Supplementary materials

Table S1. Aboveground dry matter biomass (AGB) and leaf area index (LAI) collected in 2020 and 2021 in the two study-sites (sample mean and standard deviation of eight sub-samples in Marradi and four sub-samples in Borgo San Lorenzo).

Var.	Site M (Marradi)				Site B (Borgo San Lorenzo)							
					B1				B2			
	2020		2021		2020		2021		2020		2021	
AGB	doy	kg m^{-2}	doy	kg m^{-2}	doy	kg m^{-2}	doy	kg m^{-2}	doy	kg m^{-2}	doy	kg m^{-2}
	139	0.22±0.08	89	0.03±0.01	131	0.10±0.10	62	0.03±0.02	147	0.08±0.01	62	0.04±0.02
	154	0.18±0.09	138	0.09±0.04	147	0.04±0.05	110	0.08±0.04	161	0.13±0.04	100	0.05±0.01
	167	0.12±0.06	166	0.05±0.02	161	0.03±0.04	125	0.08±0.02	174	0.23±0.06	125	0.08±0.03
	180	0.07±0.03	202	0.03±0.02	174	0.02±0.02	152	0.15±0.08	188	0.15±0.06	152	0.17±0.12
	194	0.05±0.02	257	0.03±0.02	188	0.02±~0.00	165	0.10±0.09	202	0.19±0.11	165	0.12±0.03
	209	0.04±0.02	-	-	202	0.02±~0.00	188	0.07±0.06	286	0.04±0.03	188	0.13±0.08
	-	-	-	-	286	0.02±~0.00	244	0.03±0.03	-	-	244	0.06±0.04
	-	-	-	-	-	-	287	0.01±0.01	-		287	0.03±0.02
LAI	doy	m^2 m^{-2}	doy	m^2 m^{-2}	doy	m^2 m^{-2}	doy	m^2 m^{-2}	doy	m^2 m^{-2}	doy	m^2 m^{-2}
	154	1.67±0.85	89	0.72±0.27	161	0.42±0.44	62	0.21±0.25	161	1.30±0.84	62	0.28±0.39
	167	1.20±0.55	138	1.97±0.69	174	0.26±0.09	110	1.27±1.12	-	-	110	0.80±0.44
	180	0.82±0.56	166	1.12±0.69	202	0.12±0.12	125	1.36±0.66	188	2.56±1.21	125	0.80±0.47
	194	0.58±0.28	-	-	286	0.10±0.06	152	2.55±1.79	202	1.93±2.01	152	2.46±1.59
	209	0.70±0.30	-	-	-	-	165	0.58±0.19	286	0.52±0.40	165	1.22±0.39

Table S2. Climate models used in this study, an indication of their origin (institute), version, realisation and frequency. The suffixes i and p of each realisation (r) indicate the initialisation and physics indices, respectively.

Institute	Global Climate Model (GCM)	Experiment	Realisation	Regional Climate Model (RCM)	Frequency
CLMcom	CNRM-CERFACS-CNRM-CM5	RCP4.5	r1i1p1	CLMcom-CCLM4-8-17	day
		RCP8.5	r1i1p1		day
	ICHEC-EC-EARTH	RCP4.5	r12i1p1		day
		RCP8.5	r12i1p1		day
	MOHC-HadGEM2-ES	RCP4.5	r1i1p1		day
		RCP8.5	r1i1p1		day
	MPI-M-MPI-ESM-LR	RCP4.5	r1i1p1		day
		RCP8.5	r1i1p1		day
DMI	NCC-NorESM1-M	RCP4.5	r1i1p1	DMI-HIRHAM5	day
		RCP8.5	r1i1p1		day
IPSL-INERIS	IPSL-IPSL-CM5A-MR	RCP4.5	r1i1p1	IPSL-INERIS-WRF331F	day
		RCP8.5	r1i1p1		day
KNMI	ICHEC-EC-EARTH	RCP4.5	r1i1p1	KNMI-RACMO22E	day
		RCP4.5	r1i1p1		day
	MOHC-HadGEM2-ES	RCP8.5	r1i1p1		day
		RCP4.5	r1i1p1		day
MPI-CSC	MPI-M-MPI-ESM-LR	RCP4.5	r1i1p1	MPI-CSC-REMO2009	day
		RCP8.5	r1i1p1		day
SMHI	CNRM-CERFACS-CNRM-CM5	RCP4.5	r1i1p1	SMHI-RCA4	day

ICHEC-EC-EARTH	RCP8.5	r1i1p1	day
	RCP4.5	r12i1p1	day
	RCP8.5	r12i1p1	day
IPSL-IPSL-CM5A-MR	RCP4.5	r1i1p1	day
	RCP8.5	r1i1p1	day
MOHC-HadGEM2-ES	RCP4.5	r1i1p1	day
	RCP8.5	r1i1p1	day
MPI-M-MPI-ESM-LR	RCP4.5	r1i1p1	day
	RCP8.5	r1i1p1	day

Table S3. Summary of the PaSim parameters considered for the calibration.

Parameters			Value
Name	**Description**	**Unit**	
Canopy height parameter 1 (*hcanhalf*)	This parameter expresses the leaf area index for which the canopy corresponds to half the maximum height.	$m^2\ m^{-2}$	4
Canopy height parameter 2 (*hcanmax*)	This is the height of the flowering plant, the highest leaf not being elongated.	m	1.203
Maximum specific leaf area (*slam*)	The maximum value of the specific leaf area is the maximum ratio of leaf area to dry weight, used to derive the canopy leaf area from the leaf biomass.	$m^2\ kg^{-1}$	27.2
Light-saturated leaf photosynthetic rate for reproductive stage (*pmco2rep*)	They represent the influence of developmental stage on the photosynthetic rate of light-saturated leaves (defined under standard conditions of temperature and atmospheric CO_2 concentration), which is a component of the photosynthetic rate of the canopy.	μmol C $m^{-2}\ s^{-1}$	12.88
Light-saturated leaf photosynthetic rate for vegetative stage (*pmco2veg*)		μmol C $m^{-2}\ s^{-1}$	9.49
Root turnover parameter (*kturnrt20*)	It is the root turnover rate at 20 °C.	d^{-1}	0.0155
Shoot turnover parameter (*kturnsh20*)	It is the shoot turnover rate at 20 °C.	d^{-1}	0.0468
Parameter of the fractional N content of new plant structural dry matter (*fnref*)	This parameter is used to derive the nitrogen concentration of the newly produced structural dry matter.	kg N kg^{-1} DM	0.033
Temperature dependence factor of the soil respiration (*kfactor*)	It multiplies the temperature-dependent function to estimate soil respiration.	-	2
Relative root distribution (*froot*)	This is the relative dry matter of the roots in the different soil layers (one value per soil layer).	%	0.095 0.297 0.238 0.145

			0.195
			0.030
Base temperature (*Tbase*)	This is the air temperature below which plant growth and development are nil.	K	277.94
Normalisation factor for development (*tasumrep*)	This parameter (which divides the sum of the thermal units) normalises the developmental stage index in such a way that a value 1 marks the transition from the reproductive to the vegetative stage.	K-d	734.3

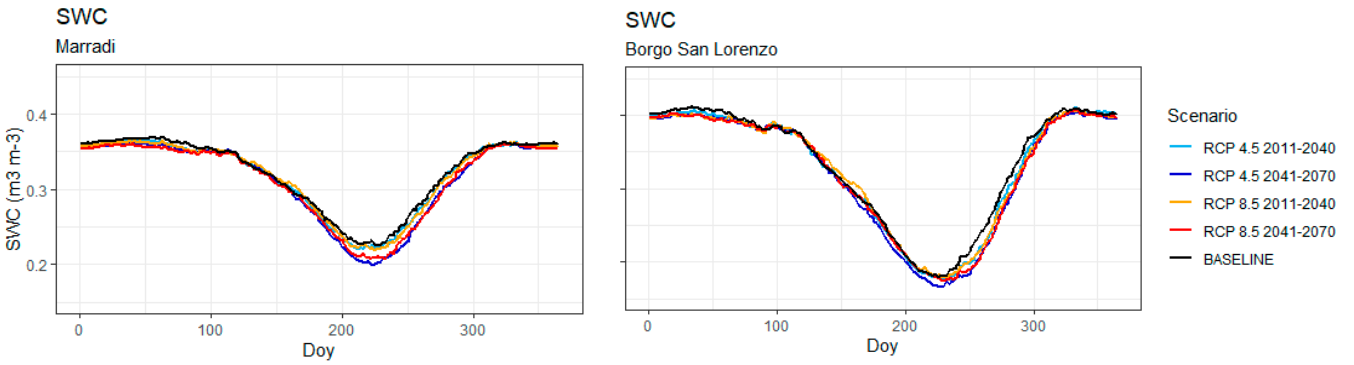

Figure S1. Daily simulation (30-year mean) of 0.35-m soil water content (SWC) with PaSim for baseline and climate-change scenarios under business-as-usual management at both study-sites. RCP4.5 and 8.5 are the different Representatives Concentration Pathways used in the simulations.

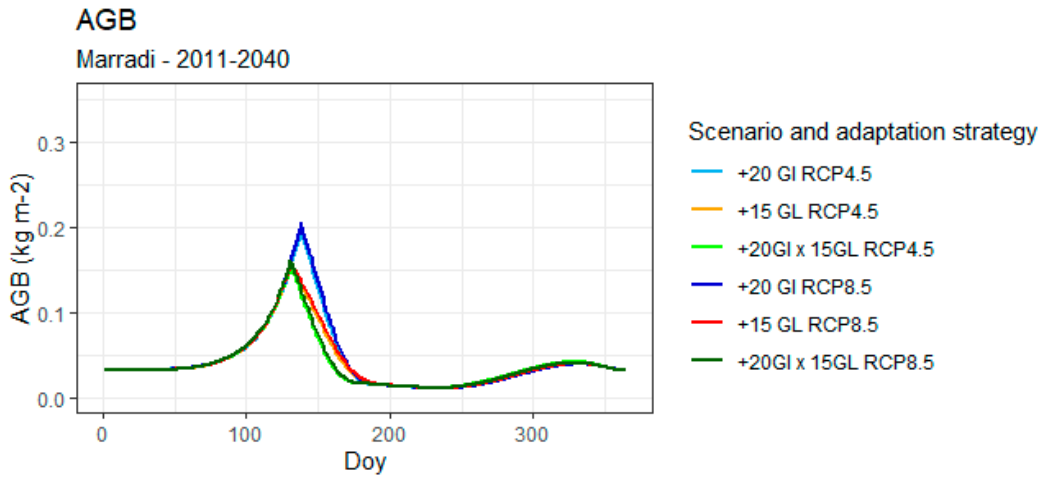

Figure S2. Daily simulation (30-year mean) of aboveground biomass (AGB) with PaSim for climate-change scenarios under different adaptation strategies at Marradi site for 2011-2040 period. +20 GI represent a 20% rise in animal stocking rate, 15 GL a 15% increase in grazing length and +20 GI×15 GL a combination of these two management factors. RCP4.5 and 8.5 are the different Representatives Concentration Pathways used in the simulations.

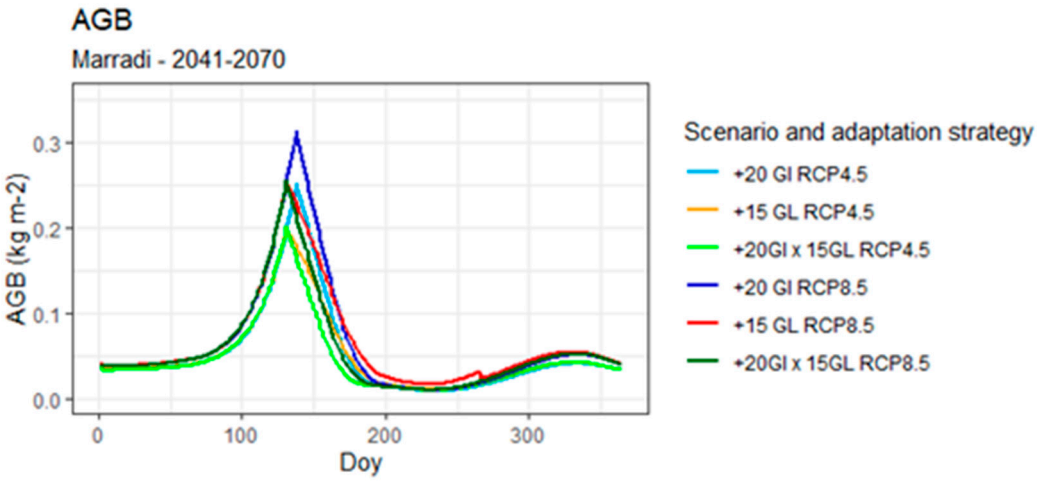

Figure S3. Daily simulation (30-year mean) of aboveground biomass (AGB) with PaSim for climate-change scenarios under different adaptation strategies at Marradi site for 2041-2070 period. +20 GI represent a 20% rise in animal stocking rate, 15 GL a 15% increase in grazing length and +20 GI×15 GL a combination of these two management factors. RCP4.5 and 8.5 are the different Representatives Concentration Pathways used in the simulations.

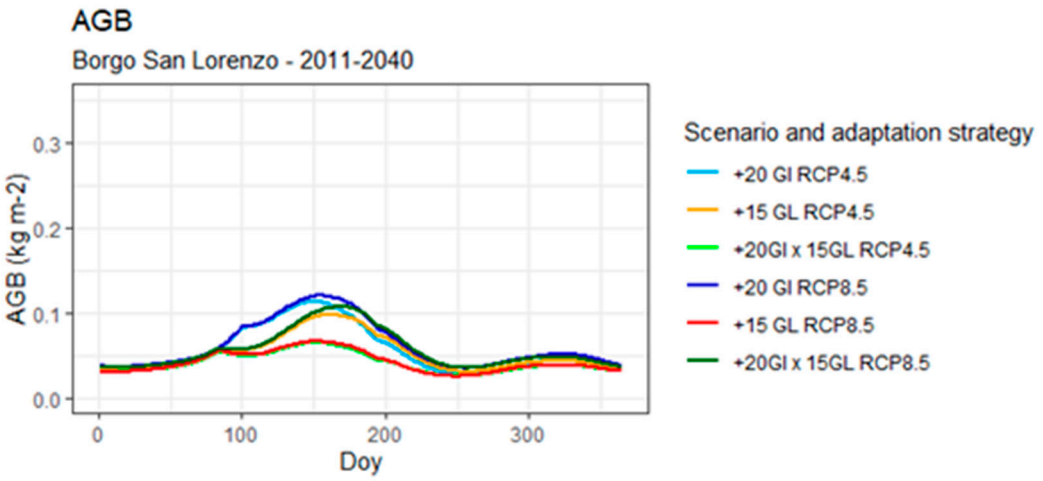

Figure S4. Daily simulation (30-year mean) of aboveground biomass (AGB) with PaSim for climate-change scenarios under different adaptation strategies at Borgo San Lorenzo site for 2011-2040 period. +20 GI represent a 20% rise in animal stocking rate, 15 GL a 15% increase in grazing length and +20 GI×15 GL a combination of these two management factors. RCP4.5 and 8.5 are the different Representatives Concentration Pathways used in the simulations.

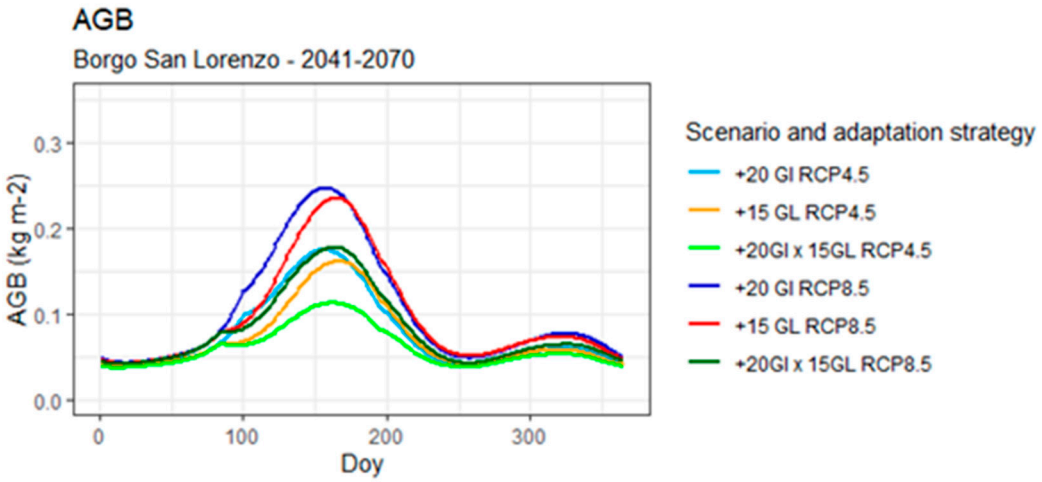

Figure S5. Daily simulation (30-year mean) of aboveground biomass (AGB) with PaSim for climate-change scenarios under different adaptation strategies at Borgo San Lorenzo site for 2041-2070 period. +20 GI represent a 20% rise in animal stocking rate, 15 GL a 15% increase in grazing length and +20 GI×15 GL a combination of these two management factors. RCP4.5 and 8.5 are the different Representatives Concentration Pathways used in the simulations.

Table S4. Simulated flux components (30-year mean) from the two study-sites for the baseline (1981-2010) and climate scenarios (RCP4.5 and RCP8.5) under different management options, estimated using PaSim (GPP: gross primary production; RECO: ecosystem respiration; NEE: net ecosystem exchange). +20 GI represent a 20% rise in animal stocking rate, 15 GL a 15% increase in grazing length and +20 GI×15 GL a combination of these two management factors. RCP4.5 and 8.5 are the different Representatives Concentration Pathways used in the simulations.

Marradi		**CH_4**		**N_2O**		**GPP**		**RECO**		**NEE**	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
BAU	Baseline	2.2	2.2	4.7	4.7	337.3	337.3	718.7	718.7	381.3	381.3
	2011-2040	2.9	3.0	0.7	0.6	511.8	539.0	544.7	568.4	32.9	29.4
	2041-2070	3.5	3.9	0.4	0.3	716.5	962.4	701.3	911.2	-15.1	-51.2
+20 GI	2011-2040	2.7	2.9	0.7	0.7	469.5	491.3	505.0	523.9	35.5	32.6
	2041-2070	3.3	3.8	0.4	0.4	621.5	813.6	616.3	784.0	-5.2	-29.6
+ 15 GL	2011-2040	2.6	2.8	0.7	0.6	434.9	456.5	471.5	491.4	36.6	34.9
	2041-2070	3.4	4.0	0.4	0.3	602.1	837.0	595.4	797.0	-6.8	-39.9
+20 GI x 15 GL	2011-2040	2.5	2.6	0.7	0.7	404.2	422.2	443.1	459.6	38.9	37.3
	2041-2070	3.2	3.8	0.4	0.4	535.5	716.8	534.7	693.4	-0.8	-23.4

Borgo San Lorenzo		**CH_4**		**N_2O**		**GPP**		**RECO**		**NEE**	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
BAU	Baseline	1.8	1.8	4.6	4.6	509.4	509.4	859.5	859.5	350.1	350.1
	2011-2040	2.2	2.3	0.8	0.8	714.5	792.0	737.0	807.2	22.5	15.2
	2041-2070	2.5	2.7	0.4	0.4	965.0	1258.1	932.3	1187.9	-32.7	-70.3
+20 GI	2011-2040	2.4	2.5	0.7	0.7	610.3	679.6	632.9	695.8	22.6	16.2
	2041-2070	2.8	3.1	0.4	0.4	875.3	1185.0	844.7	1113.0	-30.5	-72.0
+ 15 GL	2011-2040	2.1	2.2	0.7	0.7	552.2	607.0	580.4	629.5	28.2	22.5
	2041-2070	2.5	2.8	0.4	0.4	807.3	1104.3	780.1	1036.3	-27.3	-68.0
+20 GI x 15 GL	2011-2040	2.1	2.1	0.7	0.7	445.4	459.0	477.8	489.5	32.4	30.5

	2041-2070	2.7	3.1	0.4	0.3	701.3	979.3	678.2	912.6	-23.1	-66.7