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Supplement of

ORCHIDEE-CROP (v0), a new process based Agro-Land Surface Model: model description and evaluation over Europe

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Supplementary equations

Eqn. 1

$$RFVI = \frac{\sum_{I=IGER} JVI - 7}{\mathrm{JVC} - 7}$$

Eqn. 2

$$RFPI = \frac{PHOI - PHOBASE}{PHOSAT - PHOBASE}\ , and, 0 \leq RFPI \leq 1$$

Eqn. 3

$$\mathrm{I} = \mathrm{IGER\ if\ SOMGER(I)} = \sum_{J=IPLT}^{I} [(TSOL(PROFSEM) - TGMIN) \cdot HUMIRAC(SB, J)] = STPLTGER\ , and, SB = PROFSEM \pm 1cm$$

Where, SOMGER is the accumulated growing degree-days since planting (IPLT), TSOL and TGMIN is soil temperature and base temperature for germination. The soil moisture in the seed bed (SB ±1cm) influences germination through the HUMIRAC variable,

$$\mathrm{if}\ HUMSOL(\mathrm{SB,I}) > HN_S, then, HUMIRAC(SB, I) = SENSRSEC + (1 - SENSRSEC)\frac{HUMSOL(SB, I) - HN_S}{HX_S - HN_S}$$

$$\text{if } HUMSOL(\mathrm{SB},\mathrm{I}) < HN_S, then, HUMIRAC(SB,I) = \frac{SENSRSEC}{HN_S} HUMSOL(SB,I)$$

where, *HUMSOL*, HN_S and HX_S are actual water content, the wilting point and the field holding capacity in the seed bed (SB), respectively, and *SENSRSEC* is a plant parameter which can be given a value between 0 and 1. If *SENSRSEC* = 1 the effect of soil dryness on all the functions of root growth is only effective for water contents below the wilting point.

Eqn. 4

$$ELONG(I) = ELMAX\left[1 - e^{\left(-(BELONG \times \sum_{J=IGER}(HUMIRAC(SB,J)\cdot(TSOL(PROFSEM)-TGMIN)))^{CELONG}\right)}\right]$$

Where, ELONG is the elongation of the epicotyl, ELMAX, BELONG, and CELONG are crop specific parameters.

Eqn. 5

$$DELTAI(I) = DELTAI_{dev} \cdot DELTAI_T \cdot DELTAI_{dens} \cdot DELTAI_{stress}$$

Where, for $DELTAI_{dev}$

$$if\ ULAI < UDLAIMAX, then, DELTAI_{dev} = \frac{DLAIMAXBRUT}{1 + e^{(PENTLAIMAX \times (VLAIMAX - ULAI))}},$$

$$if\ ULAI \geq UDLAIMAX, then, DELTAI_{dev} = DELTAI_{dev} \times MAX\left(1 - \frac{ULAI - UDLAIMAX}{3 - UDLAIMAX}\right)^2$$

And ULAI is a normalized leaf development unit, which is equal to 1 at crop emergence and 3 at the starting point of maximum LAI plateau (ILAX). At the end of the juvenile stage (IAMF), the ULAI is equal to VLAIMAX, a crop specific parameter, when the inflexion of the dynamics also occurs. DLAIMAXBRUT and PENTLAIMAX, as crop specific parameters, are the asymptote and the slope at the inflexion point for the logistic function of LAI growth.

For $DELTAI_T$,

$$if\ TCULT \leq TCMIN, DELTAI_T = 0.0$$

$$if\ TCMIN \leq TCULT \leq TCMAX, DELTAI_T = TCULT - TCMIN$$

$$if\ TCMAX \leq TCULT \leq TCXSTOP, DELTAI_T = \frac{TCMAX - TCMIN}{TCMAX - TCXSTOP}(TCULT - TCXSTOP)$$

$$if\ TCULT \geq TCXSTOP, DELTAI_T = 0.0$$

Where, TCULT, TCMIN, TCMAX and TCXSTOP is crop temperature, minimum cardinal temperature, maximum cardinal temperature, and extreme temperature threshold, respectively.

For $DELTAI_{dens}$,

$$if\ LAI \geq LAICOMP\ and\ DENSITE \geq BDENS, then, DELTAI_{dens} = DENSITE\left(\frac{DENSITE}{BDENS}\right)^{ADENS}$$

$$if\ LAI < LAICOMP\ and\ DENSITE < BDENS, then, DELTAI_{dens} = DENSITE$$

Where DENSITE is the plant density, LAICOMP is a crop specific parameter for a given LAI threshold when the density function $DELTAI_{dens}$ is active solely. BDENS is a density threshold, below which plant leaf area is assumed independent of density. ADENS represents the plant's branching or tillering ability. For single-stem plants, ADENS represents competition between plant leaves within a given stand.

Whereas for $DELTAI_{stress}$, $DELTAI_{stress} = \min(TURFAC, INNLAI, EXOLAI)$

Where TURFAC, INNLAI, and EXOLAI is water, nitrogen, and water-logging stress, respectively.

Eqn. 6

$$DLTAGS(I+1) = [IRCARB(I+1) \cdot MASEC(I+1) - IRCARB(I) \cdot MASEC(I)]FTEMPREMP(I)$$

Where, DLTAGS is the daily grain filling, FTEMPREMP is a thermal stress which may stop the carbon filling of harvested organs, IRCARB and MASEC is the harvesting index and shoot biomass, respectively. Therefore, the total grain yield since the starting grain filling (IDRP) can be calculated by the following equation:

$$\mathrm{MAFRUIT(I)} = \sum_{J=IDRP}^{I} DLTAGS(J) - \frac{PGRAINGEL(I)}{100}$$

Where, PGRAINGEL is the frozen grain weight, 100 is the conversion factor from unit of g m^{-2} to t ha^{-1}.

Supplementary Figures

Figure S1.

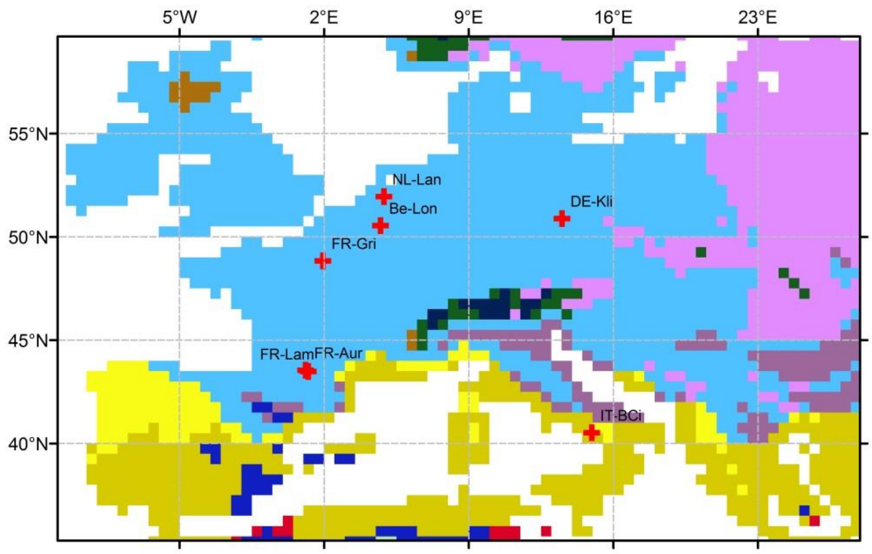

Fig. S1. Geographical locations and climate regimes for the seven CarboEurope-IP sites. The colored background indicates the Koppen Geiger climate classification (in detail see http://koeppen-geiger.vu-wien.ac.at/present.htm).

Figure S2.

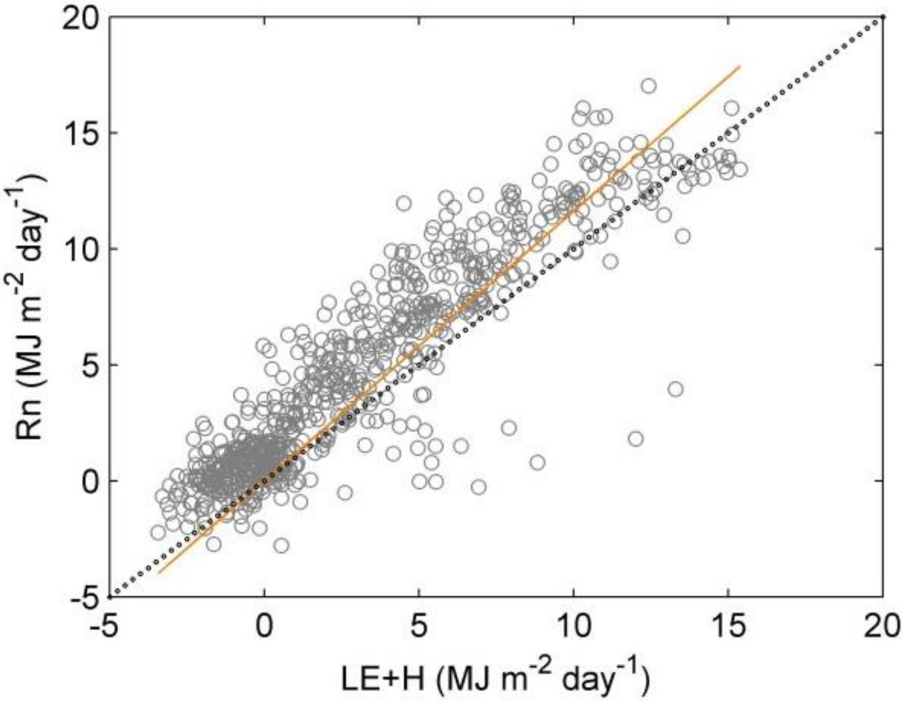

Fig. S2. Comparisons between the observed daily net radiation (Rn) and the sum of daily latent heat (LE) and sensible heat (H) for site of BE-Lon in Belgium (see Fig. S1). The dotted line and orange line is 1:1 line and the linear fit, respectively.

Figure S3.

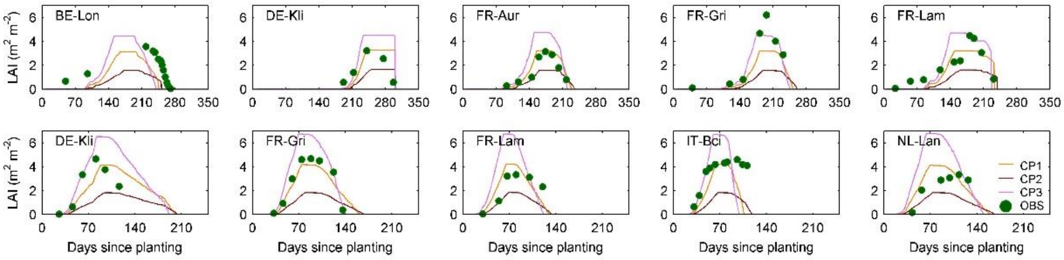

Fig. S3. Temporal evolution of leaf area index since planting from observations (green dots) and ORCHIDEE-CROP with nitrogen limitation for leaf growth of 0.5 (ORC-CP1, orange line), 0.2 (brown line, ORC-CP2) and 0.9 (purple line, ORC-CP3). The upper and lower panel shows the results for winter wheat and maize, respectively.

Figure S4.

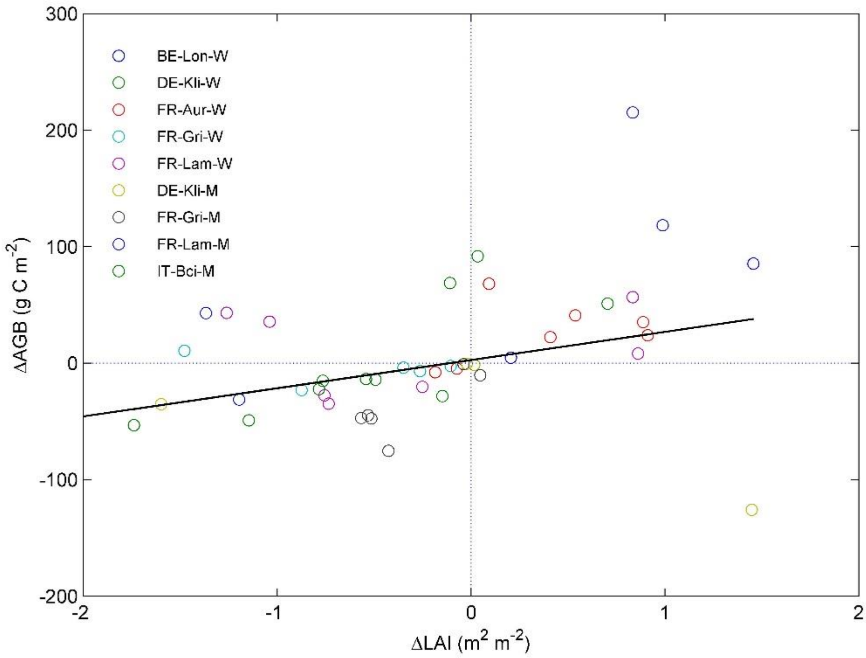

Fig. S4. Relationship between bias (representing the difference between simulations and observations) of simulated leaf area index (ΔLAI) and bias of simulated aboveground biomass (ΔAGB) for all crop sites (with –W and –M for winter wheat and maize, respectively) except the maize at NL-Lan (the AGB for maize at NL-Lan is systematically underestimated in ORC-CP1 with a relatively good simulation for LAI, in detail see Fig. 2 and Fig. 4 in main text). The black line is the linear fit ($\Delta\text{AGB} = 19.74 + 35.57\Delta\text{LAI}$, $p < 0.005$).

Figure S5

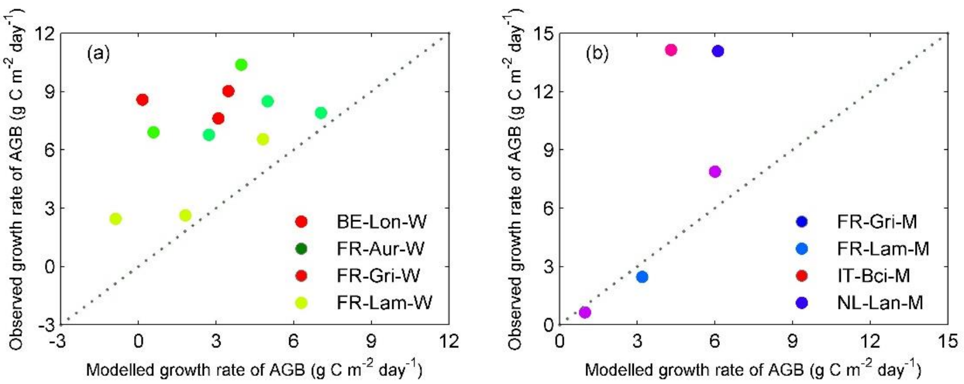

Fig. S5. Comparisons between the modelled (ORC-CP1) and observed daily growth rate of aboveground biomass (AGB) for winter wheat (a) and maize (b). Different colors indicate different sites. The dotted line is 1:1 line.

Figure S6.

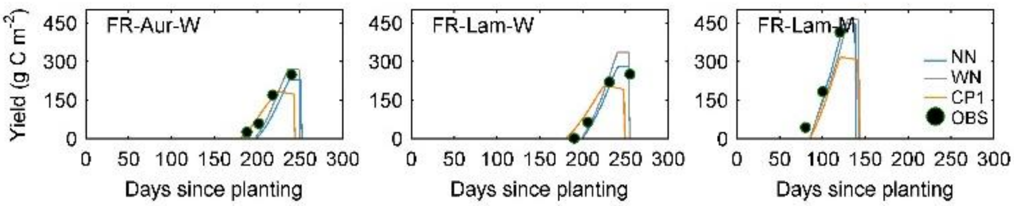

Fig. S6. Comparisons between the observations (black dots) and simulated temporal evolutions of grain yield (orange line, ORC-CP1, blue line, STI-NN, honeydew line, STI-WN, in detail see Table 3 in main text) for winter wheat (FR-Aur-W and FR-Lam-W) and maize (FR-Lam-M).

Figure S7

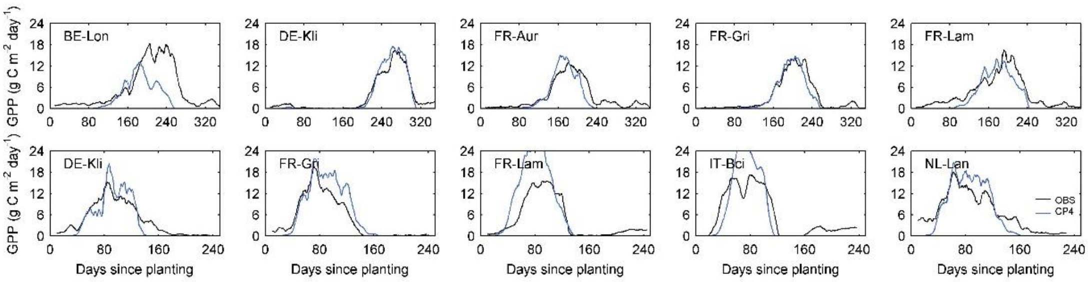

Figure S7. Temporal evolution of GPP from observations (black line) and ORCHIDEE-CROP with moderate nitrogen limitation for leaf growth (blue line, ORC-CP1). The upper and lower panel shows the results for winter wheat and maize, respectively.

Fig. S8.

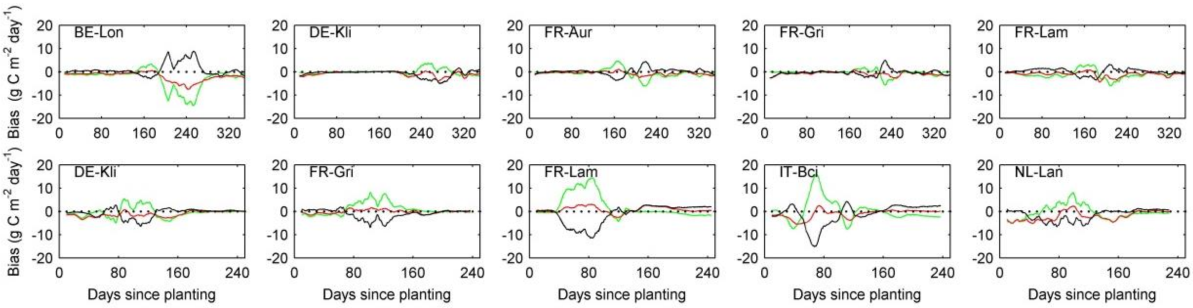

Fig. S8. Comparisons of the biases in simulated (ORC-CP1) GPP (green line), TER (red line) and NEE (black line) for different sites of winter wheat (upper panel) and maize (lower panel).

Fig. S9

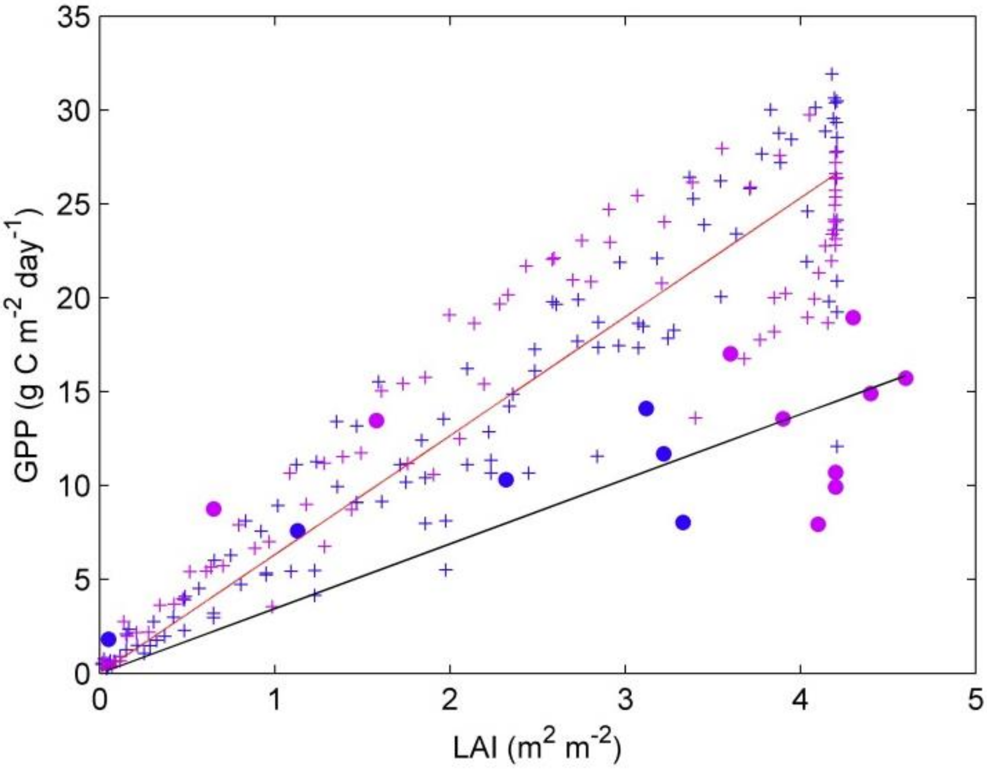

Figure S9. Relationships between the observed GPP and LAI (dots) and modelled GPP and LAI (crosses) for maize from ORC-CP1. Different colors indicate different sites with blue and purple for FR-Lam and IT-Bci, respectively. The orange and black lines are linear fits for the relationships between LAI and GPP from model simulations and observations, respectively.

Figure S10.

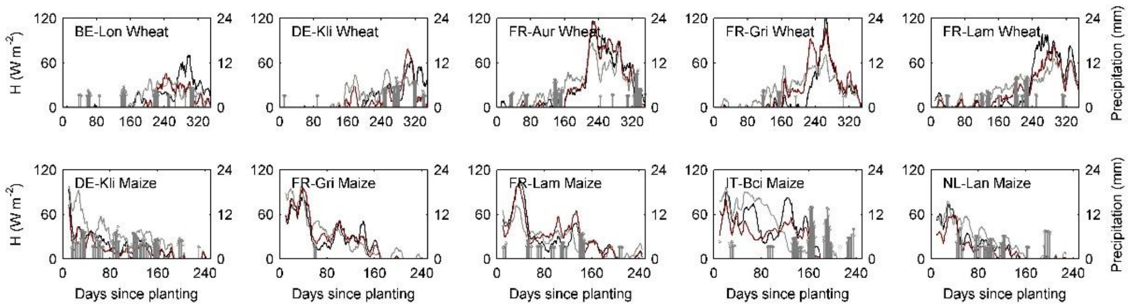

Figure S10. Temporal evolutions of sensible heat fluxes from observations (black line), ORCHIDEE (grey line) and ORCHIDEE-CROP (blue line: ORC-CP1, brown line: ORC-CP5). The grey stems indicate the relative large rainfall events (with daily summed rainfall ≥ 3 mm) during the modelled growing season. The upper and lower panel shows the results for winter wheat and maize, respectively.

Figure S11

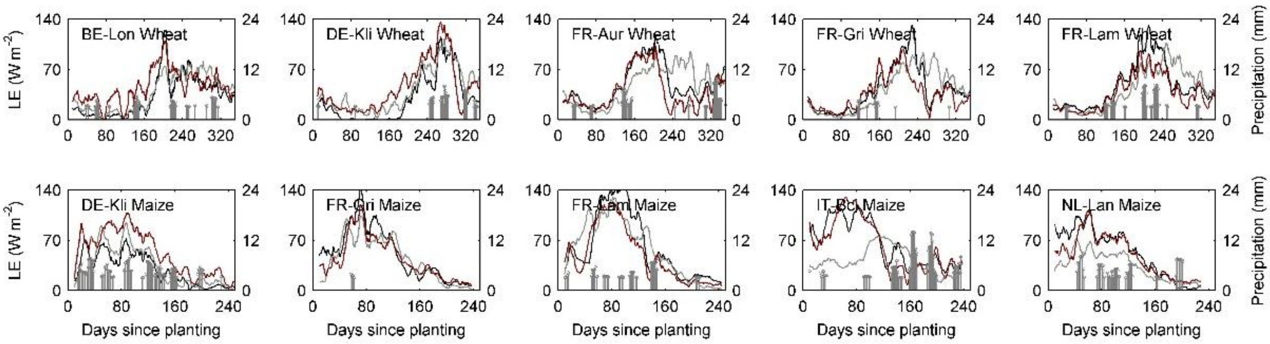

Figure S11. Same to Fig. S10 but for latent heat fluxes.

Fig. S12

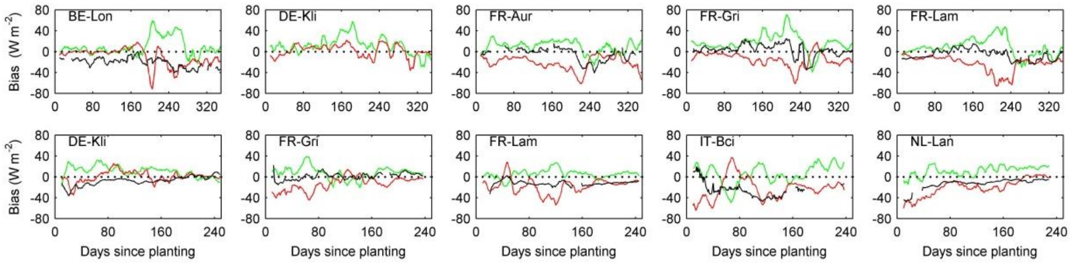

Figure S12. Comparisons of the biases in simulated (ORC-CP5) sensible heat fluxes (green line), latent heat fluxes (red line) and net radiation (black line) for different sites of winter wheat (upper panel) and maize (lower panel). Note that we lack the observed net radiation data for wheat year in DE-Kli.

Figure S13.

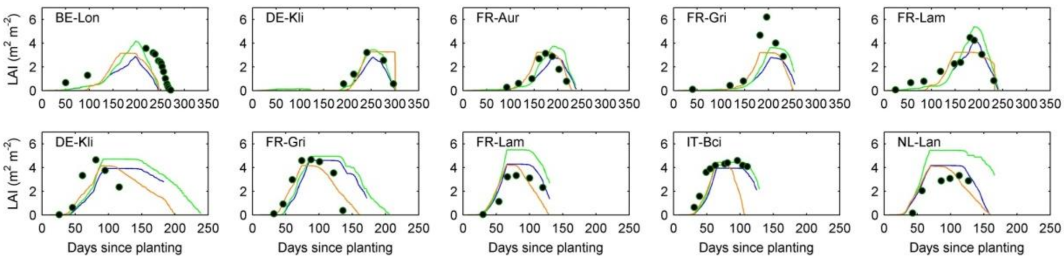

Figure S13. Comparisons of observed (black dots) and modelled LAI derived from ORCHIDEE-CROP (ORC-CP1, orange line) and STICS with (STI-WN, green line) and without fertilizations (STI-NN, blue line) (in detail see Table 3). The upper and lower panel shows the results for different sites of winter wheat and maize, respectively.

Figure S14.

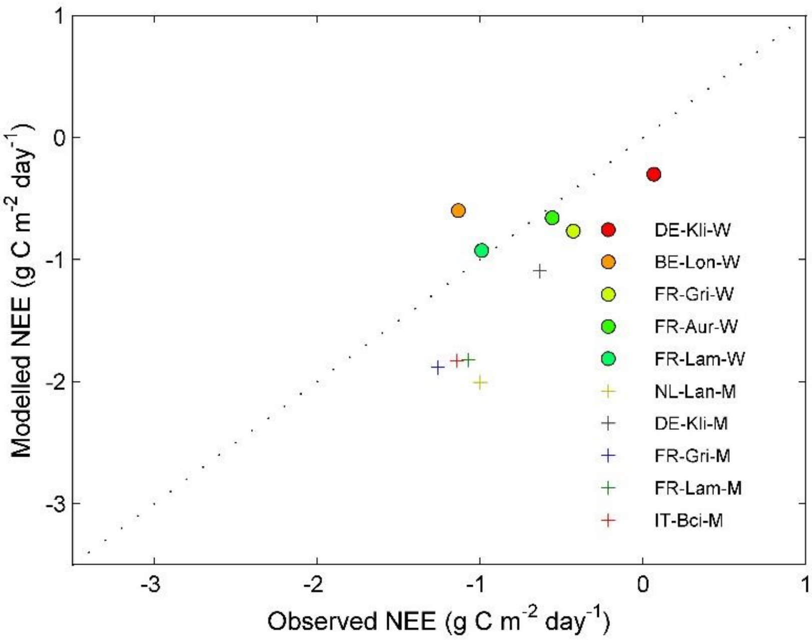

Figure S14. Comparisons between the observed and modelled (based on ORC-CP5) mean growing season NEE among different crop sites for winter wheat (circle, -W) and maize (cross, -M). Different colors indicate different sites.

Figure S15.

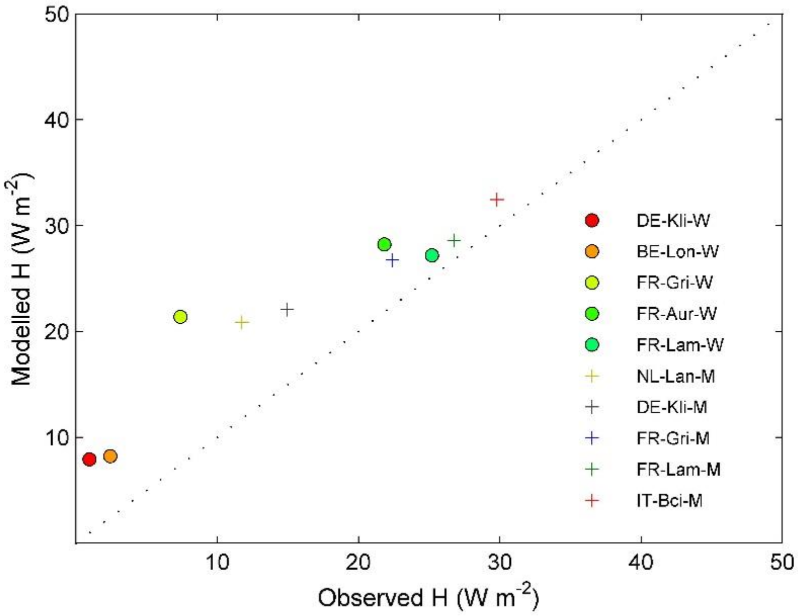

Figure S15. Comparisons between the observed and modelled (based on ORC-CP5) mean growing season sensible heat flux (H) among different crop sites for winter wheat (circle, -W) and maize (cross, -M). Different colors indicate different sites.

Figure S16.

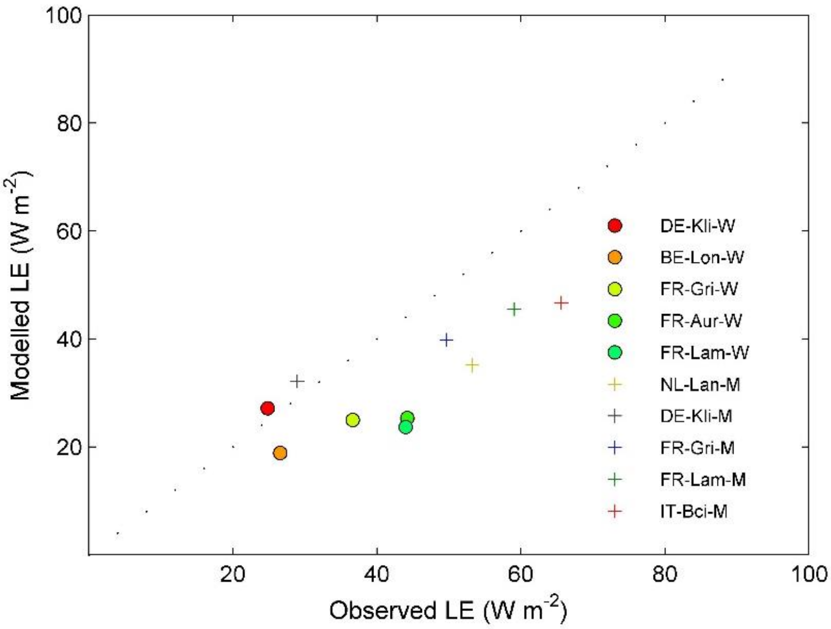

Figure S16. Comparisons between the observed and modelled (based on ORC-CP5) mean growing season latent heat flux (LE) among different crop sites for winter wheat (circle, -W) and maize (cross, -M). Different colors indicate different sites.