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Developing an eco-physiological process-based model of soybean growth and yield (MATCRO-Soy v.1): model calibration and evaluation

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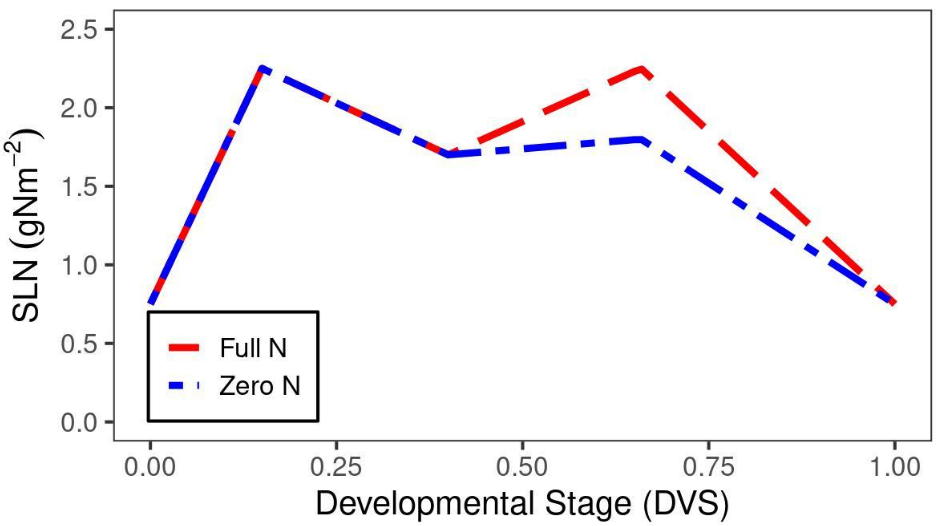

Figure S1. The specific leaf nitrogen (SLN, in g(N)m-2) toward the developmental stages (DVS) under zero nitrogen fertilizer (blue dotted-dashed line) and full nitrogen fertilizer (red long-dashed line) adopted from La Menza et al. (2023). In the absence of observed data, values were derived based on model assumptions.

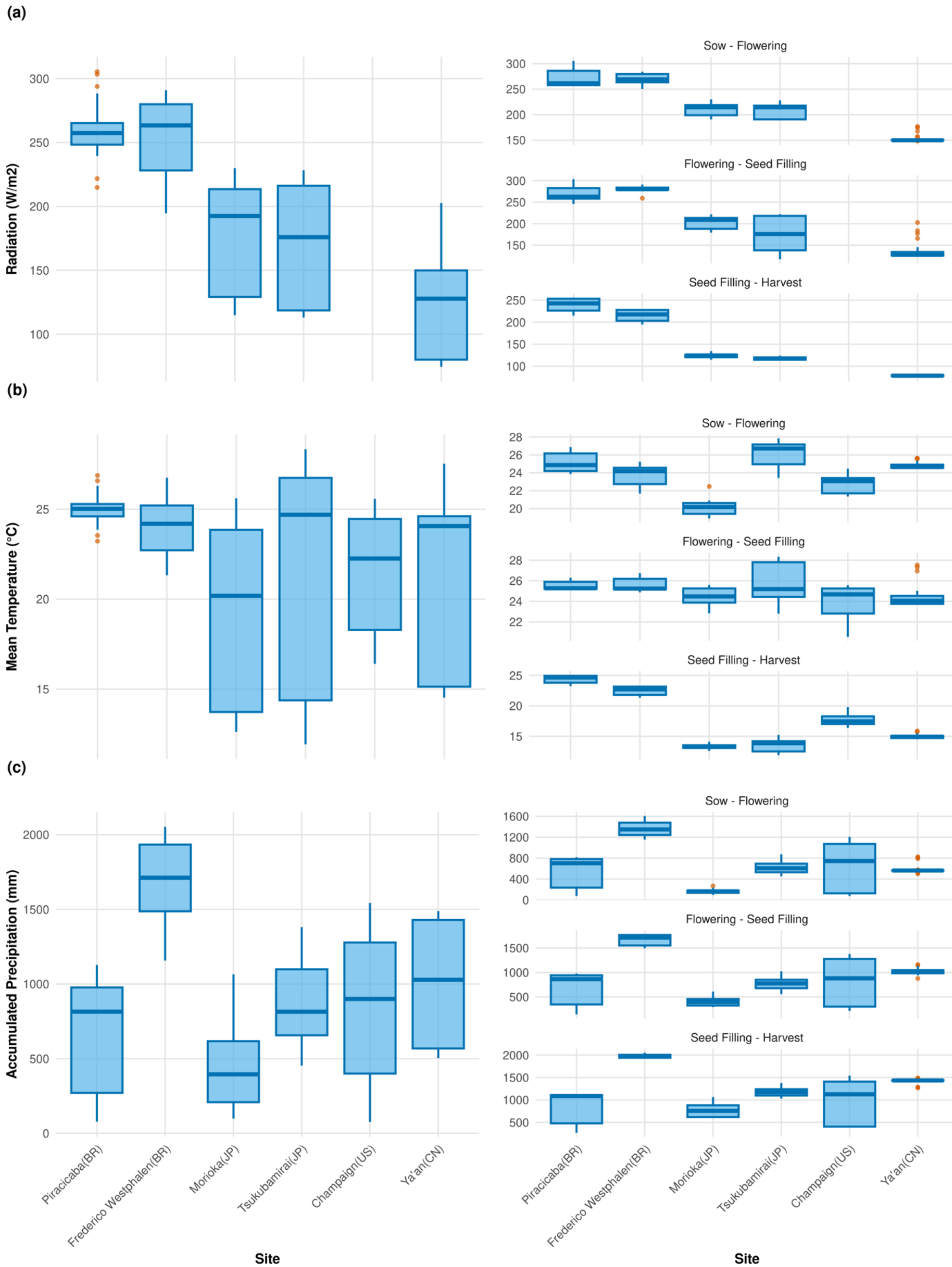

Figure S2. Daily average temperature (a), solar radiation (b) and total precipitation (c) during the growing season (left) and separated into the phenological stage (right) in the experimental dataset for calibration. No observation weather data of solar radiation in Champaign (US).

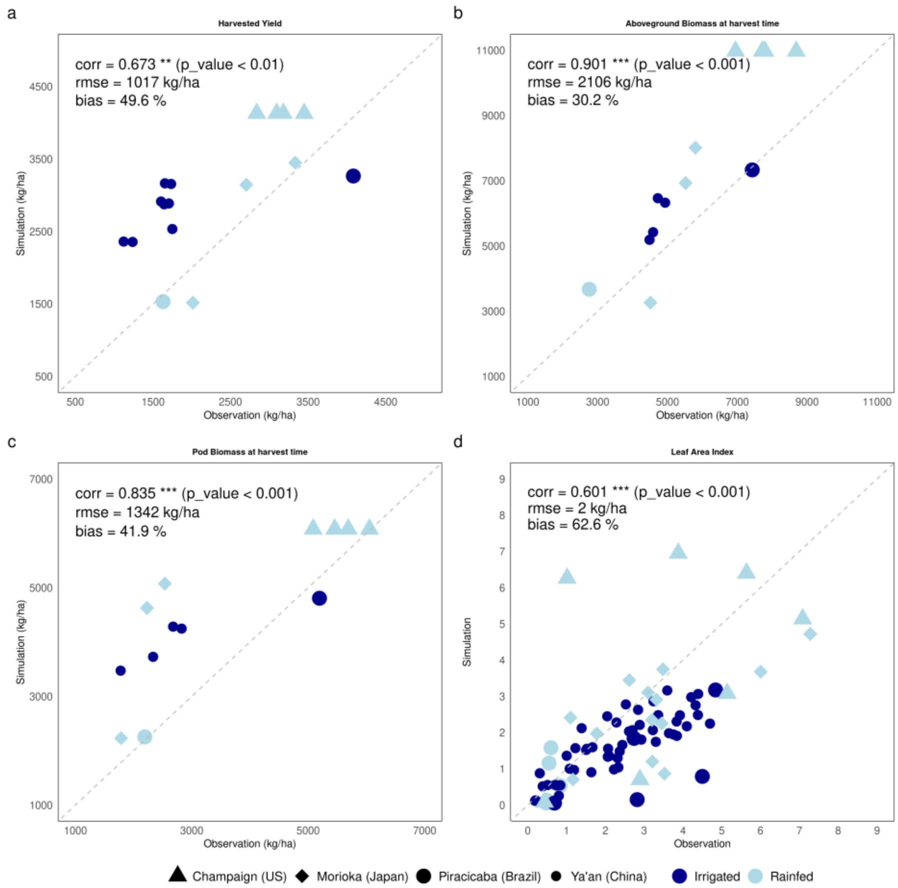

Figure S3. Comparison of simulated and observed soybean yield (a), aboveground biomass (b), pod (c), and leaf area index (d). The dark blue shows the data under irrigated management, while light blue shows the data under rainfed management. The shape of square represents Champaign (US) data, triangle represents Morioka (Japan), diamond represents Piracicaba (Brazil), and circle represents Ya'an (China). Calculation of statistical correlation used Pearson-correlation (corr) with *** denotes the regression is statistically significant at $p < 0.001$, root mean square error (RMSE), and bias.

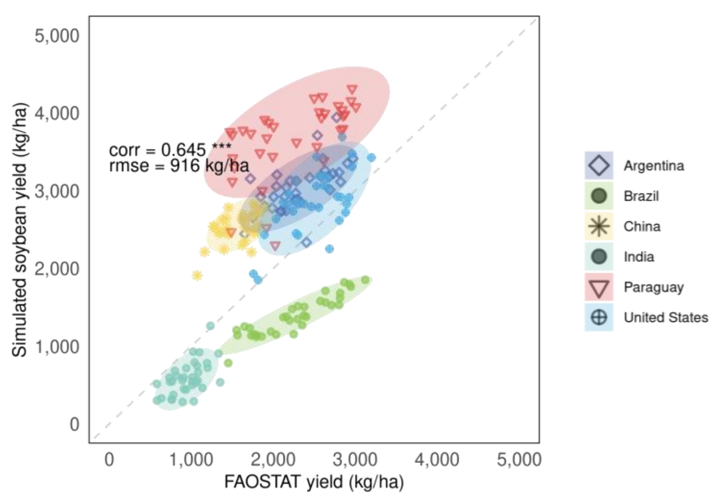

Figure S4. Comparison between simulated yield by MATCRO-Soy and FAOSTAT of the country mean yield during 1981-2014 in 6 major soybean producing countries (e.g., Argentina, Brazil, China, India, Paraguay, and the United States). Ellipsoid shows 90% confidence range of annual yield.

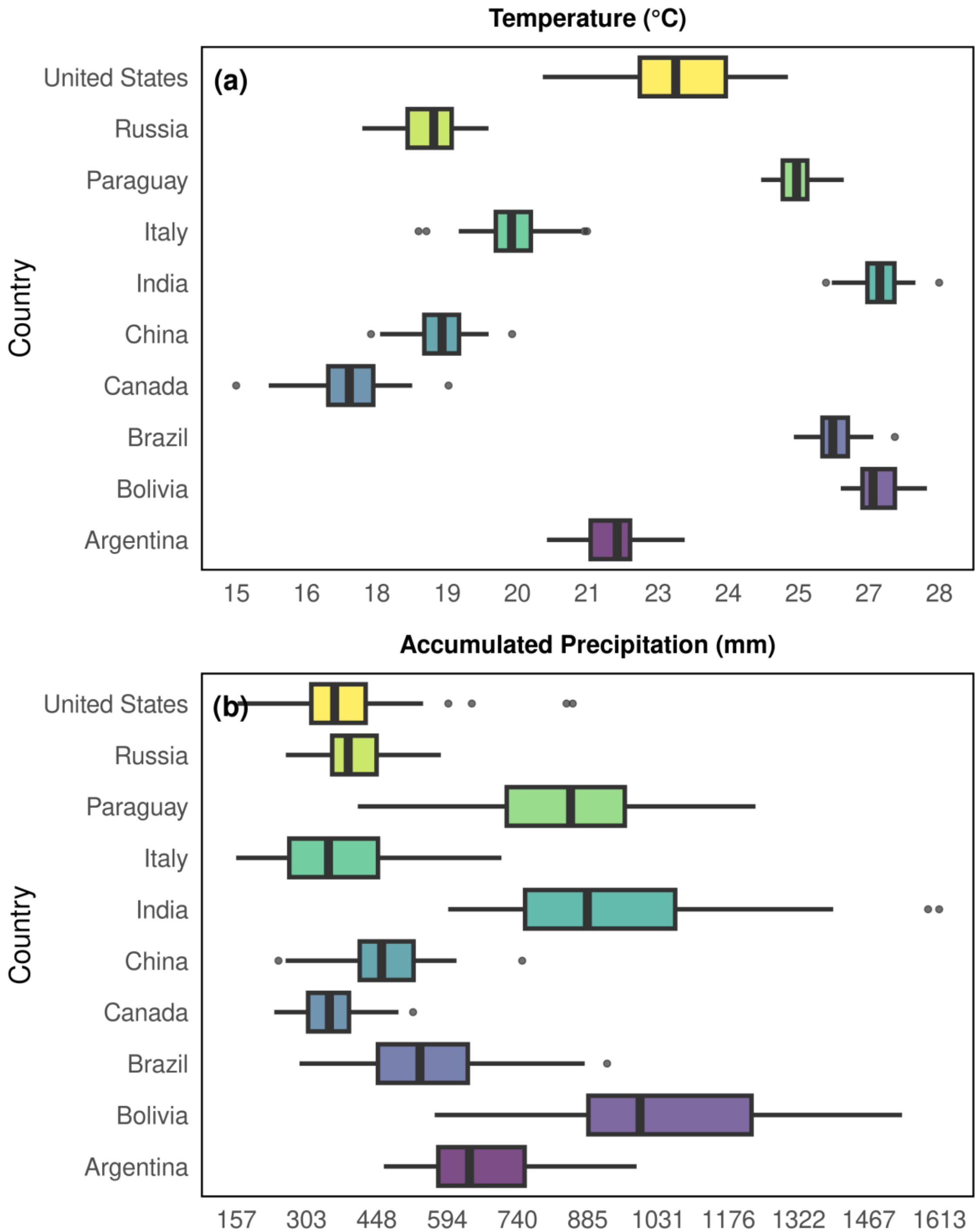

Figure S5. Daily average temperature (a) and total precipitation (b) during the growing season in 10 major soybean-producing countries averaged from 1981-2014 in the represented specific point-scal

Table S1. Statistical comparison on model performance using components of mean squared deviation (MSD) and RMSE for global yield simulation (X) and global yield observation from FAOSTAT (Y). *n* means number of years.

Metrics	**Squared bias (SB)**	Pearson correlation coefficient (corr)	**Sum of difference in standard deviation (SDSD)**	**Lack of positive correlation (LCS)**	**Mean squared deviation (MSD)**	**Root mean square error (RMSE)**
equation	$(\bar{X} - \bar{Y})^2$	$\frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 (Y_i - \bar{Y})^2}}$	$(SD_X - SD_Y)^2$	$2SD_X SD_Y(1 - corr)$	$SB_y + SDSD_y + LCS_y$	$\sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - Y_i)^2}$
Yield	63,780*	0.810	1,355	23,789	88,924	232 kg/ha
Detrended yield	0	0.446	4,432	14,389*	18,823	137 kg/ha
Long term yield trend	64,133*	1	6,323	0	69,456	264 kg/ha

*the metric contributed to major error in MSD components

Table S2. Statistical comparison on model performance in 10 major soybean-producing countries using components of mean squared deviation (MSD) for yield.

Countries	**SB**	Corr	**SDSD**	**LCS**	**MSD**	$RMSE$ (kg/ha)
Argentina	527,170*	0.62	1,562	85,352	614,085	784
Bolivia	3,387,737*	0.03	4,577	153,911	3,546,225	1,883
Brazil	754,537*	0.91	44,536	19,409	818,482	905
Canada	43,992	0.15	20,643	234,074*	298,708	547
China	909,527*	0.55	203	37,335	947,064	973
India	133,681*	0.57	303	36,099	170,083	412
Italy	163,759	0.42	21,430	197,598*	382,788	619
Paraguay	2,032,508*	0.58	1,384	216,663	2,250,554	1,500
Russia	2,937,148*	(0.05)	25,968	163,769	3,126,885	1,768
United States	136,054*	0.64	2,264	99,479	237,797	488

*country with bold font has RMSE below 700 kg/ha.

Table S3. Statistical comparison on model performance in 10 major soybean-producing countries using components of mean squared deviation (MSD) for detrended yield.

Countries	**SB**	Corr	**SDSD**	**LCS**	**MSD**	$RMSE$ (kg/ha)
Argentina	0	0.25	6,089	80,370*	86,459	294
Bolivia	0	(0.32)	8,259	99,559*	107,818	328
Brazil	0	0.50	5,639	19,267*	24,907	158
Canada	0	0.01	24,218	230,499*	254,724	505
China	0	0.19	1,095	33,441*	34,537	186
India	0	0.40	3,256	30,813*	34,069	185
Italy	0	0.43	26,185	186,182*	212,367	461
Paraguay	0	0.62	673	171,834*	172,508	415
Russia	0	0.30	68,410*	51,532	119,945	346
United States	0	0.57	34,201	51,637*	85,838	293

*the metric contributed to major error in MSD components.

Table S4. Statistical comparison on model performance in 10 major soybean-producing countries using components of mean squared deviation (MSD) and RMSE for long-term trend.

Countries	**SB***	Corr	**SDSD**	**LCS**	**MSD**	$RMSE$ (kg/ha)
Argentina	527,886	1	456	0	528,342	727
Bolivia	3,390,158	1	50,672	0	3,440,830	1,855
Brazil	752,821	1	39,037	0	791,858	890
Canada	42,835	1	0	0	42,835	207
China	911,953	1	3,002	0	914,956	957
India	133,583	1	2,334	0	135,917	369
Italy	163,675	1	6,661	0	170,336	413
Paraguay	2,034,840	1	45,538	0	2,080,378	1,442
Russia	2,932,711	(1)	10,879	58,917	3,002,507	1,733
United States	136,262	1	15,905	0	152,168	390

*the metric contributed to major error in MSD components.

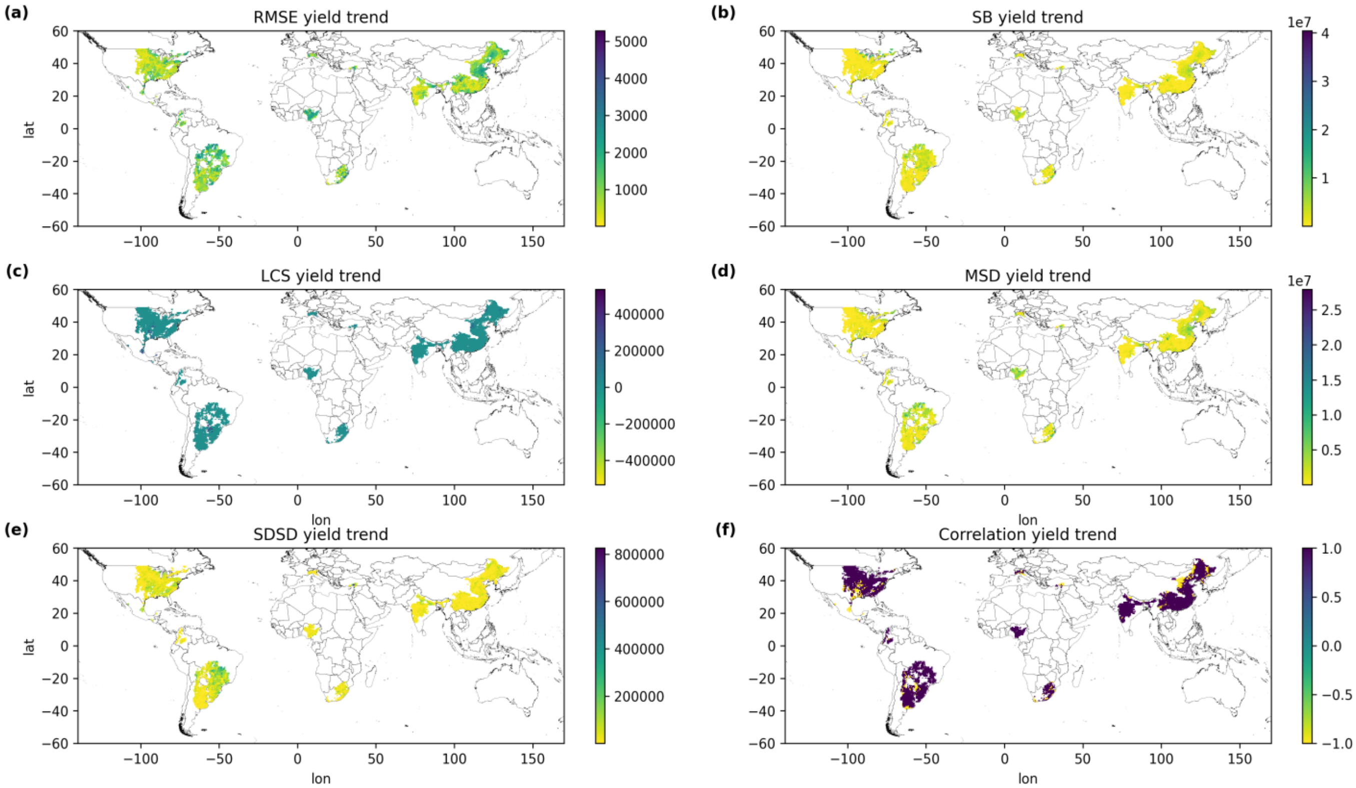

Figure S6. RMSE and MSD components of long-term yield trend between MATCRO-Soy and GDHY dataset during 1980-2014: (a) root mean square error (RMSE), (b) squared bias (SB), (c) lack of positive correlation (LCS), (d) mean squared deviation (MSD), (e) sum of difference in standard deviation (SDSD), (f) Correlation. Major contributor in MSD components is squared bias (SB).

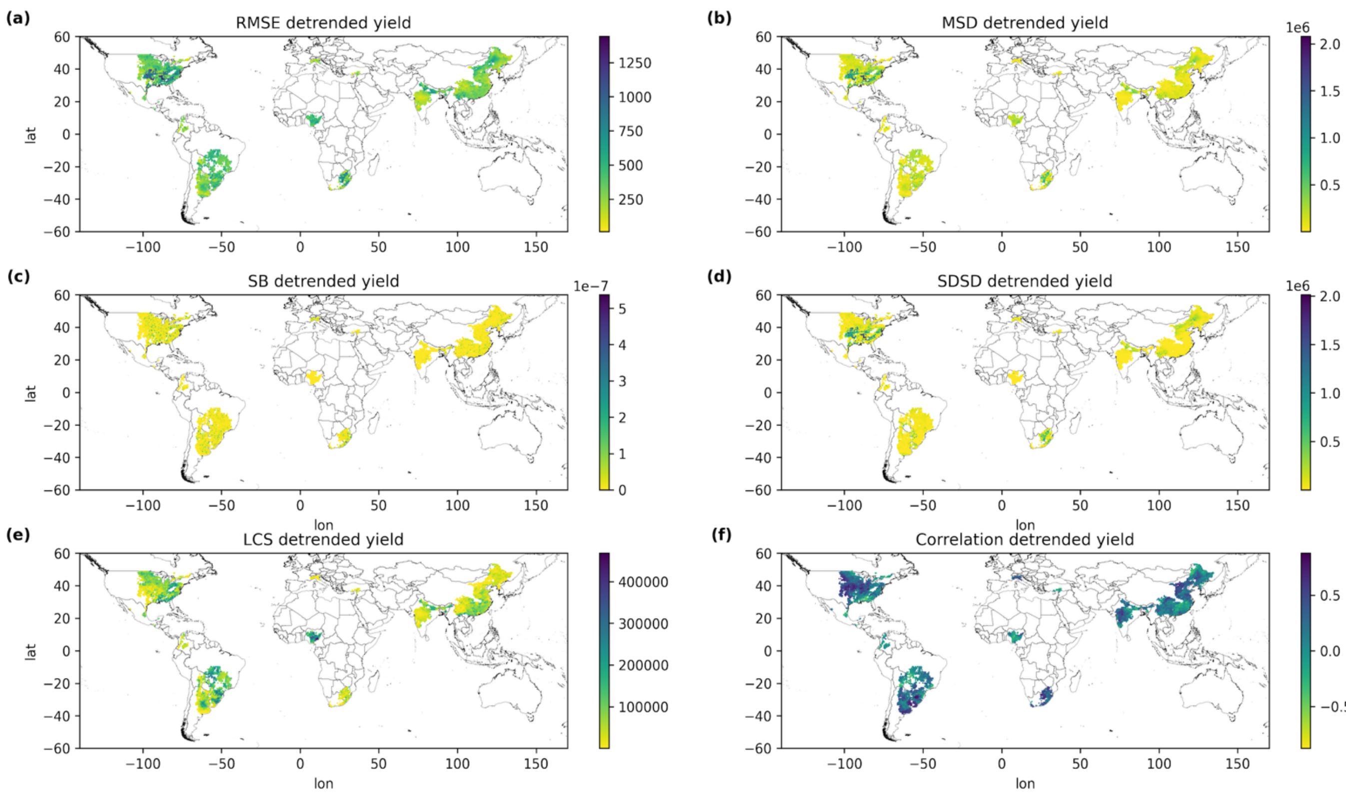

Figure S7. RMSE and MSD components of detrended yield between MATCRO-Soy and GDHY dataset during 1980-2014: (a) root mean square error (RMSE), (b) mean squared deviation (MSD), (c) squared bias (SB), (d) sum of difference in standard deviation (SDSD), (e) lack of positive correlation (LCS), and (f) Correlation. Major contributor(e) of error in MSD components is SDSD where mostly higher in South Africa and Midwest United States.