Unravelling the physical and physiological basis for the solar-induced chlorophyll fluorescence and photosynthesis relationship using continuous leaf and canopy measurements of a corn crop

Response to reviewers' comments

Peiqi Yang, Christiaan van der Tol, Petya K. E. Campbell, Elizabeth M. Middleton

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Short comment from Dr. Kaiyu Guan

Review for "Unravelling the physical and physiological basis for the solar-induced chlorophyll fluorescence and photosynthesis relationship" by Yang et al.

General comments

This manuscript used field measured leaf and canopy fluorescence and photosynthesis and investigated the physical and physiological basis of SIF-GPP relationship at a corn field. They found that APAR dominated the positive SIF-GPP relationship. They further used the continuous active fluorescence measurements from the MoniPAM system to analyze the relationship between fluorescence yield and photochemical yield at leaf scale and found a moderate correlation between the efficiencies of fluorescence emission and photochemistry for sunlit leaves but a weak correlation for shaded leaves. The manuscript has some strength.

The major strengths are: (1) The author combined leaf-scale active fluorescence measurements to fully investigate the physiological basis of the SIF-GPP relationship which is lacking in many studies. (2) The authors are on top of the most recent literatures in this topic. The references used are up to date, and the authors had a very thorough summary of the past literatures. The manuscript is also well-written. However there are several unclear points which should be addressed:

Dear Dr. Guan, Thank you for your positive and encouraging feedback, as well as the clear summary and constructive suggestions. We have revised our manuscript according to your and the other two reviewers' comments.

(1) The reliability of relative efficiency of the sustained heat dissipation ($\Phi D*$) calculation. In L210, the author claims that "Because Fm was measured during the night in the absence of both reversible heat dissipation and photochemistry, a change in Fm must be caused by a change in the sustained heat dissipation". But during night, there are still ΦN and ΦF from Fig. 5. I am concerned about the reliability of $\Phi D*$ calculation since to my knowledge, this calculation hasn't been used in previous studies. The author should provide more literature to back up this method.

Response: You are absolutely right that, as far as we know, the derivation of $\Phi D*$ has not been reported in other places. It is also correct that ΦF is still present in the night because ΦF is derived from MoniPAM Ft measurements, which are induced by the measuring light. The values are below 100 in the night since leaves are dark-adapted and have maximal ΦP. The nighttime ΦN is not at the absolute zero, but it is very small (<0.05, and <1% from the pie chart), which is most likely due to the uncertainties in the MoniPAM measurements.

Our idea is that ΦN is negligible in the night and ΦP is zero when saturating light is applied. Hence, the change of ΦF (i.e., Fm) represents the change of ΦD, since ΦN+ ΦP+ ΦD+ ΦF = 1, where ΦN≈0 and ΦP=0. We hope our explanation makes the issue clear.

(2) The data availability across the whole growing season is not provided. In L154, the author mentioned that they excluded 29 days rainy and cloudy data, but the whole period of available canopy

data is not provided. The author could provide a time series of the SIF, GPP, APAR data in the supplementary. Also, the availability of the active PAM measurements is also not explicitly provided.

Response: We had provided all the measurements of GPP, SIF, and MoniPAM measurements in a supplement. The link to the data is on the same page with the manuscript below the manuscript pdf icon (https://bg.copernicus.org/preprints/bg-2020-323/bg-2020-323-supplement.zip).

(3) The author reported the overall correlation between $\Phi Pcanopy$ and $\Phi Fcanopy$. It would be good that they provide the scatter plot and compare this with the leaf scale relationship.

Response: We have included the suggested plot in the appendix (Fig. A2).

(4) L423 They found no clear relationships between $\Phi Pcanopy$ vs. ΦP or $\Phi Fcanopy$vs. $\Phi F*$. This result needs more explanation, such as this poor correlation is for sunlit leaves or for shaded leaves or both and what causes this poor correlation. Of course, they are from different levels (leaf vs canopy) and canopy structure plays a role here. Although fesc calculation still has large uncertainty, there are several methods proposed to quantify this term (e.g., NIRv/fPAR). The author should try to correct fesc effect and get canopy total $\Phi Fcanopy$ and compare with leaf $\Phi F*$.

Response: Thank you for this comment. We have included scatter plots of the leaf and canopy efficiencies in the appendix for (both sunlit and shaded) as shown in Fig. A3. Furthermore, we have added a section discussing about the role of fesc on the SIF-GPP relationship. We found that the accuracy of fPAR is crucial to estimate fesc and total emitted SIF when using either FCVI or NIRv. Although we did not find an improvement in GPP estimation after correction TOC SIF for fesc, we believe that canopy total emitted SIF is a better indicator of GPP compared with TOC SIF. With either a better estimation or measurement of fPAR or i0, we can improve the relationship between SIF and GPP by accounting the fesc effects.

(5) L440. They found progressive increase of sustained heat dissipation ($\Phi D*$) during senescence. In contrast with no seasonal variation of ΦN. Why there is no seasonal variation of ΦN? What factor determined the seasonal variation of ΦN.

Response: As far as we know, ΦN is mainly determined by the radiation levels, which is more pronounced in a diurnal cycle. There is some seasonal variation of ΦN, but its variation has no clear pattern since it is determined by instant radiation levels.

(6) L455. The author mentioned that reversible heat dissipation is responsible for the positive relationship between ΦF and ΦP at diurnal scale, but there is no diurnal relationship between ΦF and ΦP in the current manuscript. The author only provided the seasonal and seasonal+diurnal relationships.

Response: Thanks for this comment. Indeed, we did not provide the diurnal relationships between ΦF and ΦP separately. We have included a figure for their diurnal relationship in the revised manuscript in the appendix (Fig. A1).

(7) L520. The author claimed that a stronger relationship between SIF and GPP for dense canopies is expected since ΦF sunlit and ΦP sunlit are moderately correlated. I am not convinced that dense canopy means the fraction of sunlit leaves is larger. Also, the poor correlation between SIF and GPP at senescent stage is probably due to the less data points and more uncertainty of the SIF retrieval.

Response: We agree that the less data points and larger uncertainties of the SIF retrieval are also possible reasons for the lower correlation between SIF and GPP at the senescent stage. We believe that leaves in the upper layer absorb a major part of the incoming PAR, and thus contribute more to TOC SIF and GPP for dense canopies. These leaves are normally sunlit, for which ΦF and ΦP are moderately correlated. Dense canopy does not mean that the fraction of sunlit leaves is larger. In fact, the simulations (Fig. 12 in the revised manuscript) show that larger LAI leads to lower sunlit fraction. However, the relevant quantity is fPARsunlit/fPARtot, which supposes to be higher for dense canopies.

(8) L528. The author claimed that under cloudy conditions, SIF-GPP relationship becomes worse. But this is opposite to the previous study from Yang et al. (2018) in a rice paddy. They found similar relationship under sunny and cloudy conditions. Why will diffuse condition lead to a worse SIF-GPP relationship?

Response: Thanks for pointing this out. Indeed, Yang et al. (2018) reported that an identical correlation between SIF and GPP for sunny and cloudy days as indicated by the R2 and rRMSE values (Fig. 4 in Yang et al, 2018). We think that this is not opposite to our results, but suggests that the relationship between SIF and GPP changes under various environmental conditions. The possible cause of a worse SIF-GPP relationship under diffuse (or cloudy) condition, we think, are 1) the higher contribution to TOC SIF from shaded leaves, in which a very weak ΦF-ΦP relationship occurs, and 2) measurements of TOC SIF are more likely to be more noisy under diffuse illumination in cloudy days.

Yang, K., Ryu, Y., Dechant, B., Berry, J. A., Hwang, Y., Jiang, C., ... & Yang, X. (2018). Sun-induced chlorophyll fluorescence is more strongly related to absorbed light than to photosynthesis at half-hourly resolution in a rice paddy. Remote Sensing of Environment, 216, 658-673.

(9) Overall, I feel that the link between MoniPAM active fluorescence and canopy SIF is weak and the author analyzed these two datasets separately. Although they used to SCOPE but only to model the leaf scale relationship. It would be good if the author can use the leaf measurements to run SCOPE and get canopy SIF and GPP and compare with observations.

Response: We agree with the importance of the link between leaf and canopy measurements. However, to run SCOPE, many more properties of the leaf and canopy structure are required. We have done such an experiment, but we think it is better to present in a separated paper, since many details are required to interpret correctly the experiment and results.

Finally, I want to provide encouragements for this work. The general goal that this work aims to achieve is worth praising. I enjoyed the reading of this manuscript and it clearly shows the authors have been putting lots of efforts into the literature review. I can see that this work could have a good impact and contribution to this field if all the above concerns can be properly addressed. Thus I fully encourage moderate revision of this work. Meanwhile, please understand that a rigorous scrutiny is necessary here as this topic that you are addressing is very important and your conclusion can have a large impact for the general public’s understanding about SIF and photosynthesis.

Response: We agree totally with your recommendation and appreciate the constructive comments. We hope that the additional figures and section we added have addressed your concerns. Thank you again!