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Interactive comment on "JULES-crop: a parametrisation of crops in the Joint UK Land Environment Simulator" *by* T. Osborne et al.

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AC: This is a comment in reponse to reviewer's comments. We really value the input from the reviewer and thank them for this.

Reviewer overview: This paper describe a new simple parametrization included in the JULES land surface model to take into account for specific behaviour of crops into the model. This follow a general and important recent trend in global land surface models to better represent the behaviour of ecosystem largely managed that greatly differ from natural vegetation. I think that it is an important and necessary effort for land surface model and then I greatly support such kind of development in the JULES model. Moreover this kind of paper perfectly fit with the scope of geoscientific model development. So I recommend the publication of the paper. However I think that it can

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be improved in several ways. This is the reason why I quoted "major revision", even if it doesn't means a lot of additional efforts.

RC: As general comment, I find the paper clear and the equation well described even if the style of the paper is sometime a little surprising. In particular, it ask some questions to the reader like "how much detail is required ?" "what's more ?" etc.. which is not very conventional !

AC: The text has been modified to remove these questions.

New Text: Partition coefficients for a given crop are typically pre-defined in process-based crop models according to either the length of time since emergence, or to crop development stage (DVI, i.e. a function of thermal time since emergence). They are represented by fixed values for a given period of time (or thermal time) since emergence, and these values are listed in a look-up table and referenced for each iteration of the model (e.g. WOFOST, **?**).

Here we define the partition coefficients as a function of thermal time using 6 parameters to describe continuously varying partition coefficients over the duration of the crop cycle. We use a multinomial logistic to define this function:

RC:My main concern is that the model evaluation part is a little light and should be enhanced. For instance model is only evaluated on 3 sites for a total of four sites/years. Then only soy bean and maize is represented. A large set of sites on crops are now available with some sites that have more than 10 years of data. This allows to cover the main crops types and several regions in the word. So it is really a pity that model be compared to a so limited set of data. I think that evaluation should be really improved by comparing with a larger dataset that allow evaluation of the 4 crops types represented, for different regions and considering longer time period to evaluate the ability of model to represent the interannual variability for each site. Only H and LE are compared. Why did you not included the NEE fluxes that are probably available for these sites ?(or at least an estimation of the GPP as if I understand well, there is only a short model

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spinup that does not allow to equilibrate the soil carbon).

AC: We are limited to sites that have the appropriate forcing data for JULES as well as useful evaluation data. We have included more sites to the evaluation of Soybean and Maize but were unable to include sites for Wheat or Rice. We have also included plots of GPP and yield for the sites where these data were available. The emphasis of this paper was on the global runs as including crops as a component of our earth system model was the motivation for the model development. As such we focused the analysis of inter-annual variability on the global runs. The site evaluations were included to demonstrate the flexible nature of the model. However, we have added more years to the site evaluation so readers can see how the model performed.

New Text: Figures added - see attached. These new figures are discussed in the results and discussion sections. Figures **??** and **??** compares JULES-crop simulations for the soybean crop type with standard JULES C_3 grass plant functional type with and without phenology, and with observations where available. The crop parametrisation captures the evolution of leaf area index (LAI) and canopy height across the season, although the model underestimates these growth variables. The model also simulates lower gross primary production (GPP) fluxes compared to observations which leads to an under estimation of crop yields. The standard C_3 grass with phenology configuration of JULES also simulates growth and decay of vegetation cover but over a longer period of time than the observed growing season. Without the phenology routine the LAI is set to the default for C_3 grass of 2.0 all year. Interestingly, the more realistic simulation of vegetation cover does not lead to improved simulation of surface fluxes. At all sites similar characteristics of the simulations are evident. During winter all three configurations simulate similar latent and sensible heat fluxes in line with observations (Fig **??**) . Towards the start of the growing season the standard configuration of JULES with constant LAI = 2.0 overestimates latent heat flux due to an unrealistically large vegetation coverage. The simulations with phenology and crops have lower vegetation cover and simulate lower latent heat flux but are still noticeably greater than observations. At around the peak of crop cover all simulations underestimate the latent heat flux and over estimate the sensible heat flux due to lower simulated LAI compared to observations.

Site level simulations for the maize crop type are shown in Figures ?? and ??. The crop parametrisation is reasonably successful in capturing LAI and canopy height of maize at all evaluation sites although again does not simulate maximum values. Again GPP and yields are lower than observed although the seasonal pattern of GPP is close to observations. Overall, model simulations broadly capture the patterns of latent and sensible heat fluxes although again there are no major improvements in model performance with the explicit inclusion of crops. At Fermi in 2006 the crop specific simulation captures the observed evolution of LAI reasonably well with peak LAI slightly closer to observations than the standard JULES simulations. However, this again does not improve the simulation of heat fluxes.

All model configurations overestimate the partitioning of energy in to latent heat before the growing season begins and underestimate it during the crop growing season, despite widely varying LAI values. This could be due to the realtively weak LAI-surface conductance relationship found in JULES (?). This is reflected in the low sensitivity to LAI between fixed and grass phenology. In these simulations we would therefore not expect a large response to an alternative representation of crop LAI phenology. This comparison serves as a reminder that improving the realism of a model may not guarantee improved performance in the model in other aspects. The results also show that JULES (crop and standard configurations) is not able to capture the magnitude of observed GPP fluxes. This suggests that using the standard physiological parameters for C_3 and C_4 grasses is not appropriate when representing crops particularly as JULES does not include nitrogen fertilization explicitly. Tuning of parameters that describe leaf nitrogen for example may improve fluxes of GPP and hence overall yields. It is worth also noting that the parameters used for the crop model in the site simulations are from the global set-up and hence are probably not optimal for site simulations.

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RC: In the simulation at global scale only maps from model results and comparison to averaged global yields is shown. A more regional view of ability of model to reproduced spatial distribution of yields is missing. Obviously, as mentioned by the authors direct comparison the actual yields is difficult since the model does not take into account for specific local management an species. But at least in would be important to see if model is able to reproduce regional climate driven difference in estimated yield.

AC: Regional variations in yield are due to a combination of climate and management. Because we do not include spatial variations in management (which was beyond scope of the initial model development) a better evaluation would be comparing simulated and observed year to year variability for key countries. As such we have included country level time series of yield for each crop type.

New Text: Figures added. These new figures are discussed in the results and discussion sections.

The simulated grid box annual yield for each crop averaged over the 50 years is shown in Fig. ?? along side global gridded observations for circa 2000 (?). Fig. ?? shows that in general the model is under-estimating yields in arid, irrigated regions and over-estimating them in tropical regions. In particular simulated maize yields are significantly larger than observations in tropical regions. Given that the model does not include any information on the yield gap (the difference between actual farm level yield and potential yield) or important land management such as irrigation the spatial variability of model output should not be too closely compared to that of observed yield. Instead, a greater appreciation of model performance can be gained from examining the year to year fluctuations in yield, given that the effects of changes in management and technology materialise over several years.

Figures ?? and ?? show the simulated global and country level yield for wheat, soybean, maize and rice between 1960–2008 compared to the reported yields of ?. Simulated global yield was determined by multiplying the simulated annual maximum yield at

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each grid cell by the observed harvested area from **?** regridded to the HadGEM2-ES spatial resolution. This grid cell estimate of production was summed over all grid cells to produce an estimate of global production which was then divided by the total harvested area to provide an estimate of global yield. Grid cell yields were determined from the annual maximum value of C_{harv} which was multiplied by 2 to convert from carbon mass to total biomass, by 1.16 to account for grain moisture content, and by 10 to convert from $\mathrm{kg\,m^{-2}}$ to $\mathrm{Mg\,ha^{-1}}$. Not all grid cells were included in the analysis. Cells were excluded if the annual maximum DVI was less than 1.5 which was possible if the growing season was curtailed if LAI > 15 or $t_{soil,2} < T_{bse}$. A similar analysis was conducted to determine country level yields with averages taken over all gridcells within a particular country.

The average simulated yield for maize is over-estimated however, the model does a reasonable job of reproducing the inter-annual variability at the global ($r = 0.48$) and country scale (Fig. **??** a). For soybean, average yield is again much greater then observed but year on year variability is correlated with observations ($r = 0.37$) providing some confidence in the model's ability to simulate the observed response of soybean yield to climate. Regionally, in countries such as USA ($r = 0.39$) and India ($r = 0.52$) JULES-crop is able to reasonably capture inter-annual variability of yields (Fig. **??** b). For rice, yield levels are higher than reported, variability is overestimated and not correlated with observations ($r = 0.24$). At the country level, model simulations in India ($r = 0.57$) correlate with observations (Fig. **??** c). The average simulated yield level for wheat is similar to the most recent observations but when comparing the year to year fluctuations in yield, the correlation between simulated and observed is low ($r = 0.019$). Because JULES-crop only simulates spring wheat then the comparison to reported wheat yields is slightly unfair given that the majority of wheat produced globally is from winter varieties. It is encouraging that the best agreement between simulated and observed yield fluctuations at the national level is for Turkey ($r = 0.46$) and Australia ($r = 0.53$), in which spring wheat varieties dominate.

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For all crops there is a tendency for JULES-crop to simulate larger variability than observed. This may in part be explained by the lack of certain processes in the model (particularly those to do with land management). For example not including a representation of irrigation in the model may explain why the model predicts lower yields than observations as irrigation would act to reduce the extent of crop failure in drought years. The model also does not include the impacts of pests and disease which may reduce overall yields in some years. Importantly, the model does not as yet include a nitrogen cycle which may reduce overall GPP bringing the simulations in line with observations.

To evaluate the impact of including the crop parametrisation on JULES, output from the simulation with crops included is compared to a control simulation of the standard JULES configuration with grass plant functional types taking the land fraction of crops. Impacts on the land surface will be mostly mediated via direct changes to the vegetation structure and also via indirect effects on state variables, most obviously the soil moisture content. To begin to examine the potential for impact, the changes to a key vegetation variable leaf area index (LAI) are shown in Fig. **??** for four major crop producing countries. To produce the country averages, grid cell LAI are combined by weighting by the grid cell contribution to total country crop area. In the USA and China each crop growing season occupies the similar set of summer months, whereas for India and Brazil the wheat cropping season is distinct from the other three crops. Peak LAI is greatest in Brazil and lowest in China which is most likely a reflection of the absence of irrigation in the model and the relative abundance of rainfall in each country. In comparison to the standard JULES configuration the addition of crops adds a seasonality to LAI as there is no default seasonality to vegetation characteristics in JULES. The annual variation of crop LAI is dampened when aggregated with the other plant functional types which explains the non-zero LAI in the non-growing season in the JULES-crop simulation. Fig. **??** shows that the inclusion of crops alters the gridbox net primary production (NPP) in terms of the timing of peak fluxes. There are also lower fluxes in winter due to the more reaslitic treatment of LAI at this time. Therefore, including a representation of crops in JULES may help improve the seasonality of LAI and which affects carbon fluxes.

Figure ?? shows that the impact of these differences in vegetation size during the year is greatest for the surface moisture flux and sensible heat flux rather than the components of the radiation balance. The largest impacts are on the sensible heat flux towards the end of the crop growing season which is higher with the inclusion of crops. For India there is a concomitant decrease in the surface moisture flux implying that the total available energy at the surface is unaltered but is partitioned differently between sensible and latent heat fluxes. The impact of JULES-crop on the energy balance is however minimal. In this configuration the model is forced by prescribed meteorology at screen height. This has the tendency to damp the model in comparison to a full atmospheric simulation in which the boundary layer state is able to evolve. It may therefore be expected that a GCM may be more sensitive to changes in the surface state.

RC: Likewise several model configurations have been implemented but are not evaluated in the paper. For instance a method to automatically determine the sowing date has been implemented but no results are shown in the paper. A method to take into account for photoperiod constraint on estimation of the development index was also included but not used in the simulations. I think it would be important to add a part showing the impact of these different parametrisations on simulated fluxes and yields.

AC: The “dynamic sowing” option is one that we feel needs more testing and as such results have not been included in this paper. However, we wish to inform users of this functionality and so describe it in the paper. We have added a sentence to explain why results from this option are not included. The photoperiod sensitivity was not included because it made determining TTveg, TTrep almost impossible. This is because we would then have three variables that needed calibrating at each grid cell (total TT, critical photoperiod, and sensitivity to photoperiod) from one observation (growing season duration). There are other options for determining TTveg and TTrep and so we included it as an option for future users if their studies required it.

New text: We wish to make users aware of this sowing option however, we feel it needs further optimizing and so results using the dynamic sowing date will not be included here.

Photoperiod sensitivity was not considered.This is because including it would have made calculating TT_{veg} and TT_{rep} almost impossible, because three variables would need calibrating at each grid cell (total TT, critical photoperiod, and sensitivity to photoperiod) from one observation (growing season duration).

Specific comments:

RC:p 6780: Even if the different model parameters are defined in table 1, it would be more convenient for the reader to remind it after equation, this is for instance the case for TTemr,TTveg abd TTrep in equation 3

AC: Description added New text: where TTemr is the thermal time between sowing and emergence, TTveg is the thermal time between emergence and flowering and TTrep is the thermal time between flowering and harvest

RC:p 6780 eq 4: what is the meaning of the 0.012 term ?

AC:The factor 0.012 is a unit conversion (mol CO2 m$-$2 s$-$1 to kg C m$-$2 s$-$1)

RC:p 6781: there is a paragraph that justify definition of continuous coefficients for allocation to biomass compartments that is very long and not very clear. I think this could be shortened as it is obvious for me that defining a parametrisation for allocation coefficient is ever better than a lookup table !

AC:This paragraph has been simplified. See above

RC:p 6783 eq 9,11,13: I didn't find the definition of fc ?

AC:The description is in Table 1.

RC:p 6785 l 19: Typo, Missing the T of "The"

AC:Amended

RC:p 6790 : I am surprised in figure 8 to see so little differences in simulated LE flux for instance considering the large difference in LAI between the standard and crop version. In particular there is a large LE pic in May simulated all the versions even if LAI is very low in the crop version. Do you have an explanation for that ? I think it would be important to discuss this point as it is mentioned that at the end, the new parametrization does not change a lot the result, which is indeed what we see in the site simulation but that is strange for me as LE should be, in spring and summer, largely driven by plant transpiration and then by LAI. So I would expect that the large LAI change induced by the new crop parametrization should has a larger impact on fluxes.

AC:We were surprised by this also. It could be due to a weak relationship between LAI and evaporation in JULES (Lawrence and Slingo, 2004). We added some discussion of this to the text.

New Text:This could be due to the realtively weak LAI-surface conductance relationship found in JULES (?). This is reflected in the low sensitivity to LAI between fixed and grass phenology. In these simulations we would therefore not expect a large response to an alternative representation of crop LAI phenology.

These impacts were marginal at the country and site scale despite quite large differences in LAI. It is possible that the relationship between LAI and evaporation is too weak in JULES (?) which may explain why more realistic representation of LAI did not improve the energy fluxes. We may expect a higher sensitivity in fully coupled atmosphere model.

Interactive comment on Geosci. Model Dev. Discuss., 7, 6773, 2014.

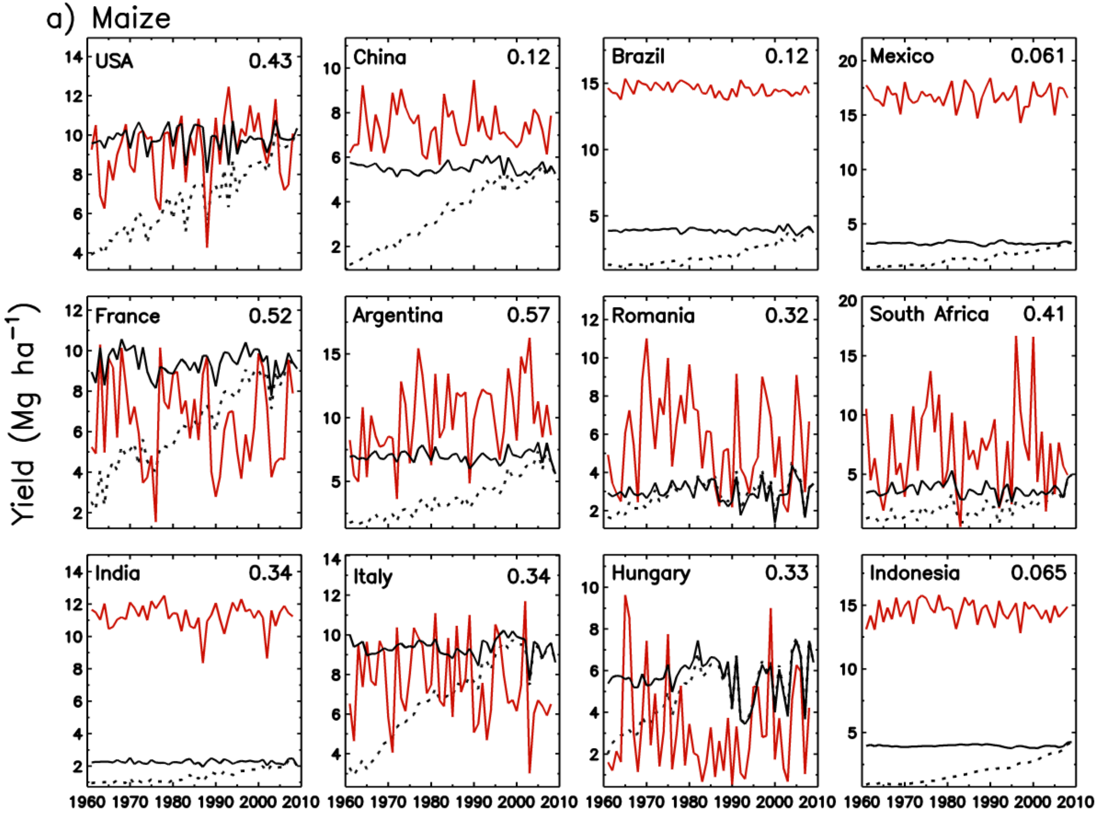

Fig. 1. Simulated (red), observed (black dashed) and de-trended observed (black) country level yields of a) Maize between 1961-2008. Value

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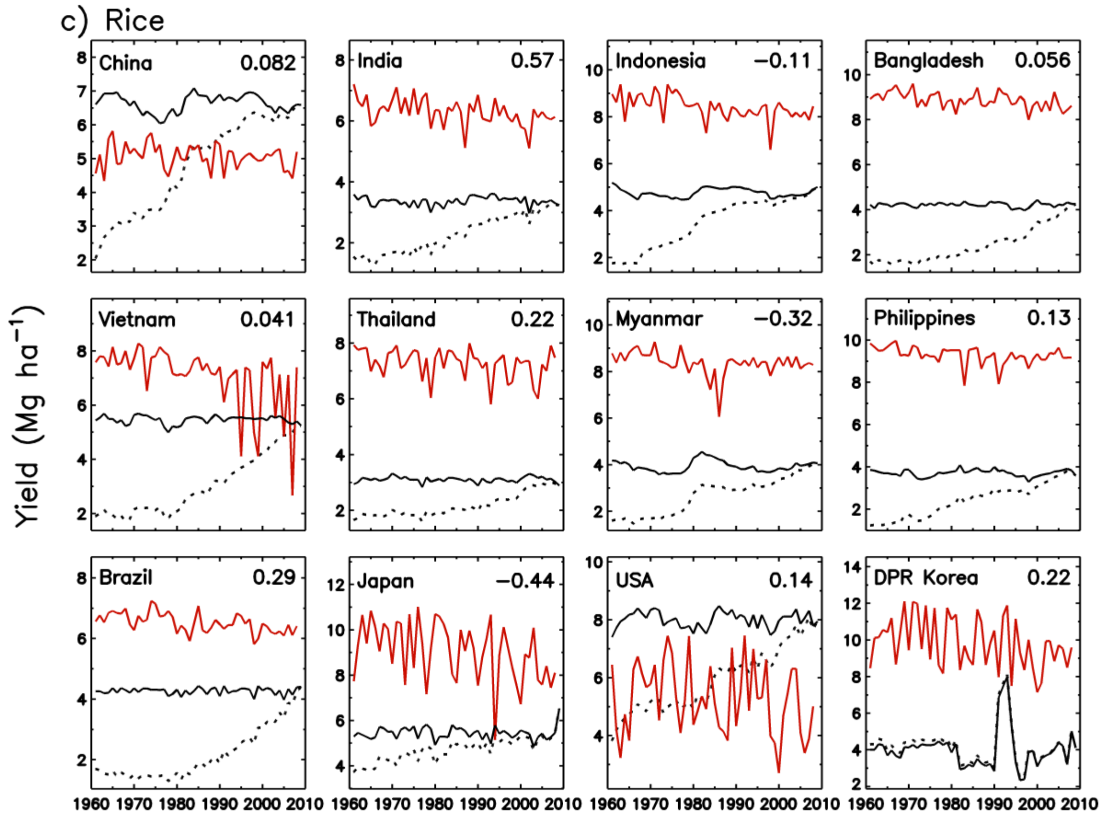

Fig. 2. Simulated (red), observed (black dashed) and de-trended observed (black) country level yields of c) Rice between 1961-2008. Values in the top right are results of a

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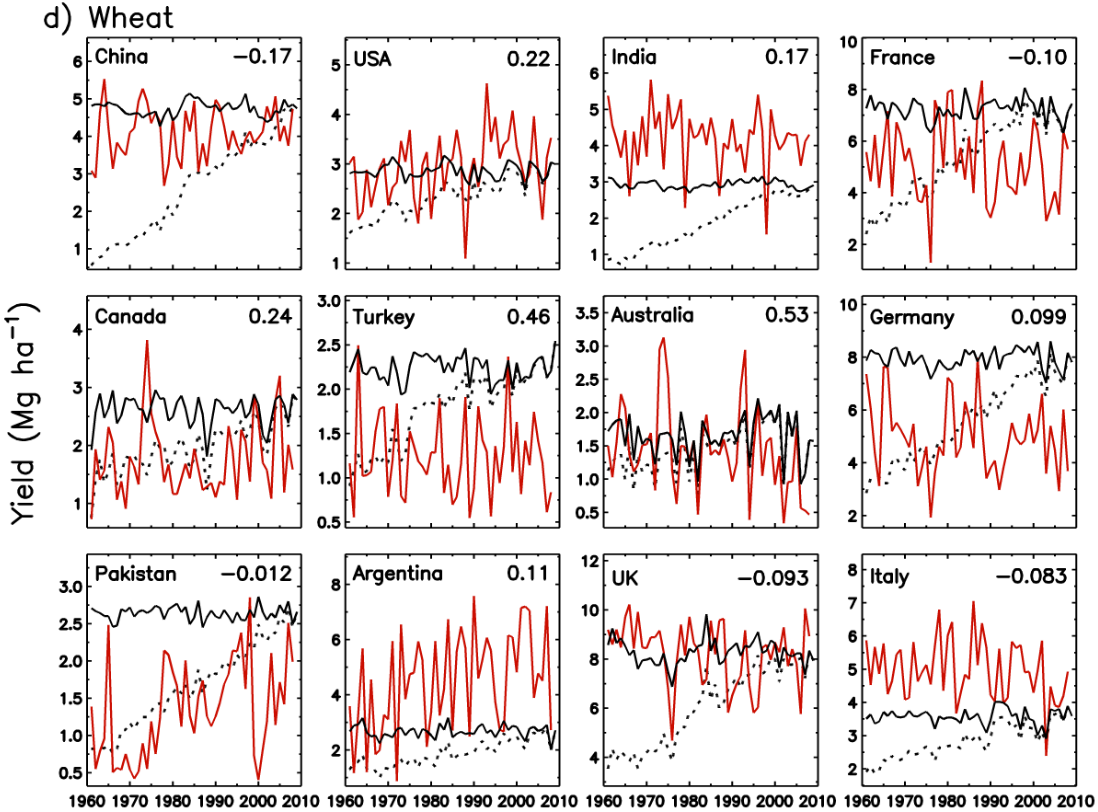

Fig. 3. Simulated (red), observed (black dashed) and de-trended observed (black) country level yields of d) Wheat between 1961-2008. Values in the top right are results of a

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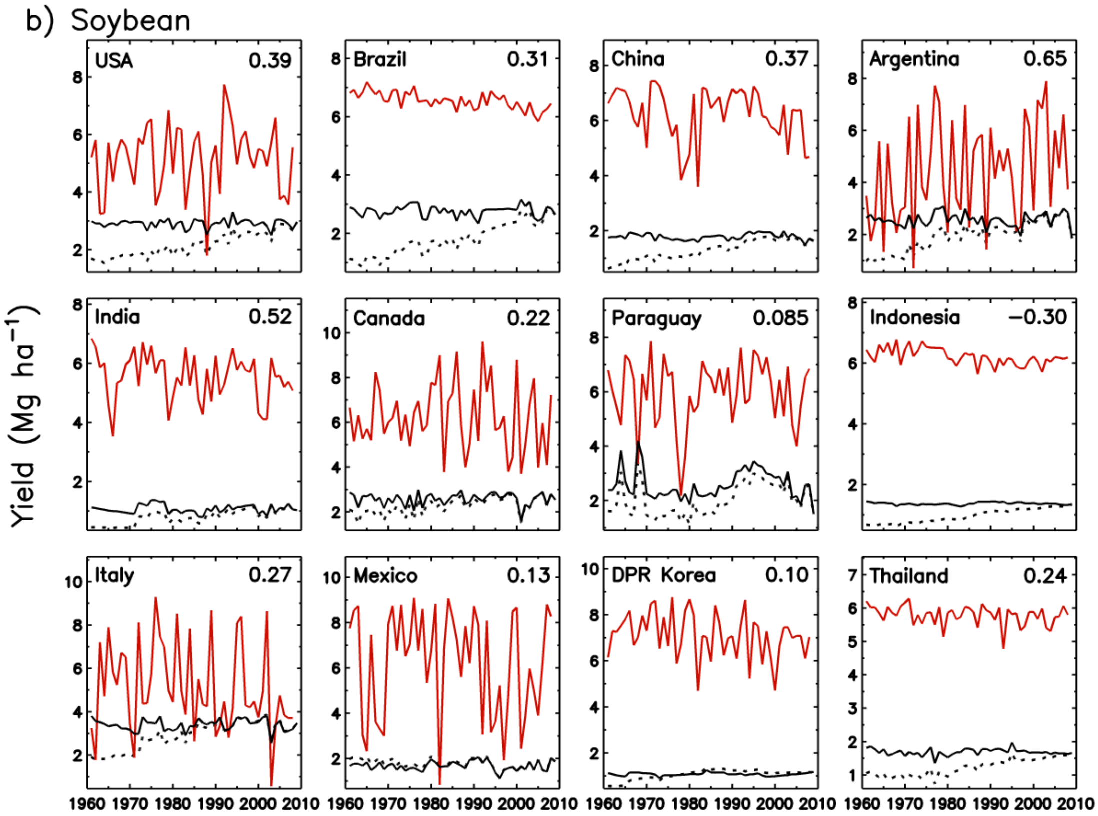

Fig. 4. Simulated (red), observed (black dashed) and de-trended observed (black) country level yields of b) Soybean between 1961-2008. Values in the top right are results of a

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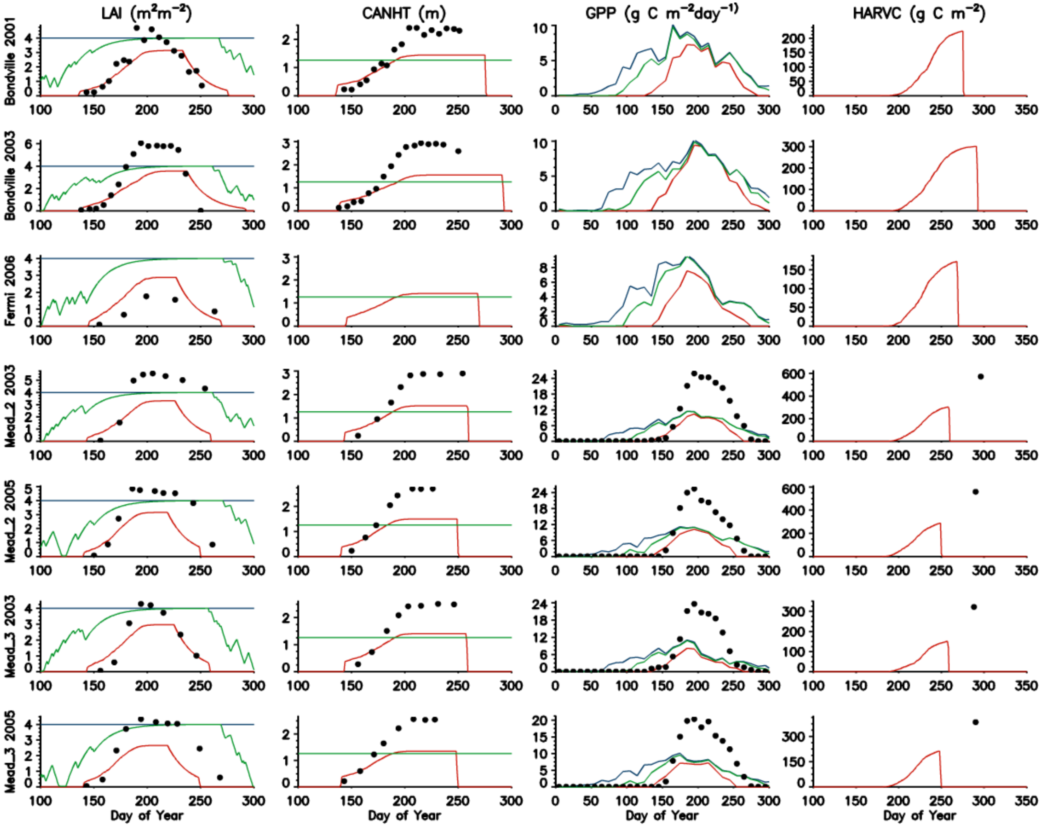

Fig. 5. Simulated (solid lines) and observed (dots) Leaf Area Index (LAI), Canopy Height (CANHT), Gross Primary Production (GPP) and Harvest Carbon (HARVC) at a range of fluxnet sites and years.

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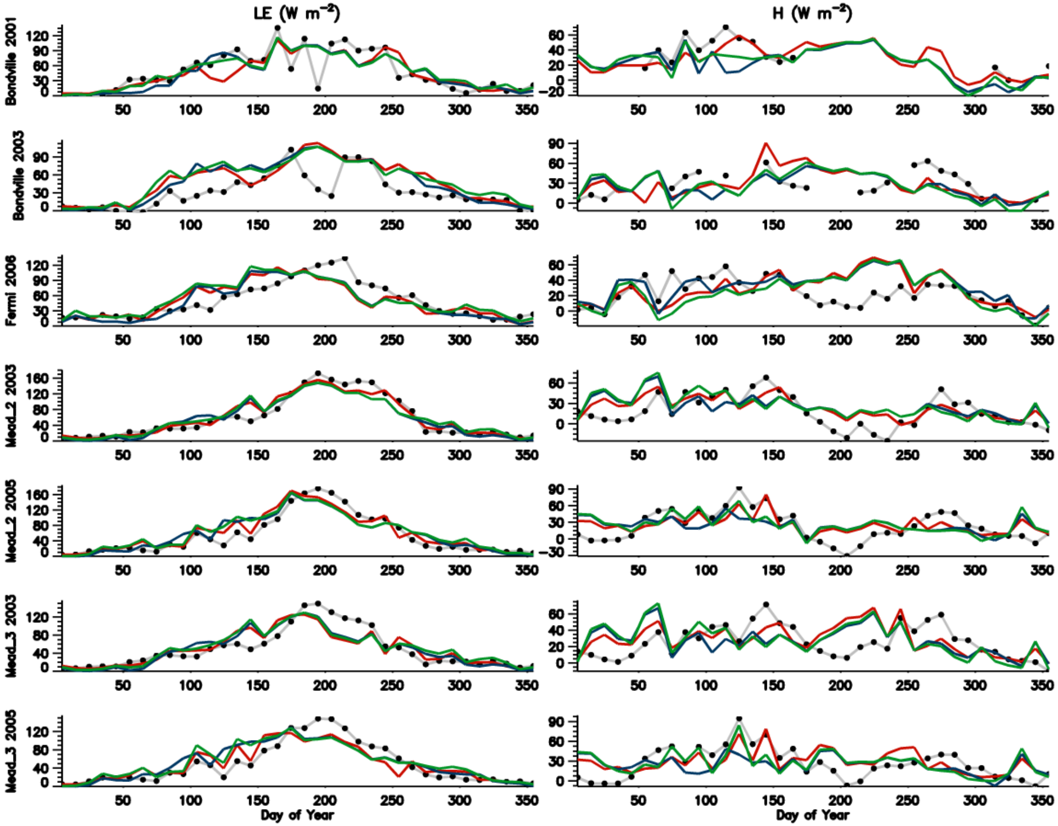

Fig. 6. Simulated (solid lines) and observed (dots) Latent (LE) and Sensible (H) heat fluxes at a range of fluxnet sites and years.

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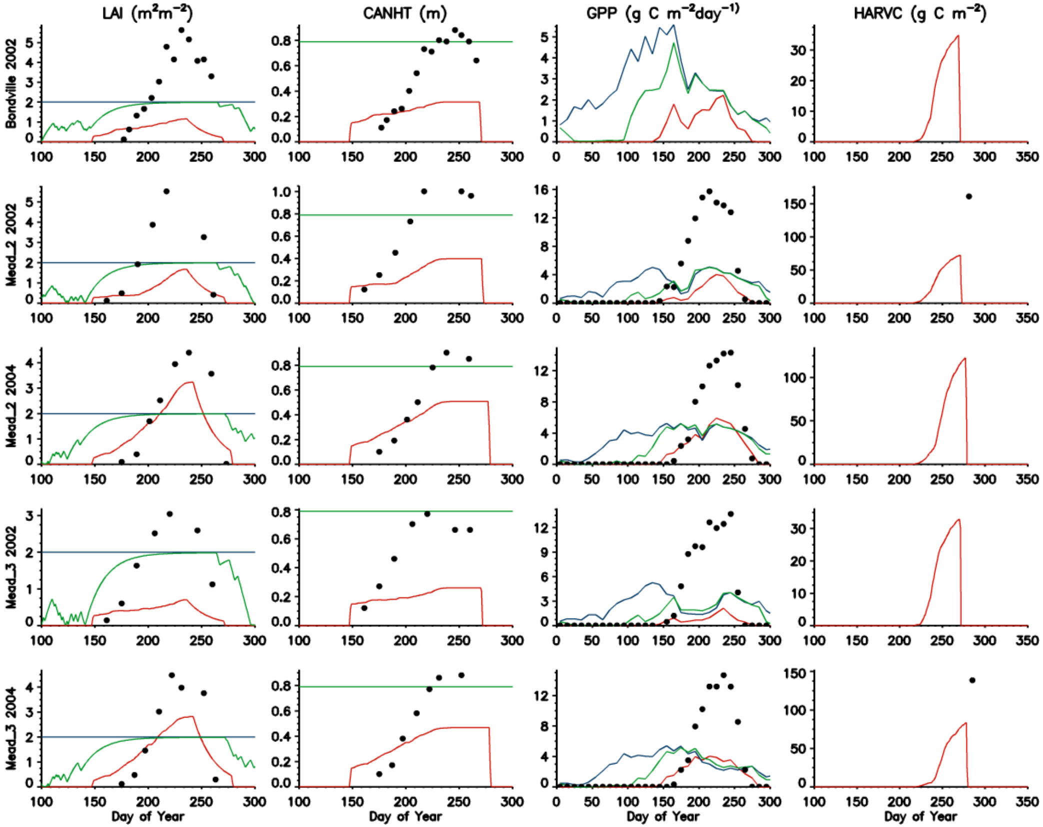

Fig. 7. Simulated (solid lines) and observed (dots) Leaf Area Index (LAI), Canopy Height (CANHT), Gross Primary Production (GPP) and Harvest Carbon (HARVC) at a range of fluxnet sites and years

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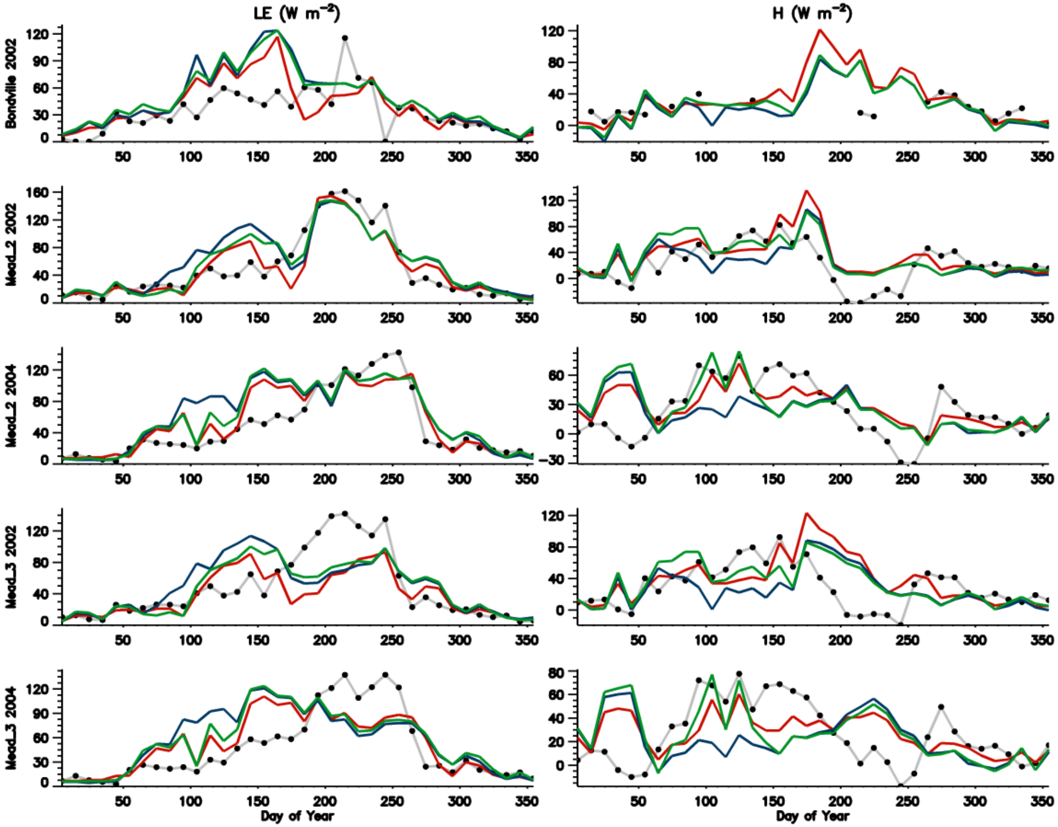

Fig. 8. Simulated (solid lines) and observed (dots) Latent (LE) and Sensible (H) heat fluxes at a range of fluxnet sites and years.