Green water availability and water-limited crop yields under a changing climate in Ethiopia

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Table S1: List of the administrative zones within the nine regional states of Ethiopia based on pre-2010 divisions. The short names are arbitrary designations used in Fig. 1.

Short name	Long name	Region
NWT	North West Tigray	Tigray
CTI	Central Tigray	
ETI	Eastern Tigray	
STI	Southern Tigray	
WTI	Western Tigray	
ZO1	Zone 1	Afar
ZO2	Zone 2	
ZO3	Zone 3	
ZO4	Zone 4	
ZO5	Zone 5	
NGO	North Gondar	Amhara
SGO	South Gondar	
NWO	North Wello	
SWO	South Wello	
aNSH	North Shewa	
EGO	East Gojam	
WGO	West Gojam	
WAG	Wag Himra	
AWI	Awi	
ORO	Oromia	
WWL	West Wellega	Oromia
EWL	East Wellega	
ILU	Ilu Aba Bora	
JIM	Jimma	
WSH	West Shewa	
oNSH	North Shewa	
ESH	East Shewa	
ARS	Arsi	
WHA	West Hararge	
EHA	East Hararge	
BAL	Bale	
BOR	Borena	
SWS	South West Shewa	
GUJ	Guji	
wARS	West Arsi	

Short name	Long name	Region
SHI	Shinile	Somali
FAF	Fafan	
LIB	Liben	
AFD	Afder	
DOL	Dolo	
JAR	Jarar	
SHB	Shabelle	
KOR	Korahe	
SIT	Siti	
NOG	Nogob	
MET	Metekel	Benishangul-gumz
ASO	Asosa	
KEM	Kemashi	
GUR	Gurage	SNNPR
HAD	Hadiya	
KET	Kembata Tibaro	
KEF	Kefa	
GGO	Gamo Gofa	
BMJ	Bench Maji	
YEM	Yem Special	
AMA	Amaro Special	
BUR	Burji Special	
KONs	Konso Speicial	
DER	Derashe Special	
DAW	Dawuro	
BAS	Basketo Special	
KON	Konta Special	
SIL	Siltie	
ALB	Alaba Special	
ALL	Alle	
WOL	Wolaita	
SOM	South Omo	
SID	Sidama	Sidama
AGN	Agnuak	Gambela
MAJ	Majang	
NUE	Nuer	

Table S2: List of the CMIP6 model projections used for the projection of the precipitation, maximum and minimum temperature and incoming shortwave radiation over Ethiopia. The ‘x’ marks show the variables that were used from the indicated model.

Model	**Institution (country/region)**[1]	**Precip**	**Tmax**	**Tmin**	**Rsw**	**Reference**
ACCESS-CM2	CSIRO (Australia)	x	x	x	x	(Bi et al., 2020)
AWI-CM-1-1-MR	AWI (Germany)	x	x	x	x	(Semmler et al., 2020)
BCC-CSM2-MR	BCC (Asia)	x			x	(Wu et al., 2019)
CAMS-CSM1-0	CAMS (China)	x			x	(Rong et al., 2019)
CanESM5-CanOE	CCCma (Canada)	x	x	x	x	(Christian et al., 2022)
CESM2	NCAR (USA)	x			x	(Danabasoglu et al., 2020)
CIESM	THU (China)		x	x		(Lin et al., 2020)
CMCC-CM2-SR5	CMCC (Italy)	x			x	(Cherchi et al., 2019)
CMCC-ESM2		x	x	x	x	(Lovato et al., 2022)
CNRM-CM6-1	CNRM (France)	x	x	x	x	(Voldoire et al., 2019)
CNRM-CM6-1-HR		x	x	x	x	
CNRM-ESM2-1		x	x	x	x	
EC-Earth3-Veg-LR	EC-Earth (Europe)		x	x		(Döscher et al., 2022)
FGOALS-g3	CAS (China)	x	x	x	x	(Li et al., 2020)
FIO-ESM-2-0	FIO-QNLM (China)	x	x	x	x	(Bao et al., 2020)
GFDL-ESM4	NOAA-GFDL (USA)	x	x	x	x	(Dunne et al., 2020)
HadGEM3-GC31-LL	MOHC (UK)	x	x	x	x	(Andrews et al., 2020)
IITM-ESM	CCCR-IITM (India)	x	x	x	x	(David A. et al., 2019)
INM-CM4-8	INM (Russia)		x	x		(Volodin et al., 2018)
INM-CM5-0		x	x	x	x	
IPSL-CM6A-LR	IPSL (France)	x	x	x	x	(Boucher et al., 2020)
MIROC6	MIROC (Japan)	x	x	x	x	(Tatebe et al., 2019)
MIROC-ES2L		x	x	x	x	(Hajima et al., 2020)
MPI-ESM1-2-LR	MPI (Germany)	x	x	x	x	(Gutjahr et al., 2019)
NESM3	NUIST (China)	x			x	(Cao et al., 2018)
NorESM2-MM	NCC (Norway)	x			x	(Seland et al., 2020)
TaiESM1	AS-RCEC (Taiwan)	x			x	(Wang et al., 2021)
UKESM1-0-LL	MOHC (UK)	x	x	x	x	(Sellar et al., 2019)

[1] The full names of the institutions can be found in (IPCC, 2021)

Table S3: List of the nine surface runoff measurement sites and measurement periods collected from published literature for the validation of the simulated surface runoff.

Measurement site	Lat (° N)	Lon (° E)	Measurement periods (Values used in the evaluation)	Reference
Maybar	11.02	39.67	1982-1993 (mean)	(Herweg and Ludi, 1999; Herweg and Stillhardt, 1999)
Hunde lafto	9.07	41.00	1983-1993 (mean)	
Andit Tid	9.80	39.72	1982-1992 (mean)	
Anjeni	10.81	37.57	1985-1993 (mean)	
Gununo	6.92	37.65	1982-1992 (mean)	
Dendi	9.13	37.12	2007-2009 (annual)	(Adimassu et al., 2014)
Holeta	9.07	38.48	2009-2010 (annual)	(Adimassu et al., 2019)
Debre Mawi	11.33	37.43	2008-2009 (annual)	(Amare et al., 2014)
Chefe donsa	8.96	39.11	2001-2002 (annual)	(Erkossa et al., 2006)
Dera	8.36	39.34	2004 (annual)	(Welderufael et al., 2008)
Yeku	12.52	39.07	2003 (annual)	(Collick et al., 2009)
Guder*	9.84	36.67	2003 (annual)	(Tumsa et al., 2022)
Dodota*	11.50	39.92	1994-2000 (mean)	(Teso et al., 2010)
Keleta	8.12	39.46	1981, 1990 (annual)	(Tibebe and Bewket, 2011)
Suluh*	13.80	39.50	1992-2003 (mean)	(Abebe, 2014)
Hare*	6.25	37.55	1990-1999 (mean)	(Wagesho et al., 2013)
Bilate*	7.50	37.94	1990-1999 (mean)	

*These are model-calibrated surface runoff data: Guder (SWAT+), Dodota (SWAT), Suluh (HEC-HMS), Hare and Bilate (SWAT)

Table S4: Published potential (fully irrigated, optimally fertilized) yield measured at 14 experimental sites across the RFA region of Ethiopia.

Experimental site	Potential yield, Yp (ton/ha)	Lat (° N)	Lon (° E)	Reference
Salaklaka, Northwest Tigray	7.3	14.3	38.72	(Gebreigziabher, 2020)
Melkasa, East Shoa	7.9	8.4	39.35	(Seid, Mulugeta M; Narayanan, 2015)
Boloso Sore, Wolayta	8.8	7.0	37.75	(Chinasho et al., 2023)
Tepi, SW Ethiopia	6.8	7.187	35.42	(Zeleke, 2020)
Raya, South Tigray	8.7	12.7	39.7	(Mehari et al., 2020)
Arba Minch, Gamo Gofa	8.0	6.08	37.58	(Setu et al., 2023)
Koga, West Gojam	5.9	11.37	37.12	(Abiyu and Alamirew, 2015)
Haru ARC, West Wollega	8.4	8.90	35.87	(Admasu et al., 2017)
Adami Tulu, East Shoa	4.5	7.75	38.65	(Furgassa, 2017)
Mehoni, South Tigray	5.7	12.87	39.64	(Mebrahtu and Mehamed, 2019)
Haramaya, East Hararge	7.1	9.417	42.04	(Mengiste and Tilahun, 2009)
Hawassa, Sidama	9.0	7	38	(Jemal and Berhanu, 2020)
Koka, East Shoa	6.3	8.43	39	(Meskelu et al., 2018)
Gumselasa, South Tigray	9.9	13.25	39.51	(Mintesinot et al., 2004)

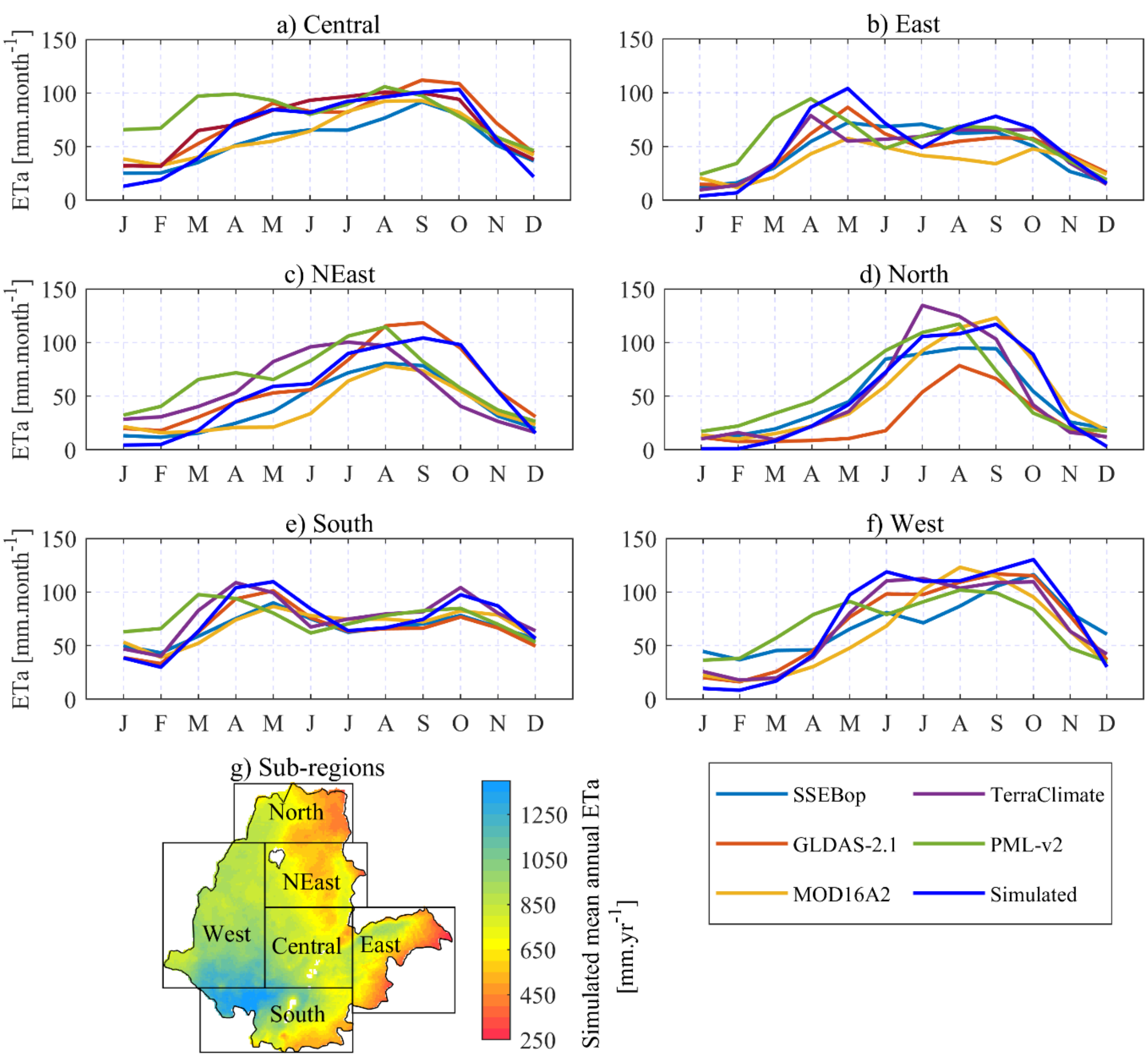

Figure S1: Comparison of area-averaged monthly cycles of the simulated ETa and other independent ETa products (a-f) at six arbitrarily defined sub-regions (g) for the record period 2003-2010.

Figure S2: Comparison of simulated and independent (observed) annual ETa (a-f) at the six sub-regions (see Fig. S1g) for the record period 2003-2010.

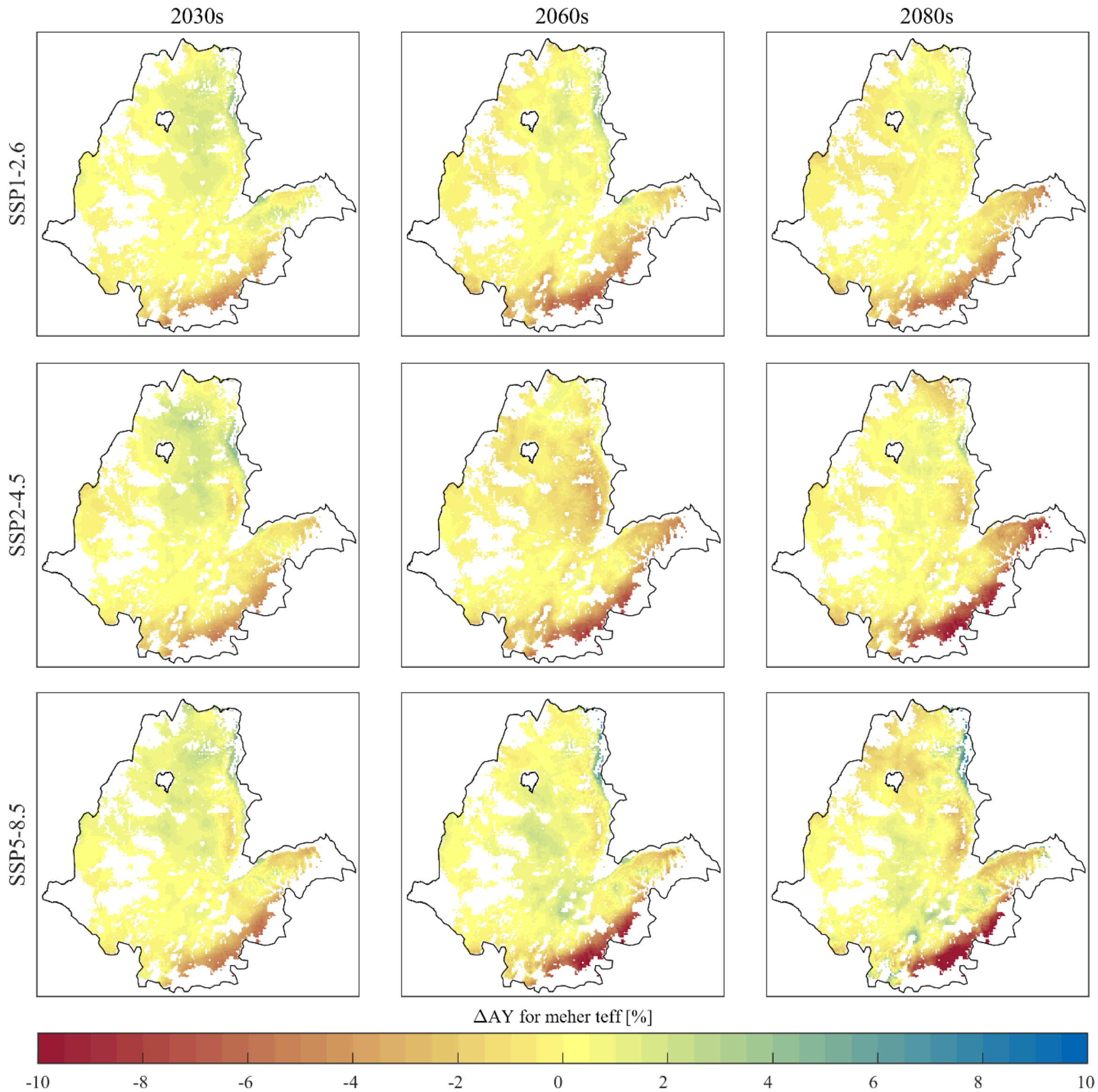

Figure S3: Projected changes in Meher water-limited attainable yield (AY) for teff under the SSP1-2.6, SSP2-4.5, and SSP5-8.5. The RFA region was masked using cropland suitability maps (Wakjira et al., under review) to restrict the analysis to areas potentially suitable for each crop. The non-producing areas during both seasons were also masked out following the Atlas of Ethiopian Rural Socioeconomy (IFPRI and CSA, 2006).

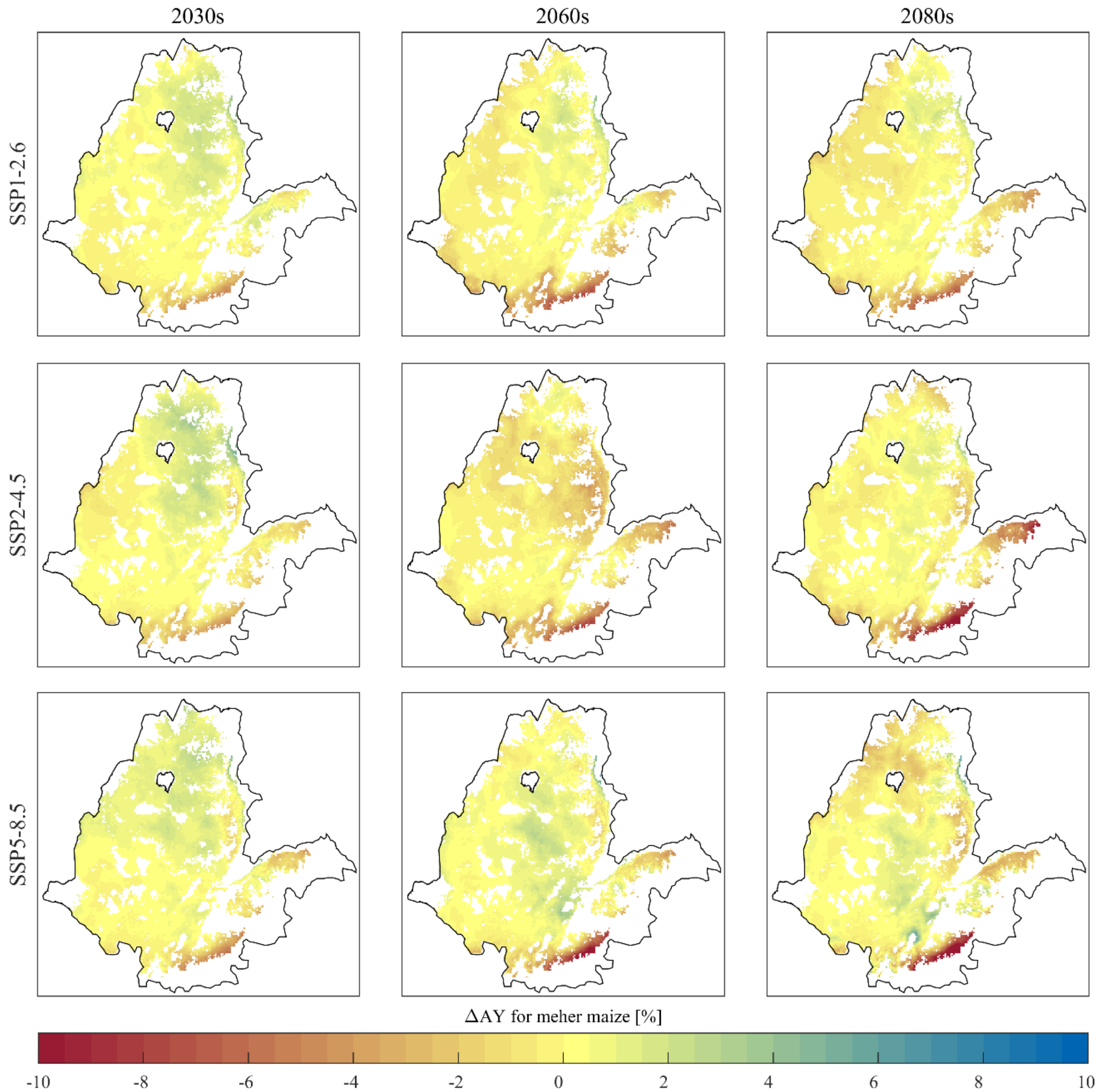

Figure S4: The same as Fig. S3, but for maize

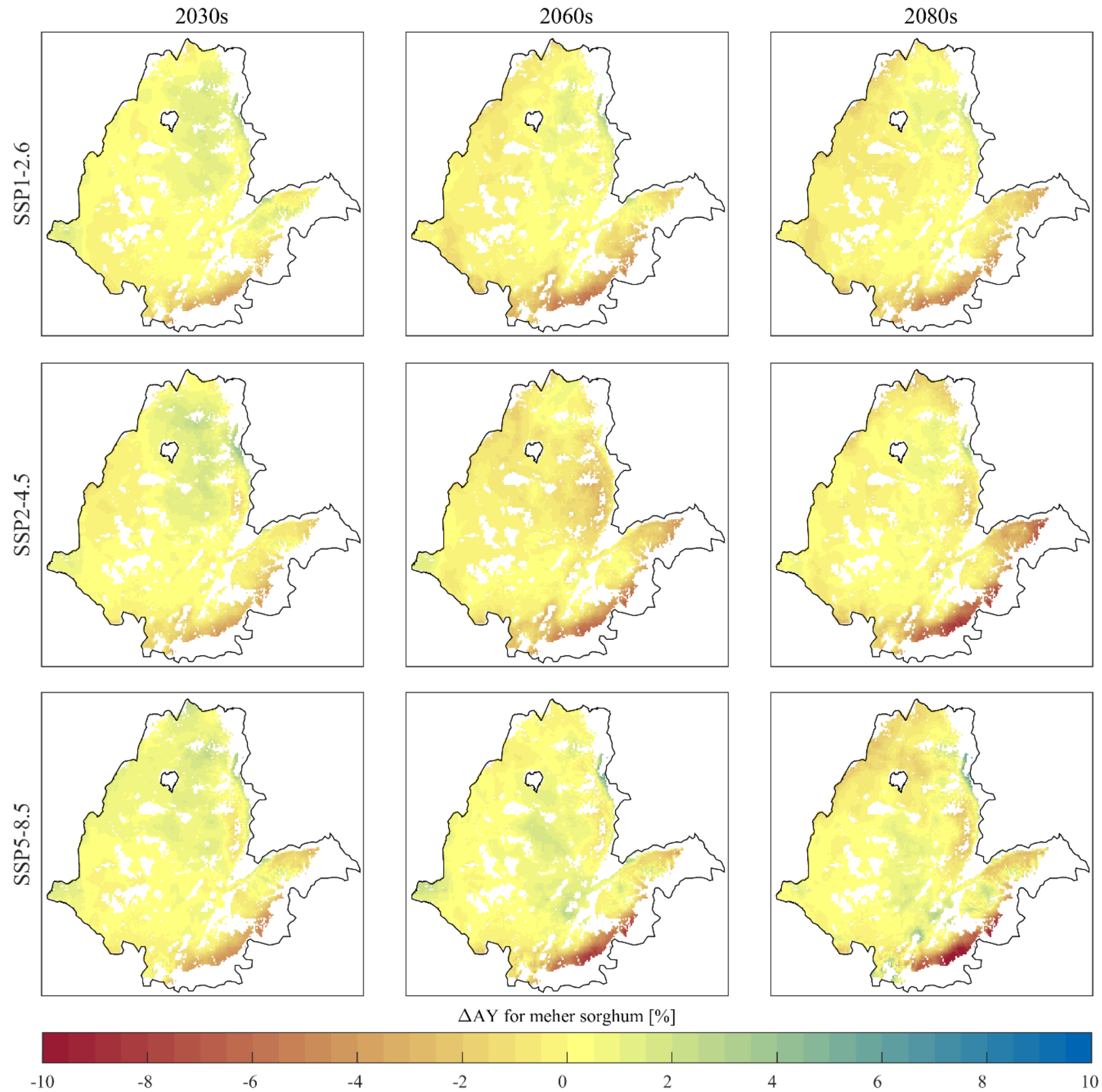

Figure S5: The same as Fig. S3, but for sorghum

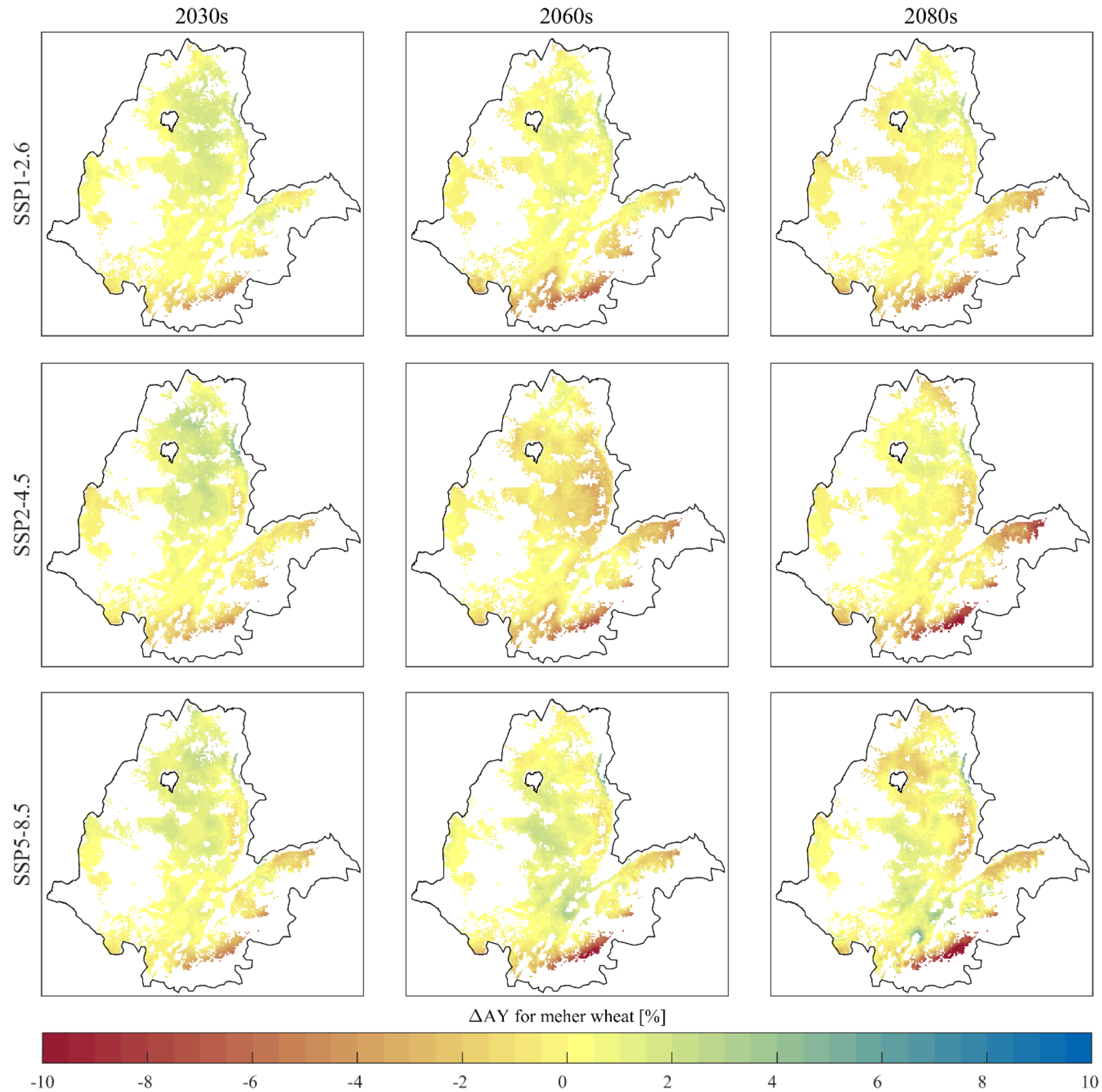

Figure S6: The same as Fig. S3, but for wheat

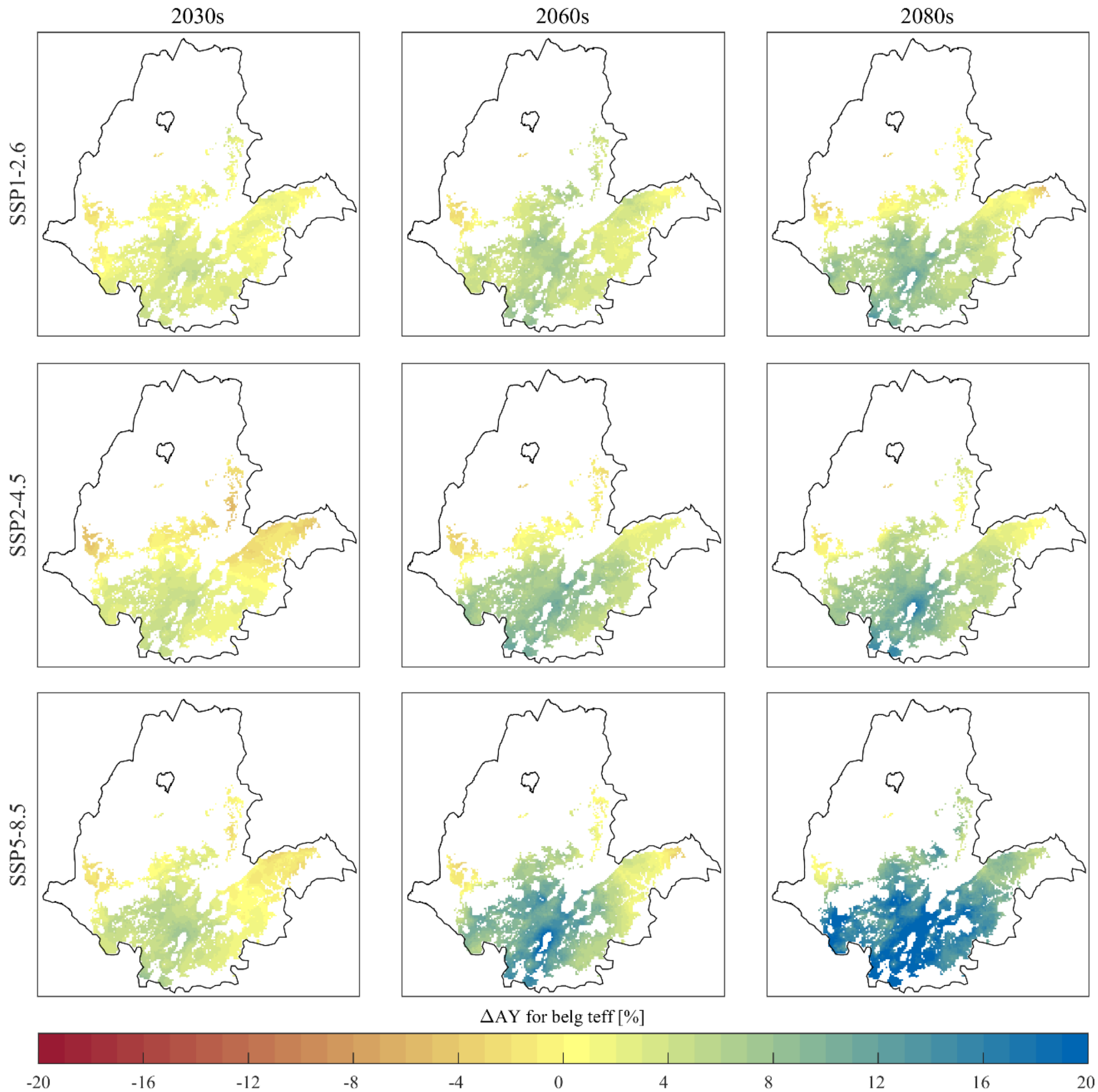

Figure S7: Projected changes in Belg water-limited attainable yield (AY) for teff under the SSP1-2.6, SSP2-4.5, and SSP5-8.5. The RFA region was masked using cropland suitability maps (Wakjira et al., under review) to restrict the analysis to areas potentially suitable for each crop. The non-producing areas during both seasons were also masked out following the Atlas of Ethiopian Rural Socioeconomy (IFPRI and CSA, 2006).

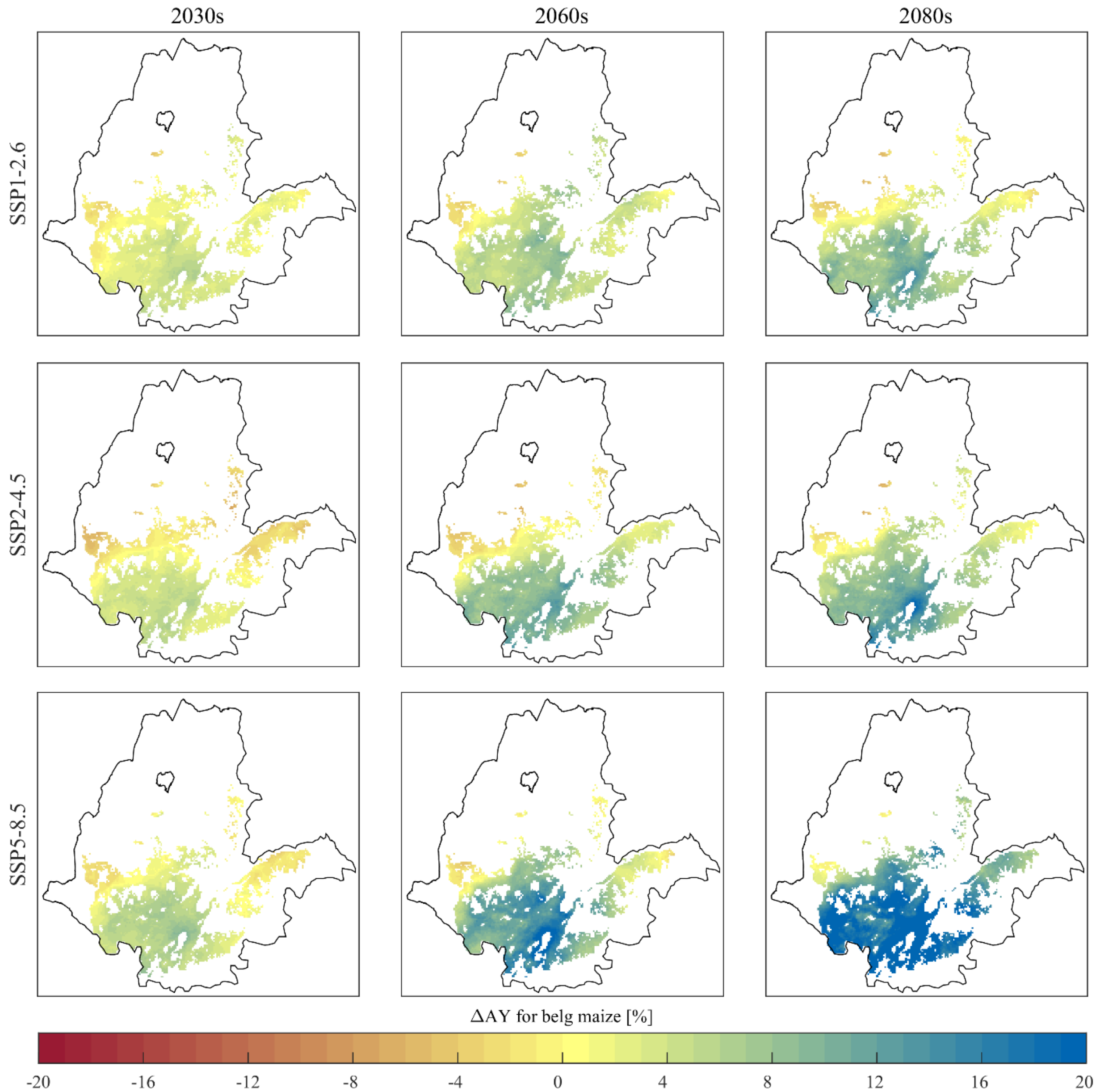

Figure S8: The same as Fig. S7, but for maize

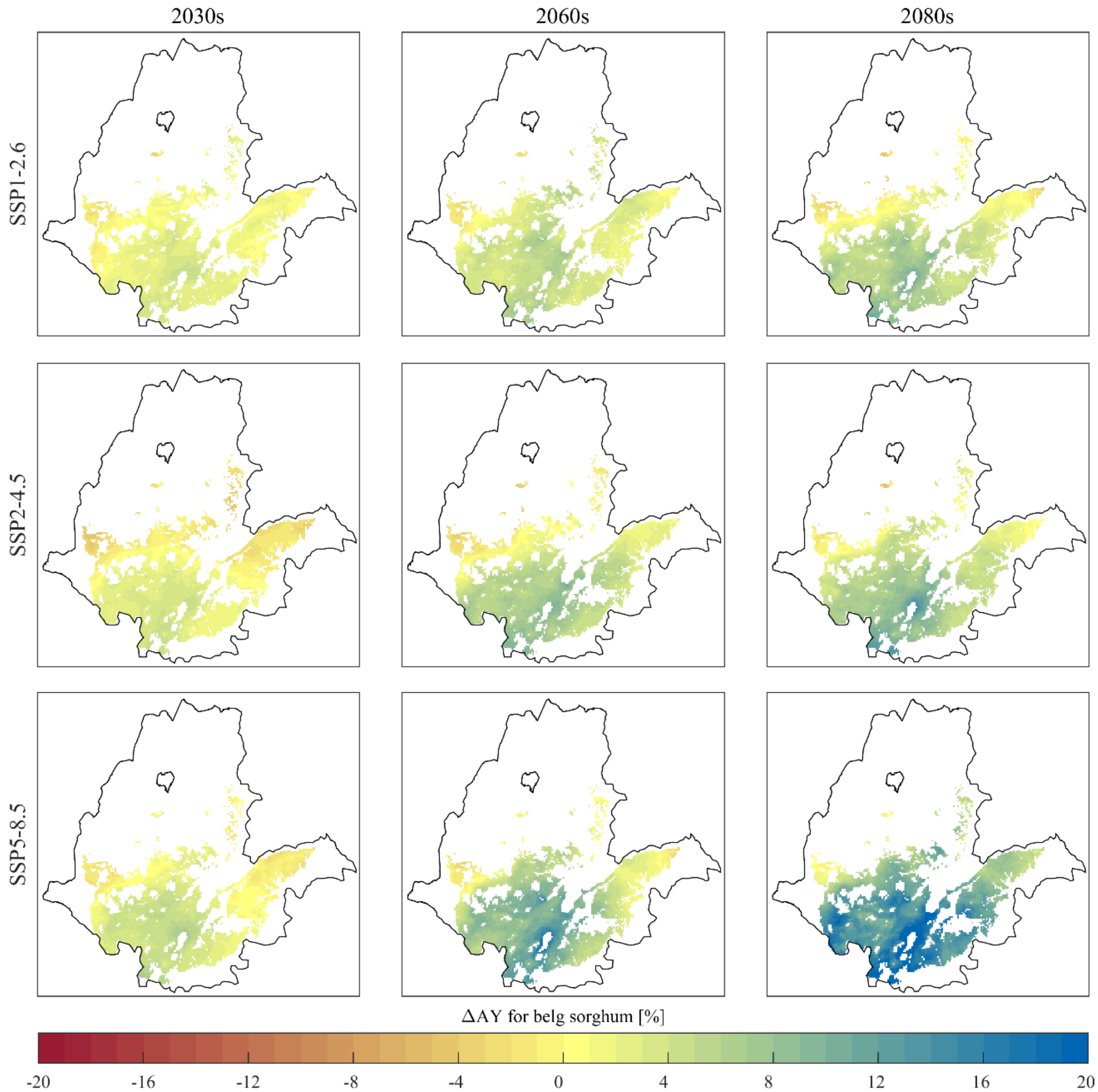

Figure S9: The same as Fig. S7, but for sorghum

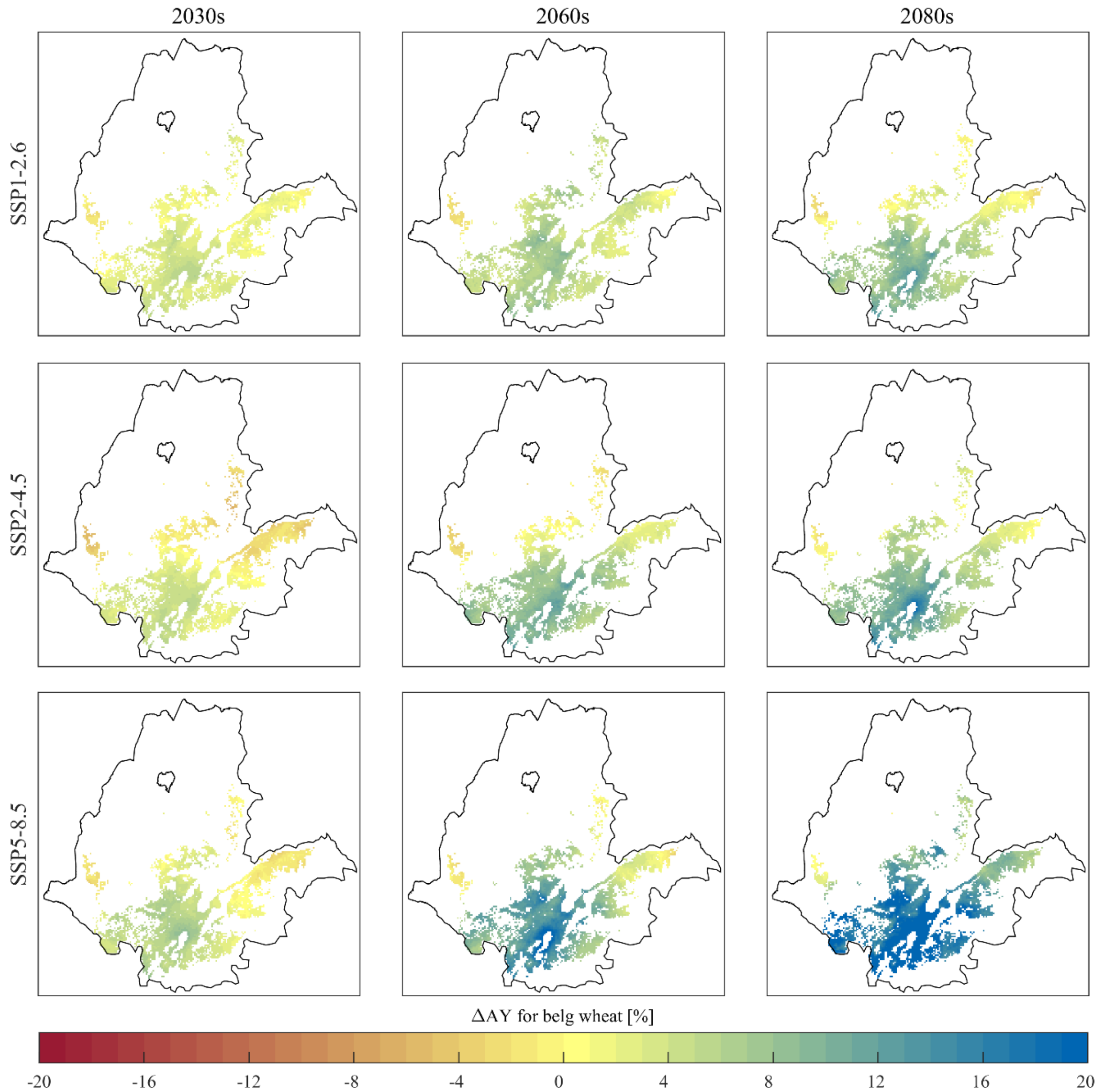

Figure S10: The same as Fig. S7, but for wheat

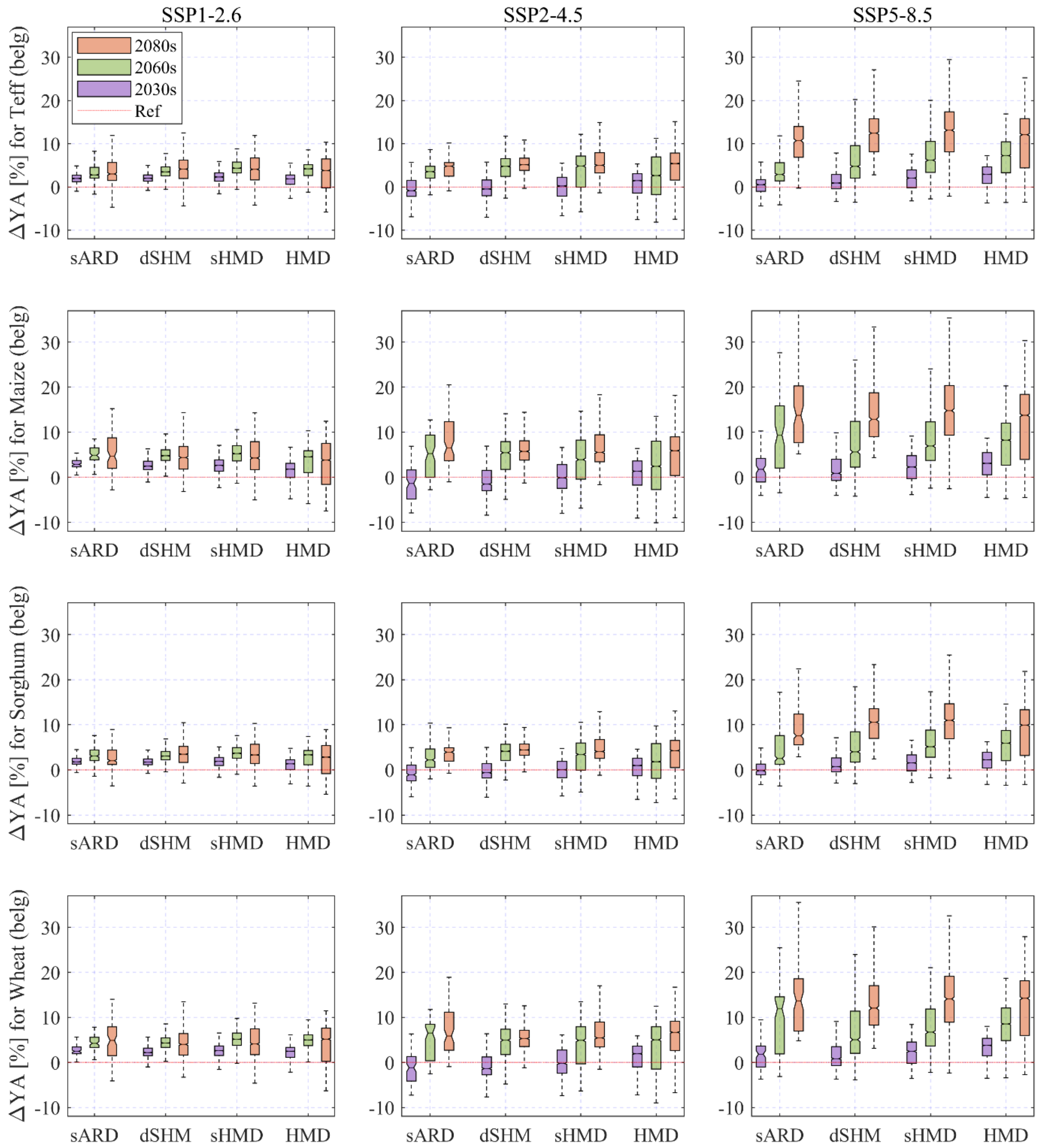

Figure 11: Boxplots of the projected changes in water-limited yields (AY) of the four major cereal crops produced in Ethiopia in different climatic regimes under the three SSPs during the three future periods, during the Belg growing season. Each boxplot represents the distribution of AY changes within Belg-producing areas for all grid cells in the respective climatic regime. Outlier values have been excluded.

Figure S12: Area-averaged relative sensitivity (β_{ratio}) of water-limited attainable yields (AY) to rainfall and atmospheric evaporative demand (AED) for the Belg growing season at the administrative zone level under the low, intermediate, and high emission scenarios for teff, maize, sorghum, and wheat. The mapped values represent the average of β_{ratio} of all grid cells within each zone, and all three future periods. The short names of the 62 administrative zones within the RFA region of Ethiopia are indicated in Fig. 1. The long names are listed in Table S1 of the supplementary material.

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