Anonymous Referee #3

The authors report on a new parameterisation of a key parameter, the nominal LUE (beta_n) for the coupled energy balance carbon cycle model TSEB-LUE. Overall the work is very solid: the authors are able to rely on an impressive set of field data (eddy covariance flux measurements, ancillary meteorological data, biophysical data, ...) from four field sites (rainfed/irrigated maize/soybean); the paper is well written, the presentation is solid; discussion and conclusions are appropriately based on the results.

Having said this, the paper still left me somewhat unsatisfied as the major finding is actually incremental: when replacing the constant beta_n parameter with the new parameterisation (which is a function of time-varying leaf chlorophyll content), the authors find that the canopy photosynthesis simulations (and less so evapotranspiration) improve. This, in my view, is not surprising as the new model has more degrees of freedom – the authors would have been able to achieve the same results simply by fitting a polynomial to the residuals. The latter (provocative) comment is of course stupid, as the novel aspect of this study is that the authors are able to relate changes in beta_n over time to changes in the leaf chlorophyll content which, in theory, enables remote estimation of beta_n. I suggest the authors to further work on this innovative aspect of their study in order to make this a more significant paper.

To this end I have the following suggestions: (i) To me it is striking that, despite differences between rainfed/irrigated maize/soybean, the same relationship (Fig. 4) can be used (although separate relationships were not explored). This merits further analysis. The authors discuss that differences in canopy structure (leaf angle distribution, planting density) may be responsible for the observed deviations from the fitted line. This would be an area that would merit further analysis to explore the hypothesis made using for example a mathematical model of canopy radiative transfer and leaf photosynthesis. Possibly, the structural differences between the different canopies could be accounted for, making the relationship more universal. On a plant physiological ground the convergence between a C3 and C4 plant to the same relationship merits further discussion as well.

Author Response

We agree that there needs to be a more robust explanation of the outliers and more elaboration on functional differences in the Chl– β_n relationships. For the outliers, we offer a secondary explanation other than plant density. The fraction of green (fg) may be the ultimate reason why rain-fed maize appear to have higher β_n for a given Chl value. Indeed if one simply does not multiply Chl by fg it falls in line with the rest of the relationship (see figure below in comparison with Fig. 4 in the text). Since the measured Chl values were taken at the earleaf level (conversation with Anatoly Gitelson) the lower plant density allows for the measured Chl values to be more representative of the canopy as a whole. In this case multiplying by fg actually introduces error. The implications are that when using the functional relationship developed in the paper to estimate β_n at the satellite scale (i.e. Landsat) the rain-fed maize will actually fall in line with the functional relationship.

Separate soybean and maize specific relationships were explored, but we conclude that a more elaborate dataset on soybean (this study included data from only field 2 (2002,2004) and field 3 (2002)) will be needed for further investigations into functional differences in the Chl – β_n response between soybean and maize.

We have added

While separate functional relationships for soybean and maize were explored (not shown), the benefits of employing these species-specific relationships did not outweigh the advantage of having a single functional fit. A more elaborate dataset on soybean will be needed for further investigations into functional differences in the Chl– β_n between soybean and maize.

And we have added

While semi-mechanistic relationships between leaf chlorophyll content and leaf photosynthetic capacity demonstrate the importance of distinguishing between species utilizing differing photosynthetic pathways (C3 versus C4) (Houborg et al., 2013), relationships at the canopy scale are governed by different mechanism sometimes yielding more universal relationships (Gitelson et al., 2006).

Reviewer comment :

(ii) The chlorophyll content measurements were inferred from hyperspectral reflectance measurements at the leaf level, calibrated against chlorophyll extractions, which were scaled up to the canopy level. When TSEB-LUE is driven only by remote sensing data, the question arises on the relationship between the up-scaled leaf level data used in this study and corresponding RS measurements. This is something that the authors at least should address in the discussion/conclusion. Possibly, remote sensing of the chlorophyll content may introduce uncertainty into the estimation of beta_n which negates the advantage of the proposed parameterisation (e.g. would further reduce the R2 in Fig. 4). This is in particular an issue as any chlorophyll content inferred from RS will have a "canopy structure" effect, similar to the author's arguments regarding variability in Fig. 4. A great addition would be hyperspectral ecosystem-scale data from field spectrometry or airborne remote sensing to actually demonstrate this effect.

Author Response

We agree that it is entirely possible that the estimation of remotely sensed Chl may introduce uncertainty in β_n, but in most cases it will still be an improvement over a fixed β_n value seasonally. That being said the relationship developed here was specifically designed to not depend on canopy structure because we are using leaf level chlorophyll measurements averaged over the canopy via the fraction of green. Leaf level chlorophyll measurements can be estimated from remotely sensed data using radiative transfer inversion techniques (Houborg et al. 2013; 2015). Indeed we are working on a paper at

the moment using remotely sensed leaf level chlorophyll content retrieved from the REGularized canopy reFLECtance model (REGFLEC) (Houborg & Anderson, 2009) to estimate carbon assimilation using the functional relationship developed in this paper. The initial results look promising and have been presented at the 2014 AGU annual fall meeting.

Gitelson, A. A., Viña, A., Verma, S. B., Rundquist, D. C., Arkebauer, T. J., Keydan, G., Suyker, A. E. (2006). Relationship between gross primary production and chlorophyll content in crops: Implications for the synoptic monitoring of vegetation productivity. *Journal Of Geophysical Research-Atmospheres*, *111*(D).

Houborg, R., & Anderson, M. C. (2009). Utility of an image-based canopy reflectance modeling tool for remote estimation of LAI and leaf chlorophyll content at regional scales. *Journal Of Applied Remote Sensing*, *3*(1), 3529.

Houborg, R., Cescatti, A., Migliavacca, M., & Kustas, W. P. (2013). Satellite retrievals of leaf chlorophyll and photosynthetic capacity for improved modeling of GPP. *Agricultural And Forest Meteorology*, *177*, 10–23.

Houborg, R., McCabe, M. F., Cescatti, A., Gao, F., Schull, M., & Gitelson, A. A. (2015). Joint leaf chlorophyll content and leaf area index retrieval from Landsat data using a regularized model inversion system. *Remote Sensing of Environment (In Press)*.

Technical Corrections:

Minor comments: p. 14135, l. 17-19: in the equation Re however has a positive sign

Author Response

We agree. This sentence has been changed to:

Many studies derive GPP from eddy-covariance observations of NEE and estimates of daytime ecosystem (soil + plant) respiration (Re) as GPP = NEE+**Re** (Suyker & Verma, 2010, 2012). Here, carbon uptake by plants is defined as positive while respiration, or carbon release, is negative.

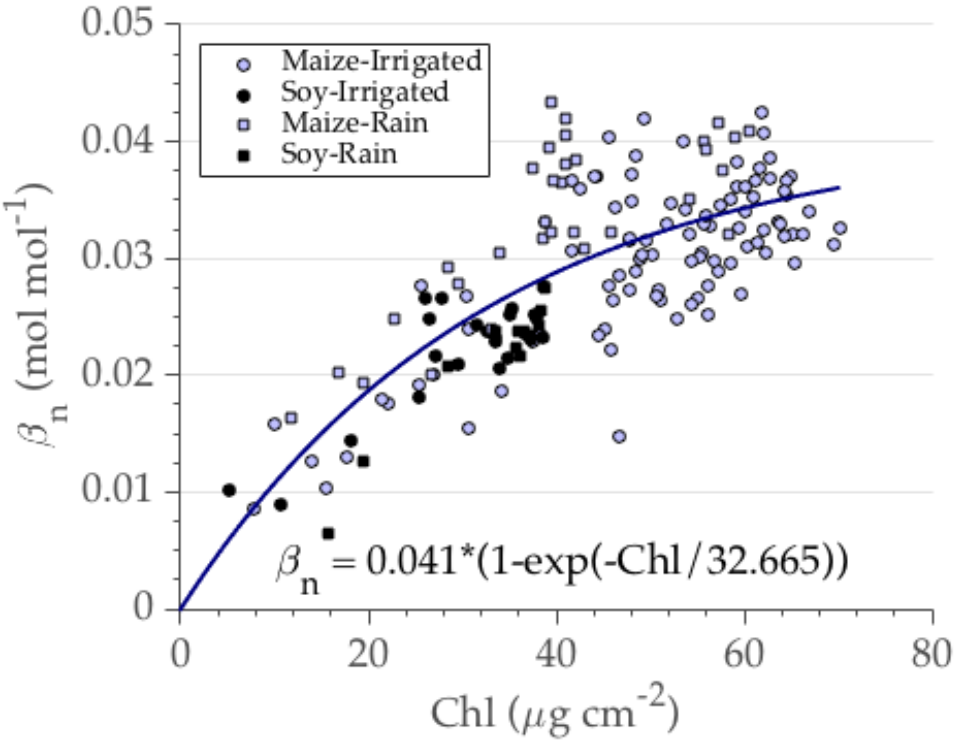

Fig. R1. Manuscript figure 4 without multiplying fg to leaf level chlorophyll for rain-fed corn.