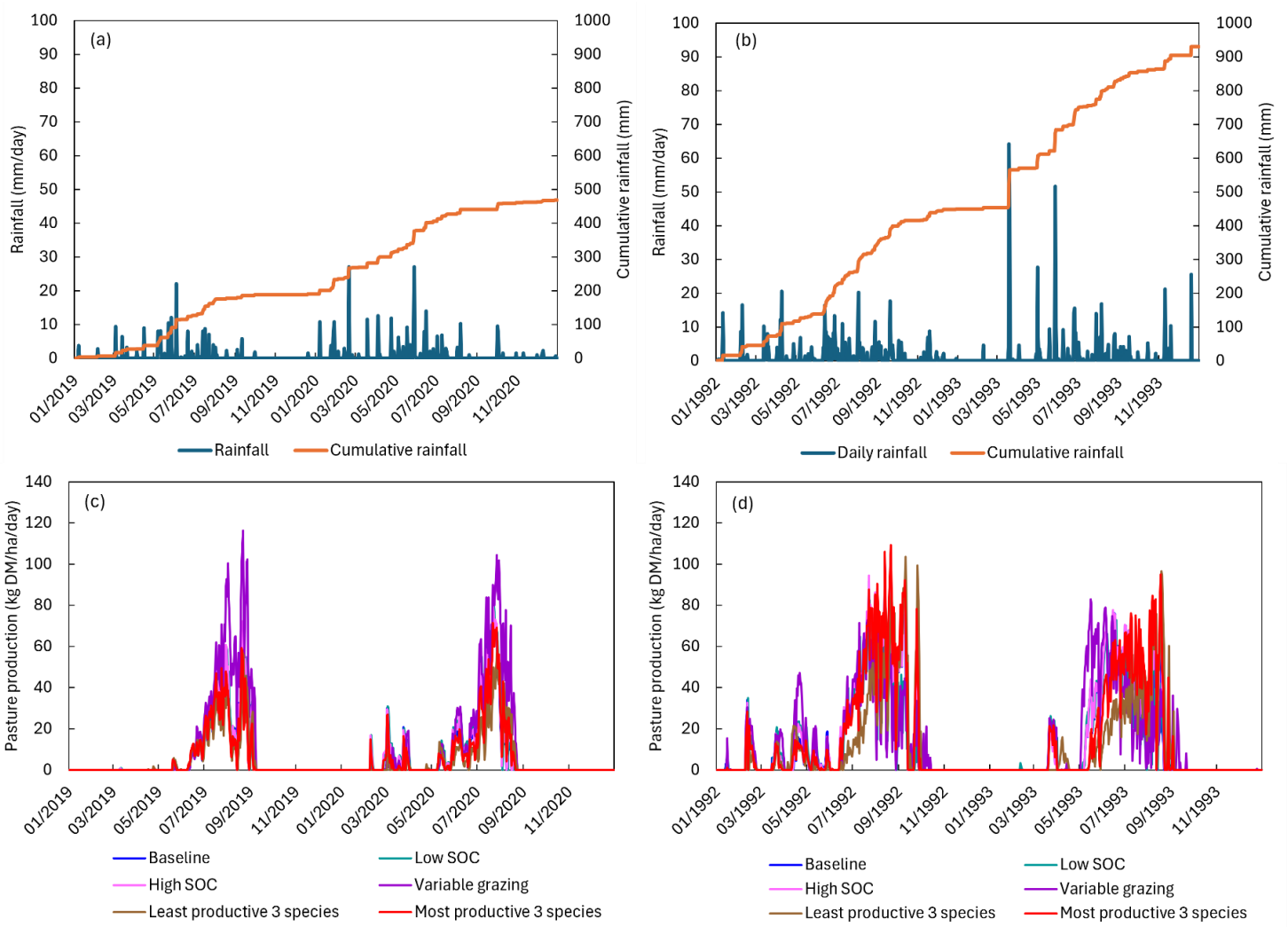
nature food

Supplementary information

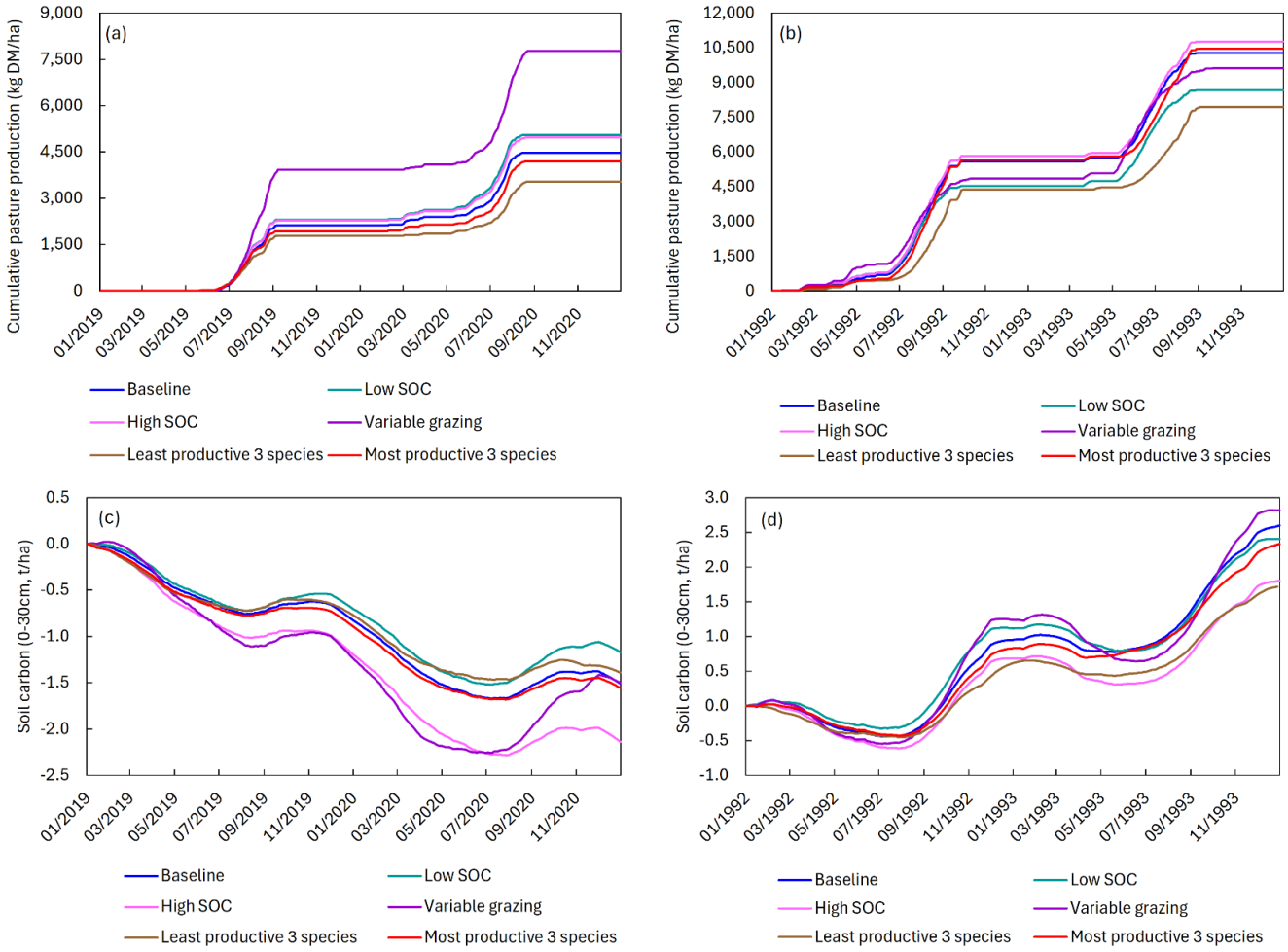
https://doi.org/10.1038/s43016-026-01331-2

Regenerative agriculture improves productivity and profitability while reducing greenhouse gas emissions on Australian sheep farms

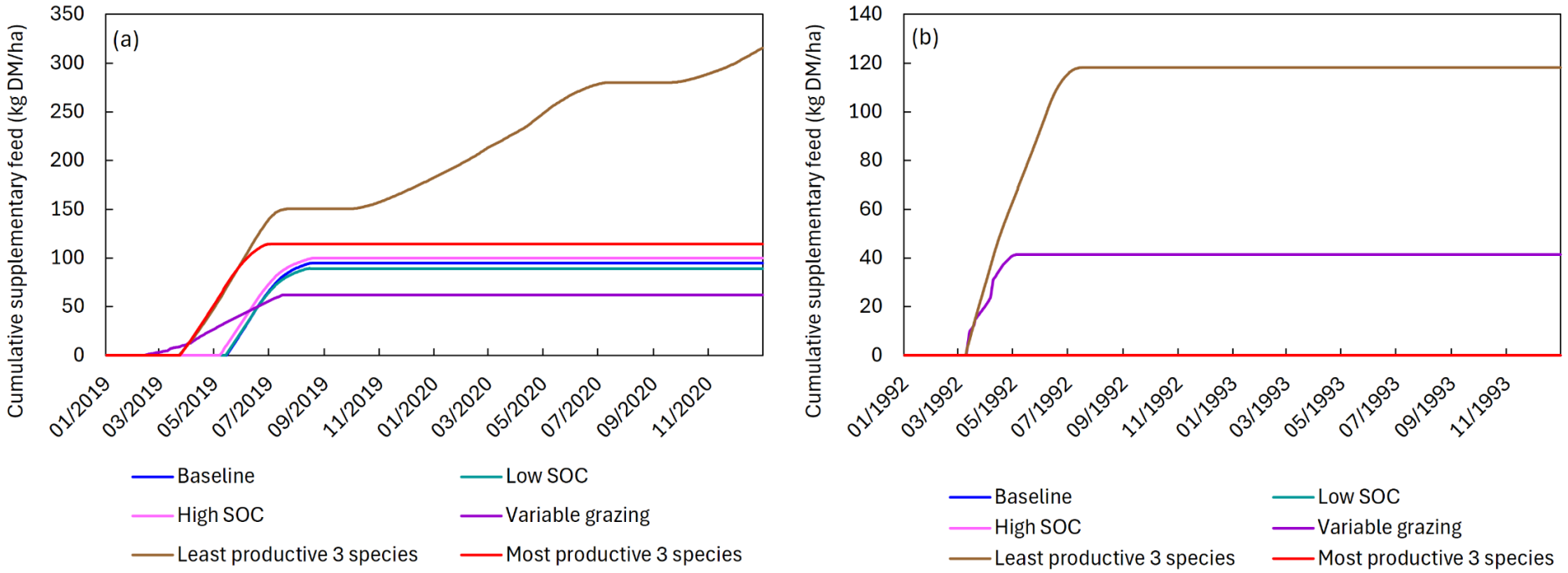
In the format provided by the authors and unedited



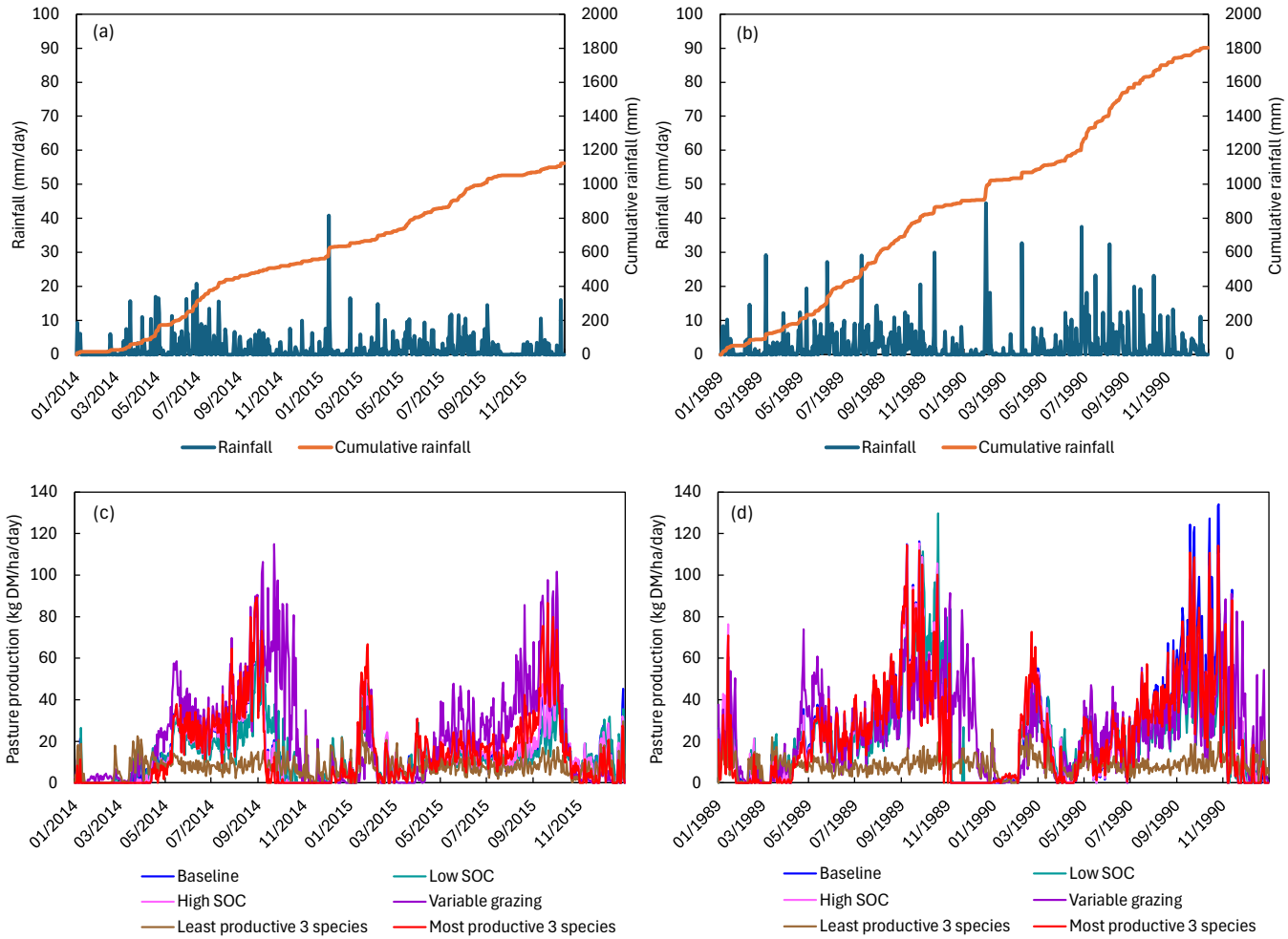
Supplementary Figure 1. Daily and cumulative rainfall and daily pasture production for farm F1 (long-term average rainfall 353 mm yr^{-1}) under very low rainfall (2019–20; left column) and very high rainfall (1992–93; right column). Upper panels show daily and cumulative rainfall (**a, b**), lower panels show daily pasture growth rates (**c, d**). Low and high rainfall periods averaged 231 mm yr^{-1} and 465 mm yr^{-1}, respectively. Baseline represents existing pasture species and set stocking; low/high SOC represent simulations initialised with low or high SOC concentrations; least/most productive species represent swards containing three species with lowest or highest average annual production for that location (see Methods). Horizontal axes show date (month/year). DM, dry matter; F, farm; SOC, soil organic carbon.



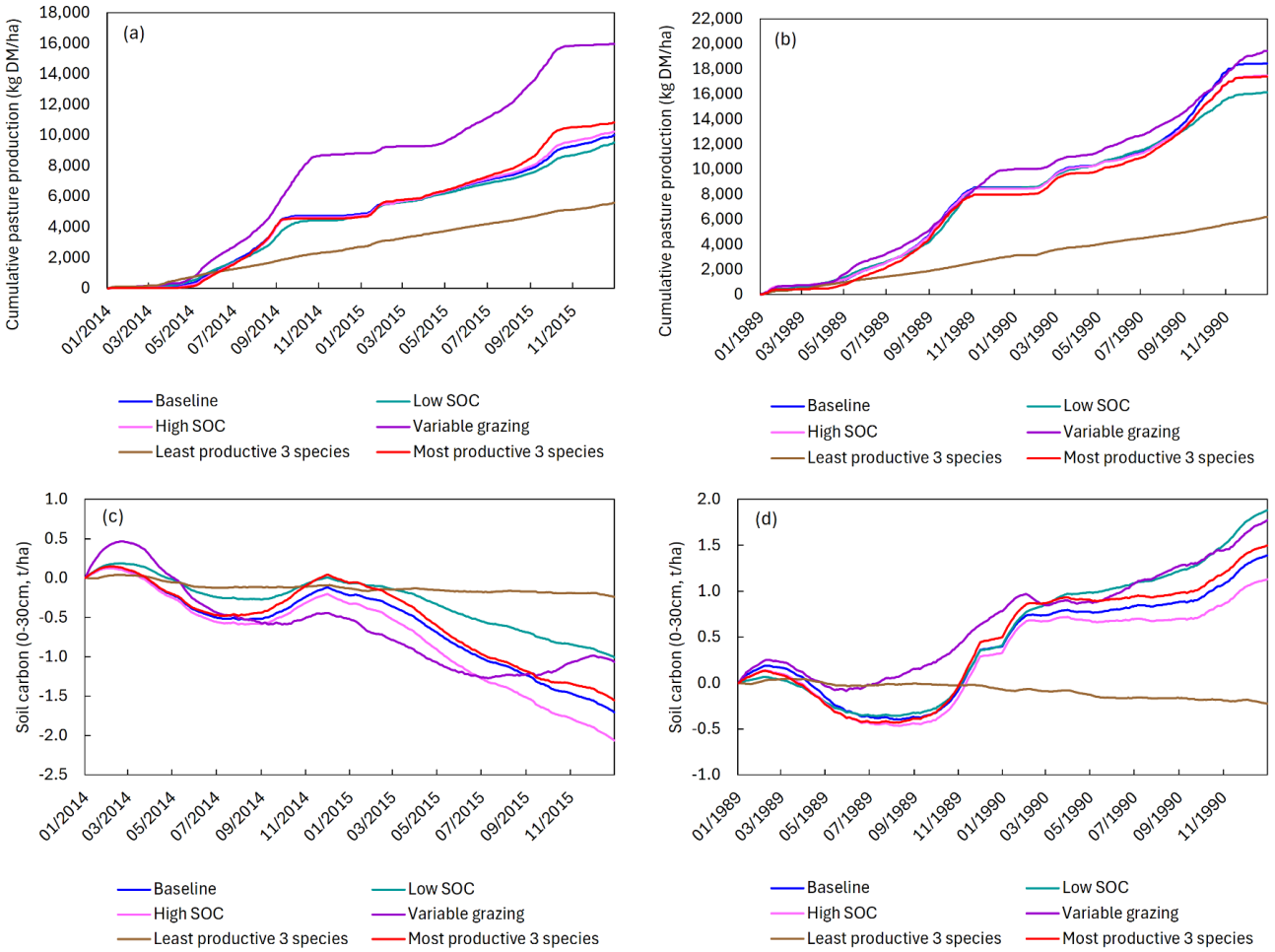
Supplementary Figure 2. Cumulative pasture production and SOC flux for farm F1 (long-term average rainfall 353 mm yr^{-1}) under very low rainfall (2019-20; left column) and very high rainfall (1992-93; right column). Upper panels show cumulative pasture production (**a** and **b**) and lower panels show SOC stocks (0-30 cm; **c** and **d**). SOC fluxes were normalised to the SOC stock on 1 Jan 2019 (**c**) or 1 Jan 1992 (**d**). Note differences in y-axis scales across panels. Baseline represents existing pasture species and set-stocking; high/low SOC represent simulations initialised with high or low SOC concentrations; least/most productive species represent swards containing three species with lowest or highest average annual production for that location; variable grazing represents grazing regime duration adjusted dynamically according to seasonal conditions and pasture biomass. Horizontal axes show date (month/year). Abbreviations: DM, dry matter; SOC, soil organic carbon.



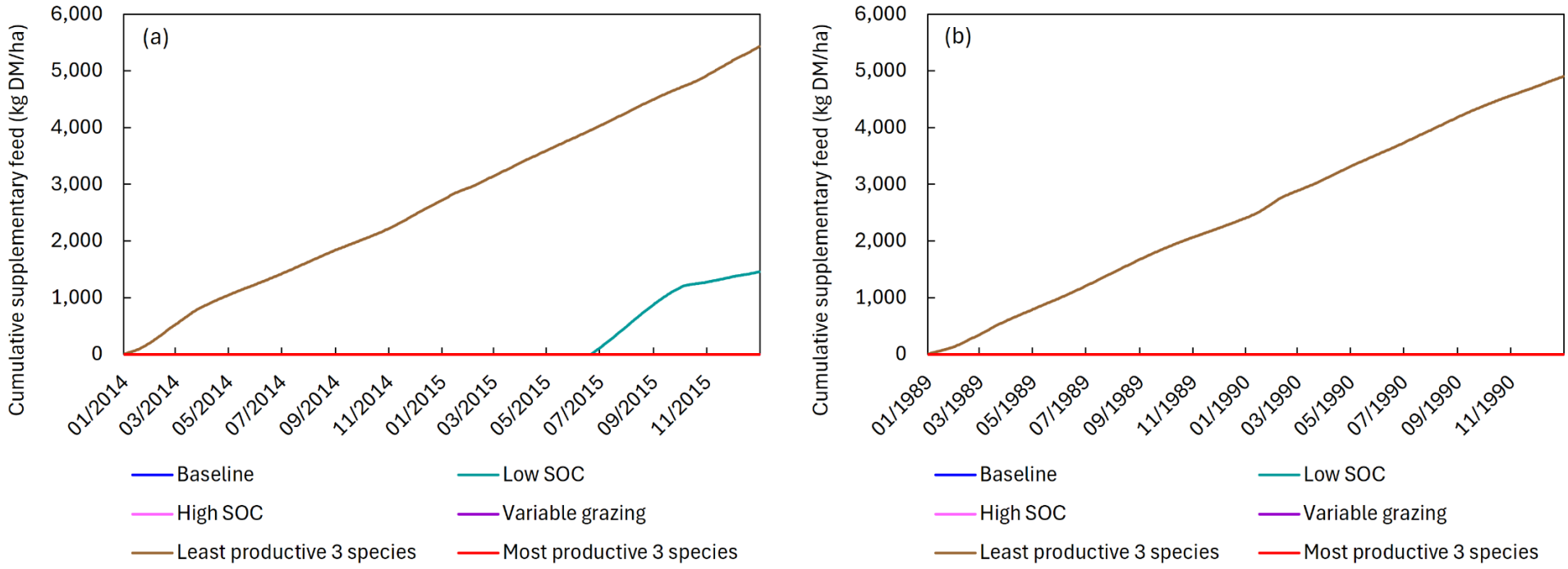
Supplementary Figure 3. Cumulative supplementary feed requirements for farm F1 (long-term average rainfall 353 mm yr^{-1}) under very low rainfall (2019-20; left column) and very high rainfall (1992-93; right column). Note differences in y-axis scales. Baseline represents existing pasture species and set-stocking; high/low SOC represent simulations initialised with high or low SOC concentrations; least/most productive species represent swards containing three species with lowest or highest average annual production for that location; variable grazing represents grazing regime duration adjusted dynamically according to seasonal conditions and pasture biomass. Horizontal axes show date (month/year). Abbreviations: DM, dry matter; SOC, soil organic carbon.



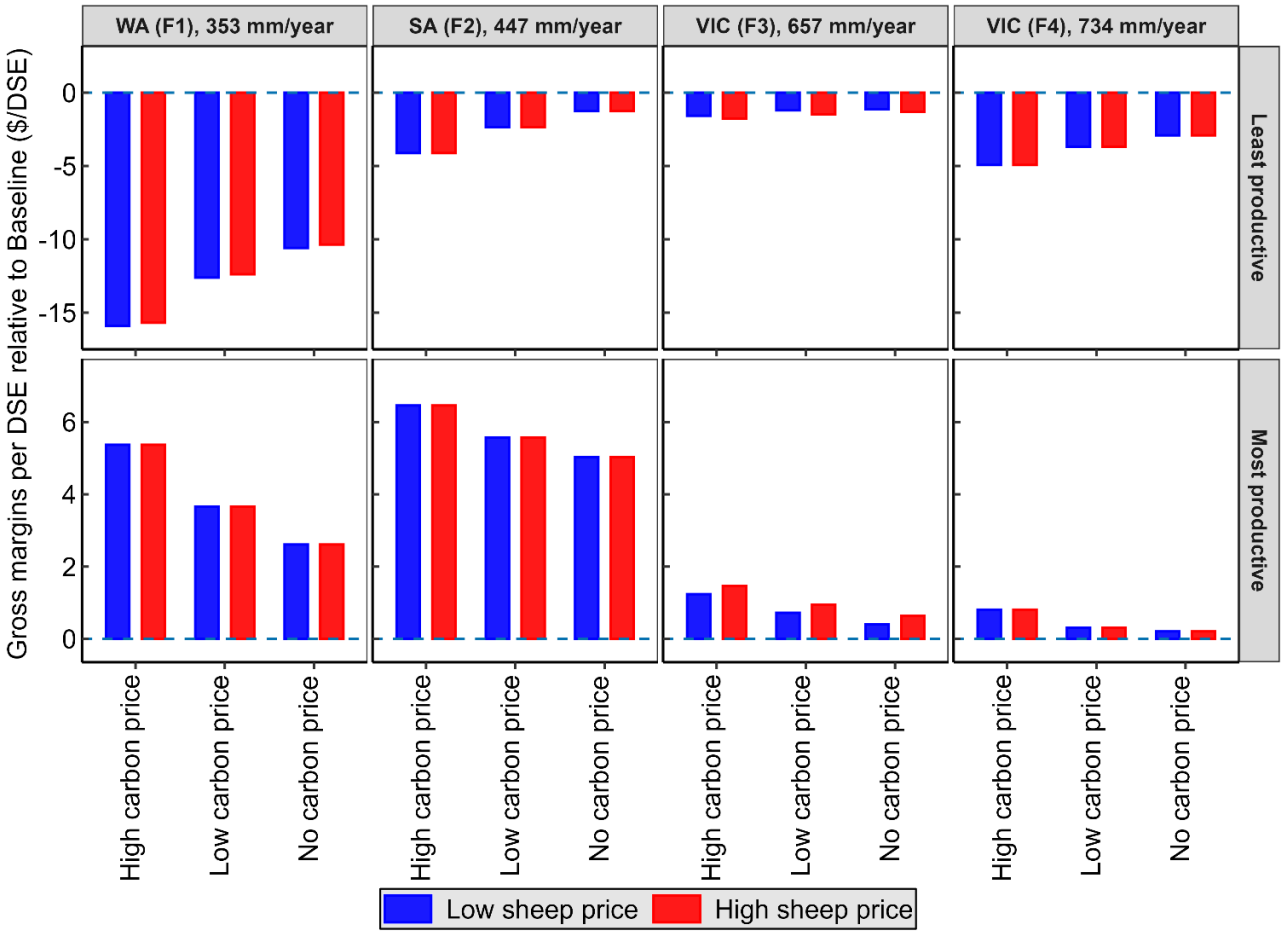
Supplementary Figure 4. Daily and cumulative rainfall and daily pasture production for farm F4 (long-term average rainfall 734 mm yr^{-1}) under very low rainfall (2014-15; left column) and very high rainfall (1989-90; right column). Upper panels show daily and cumulative rainfall (**a** and **b**), lower panels show daily pasture growth rates (**c** and **d**). Low and high rainfall periods averaged 561 mm year^{-1} and 901 mm year^{-1}, respectively. Baseline represents existing pasture species and set-stocking; high/low SOC represent simulations initialised with high or low SOC concentrations; least/most productive species represent swards containing three species with lowest or highest average annual production for that location; variable grazing represents grazing regime duration adjusted dynamically according to seasonal conditions and pasture biomass. Horizontal axes show date (month/year). Abbreviations: DM, dry matter; SOC, soil organic carbon.



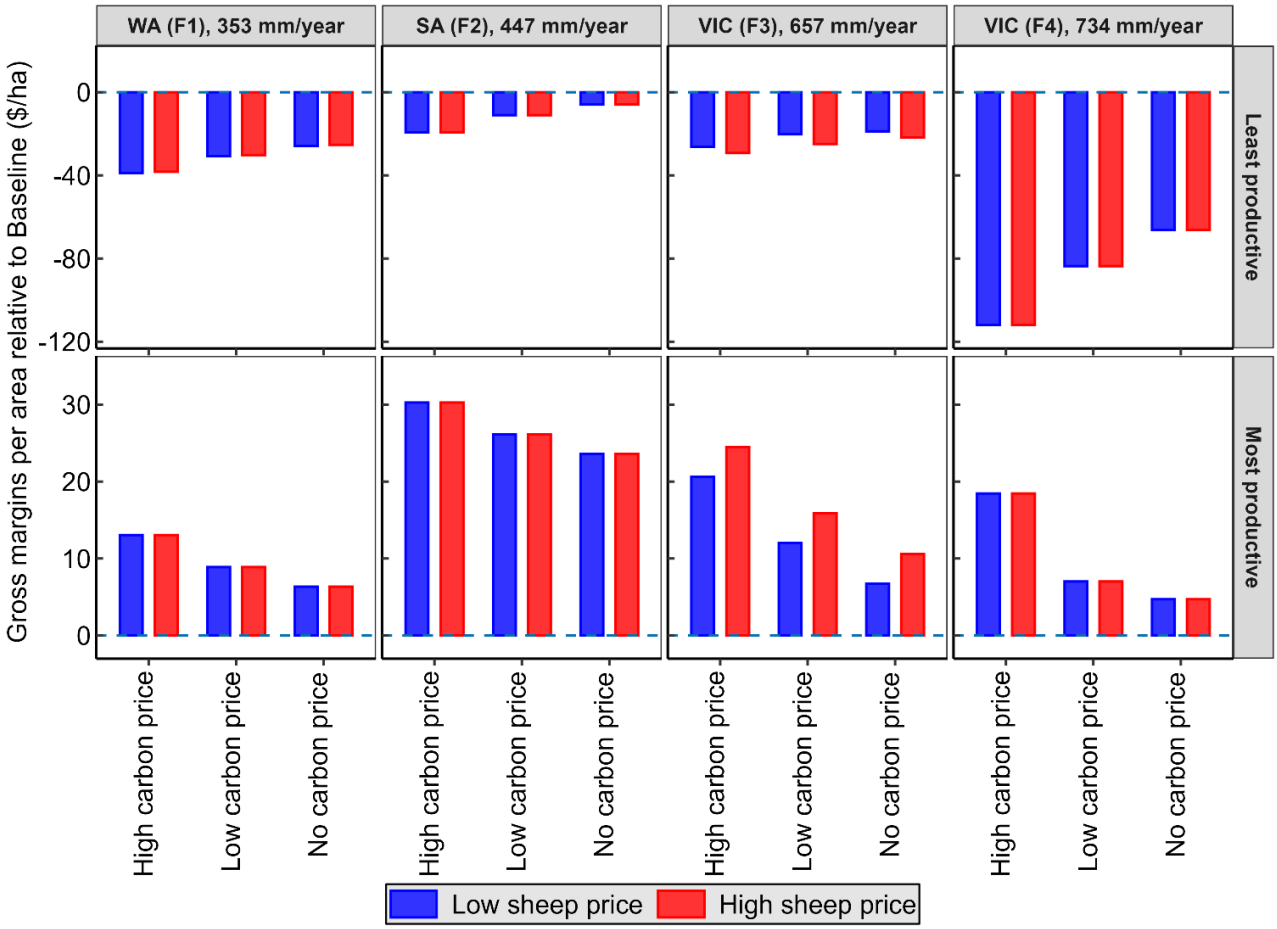
Supplementary Figure 5. Cumulative pasture production and SOC flux for farm F4 (long-term average rainfall 734 mm yr^{-1}) under very low rainfall (2014-15; left column) and very high rainfall (1989-90; right column). Cumulative pasture production (**a** and **b**) and SOC stocks (0-30 cm; **c** and **d**) are shown. SOC fluxes were normalised to the SOC stock on 1 Jan 2014 (c) or 1 Jan 1989 (d). Note differences in y-axis scales across panels. Baseline represents existing pasture species and set-stocking; high/low SOC represent simulations initialised with high or low SOC concentrations; least/most productive species represent swards containing three species with lowest or highest average annual production for that location; variable grazing represents grazing regime duration adjusted dynamically according to seasonal conditions and pasture biomass. Horizontal axes show date (month/year). Abbreviations: DM, dry matter; SOC, soil organic carbon.



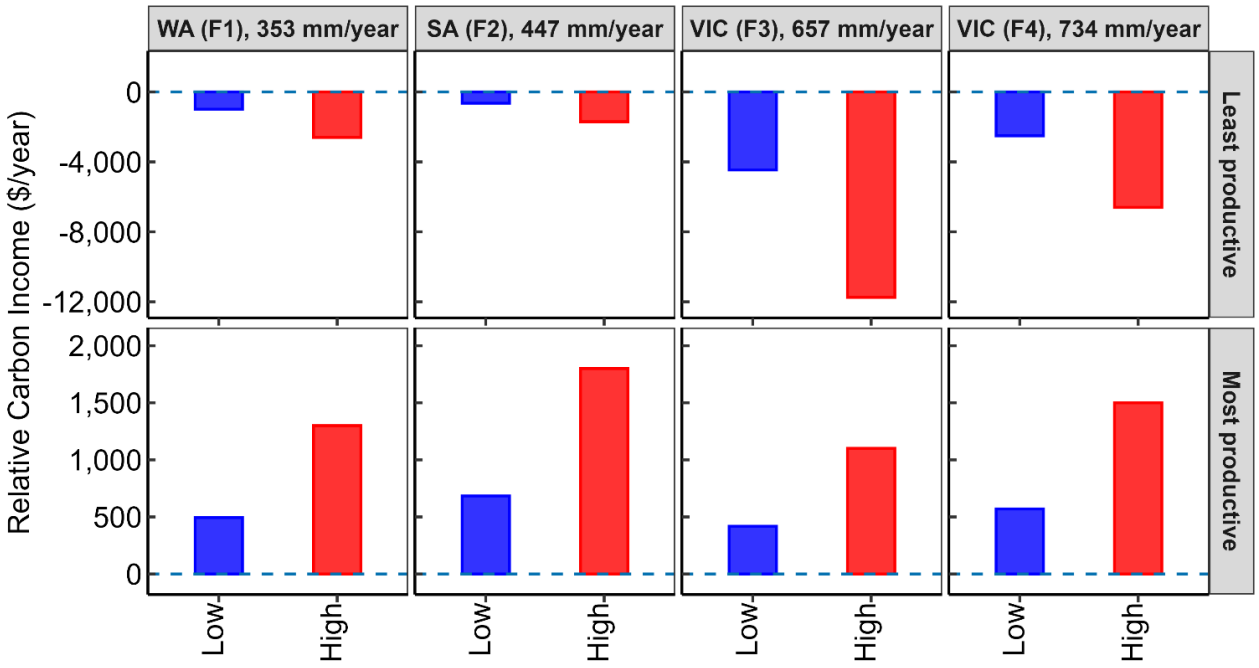
Supplementary Figure 6. Cumulative supplementary feed requirements for farm F4 (long-term average rainfall 734 mm yr^{-1}) under very low rainfall (2014-15; left column) and very high rainfall (1989-90; right column). Baseline represents existing pasture species and set-stocking; high/low SOC represent simulations initialised with high or low SOC concentrations; least/most productive species represent swards containing three species with lowest or highest average annual production for that location; variable grazing represents grazing regime duration adjusted dynamically according to seasonal conditions and pasture biomass. Horizontal axes show date (month/year). Abbreviations: DM, dry matter; SOC, soil organic carbon.



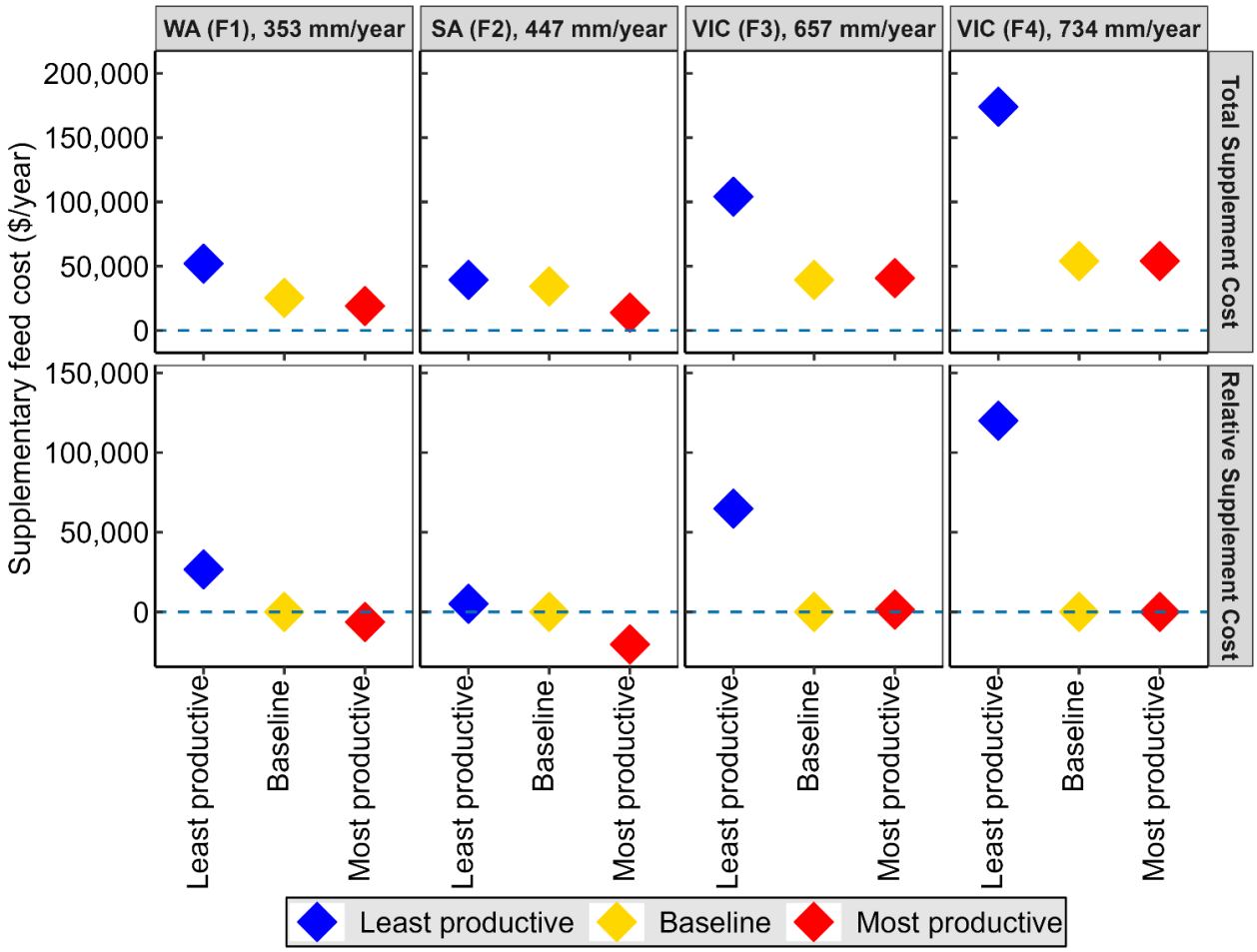
Supplementary Figure 7. Change in gross margins per DSE for high and low production botanical compositions relative to Baseline species under high, low and nil carbon prices, and under low (blue) and high (red) sheep prices. The most and least productive species (panel rows) represent the most and least productive swards, each containing three species (each bar represents mean value, with *n* = 100 samples). Panel titles indicate State (WA, Western Australia; SA, South Australia; VIC, Victoria), farm number (F1-4) and average annual rainfall. Abbreviations: DSE, dry sheep equivalent.



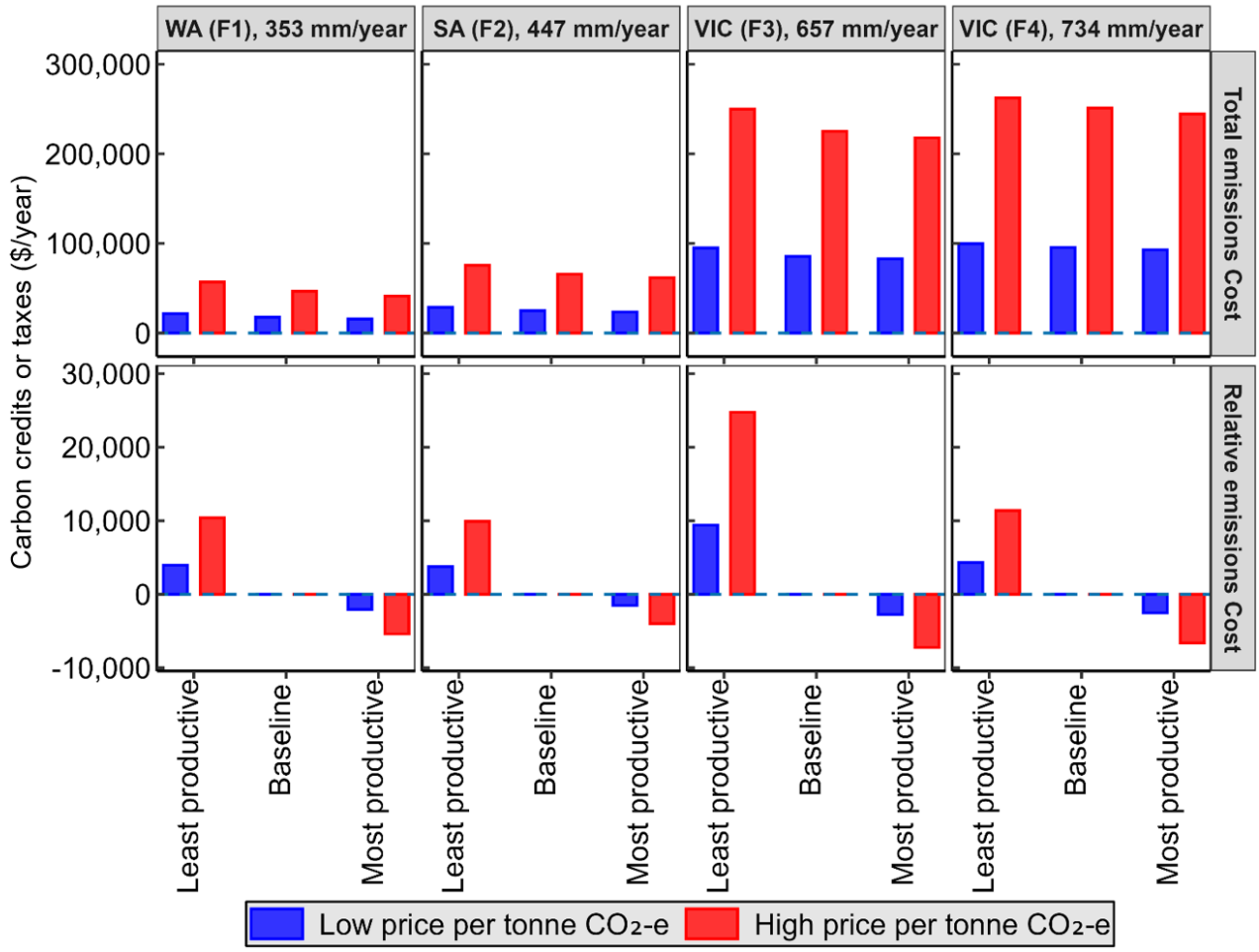
Supplementary Figure 8. Change in annual average gross margin per hectare for low and high production botanical compositions relative to baseline species under high, low and nil carbon prices, and under low (blue) and high (red) sheep prices. The most and least productive species (panel rows) represent the most and least productive swards, each containing three species (each bar represents mean value, with *n* = 100 samples). Panel titles indicate State (WA, Western Australia; SA, South Australia; VIC, Victoria), farm number (F1-4) and average annual rainfall.



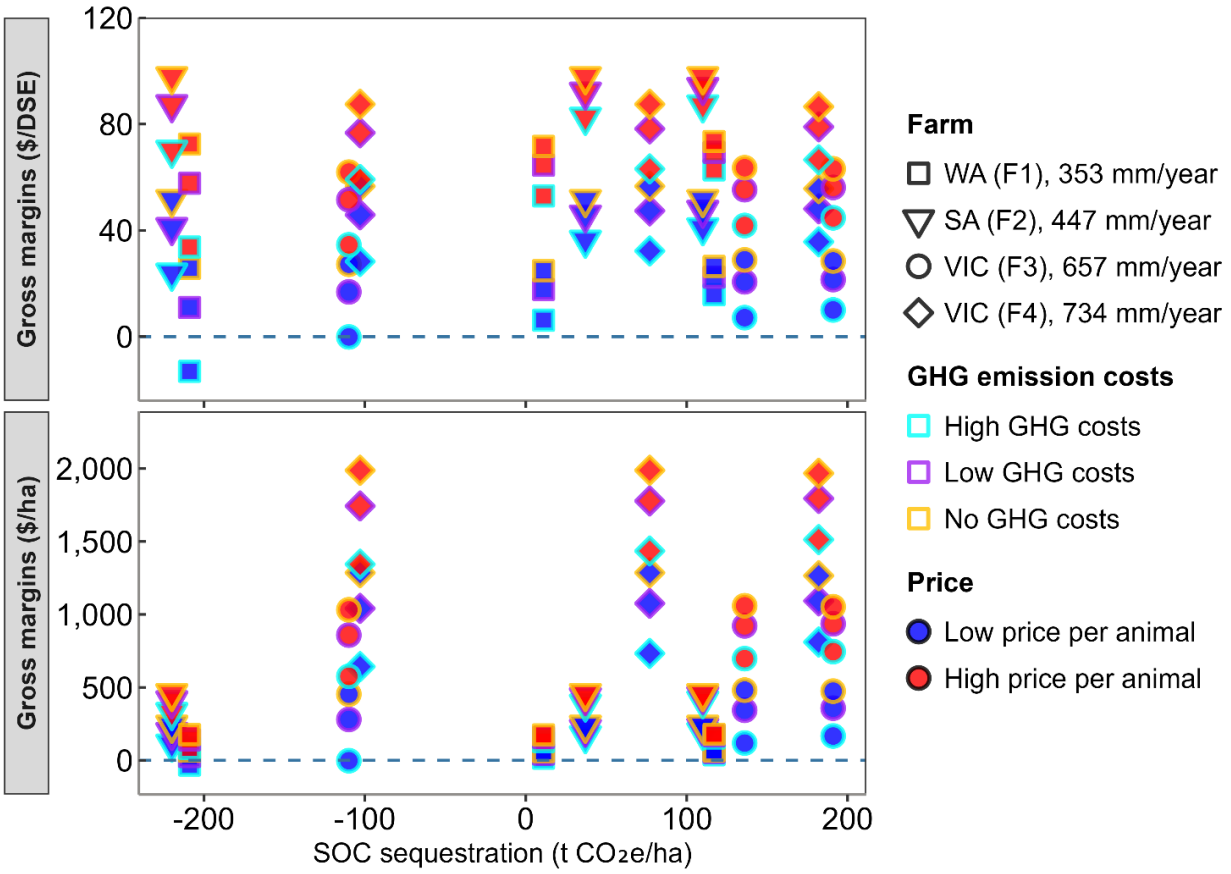
Supplementary Figure 9. Change in annual average income associated with high and low production botanical compositions relative to baseline at low (blue) and high (red) carbon prices (horizontal axis). The most and least productive species (panel rows) represent the most and least productive swards, each containing three species (each bar represents mean value, with *n* = 100 samples). Panel titles indicate State (SA, South Australia; VIC, Victoria; WA, Western Australia), farm number (F1-4) and average annual rainfall.



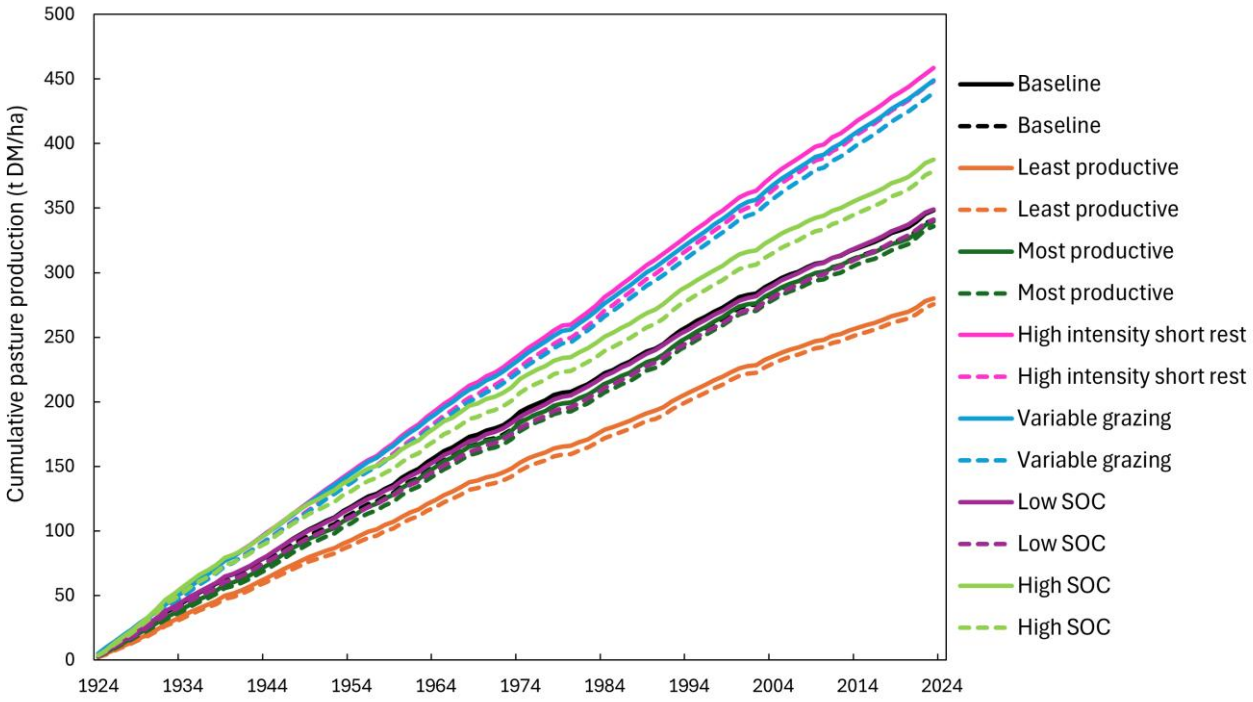
Supplementary Figure 10. Total annual and relative supplementary feed costs associated with the least and most productive botanical compositions across four agroecological regions. Relative supplementary feed cost was computed as the change in annual average supplementary feed cost for the most and least productive botanical compositions compared with the Baseline of each farm (negative values indicate lower supplementary feed cost than the Baseline). The most and least productive species represent the most and least productive swards, each containing three species (each bar represents mean value, with *n* = 100 samples). Panel titles indicate State (SA, South Australia; VIC, Victoria; WA, Western Australia), farm number (F1-4) and average annual rainfall.



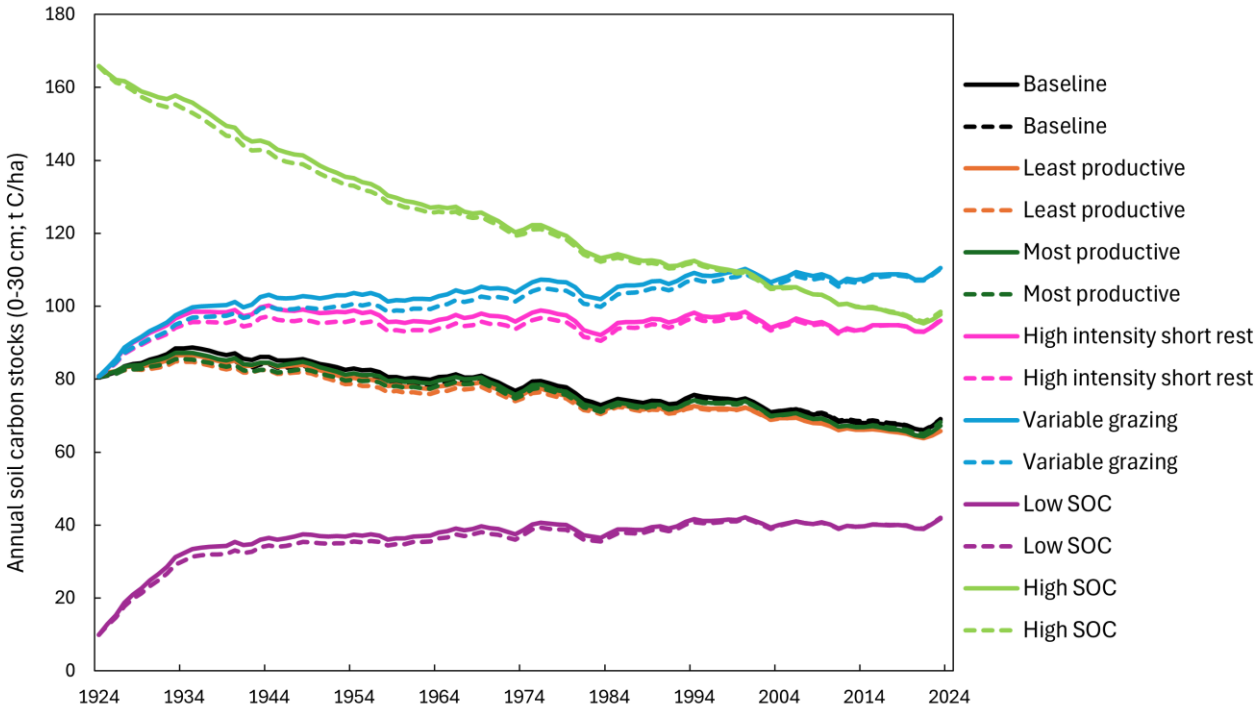
Supplementary Figure 11. Average total and relative carbon credits (income) or taxes (loss) associated with the most and least productive botanical compositions at low and high carbon prices. Carbon tax was computed relative to Baseline greenhouse gas (GHG) emissions for each farm (higher GHG compared with the Baseline attract a carbon tax, lower GHG result in carbon credits). The most and least productive species represent the most and least productive swards, each containing three species (each bar represents mean value, with *n* = 100 samples). Panel titles indicate State (SA, South Australia; VIC, Victoria; WA, Western Australia), farm number (F1-4) and average annual rainfall.



Supplementary Figure 12. Gross margins per dry sheep equivalent (DSE) and per grazed area relative to soil organic carbon (SOC) accrual for baseline, low (0.3%) and high (6%) antecedent SOC levels. Gross margins were computed for high (red) and low (blue) sheep prices, with high (light blue outline), low (purple outline) and nil (yellow outline) carbon prices (each point represents mean value, with *n* = 100 samples). Panel titles indicate State (SA, South Australia; VIC, Victoria; WA, Western Australia), farm number (F1-4) and average annual rainfall.

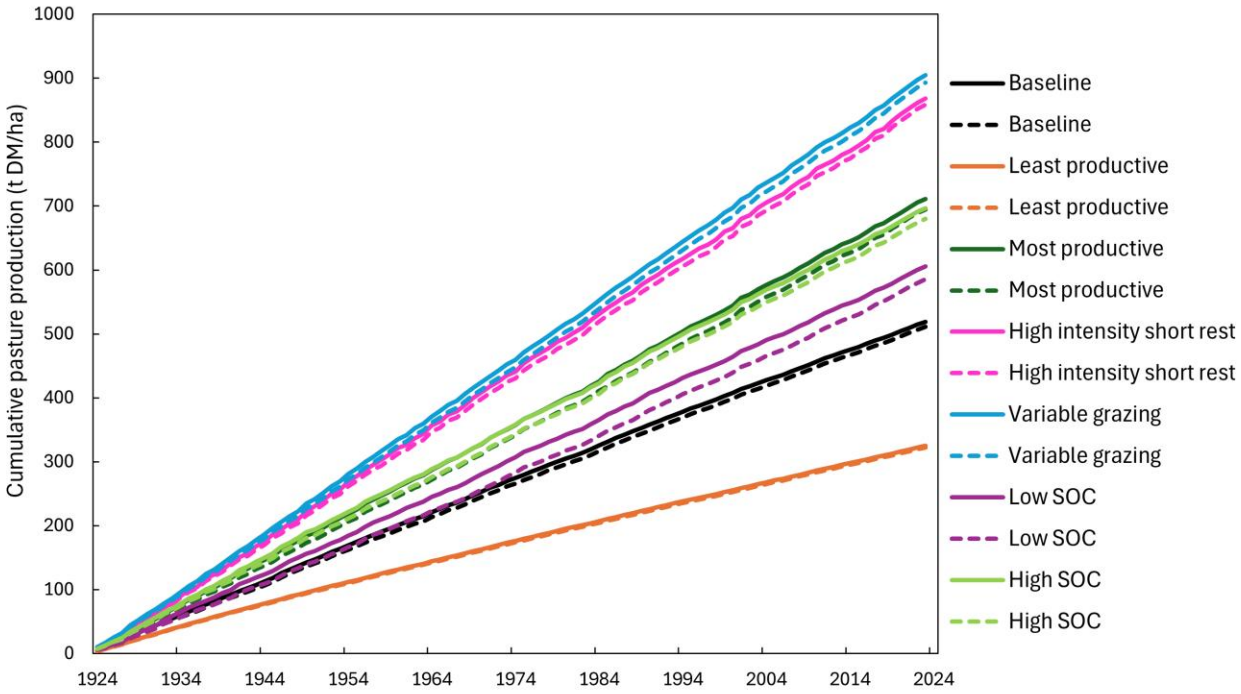


Supplementary Figure 13. Cumulative pasture production for farm F1 (long-term average rainfall 353 mm yr^{-1}). Data are shown for baseline, least and most productive botanical compositions, high intensity short rest and variable grazing regimes, low (0.3%) and high (6%) antecedent soil organic carbon (SOC) levels, with atmospheric carbon dioxide concentrations set at a constant 380 ppm (solid lines) or scaled from 300 ppm in 1924 to 420 ppm in 2023 (broken lines). The most and least productive species represent the most and least productive swards, each containing three species. Variable grazing indicates that grazing duration is dynamically adjusted according to seasonal conditions. DM, dry matter.

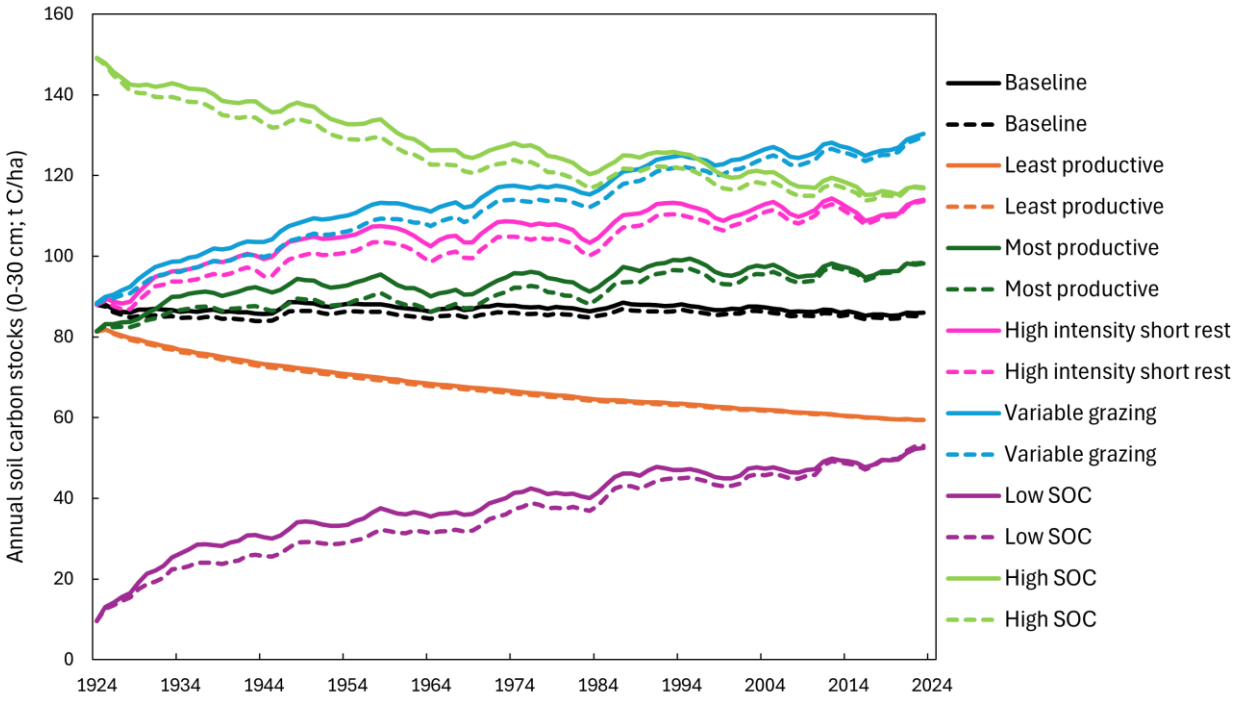


Supplementary Figure 14. Average annual soil organic carbon (SOC) stocks for farm F1 (long-term average rainfall 353 mm yr^{-1}). Data are shown for baseline, least and most productive botanical compositions, high intensity short rest and variable grazing regimes, low (0.3%) and high (6%) antecedent SOC levels, with atmospheric carbon dioxide concentrations set at a constant 380 ppm (solid lines) or scaled from 300 ppm in 1924 to 420 ppm in 2023 (broken lines). The most and least productive species represent the most and least productive swards, each containing three species. Variable grazing indicates that grazing duration is dynamically adjusted according to seasonal conditions.

.



Supplementary Figure 15. Cumulative pasture production for farm F4 (long-term average rainfall 734 mm yr^{-1}). Data are shown for the Baseline, least and most productive botanical compositions, high intensity short rest and variable grazing regimes, low (0.3%) and high (6%) antecedent SOC levels, with atmospheric carbon dioxide concentrations set at a constant 380 ppm (solid lines) or scaled from 300 ppm in 1924 to 420 ppm in 2023 (broken lines). The most and least productive species represent the most and least productive swards, each containing three species. Variable grazing indicates that grazing duration is dynamically adjusted according to seasonal conditions. DM, dry matter.



Supplementary Figure 16. Average annual SOC stocks for farm F4 (long-term average rainfall 734 mm yr^{-1}). Data are shown for the Baseline, least and most productive botanical compositions, high intensity short rest and variable grazing regimes, low (0.3%) and high (6%) antecedent SOC levels, with atmospheric carbon dioxide concentrations set at a constant 380 ppm (solid lines) or scaled from 300 ppm in 1924 to 420 ppm in 2023 (broken lines). The most and least productive species represent the most and least productive swards, each containing three species. Variable grazing indicates that grazing duration is dynamically adjusted according to seasonal conditions. DM, dry matter; SOC, soil organic carbon.

Supplementary Table 1. Effect of pasture species diversity on long-term average annual pasture productivity, supplementary feed, and SOC accrual across four agroecological regions along a rainfall gradient. Data are shown for swards with existing species (Baseline) as well as for the most and least productive swards containing three or five species at each location. Absolute SOC accrual was calculated as the change in SOC stocks over 100 years relative to the initial year (1924). Relative SOC was computed as the change in absolute SOC compared with the Baseline over the same period. Farms abbreviated by State (WA, Western Australia; SA, South Australia; VIC, Victoria), farm number (F1–4) and long-term average annual rainfall. DM, dry matter; SOC, soil organic carbon.

Botanical composition	WA (F1), 353 mm yr^{-1}	SA (F2), 447 mm yr^{-1}	VIC (F3), 657 mm yr^{-1}	VIC (F4), 734 mm yr^{-1}
Monthly pasture growth rate (kg DM ha^{-1} day^{-1})				
Baseline	9.2	9.8	15.8	19.2
Least productive individual species	6.2	6.0	6.1	9.0
Least productive three species	6.3	6.1	14.0	14.2
Least productive five species	8.5	10.6	14.0	17.5
Most productive individual species	8.9	11.3	15.8	19.3
Most productive three species	9.8	11.7	16.4	20.0
Most productive five species	9.0	10.8	15.1	19.1
Annual pasture production (kg DM ha^{-1} yr^{-1})				
Baseline	3,386	3,608	5,898	7,045
Least productive individual species	2,300	2,211	2,236	3,296
Least productive three species	2,328	2,253	2,300	5,190
Least productive five species	3,242	3,554	5,120	6,411
Most productive individual species	3,275	3,748	5,886	7,058
Most productive three species	3,738	3,923	6,004	7,298
Most productive five species	3,302	3,920	5,381	6,982
Absolute SOC (t C ha^{-1})				
Baseline	3	10	37	21
Least productive individual species	-5	-8	-3	-20
Least productive three species	-4	-5	-1	-2
Least productive five species	1	9	31	11
Most productive individual species	2	12	32	19
Most productive three species	7	17	41	29
Most productive five species	5	15	34	23
Relative SOC (t C ha^{-1})				
Least productive individual species	-8	-18	-40	-41
Least productive three species	-7	-15	-38	-23
Least productive five species	-2	-1	-6	-10
Most productive individual species	-1	2	-5	-2
Most productive three species	4	7	4	7
Most productive five species	2	5	-3	2
Annual supplementary feed intake (kg DM^{-1} $animal^{-1}$ yr^{-1})				
Baseline	24	47	19	18
Least productive individual species	74	74	127	114
Least productive three species	49	54	108	58
Least productive five species	24	35	25	29
Most productive individual species	19	20	25	21
Most productive three species	18	19	21	18
Most productive five species	22	28	24	19

Supplementary Table 2. Effect of antecedent SOC used for model initialisation on long-term average annual pasture productivity, supplementary feed, and SOC accrual (0–30 cm and 30–50 cm) across four agroecological regions along a rainfall gradient. Absolute SOC accrual calculated as the change in SOC stocks over 100 years relative to the initial year (1924). Relative SOC was computed as the change in absolute SOC compared with the Baseline over the same period. Farms abbreviated by State (WA, Western Australia; SA, South Australia; VIC, Victoria), farm number (F1–4) and long-term average annual rainfall. DM, dry matter; SOC, soil organic carbon.

Antecedent SOC level	WA (F1), 353 mm yr^{-1}	SA (F2), 447 mm yr^{-1}	VIC (F3), 657 mm yr^{-1}	VIC (F4), 734 mm yr^{-1}
Average monthly pasture growth rate (kg DM ha^{-1} day^{-1})				
Baseline	9	10	16	19
Low SOC (0.3%)	10	10	15	17
High SOC (6%)	10	10	16	19
Mean annual pasture production (kg DM ha^{-1} yr^{-1})				
Baseline	3,386	3,608	5,808	7,045
Low SOC (0.3%)	3,484	3,592	5,440	6,122
High SOC (6%)	3,460	3,604	5,873	6,908
Absolute SOC (t C ha^{-1}; 0-30 cm soil depth)				
Baseline	3	10	37	21
Low SOC (0.3%)	32	30	52	47
High SOC (6%)	-57	-60	-30	-28
Absolute SOC (t C ha^{-1}; 30-50 cm soil depth)				
Baseline	-5	-4	-6	-5
Low SOC (0.3%)	1	1	2	2
High SOC (6%)	-11	-11	-9	-10
Relative SOC (t C ha^{-1}; 0-30 cm soil depth)				
Low SOC (0.3%)	29	20	15	26
High SOC (6%)	-60	-70	-67	-49
Relative SOC (t C ha^{-1}; 30-50 cm soil depth)				
Low SOC (0.3%)	6	5	8	7
High SOC (6%)	-6	-7	-3	-5
Annual supplementary feed intake (kg DM $animal^{-1}$ yr^{-1})				
Baseline	24	47	19	18
Low SOC (0.3%)	21	47	21	21
High SOC (6%)	22	47	19	18

Supplementary Table 3. Effect of grazing regime on long-term average annual pasture productivity, supplementary feed, liveweight and SOC accrual for four regions along a rainfall gradient. Absolute SOC accrual was calculated as the change in SOC stocks over 100 years relative to initial simulation year (1924). Relative SOC was computed as the change in absolute SOC compared with the Baseline over the same period. Variable grazing represents grazing duration dynamically adjusted according to seasonal conditions (see Methods). Farms abbreviated by State (WA, Western Australia; SA, South Australia; VIC, Victoria), farm number (F1–4) and long-term average annual rainfall. DM, dry matter; SOC, soil organic carbon.

Grazing regime	WA (F1), 353 mm yr^{-1}	SA (F2), 447 mm yr^{-1}	VIC (F3), 657 mm yr^{-1}	VIC (F4), 734 mm yr^{-1}
Average monthly pasture growth rate (kg DM ha^{-1} day^{-1})				
Variable grazing	13	15	22	25
High intensity long rests	12	14	20	23
Low intensity long rests	12	13	20	23
High intensity short rests	12	13	20	23
Low intensity short rests	11	12	19	22
Set stocked (*Baseline*)	9	10	16	19
Mean annual pasture production (kg DM ha^{-1} yr^{-1})				
Variable grazing	4,704	5,223	8,243	8,986
High intensity long rests	4,552	4,998	7,306	8,571
Low intensity long rests	4,468	4,887	7,245	8,354
High intensity short rests	4,401	4,877	7,205	8,256
Low intensity short rests	4,231	4,647	7,063	8,171
Set stocked (*Baseline*)	3,386	3,608	5,808	7,045
Absolute SOC (t C ha^{-1})				
Variable grazing	27	23	79	45
High intensity long rests	23	22	72	42
Low intensity long rests	19	17	70	36
High intensity short rests	15	12	69	29
Low intensity short rests	7	5	66	24
Set stocked (*Baseline*)	3	10	37	21
Relative SOC (t C ha^{-1})				
Variable grazing	24	13	42	24
High intensity long rests	20	12	35	21
Low intensity long rests	16	7	33	15
High intensity short rests	12	2	32	8
Low intensity short rests	4	-5	29	3
Annual supplementary feed intake (kg DM $animal^{-1}$ yr^{-1})				
Variable grazing	43	66	16	12
High intensity long rests	14	39	42	45
Low intensity long rests	13	28	15	13
High intensity short rests	12	23	9	7
Low intensity short rests	12	22	8	6
Set stocked (*Baseline*)	24	47	19	18

Supplementary Table 4. Effect of pasture species diversity on gross margins per year, per DSE and per grazed area across four agroecological regions in southern Australia. Gross margins were computed for high and low sheep prices (columns) and high, low and nil carbon prices (rows). Data are shown for swards with existing species (Baseline) as well as the most and least productive swards, each containing three species. Farms abbreviated by State (WA, Western Australia; SA, South Australia; VIC, Victoria), farm number (F1–4) and long-term average annual rainfall. DSE, dry sheep equivalent.

Pasture type	Carbon price	WA (F1), 353 mm yr^{-1}		SA (F2), 447 mm yr^{-1}		VIC (F3), 657 mm yr^{-1}		VIC (F4), 734 mm yr^{-1}	
		Low Price	High Price	Low Price	High Price	Low Price	High Price	Low Price	High Price
Gross margin ($ yr^{-1})									
Least productive	High carbon price	-23,766	90,962	153,641	341,186	-30,355	295,736	314,091	622,904
	Low carbon price	12,504	127,232	199,279	386,824	123,466	449,558	477,511	786,325
	No carbon price	34,734	149,462	227,251	414,796	217,744	543,836	577,672	886,485
Baseline	High carbon price	15,066	129,241	170,350	357,895	120,394	467,298	363,411	672,224
	Low carbon price	43,276	157,451	208,790	396,335	251,593	598,497	514,319	823,132
	No carbon price	60,566	174,741	232,350	419,895	332,006	678,910	606,811	915,624
Most productive	High carbon price	28,104	142,279	196,534	384,079	132,761	481,978	371,528	680,342
	Low carbon price	52,160	166,335	231,386	418,932	258,796	608,012	517,403	826,217
	No carbon price	66,904	181,079	252,747	440,293	336,043	685,259	606,811	915,624
Gross margin per dry sheep equivalent ($ DSE^{-1})									
Least productive	High carbon price	-10	37	38	84	-3	30	31	62
	Low carbon price	5	52	49	95	12	45	48	79
	No carbon price	14	61	56	102	22	54	58	89
Baseline	High carbon price	6	53	42	88	12	47	36	67
	Low carbon price	18	65	51	98	25	60	51	82
	No carbon price	25	72	57	104	33	68	61	92
Most productive	High carbon price	12	59	48	95	13	48	37	68
	Low carbon price	21	69	57	103	26	61	52	83
	No carbon price	28	75	62	109	34	69	61	92
Gross margin per grazed area ($ ha^{-1})									
Least productive	High carbon price	-24	91	178	394	-51	493	714	1,416
	Low carbon price	13	127	230	447	206	749	1,085	1,787
	No carbon price	35	149	263	480	363	906	1,313	2,015
Baseline	High carbon price	15	129	197	414	201	779	826	1,528
	Low carbon price	43	157	241	458	419	997	1,169	1,871
	No carbon price	61	175	269	485	553	1,132	1,379	2,081
Most productive	High carbon price	52	166	227	444	221	803	844	1,546
	Low carbon price	28	142	267	484	431	1,013	1,176	1,878
	No carbon price	67	181	292	509	560	1,142	1,379	2,081

Supplementary Table 5. Supplementary feed costs ($ yr^{-1}) associated with pasture species diversity, antecedent SOC levels and grazing regime across four agroecological regions positioned along a rainfall gradient. Data are shown for swards with existing species (Baseline), the most and least productive swards, each containing three species, simulations initialised at low or high antecedent SOC, and five grazing regimes. Variable grazing indicates variable duration adjusted dynamically according to seasonal conditions. Farms abbreviated by State (WA, Western Australia; SA, South Australia; VIC, Victoria), farm number (F1–4) and long-term average annual rainfall. SOC, soil organic carbon.

	WA (F1), 353 mm yr^{-1}	SA (F2), 447 mm yr^{-1}	VIC (F3), 657 mm yr^{-1}	VIC (F4), 734 mm yr^{-1}
Pasture type				
Baseline	25,351	57,176	82,412	54,000
Least productive	52,009	65,691	104,087	174,000
More productive	19,013	33,114	50,710	54,000
Antecedent SOC levels				
High SOC	23,239	57,176	82,412	54,000
Low SOC	22,289	57,176	88,412	63,000
Grazing regimes				
Low intensity long rests	13,798	34,062	70,412	39,000
High intensity long rests	14,860	47,444	51,412	45,000
Low intensity short rests	12,737	26,763	49,412	18,000
High intensity short rests	13,837	29,780	52,412	21,000
Variable grazing	45,640	80,289	73,412	66,000

Supplementary Table 6. Carbon taxes ($ yr^{-1}) associated with low and high productivity swards, low and high antecedent SOC, five grazing regimes and low and high sheep prices. Data are shown for swards with existing species (Baseline), the most and least productive swards, each containing three species, simulations initialised at low or high antecedent SOC, and five grazing regimes. Variable grazing indicates variable duration adjusted dynamically according to seasonal conditions. Farms abbreviated by State (WA, Western Australia; SA, South Australia; VIC, Victoria), farm number (F1–4) and long-term average annual rainfall. SOC, soil organic carbon.

Intervention	WA (F1), 353 mm yr^{-1}		SA (F2), 447 mm yr^{-1}		VIC (F3), 657 mm yr^{-1}		VIC (F4), 734 mm yr^{-1}	
	Low Price	High Price	Low Price	High Price	Low Price	High Price	Low Price	High Price
Pasture type								
Baseline	17,708	46,600	24,966	65,700	87,818	231,100	95,418	251,100
Least productive	21,660	57,000	28,732	75,610	94,975	249,935	99,743	262,481
More productive	15,656	41,200	23,451	61,713	82,825	217,961	92,903	244,483
Antecedent SOC levels								
High SOC	27,997	73,677	34,314	90,300	99,788	262,600	103,702	272,900
Low SOC	14,326	37,700	20,520	54,000	77,330	203,500	82,954	218,300
Grazing regimes								
Low intensity long rests	4,788	12,600	14,554	38,300	49,742	130,900	81,776	215,200
High intensity long rests	4,940	13,000	15,808	41,600	52,630	138,500	82,802	217,900
Low intensity short rests	8,284	21,800	18,658	49,100	56,582	148,900	87,134	229,300
High intensity short rests	9,348	24,600	19,456	51,200	63,802	167,900	90,136	237,200
Variable grazing	3,002	7,900	10,488	27,600	44,764	117,800	75,544	198,800

Supplementary Table 7. Effect of antecedent SOC on gross margins per year, per DSE and per grazed area across four agroecological regions. Gross margins were computed for low and high sheep prices (columns) and nil, low and high carbon prices (rows). Simulations were initialised at low, baseline or high antecedent SOC. Farms abbreviated by State (WA, Western Australia; SA, South Australia; VIC, Victoria), farm number (F1–4) and average annual rainfall. DSE, dry sheep equivalent; SOC, soil organic carbon.

SOC level	Carbon price	WA (F1), 353 mm yr^{-1}		SA (F2), 447 mm yr^{-1}		VIC (F3), 657 mm yr^{-1}		VIC (F4), 734 mm yr^{-1}	
		Low Price	High Price	Low Price	High Price	Low Price	High Price	Low Price	High Price
Gross margin ($ yr^{-1})									
High SOC	High carbon price	-31,899	82,276	97,113	284,658	-1,352	345,552	282,723	591,537
	Low carbon price	26,738	140,913	166,739	354,284	168,280	515,184	458,307	767,121
	No carbon price	62,677	176,853	209,413	396,958	272,248	619,152	565,923	874,737
Baseline	High carbon price	15,066	129,241	147,413	334,958	71,326	418,230	322,523	631,337
	Low carbon price	43,276	157,451	185,853	373,398	206,189	553,093	473,431	782,245
	No carbon price	60,566	174,741	209,413	396,958	288,847	635,751	565,923	874,737
Low SOC	High carbon price	38,453	153,181	166,413	353,958	100,293	447,197	356,823	665,637
	Low carbon price	54,573	169,301	193,073	380,618	214,621	561,525	480,885	789,699
	No carbon price	64,453	179,181	209,413	396,958	284,693	631,597	556,923	865,737
Gross margin per dry sheep equivalent ($ DSE^{-1})									
High SOC	High carbon price	-13	34	24	70	0	35	28	59
	Low carbon price	11	58	41	87	17	52	46	77
	No carbon price	26	72	52	98	27	62	57	87
Baseline	High carbon price	6	53	36	83	7	42	32	63
	Low carbon price	18	65	46	92	21	55	47	78
	No carbon price	25	72	52	98	29	64	57	87
Low SOC	High carbon price	16	63	41	87	10	45	36	67
	Low carbon price	22	69	48	94	21	56	48	79
	No carbon price	26	73	52	98	28	63	56	87
Gross margin per grazed area ($ ha^{-1})									
High SOC	High carbon price	-32	82	112	329	-2	576	643	1,344
	Low carbon price	27	141	193	410	280	859	1,042	1,743
	No carbon price	63	177	242	459	454	1,032	1,286	1,988
Baseline	High carbon price	15	129	170	387	119	697	733	1,435
	Low carbon price	43	157	215	432	344	922	1,076	1,778
	No carbon price	61	175	242	459	481	1,060	1,286	1,988
Low SOC	High carbon price	38	153	192	409	167	745	811	1,513
	Low carbon price	55	169	223	440	358	936	1,093	1,795
	No carbon price	64	179	242	459	474	1,053	1,266	1,968

Supplementary Table 8. Effect of grazing regime on annual gross margins across four agroecological regions in southern Australia. Gross margins were computed for low and high sheep prices (columns) and nil, low and high carbon prices (rows). Data shown for swards with existing species (Baseline) and five grazing regimes. Variable grazing indicates grazing duration adjusted dynamically according to seasonal conditions. Farms abbreviated by State (WA, Western Australia; SA, South Australia; VIC, Victoria), farm number (F1–4) and long-term average annual rainfall.

Grazing regime	Carbon price	WA (F1), 353 mm yr^{-1}		SA (F2), 447 mm yr^{-1}		VIC (F3), 657 mm yr^{-1}		VIC (F4), 734 mm yr^{-1}	
		Low Price	High Price	Low Price	High Price	Low Price	High Price	Low Price	High Price
		Gross margins ($ yr^{-1})							
Baseline	Low carbon price	43,276	157,451	185,853	373,398	206,189	553,093	473,431	782,245
	High carbon price	15,066	129,241	147,413	334,958	71,326	418,230	322,523	631,337
	No carbon price	60,566	174,741	209,413	396,958	288,847	635,751	565,923	874,737
Low intensity long rests	Low carbon price	70,816	185,544	220,328	407,874	260,871	607,775	504,163	812,977
	High carbon price	67,344	182,072	200,426	387,972	195,647	542,551	378,923	687,737
	No carbon price	72,944	187,672	232,526	420,072	300,847	647,751	580,923	889,737
High intensity long rests	Low carbon price	70,135	184,863	206,415	393,960	177,249	524,153	407,973	716,787
	High carbon price	67,283	182,011	185,645	373,190	107,747	454,651	282,423	591,237
	No carbon price	71,883	186,611	219,145	406,690	219,847	566,751	484,923	793,737
Low intensity short rests	Low carbon price	66,709	181,438	221,851	409,397	274,461	621,365	518,133	826,947
	High carbon price	54,805	169,534	192,525	380,071	197,147	544,051	381,423	690,237
	No carbon price	74,005	188,734	239,825	427,371	321,847	668,751	601,923	910,737
High intensity short rests	Low carbon price	66,747	181,476	220,825	408,370	264,659	611,563	512,815	821,629
	High carbon price	54,905	169,634	191,809	379,354	176,247	523,151	372,323	681,137
	No carbon price	74,005	188,734	238,609	426,154	318,847	665,751	598,923	907,737
Variable grazing	Low carbon price	41,862	156,590	179,003	366,549	264,103	611,007	514,649	823,463
	High carbon price	43,102	157,830	167,099	354,645	209,047	555,951	401,623	710,437
	No carbon price	41,102	155,830	186,299	373,845	297,847	644,751	583,923	892,737

Supplementary Table 9. Effect of grazing regime on average annual gross margins per dry sheep equivalent ($ DSE^{-1}) across four agroecological regions in southern Australia. Gross margins were computed for low and high sheep prices (columns) and nil, low and high carbon prices (rows). Data shown for swards with existing species (Baseline) and five grazing regimes. Variable grazing indicates grazing duration adjusted dynamically according to seasonal conditions. Farms abbreviated by State (WA, Western Australia; SA, South Australia; VIC, Victoria), farm number (F1–4) and long-term average annual rainfall.

Grazing regime	Carbon price	WA (F1), 353 mm yr^{-1}		SA (F2), 447 mm yr^{-1}		VIC (F3), 657 mm yr^{-1}		VIC (F4), 734 mm yr^{-1}	
		Low Price	High Price	Low Price	High Price	Low Price	High Price	Low Price	High Price
		Gross margin ($ DSE^{-1})							
Baseline	Low carbon price	18	65	46	92	21	55	47	78
	High carbon price	6	53	36	83	7	42	32	63
	No carbon price	25	72	52	98	29	64	57	87
Low intensity long rests	Low carbon price	29	76	54	101	26	61	50	81
	High carbon price	28	75	49	96	20	54	38	69
	No carbon price	30	77	57	104	30	65	58	89
High intensity long rests	Low carbon price	29	76	51	97	18	52	41	72
	High carbon price	28	75	46	92	11	45	28	59
	No carbon price	29	76	54	100	22	57	48	79
Low intensity short rests	Low carbon price	27	74	55	101	27	62	52	83
	High carbon price	22	69	47	94	20	54	38	69
	No carbon price	30	77	59	105	32	67	60	91
High intensity short rests	Low carbon price	27	74	54	101	26	61	51	82
	High carbon price	23	70	47	94	18	52	37	68
	No carbon price	30	77	59	105	32	67	60	91
Variable grazing	Low carbon price	17	64	44	90	26	61	51	82
	High carbon price	18	65	41	87	21	56	40	71
	No carbon price	17	64	46	92	30	64	58	89

Supplementary Table 10. Effect of grazing regime on annual gross margins per grazed area (hectares) across four agroecological regions in southern Australia. Gross margins were computed for low and high sheep prices (columns) and nil, low and high carbon prices (rows). Data shown for swards with existing species (Baseline) and five grazing regimes. Variable grazing indicates grazing duration adjusted dynamically according to seasonal conditions. Farms abbreviated by State (WA, Western Australia; SA, South Australia; VIC, Victoria), farm number (F1–4) and long-term average annual rainfall.

Grazing regime	Carbon price	WA (F1), 353 mm yr^{-1}		SA (F2), 447 mm yr^{-1}		VIC (F3), 657 mm yr^{-1}		VIC (F4), 734 mm yr^{-1}	
		Low Price	High Price	Low Price	High Price	Low Price	High Price	Low Price	High Price
		Gross margin per grazed area ($ ha^{-1})							
Baseline	Low carbon price	43	157	215	432	344	922	1,076	1,778
	High carbon price	15	129	170	387	119	697	733	1,435
	No carbon price	61	175	242	459	481	1,060	1,286	1,988
Low intensity long rests	Low carbon price	71	186	255	472	435	1,013	1,146	1,848
	High carbon price	67	182	232	449	326	904	861	1,563
	No carbon price	73	188	269	486	501	1,080	1,320	2,022
High intensity long rests	Low carbon price	70	185	239	455	295	874	927	1,629
	High carbon price	67	182	215	431	180	758	642	1,344
	No carbon price	72	187	253	470	366	945	1,102	1,804
Low intensity short rests	Low carbon price	67	181	256	473	457	1,036	1,178	1,879
	High carbon price	55	170	223	439	329	907	867	1,569
	No carbon price	74	189	277	494	536	1,115	1,368	2,070
High intensity short rests	Low carbon price	67	181	255	472	441	1,019	1,165	1,867
	High carbon price	55	170	222	439	294	872	846	1,548
	No carbon price	74	189	276	493	531	1,110	1,361	2,063
Variable grazing	Low carbon price	42	157	207	424	440	1,018	1,170	1,872
	High carbon price	43	158	193	410	348	927	913	1,615
	No carbon price	41	156	215	432	496	1,075	1,327	2,029

Supplementary Table 11. Biophysical and geographical parameters of each Baseline farm system. Farms abbreviated by State (WA, Western Australia; SA, South Australia; VIC, Victoria), farm number (F1–4) and long-term average annual rainfall. Climate data are averaged over 1924–2023. Abbreviations: DAP, di-ammonium phosphate; DM, dry matter; MAP, mono-ammonium phosphate; SSP, single super phosphate.

	WA (F1), 353 mm yr^{-1}	**SA (F2), 447 mm yr^{-1}**	**VIC (F3), 657 mm yr^{-1}**	**VIC (F4), 734 mm yr^{-1}**
Farm characteristics				
Nearest township	Kulin	Meningie	Casterton	Winslow
Latitude (°S)	32.80	35.70	37.430	38.20
Longitude (°E)	118.25	139.35	141.268	142.50
Rainfall (mm yr^{-1})	353	447	657	734
Average min/max temperature (°C)	9.7/23.5	10/21.2	8.8/19.2	8.7/18.5
Management (self-classified)	Regenerative	Conventional	Conventional	Regenerative
Predominant soil types	Sandy loam, medium clay	Sand	Clay	Sandy loam
Pasture production (kg DM ha^{-1} yr^{-1})	5,621	5,479	8,212	12,374
Pasture fertilisation	47 kg ha^{-1} SSP[1]	10 kg ha^{-1} Urea, 43 kg ha^{-1} SSP, 8 kg ha^{-1} DAP[2]	167 kg ha^{-1} SSP	32 kg ha^{-1} MAP[3]
Livestock parameters				
Livestock genotype	Merino	Merino	Merino	Merino
Farm-grown supplementary feed	Barley straw	Grass silage	Grass hay	Barley, Faba beans
Purchased supplementary feed	Lupins	-	Faba beans	Barley grain
Total supplement feed (t DM)	151	115	243	65
Average mature ewe weight (kg)	74	77	52	50
Number of mature ewes sold (head yr^{-1})	360	502	941	814
Liveweight of mature ewes at sale (kg)	77	84	54	55
Mature wethers sold	-	-	-	677
Liveweight of wethers at sale (kg)	-	-	-	55
Lambs sold (head yr^{-1})	1,212	2,082	3,372	1,340
Liveweight of lambs at sale (kg)	46	50	41	27
Shearing dates	Main flock: 30-Jan, weaners: 1-Feb	Main flock: 1-Jul, weaners: 15-Sep	Main flock & weaners: 30-Apr	Main flock & wethers: Dec-15, weaners: 15-Dec
Total wool sold (t greasy wool)	15	10	18	41
Average fleece diameter (micron)	21	22	18	17
Replacement animals purchased	-	524 ewes	-	-

[1]SSP = Single Superphosphate, [2] DAP = Diammonium Phosphate, [3] MAP = Monoammonium Phosphate.

Supplementary Table 12. Costs associated with livestock sales (commissions and levies), land, pasture and stock management. Costs were held constant across scenarios to enable comparison of cost variability attributed to supplementary feed and greenhouse gas (GHG) emissions. Farms abbreviated by State (WA, Western Australia; SA, South Australia; VIC, Victoria), farm number (F1–4) and long-term average annual rainfall.

Cost type ($ yr^{-1})	WA (F1), 353 mm yr^{-1}	SA (F2), 447 mm yr^{-1}	VIC (F3), 657 mm yr^{-1}	VIC (F4), 734 mm yr^{-1}
Land management costs	25,000	7,883	18,455	13,000
Pasture management costs	100,047	52,160	232,419	105,748
Stock management costs	63,274	43,672	124,076	130,067
Sales costs: Low meat price	23,850	36,076	67,417	60,303
High meat price	29,116	44,914	83,872	74,855

Supplementary Table 13. Simulated botanical compositions comprising individual or multiple pasture species per sward. Baseline swards represent existing species. Individual species listed indicate those examined for each farm. Least or most productive swards indicate those with the lowest or greatest average annual dry matter (DM) production over the 1924–2023 simulation period. Farms abbreviated by State (SA, South Australia; VIC, Victoria; WA, Western Australia), farm number (F1–4) and long-term average annual rainfall.

Botanical compositions	**WA (F1), 353 mm yr^{-1}**	**SA (F2), 447 mm yr^{-1}**	**VIC (F3), 657 mm yr^{-1}**	**VIC (F4), 734 mm yr^{-1}**
Baseline swards	Annual ryegrass[1], subterranean clover[2], capeweed[3]	Perennial ryegrass, lucerne[4], cocksfoot[5]	Perennial ryegrass[6], subterranean clover, phalaris[7]	Subterranean clover, phalaris, perennial ryegrass
Swards with individual species				
Individual species	Perennial ryegrass, lucerne, phalaris, tall fescue[8], white clover[9], cocksfoot	Subterranean clover, phalaris, capeweed, white clover, tall fescue, annual ryegrass	Annual ryegrass, tall fescue, capeweed, cocksfoot, white clover, lucerne	White clover, tall fescue, annual ryegrass, weeds, lucerne, cocksfoot
Least productive individual pasture	Capeweed	Capeweed	Capeweed	Capeweed
Most productive individual pasture	Annual ryegrass	Subterranean clover	Subterranean clover	Subterranean clover
Swards with multiple species				
Least productive three species	Capeweed, annual ryegrass, perennial ryegrass	Capeweed, annual ryegrass, perennial ryegrass	Capeweed, annual ryegrass, perennial ryegrass	Capeweed, annual ryegrass, perennial ryegrass
Least productive five species	Annual ryegrass, subterranean clover, capeweed, perennial ryegrass, phalaris	Perennial ryegrass, lucerne, cocksfoot, subterranean clover, white clover	Perennial ryegrass, subterranean clover, phalaris, annual ryegrass, capeweed	Subterranean clover, phalaris, perennial ryegrass, white clover, annual ryegrass
Most productive three species	Lucerne, subterranean clover, phalaris	Subterranean clover, phalaris, lucerne	Subterranean clover, phalaris, lucerne	Subterranean clover, phalaris, lucerne
Most productive five species	Annual ryegrass, subterranean clover, capeweed, perennial ryegrass, tall fescue	Perennial ryegrass, lucerne, cocksfoot, subterranean clover, annual ryegrass	Perennial ryegrass, subterranean clover, phalaris, annual ryegrass, lucerne	Subterranean clover, phalaris, perennial ryegrass, white clover, lucerne

[1]Annual ryegrass (*Trifolium multiflorum*); [2]Subterranean clover (*Trifolium subterraneum*); [3]Capeweed (generic C3 low quality species such as Capeweed (*Arctotheca calendula*)); [4]Lucerne (generic C3 legume species selected to represent *Medicago sativa*); [5]Cocksfoot (*Dactylis glomerata*); [6]Perennial ryegrass (*Lolium perenne*); [7]Phalaris (*Phalaris aquatica*); [8]Tall Fescue (*Festuca arundinacea*); [9]White Clover (*Trifolium repens*).