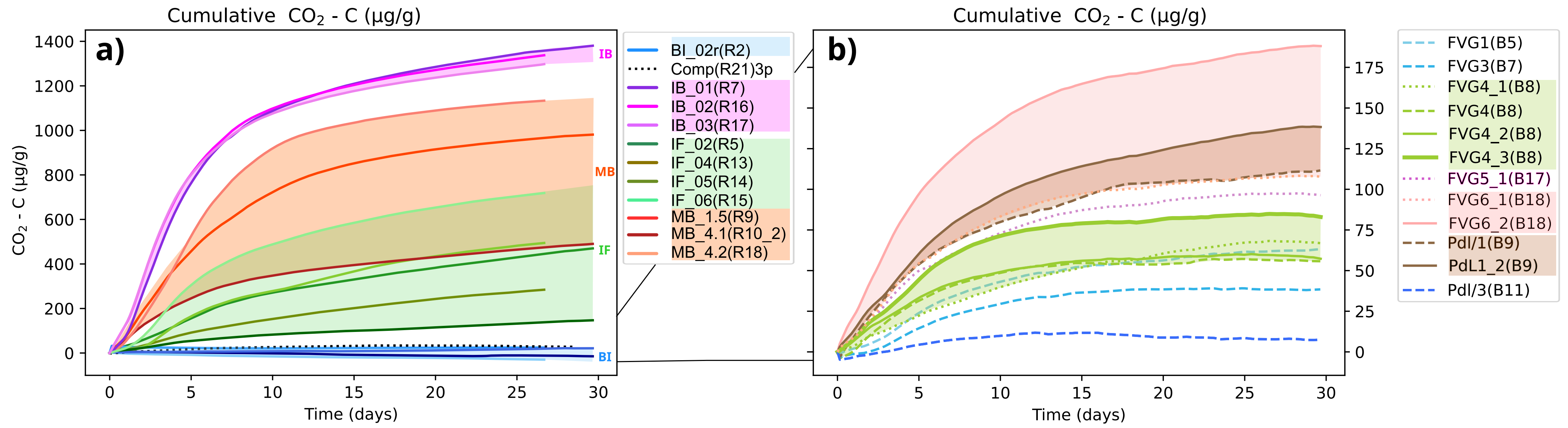
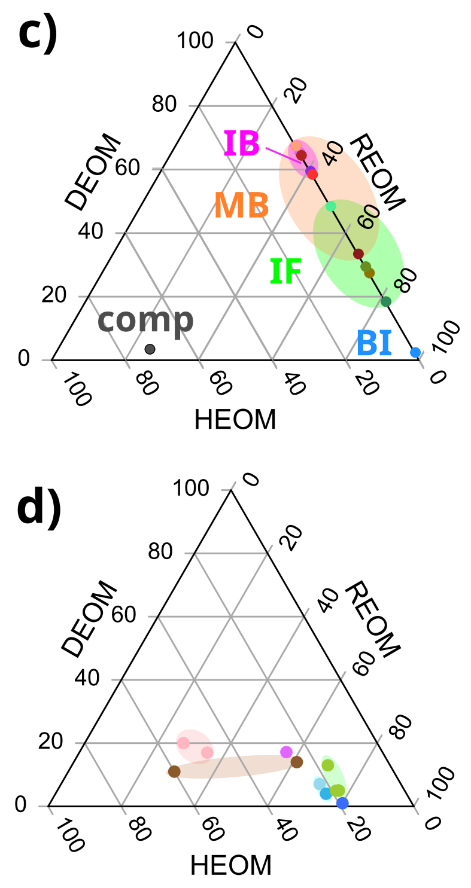


Figure 2 *Cumulative respiration during the 30-day incubation expressed as μg CO_2-C g soil^{-1}, for (a) single-component BBFs and (b) blends of BBFs and compost. Each curve is the result of outliers removal and averaging of three signals from three replicates*

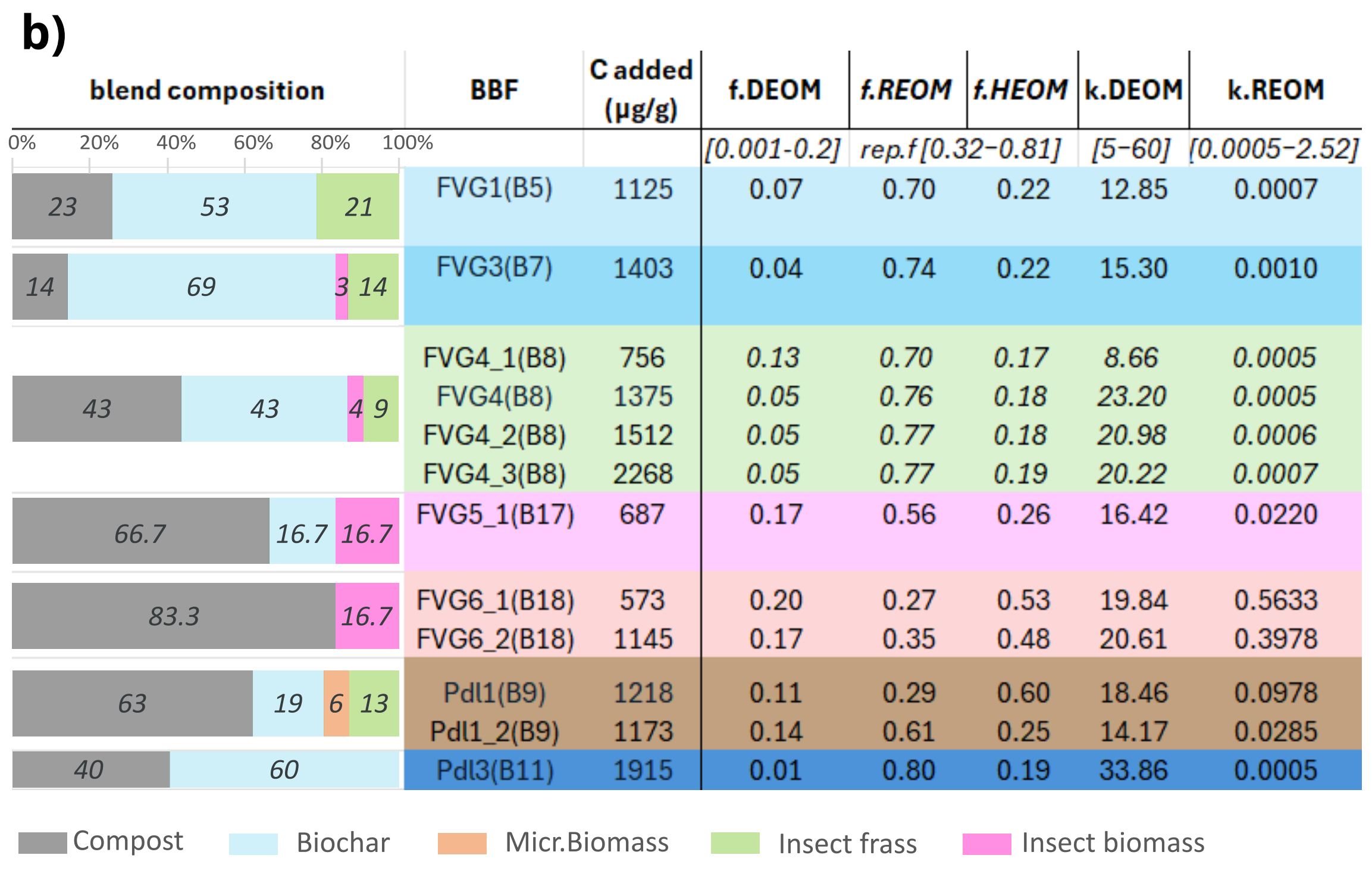
RESULTS: Calibration of kinetic parameters and long-term predictions of SOC

a)

group	type	BBF	C added (μg/g)	f.DEOM	f.REOM	f.HEOM	k.DEOM	k.REOM	feedstock
				[0.001-0.2]	rep.f [0.9999-1.]		[2.55-250]	[0.0001-2.52]	
BI	biochar	BI_02r(R2)	2278	0.02	0.98	0	5	0.0002	willow wood and peppers
				[0.01-0.1]	[0.2626−0.808]		[10-200]	[0.1-2]	
comp	compost	Comp(R21)	1055	0.03	0.25	0.71	29	0.10	urban compost
				[0.1-0.7]	rep.f [0.9999-1.]		[10-217]	[0.001-2]	
IB	insect larvae biomass	IB_01(R7)	2832	0.59	0.41	0	19	0.03	cereals
IB	insect larvae biomass	IB_02(R16)	2345	0.67	0.33	0	23	0.31	cereals
IB	insect larvae biomass	IB_03(R17)	2367	0.65	0.35	0	24	0.26	cereals
				[0.01-0.3]	rep.f [0.9999-1.]		[0-80]	[0.01-1]	
IF	hermetia insect frass	IF_02(R5)	2235	0.18	0.82	0	12	0.44	Bear bagasse
IF	hermetia insect frass	IF_04(R13)	1369	0.27	0.73	0	7	0.24	Broccoli plant
IF	hermetia insect frass	IF_05(R14)	1488	0.29	0.71	0	12	0.97	Vegetables mix
				[0.1-0.7]	rep.f [0.9999-1.]		[0-80]	[0.01-1]	
IF	hermetia insect frass	IF_06(R15)	1972	0.48	0.52		12	0.02	cereal
				[0.2-1.]	rep.f [0.9999-1.]		[10-217]	[0.010-2]	
MB	microbial biomass	MB_1.5(R9)	1208	0.33	0.67	0	27.54	1.211	Paprika
MB	microbial biomass	MB_4.1(R10_	2129	0.64	0.36	0	16.18	0.022	market waste
MB	microbial biomass	MB_4.2(R18)	2211	0.67	0.33	0	15.83	0.087	market waste: carrots



b)



blend composition	BBF	C added (μg/g)	f.DEOM	f.REOM	f.HEOM	k.DEOM	k.REOM
			[0.001-0.2]	rep.f [0.32−0.81]		[5−60]	[0.0005−2.52]
23 53 21	FVG1(B5)	1125	0.07	0.70	0.22	12.85	0.0007
14 69 3 14	FVG3(B7)	1403	0.04	0.74	0.22	15.30	0.0010
43 43 4 9	FVG4_1(B8)	756	0.13	0.70	0.17	8.66	0.0005
	FVG4(B8)	1375	0.05	0.76	0.18	23.20	0.0005
	FVG4_2(B8)	1512	0.05	0.77	0.18	20.98	0.0006
	FVG4_3(B8)	2268	0.05	0.77	0.19	20.22	0.0007
66.7 16.7 16.7	FVG5_1(B17)	687	0.17	0.56	0.26	16.42	0.0220
83.3 16.7	FVG6_1(B18)	573	0.20	0.27	0.53	19.84	0.5633
	FVG6_2(B18)	1145	0.17	0.35	0.48	20.61	0.3978
63 19 6 13	Pdl1(B9)	1218	0.11	0.29	0.60	18.46	0.0978
	Pdl1_2(B9)	1173	0.14	0.61	0.25	14.17	0.0285
40 60	Pdl3(B11)	1915	0.01	0.80	0.19	33.86	0.0005

All BBFs were modelled with two pools (Fig. 3a), except compost (three pools), and blends were modelled with three (Fig. 3b). ***BBFs:*** overlapping of pools' size, but distinct ranges for each BBF group (Fig. 3c), with low variability among IB, likely due to their uniform origin as larvae of Hermetia illucens, and greater variability in IF and MB groups, likely reflecting their diverse feedstocks (Fig. 3a).
Blends (Fig. 3d) with high biochar content cluster around high REOM values, while even a moderate amount (16.7%) of IB in the blend lowers the REOM values.

Increasing blend doses do not significantly affect parameter calibration, highlighting the stability of the calibration approach and the reliability of the respiration curves.

Figure 3 *(a, b) Tables showing estimated C-pool sizes and decay rates from DREAM, with parameter bounds in brackets, for (a) single-component BBFs and (b) blended BBFs. (c, d) Ternary plots illustrating BBF group distributions based on optimised C-pool sizes for (c) single-component and (d) blended BBFs (colour-coded as in panel b).*

Two long-term scenarios of soil amendment

Monthly averaged climate data (temperature, precipitation, and PET) of 30 years (1990-2010) and information about land management and soil coverage to take into account the conditions of typical vineyards in NE Italy.

1) single initial addition of 10 ton C/ha

10 ton C/ha

2) annual addition of 1 ton C/ha

1 ton C/ha/yr x 100

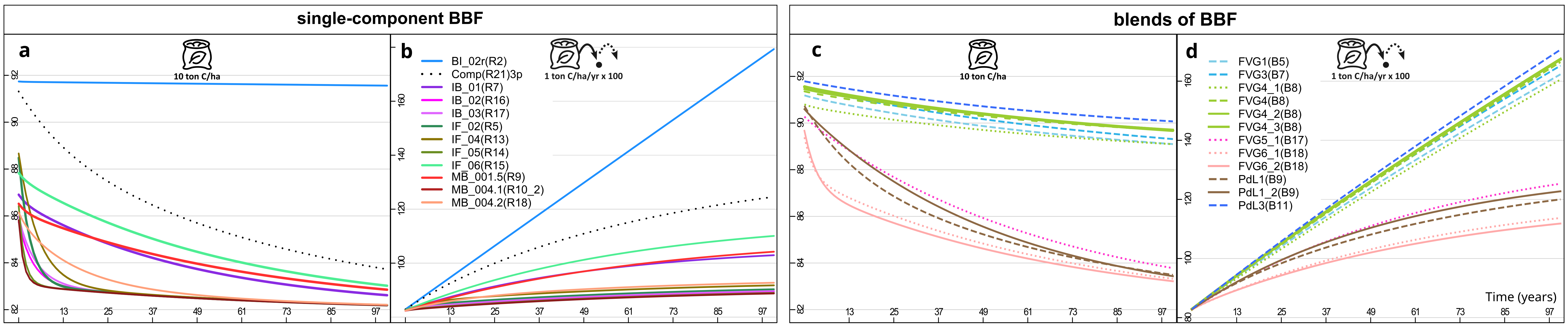


Figure 4 *Long-term SOC predictions for (a, b) single-component BBFs and (c, d) BBFs blends. (a, c) Single initial addition of 10 ton C/ha, (c, d) annual addition of 1 ton C/ha.*

DISCUSSION AND CONCLUSIONS

Single addition results show biochar's high stability, highlighting its effectiveness in soil C sequestration (Fig. 4a). In contrast, compost, insect biomass, frass, and microbial biomass degrade faster. Annual amendment simulations (Fig. 4b) show biochar increases SOC stocks by 119%, compost by 52%, while other BBFs sequester less C, but could provide additional soil benefits.

Blends with biochar show C retention varying from 13.1% to 82% after 100 years (Fig. 4c), depending on biochar content (0–60%). Biochar stabilizes degradable materials like IB and MB, boosting SOC accrual. Continuous annual amendment increases SOC stocks by 36% to 108%, correlating with biochar content ($r = 0.91$, $p < 0.05$) (Fig. 5).

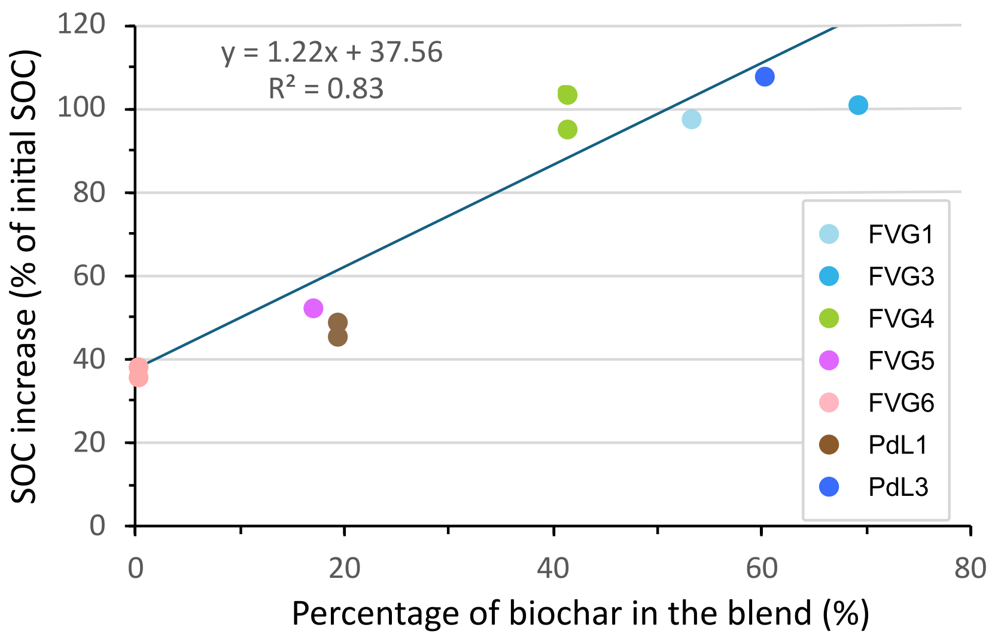


Figure 5 *SOC increase vs. % of biochar in the blend*

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