Supplementary material for:

Enhancement and validation of the state-of-the-art global hydrological model H08 (v.bio1) to simulate second-generation herbaceous bioenergy crop yield

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Table S1. Location and yield of the sites for *Miscanthus* (specified in Fig. 4) under rainfed condition.

ID	Country	Longitude	Latitude	Minimum yield [t ha^{-1} yr^{-1}]	Maximum yield [t ha^{-1} yr^{-1}]	Mean yield [t ha^{-1} yr^{-1}]	Reference
1	Indonesia	107.70	-7.00	31.9	31.9	31.9	Blair et al. 1986
2	US	-97.10	36.10	12.4	13.1	12.8	Aravindhakshan et al. 2010
3	US	-88.67	37.45	18.0	42.3	30.2	Arundale et al., 2014a, 2014b; Heaton et al., 2008
4	Turkey	33.23	38.17	1.50	13.19	7.0	Acaroğlu and Aksoy, 2005
5	US	-88.39	38.38	19.00	47.00	31.4	Arundale et al., 2014a, 2014b; Heaton et al., 2008
6	US	-90.82	39.81	12.00	36.00	25.0	Arundale et al., 2014a, 2014b; Heaton et al., 2008
7	US	-88.23	40.08	22.0	45.5	33.8	Arundale et al., 2014a; Heaton et al., 2008
8	US	-88.19	40.17	17.00	24.10	20.6	Wang et al., 2012
9	US	-88.85	41.85	5.00	29.90	17.3	Arundale et al., 2014a, 2014b; Heaton et al., 2008
10	Italy	10.32	43.67	9.00	48.00	26.2	Angelini et al., 2009; Ercoli et al., 1999; o Di Nasso et al., 2011
11	Switzerland	9.13	47.57	14.00	14.00	14.0	Poeplau and Don, 2014
12	Germany	10.00	48.00	20.00	20.00	20.0	Lewandowski and Heinz, 2003
13	Austria	14.22	48.11	15.50	24.50	20.0	Schwarz, 1993
14	Germany	9.97	48.13	12.70	16.50	15.0	Lewandowski and Kicherer, 1997
15	Austria	14.15	48.14	13.20	24.40	18.8	Schwarz, 1993
16	Austria	16.39	48.18	0.80	21.50	12.5	Schwarz, 1993
17	Austria	15.55	48.19	2.00	23.84	14.9	Schwarz, 1993; Schwarz et al., 1994a
18	Austria	15.00	48.30	17.4	24.5	21.0	Schwartz, 1993
19	Germany	11.54	48.31	0.41	20.88	12.6	Schwarz et al., 1994b
20	Germany	10.26	48.49	1.11	23.42	13.4	Schwarz et al., 1994b
21	Germany	11.63	48.60	0.28	20.43	10.2	Schwarz et al., 1994b
22	Germany	9.00	48.70	19.9	26.4	23.2	Clifton-Brown et al., 2001a
23	Germany	8.93	48.73	14.50	18.00	16.3	Boehmel et al., 2008
24	Germany	8.92	48.75	5.60	30.50	13.7	Gauder et al., 2012
25	Germany	9.19	48.78	0.51	22.54	11.2	Schwarz et al., 1994b
26	Germany	8.10	49.00	17.00	17.00	17.0	Lewandowski el al., 2003
27	Germany	6.72	49.82	15.00	15.00	15.0	Poeplau and Don, 2014
28	France	3.00	49.87	19.00	28.00	23.1	Strullu et al., 2011
29	France	3.01	49.87	14.30	28.40	22.2	Cadoux et al., 2014
30	Germany	9.90	49.90	6.2	19.8	13.0	Kahle et al., 2001
31	Germany	10.77	50.97	15.00	15.00	15.0	Poeplau and Don, 2014
32	Blegium	3.80	51.00	0.50	25.70	12.1	Muylle et al., 2015
33	UK	-1.26	51.10	0.80	23.50	14.5	Price et al., 2004
34	Poland	22.63	51.23	0.44	29.43	13.1	Borkowska and Molas, 2013
35	Germany	6.70	51.50	17.5	28.8	23.2	Heaton et al. 2008
36	Germany	6.70	51.52	1.00	20.70	12.5	Himken et al., 1997
37	Germany	7.62	51.78	1.47	18.44	10.0	Schwarz et al., 1994b
38	UK	-0.40	51.80	9.8	17.8	13.8	Christian et al. 2008
39	UK	-2.64	51.80	13.00	24.00	18.0	Price et al., 2004
40	UK	-0.35	51.80	0.10	18.70	9.1	Clifton-Brown et al., 2001a
41	UK	-0.36	51.82	12.00	14.50	12.9	Richter et al., 2008

42	UK	-0.62	52.01	13.70	16.20	15.0	Richter et al., 2008
43	UK	-0.03	52.25	0.20	17.00	10.6	Price et al., 2004
44	Poland	16.92	52.42	5.50	23.70	11.2	Jezowski, 2008; Jezowski et al., 2011
45	UK	0.09	52.42	11.50	22.50	18.4	Price et al., 2004
46	UK	-4.02	52.43	0.30	17.20	10.6	Zatta et al., 2014
47	Germany	10.80	52.60	8.8	13.5	11.2	Kahle et al. 2001
48	Germany	8.26	52.61	2.10	20.02	10.1	Schwarz et al., 1994b
49	Germany	10.81	52.62	3.72	23.89	14.2	Schwarz et al., 1994b
50	Ireland	-7.83	52.65	4.20	16.30	11.5	Clifton-Brown et al., 2001b
51	Ireland	-7.27	52.67	2.00	15.80	9.4	Clifton-Brown et al., 2001b
52	Germany	8.81	52.68	3.46	19.01	9.6	Schwarz et al., 1994b
53	Netherlands	7.06	52.88	21.8	21.8	21.8	van der Werf et al. 1993
54	UK	-3.78	53.22	14.90	22.20	18.6	Price et al., 2004
55	Netherlands	6.95	53.30	13.00	13.00	13.0	Poeplau and Don, 2014
56	Poland	19.38	53.78	5.80	28.00	13.8	Jezowski et al., 2011
57	Germany	12.60	53.90	7.5	12.6	10.1	Kahle et al. 2001; Beuch et al., 2000
58	UK	-1.11	54.12	0.50	13.00	7.8	Price et al., 2004
59	UK	-0.64	54.12	0.50	16.00	7.3	Price et al., 2004
60	Denmark	9.12	54.90	6.20	14.00	10.0	Schwarz et al., 1994b
61	Sweden	14.00	56.00	0.10	24.70	6.6	Clifton-Brown et al., 2001a
62	UK	-3.06	56.46	10.20	10.20	10.2	Richter et al., 2008
63	Denmark	9.60	56.50	9.7	16.8	13.3	Clifton-Brown et al. 2001a, 2004; Lewandowski el al., 2003
64	Denmark	9.40	56.80	7.7	8.9	8.3	Jørgensen, 1997

Table S2. Location and yield of the sites for switchgrass (specified in Fig. 4) under rainfed condition.

ID	Country	Longitude	Latitude	Minimum yield [t ha^{-1} yr^{-1}]	Maximum yield [t ha^{-1} yr^{-1}]	Mean yield [t ha^{-1} yr^{-1}]	Reference
1	US	-97.70	28.45	4.50	13.00	7.8	Muir et al., 2001
2	US	-89.94	30.30	6.00	16.00	10.1	Arundale et al., 2014a, 2014b; Heaton et al., 2008
3	US	-87.32	32.00	1.52	12.07	5.9	Bransby et al., 1990
4	US	-98.20	32.23	1.50	21.50	9.9	Muir et al., 2001; Sanderson et al., 1999
5	US	-85.90	32.44	3.71	34.60	11.3	Ma et al., 2001; Sladden et al., 1991
6	US	-85.65	32.82	3.43	9.67	7.0	Bransby et al., 1990
7	US	-87.87	33.88	0.44	13.39	8.4	Bransby et al., 1990
8	US	-85.97	34.28	2.04	9.93	5.9	Bransby et al., 1990
9	US	-88.90	35.60	7.8	16.9	12.4	Lemus, 2004
10	US	-78.70	35.70	5.1	16.7	10.9	Lemus, 2004
11	US	-83.95	35.88	11.40	23.20	18.0	Reynolds et al., 2000
12	US	-84.00	35.90	11.2	24.9	18.1	Lemus, 2004
13	US	-97.07	36.12	8.31	13.82	11.0	Aravindhakshan et al., 2011
14	China	109.32	36.85	2.36	16.55	8.6	Xu et al., 2005, 2008
15	US	-78.23	36.92	5.20	8.60	7.5	Parrish et al., 1990
16	US	-87.80	37.10	8.4	17.0	12.7	Lemus, 2004
17	US	-80.40	37.20	9.5	27.4	18.5	Lemus, 2004
18	US	-88.67	37.45	7.80	18.00	11.2	Arundale et al., 2014a, 2014b; Heaton et al., 2008
19	China	118.49	37.46	3.46	4.51	3.8	Gao et al., 2016:
20	US	-77.97	38.02	7.00	16.20	11.6	Parrish et al., 1990:
21	US	-78.10	38.20	11.2	20.4	15.8	Lemus, 2004
22	US	-88.39	38.38	4.00	16.00	11.4	Arundale et al., 2014a, 2014b; Heaton et al., 2008
23	US	-88.96	38.95	4.00	15.00	9.7	Arundale et al., 2014a; Heaton et al., 2008
24	China	113.18	39.55	4.40	9.30	6.9	Xiong et al., 2008
25	US	-79.90	39.60	12.8	20.5	16.7	Lemus, 2004
26	US	-90.82	39.81	8.00	15.00	10.3	Arundale et al., 2014a, 2014b; Heaton et al., 2008
27	US	-75.38	39.92	2.82	12.50	7.0	Stout et al., 1988
28	US	-96.77	39.99	1.90	15.69	6.2	Sanderson et al., 1999
29	US	-88.23	40.08	10.60	18.00	14.1	Arundale et al., 2014a; Heaton et al., 2008
30	China	116.12	40.19	4.20	5.90	5.2	Hou et al., 2010
31	US	-78.00	40.70	3.3	9.4	6.4	Sanderson, 2008
32	US	-93.42	40.97	5.80	17.40	10.2	Anderson et al., 1994
33	US	-93.40	41.00	6.8	13.1	10.0	Lemus et al., 2002
34	US	-83.07	41.37	2.30	7.70	5.1	Wright, 1990; Wright and Turhollow, 2010
35	US	-83.05	41.50	3.00	9.00	5.4	Wright, 1990; Wright and Turhollow, 2010
36	US	-88.85	41.85	4.00	14.10	9.0	Arundale et al., 2014a, 2014b; Heaton et al., 2008
37	US	-88.90	41.90	10.4	12.5	11.5	Heaton et al., 2008
38	US	-100.00	42.00	5.0	7.4	6.2	Schmer et al., 2010
39	US	-93.77	42.02	4.90	15.90	9.6	Anderson et al., 1994
40	US	-76.45	42.45	0.89	13.11	6.7	Pfeifer et al., 1990

41	US	-77.00	42.87	1.17	7.60	4.4	Pfeifer et al., 1990
42	US	-99.80	43.70	0.8	5.9	3.4	Mulkey et al., 2006
43	US	-100.00	44.00	4.2	8.8	6.5	Schmer et al., 2010
44	US	-96.70	44.20	1.0	6.0	3.5	Mulkey et al., 2006
45	US	-100.00	44.28	5.00	5.00	5.0	Hong et al., 2013
46	US	-96.77	44.32	7.50	7.50	7.5	Hong et al., 2013
47	Italy	11.50	44.40	7.9	11.5	9.7	Di Virgilio et al., 2007
48	US	-73.75	45.47	1.65	17.21	9.6	Madakadze et al., 1998a, 1998b, 1998c; 1999
49	US	-95.88	45.60	4.80	4.80	4.8	Hong et al., 2013
50	US	-97.23	46.65	3.50	12.80	9.4	Meyer et al., 1994
51	US	-97.02	46.95	7.30	10.30	9.0	Meyer et al., 1994
52	US	-100.00	47.00	5.6	5.8	5.7	Schmer et al., 2010
53	Germany	8.93	48.73	8.00	14.00	11.3	Meyer et al., 1994
54	Blegium	3.80	51.00	2.50	15.90	9.9	Muylle et al., 2015
55	UK	-0.35	51.80	1.19	13.97	6.8	Christian et al., 2002

Table S3. Location and yield of the sites for *Miscanthus* and switchgrass (specified in Fig. S1) under irrigated condition.

ID	Country	Longitude	Latitude	Minimum yield [t ha^{-1} yr^{-1}]	Maximum yield [t ha^{-1} yr^{-1}]	Mean yield [t ha^{-1} yr^{-1}]	Reference
1	China	108.06	34.27	3.5	44.2	16.7	Ma et al., 2011
2	China	106.47	36.01	2.8	10.6	6.2	Ma et al., 2011
3	Italy	14.35	37.38	1.2	30.6	18.0	Mantineo et al., 2009
4	Italy	15.06	37.42	3.9	27.0	16.7	Cosentino et al., 2007
5	Turkey	32.5	38.0	12.0	13.2	12.6	Acarglu and Aksoy, 2005
6	Portugal	-9.22	38.72	4.6	37.8	17.1	Clifton-Brown et al., 2001a
7	Greece	22.75	39.40	20.0	31.4	25.6	Danalatos et al., 2007
8	France	3.00	49.88	4.8	32.5	7.7	Zub et al., 2011
9	UK	0.40	51.70	8.3	19.7	14.0	Beale and Long, 1995
10	UK	0.43	51.73	19.4	19.4	19.4	Beale and Long, 1995

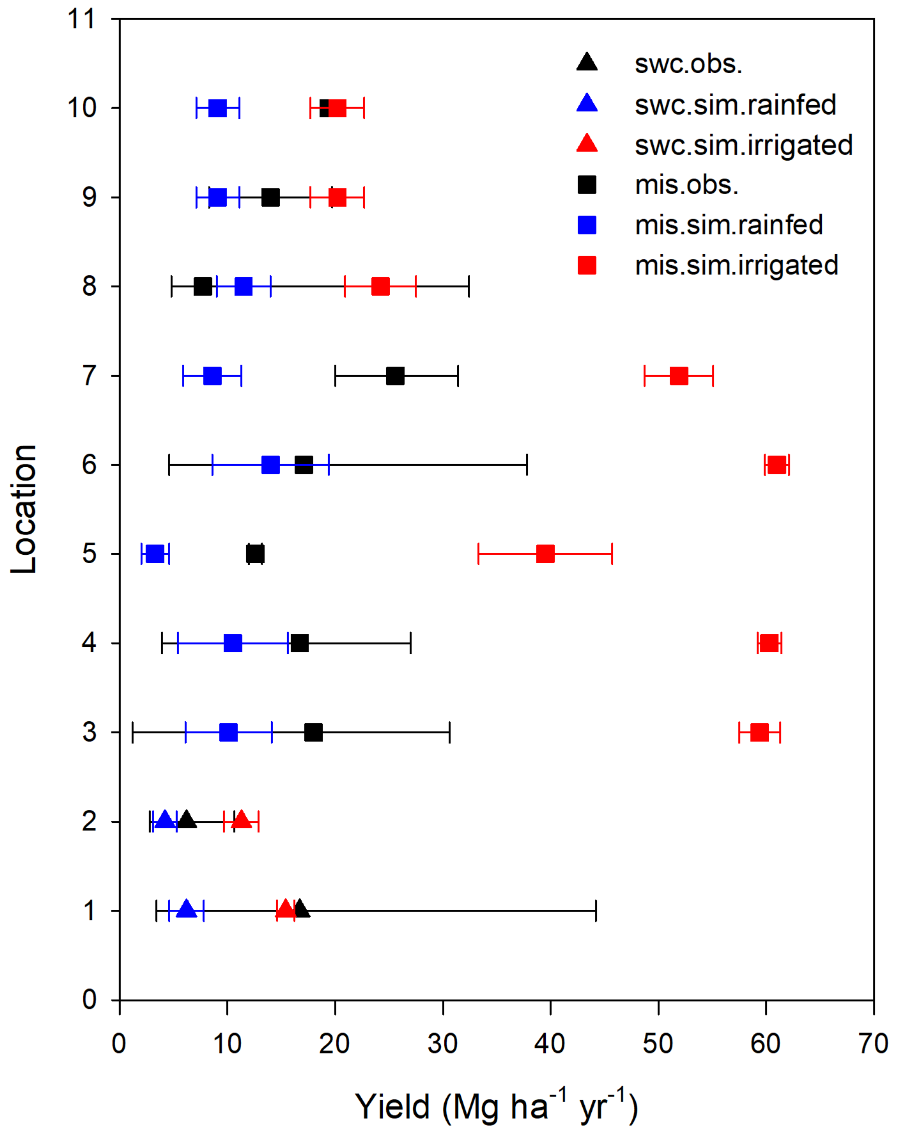

Fig. S1 Site-specific performance (shown with increasing latitude from the bottom of the vertical axis) of the simulated yield (sim.) obtained using the enhanced H08 model compared with observed yields (obs.) for *Miscanthus* (mis.) and switchgrass (swc.) under irrigated condition. The longitude and latitude of each location ID for *Miscanthus* and switchgrass are given in Tables S3. Observation indicates the observed mean yield. The error bar (in black) represents the range of the observed minimum and maximum yield. The error bar (in red) represents the standard deviation of the simulated yield from 1979 to 2016.

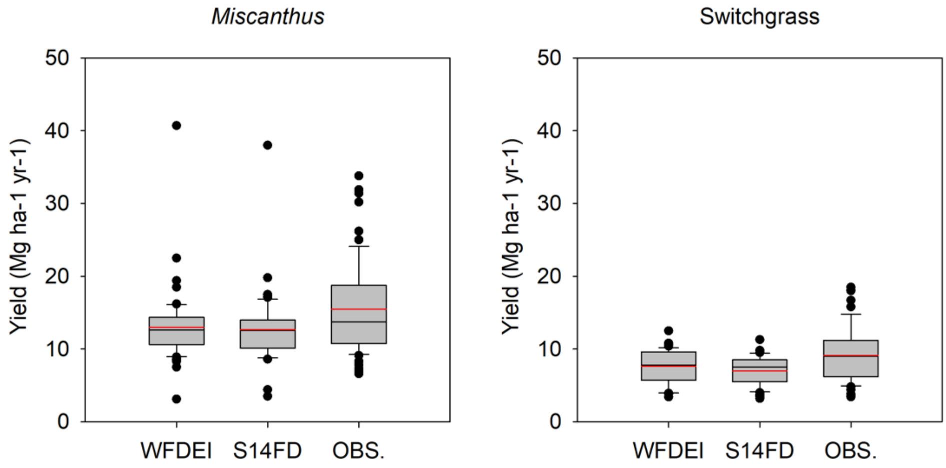

Fig. S2 Box plots showing the first (lower line), median (solid line) and third (upper line) quartiles of the yield for observed (OBS.) and simulated (with meteorological data driven by WFDEI and S14FD) *Miscanthus* and Switchgrass. The mean value is indicated by the red line.

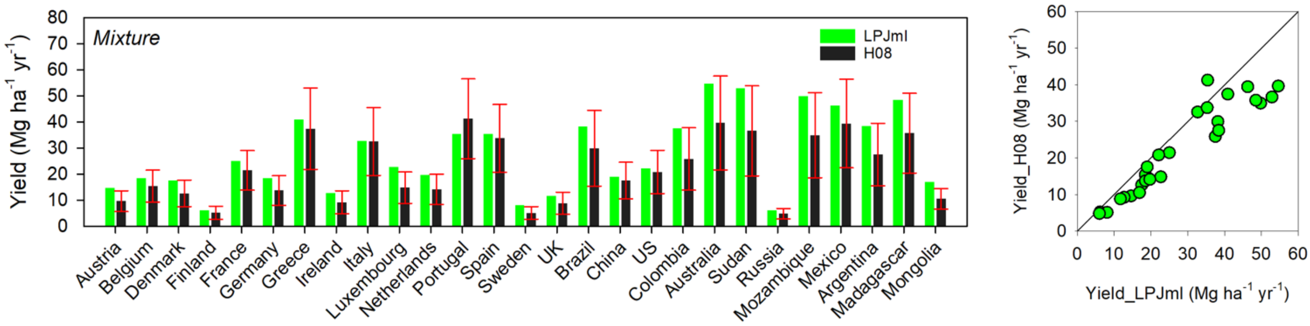

Fig. S3 Independent country-specific comparison of simulated yields from the enhanced H08 model and LPJmL under irrigated conditions.

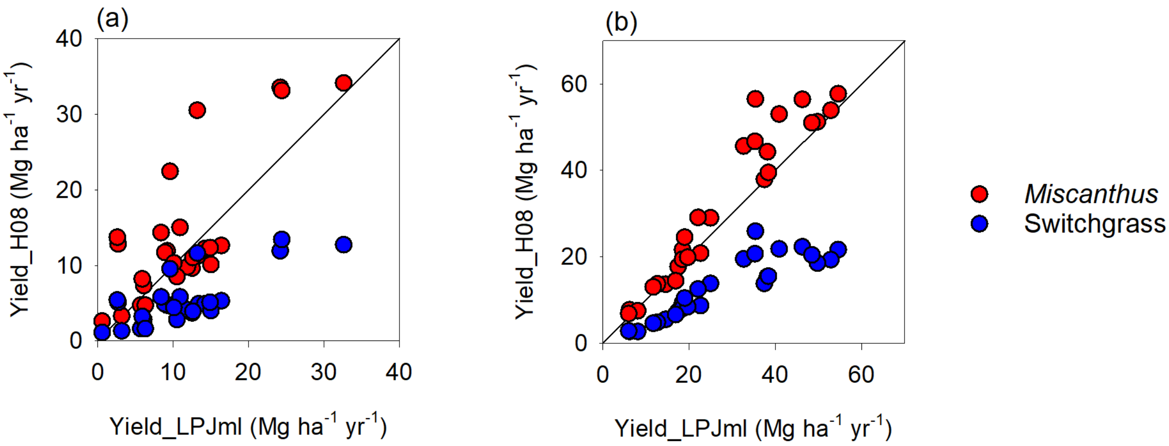

Fig. S4 Country-specific comparison of the simulated yields of *Miscanthus* and Switchgrass from the enhanced H08 model with the ensemble yield of LPJmL under rainfed (a) and irrigated conditions (b), respectively.

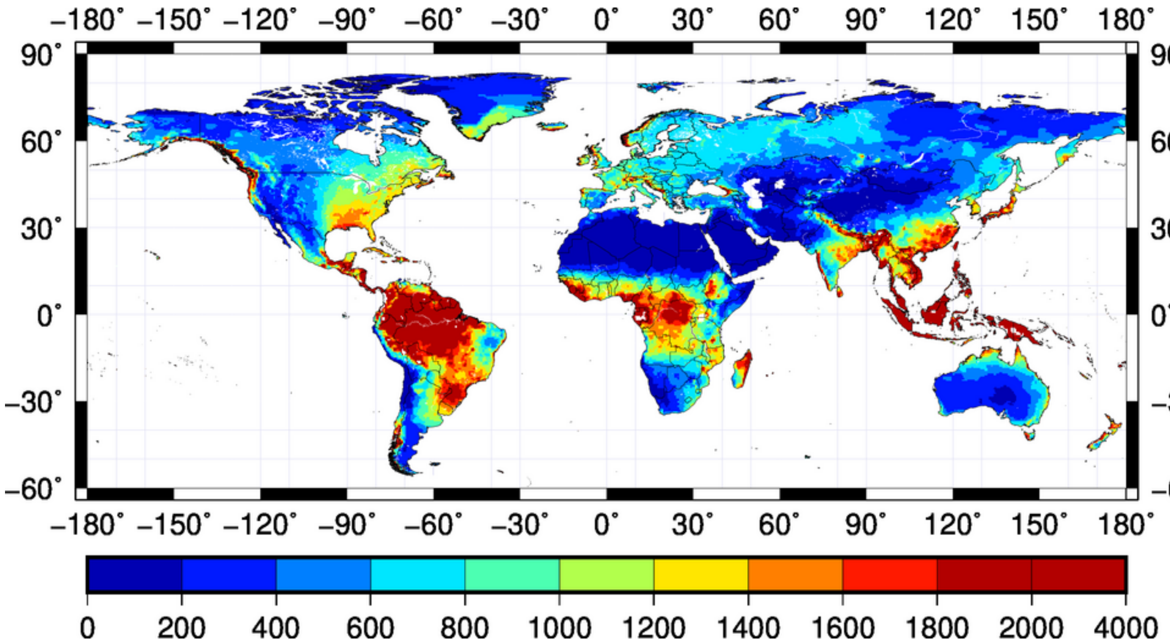

Fig. S5 Spatial distribution of averaged annual precipitation (mm yr^{-1}) from 1979 to 2016.

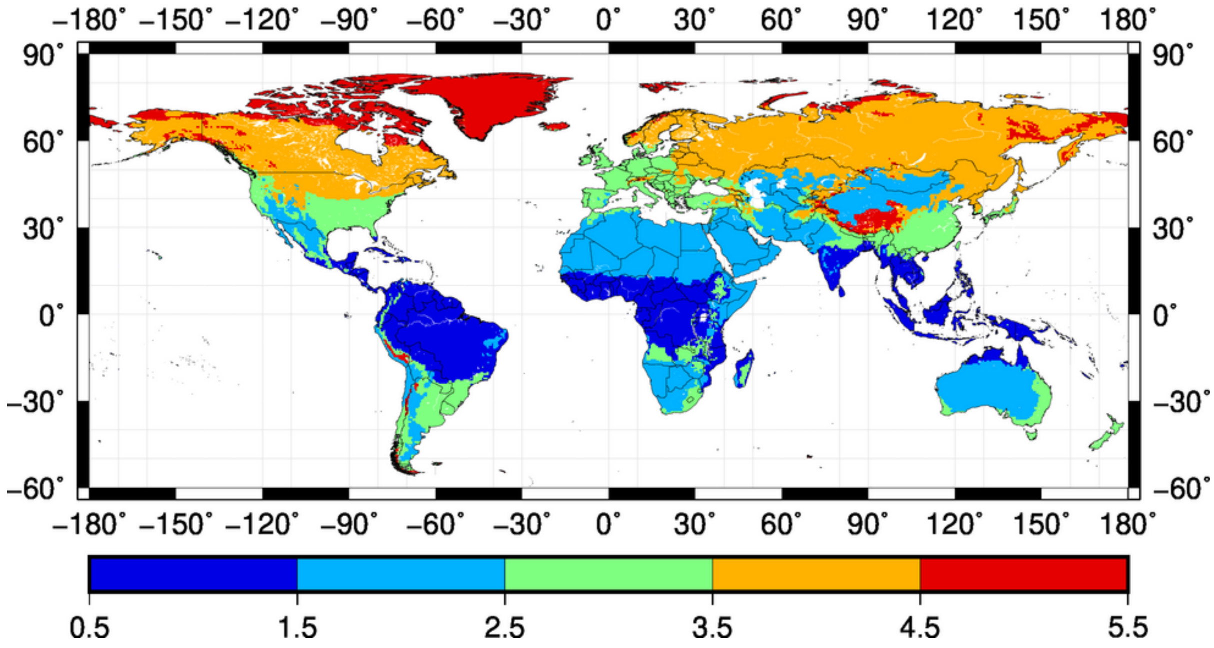

Fig. S6 Five different kinds of Köppen climate zones based on the average meteorological data from 1979 to 2016. The specific categories are as follows: 1 (dark blue) for tropical climate zone; 2 (light blue) for dry climate zone; 3 (green) for temperature climate zone; 4 (yellow) for continental climate zone; 5 (red) for polar climate zone.

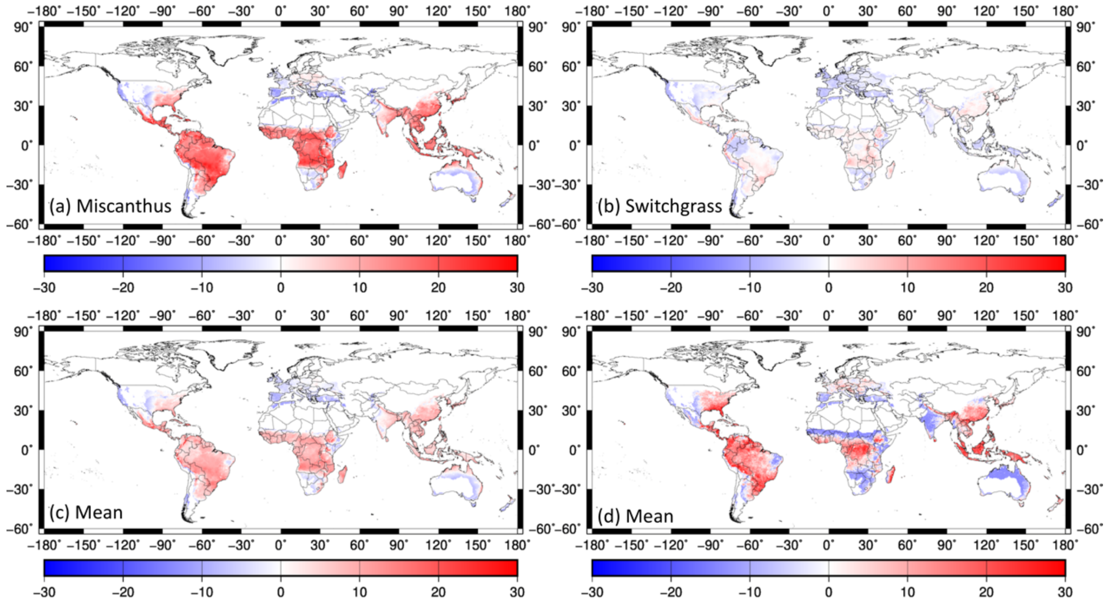

Fig. S7 Comparison of yield difference (simulated yield minus RF yields) between model simulations and the RF map (Li et al., 2020): a) for *Miscanthus* with the yield from H08 minus that from RF, b) for *Switchgrass* with the yield from H08 minus that from RF, c) for the mean of *Miscanthus* and Switchgrass with the yield from H08 minus that from RF, d) the ensemble yield of *Miscanthus* and Switchgrass with the yield from LPJml minus that from RF.

A brief description of the algorithms in crop growth sub-module of H08

To make it clear for the function of the parameters we calibrated, here we briefly describe the algorithms in the crop growth sub-module of H08. The crop module of H08 accumulates daily heat units (Huna(t)), which are expressed as the daily mean air temperature (T_a) greater than the plant's specific base temperature (Tb; given as a crop-specific parameter):

$$Huna(t) = T_a - Tb \tag{1}$$

Then the heat unit index ($Ihun$) is calculated as the ratio of accumulated daily heat units $\sum Huna(t)$ and the potential heat unit (Hun):

$$Ihun = \frac{\sum Huna(t)}{Hun} \tag{2}$$

When the accumulated daily heat units $\sum Huna(t)$ reach the potential heat unit (Hun) required for the maturity of the crop, the crop is mature and is harvested. During the growth period, the daily increase in biomass (ΔB) is calculated using a simple photosynthesis model:

$$\Delta B = be * PAR * REGF \tag{3}$$

Where be is radiation use efficiency, PAR is photosynthetically active radiation, and $REGF$ is the crop regulating factor. PAR is calculated using shortwave radiation (Rs) and leaf area index (LAI) as follow:

$$PAR = 0.02092 * Rs * [1 - \exp(-0.65 * LAI)] \tag{4}$$

LAI is calculated according to the growth stage indicated by $Ihun$, if $Ihun < \lfloor \mathrm{dpl1} \rfloor * 0.01$,

$$LAI = \frac{(dpl1 - \lfloor \mathrm{dpl1} \rfloor) * Ihun}{\lfloor \mathrm{dpl1} \rfloor * 0.01} * blai \tag{5}$$

if $\lfloor dpl1 \rfloor * 0.01 \le Ihun < \lfloor dpl2 \rfloor * 0.01$,

$$LAI = \left\{ (dpl1 - \lfloor dpl1 \rfloor) + \frac{[(dpl2 - \lfloor dpl2 \rfloor) - (dpl1 - \lfloor dpl1 \rfloor)] * (Ihun - \lfloor \mathrm{dpl1} \rfloor * 0.01)}{\lfloor dpl2 \rfloor * 0.01 - \lfloor dpl1 \rfloor * 0.01} \right\} * blai \tag{6}$$

if $\lfloor dpl2 \rfloor * 0.01 \le Ihun < dlai$,

$$LAI = \left\{ (dpl2 - \lfloor dpl2 \rfloor) + \frac{[1 - (dpl2 - \lfloor dpl2 \rfloor)] * (Ihun - \lfloor dpl2 \rfloor * 0.01)}{dlai - \lfloor dpl2 \rfloor * 0.01} \right\} * blai \tag{7}$$

if $dlai < Ihun$,

$$LAI = 16 * blai\,(1 - Ihun)^2 \tag{8}$$

$REGF$ is calculated as:

$$REGF = \min\,(Ts, Ws, Ns, Ps) \tag{9}$$

Where Ts, Ws, Ns, Ps is respectively the stress factors for temperature, water, nitrogen, and phosphorous. Temperature stress (Ts) is calculated as an asymmetrical function according to the relationship between air temperature (*Ta*) and optimal temperature (*To*). When air temperature is below (or equal) optimal temperature (*To*), Ts is calculated as:

$$Ts = exp\{ln(0.9) * [\frac{Ctsl(To-Ta)}{Ta}]^2\} \tag{10}$$

Where *Ctsl* is the temperature stress parameter for temperature below to, and is calculated as:

$$Ctsl = \frac{To+Tb}{To-Tb} \tag{11}$$

When air temperature is above optimal temperature, Ts is calculated as:

$$Ts = exp\{ln(0.9) * [\frac{(To-Ta)}{Ctsh}]^2\} \tag{12}$$

Where *Ctsh* is the temperature stress parameter for temperature below to, and is calculated as:

$$Ctsh = 2 * To - Ta - Tb \tag{13}$$

Water stress (Ws) is calculated as the ratio of actual evapotranspiration (*Ea*) to potential evapotranspiration (*Ep*) as:

$$Ws = \frac{Ea}{Ep} \tag{14}$$

As for nitrogen and phosphorous stress, currently we take it as neglectable since the bioenergy crop yield simulated by H08 is with no constrains of nutrient.

The crop yield (Yld) is finally estimated by the aboveground biomass (Bag) with crop-specific harvest index ($Harvest$) at the harvesting date as:

$$Bag = [1 - (0.4 - 0.2 * Ihun)] \sum \Delta B \tag{15}$$

$$Yld = Harvest * \frac{WSF}{WSF + \exp{(6.117 - 0.086 * WSF)}} * Bag \quad (16)$$

Where WSF is a ratio of SWU (the accumulated actual plant transpiration in the second half of the growing season), and SWP (the accumulated potential evapotranspiration accumulated actual plant transpiration):

$$WSF = \frac{SWU}{SWP} * 100 \quad (17)$$

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