Responses to the comments of RC1

Comment 1: In the AGCM simulations with different cropland conditions, how are the external forcings given (e.g., at the 1850 or 2015 level)? Will the use of different external forcing levels (e.g., at the 1850 or 2015 level) affects the climate response? This is related to the nonlinear responses of climate to land use / land cover change and external forcings such as greenhouse gases and aerosols. At least some discussions on this issue would be helpful.

Reply: *As we focus on the climatic effects of the external forcing of cropland expansion, in the AGCM simulations with different cropland conditions, other external forcings such as anthropogenic aerosol emissions and greenhouse gas concentrations were all fixed in the present-day climatological conditions (1982–2001 mean) (Eyring et al., 2016). However, as mentioned by the reviewer, due to the nonlinear responses of climate to external forcings, the use of different external forcing levels may affect climate responses. Associated discussions have been added in revised manuscript:*

Added in manuscript: Taking into account the nonlinear responses of climate to external forcing (Rohrschneider, Stevens, & Mauritsen, 2019), employing various external forcing levels such as 10000 BC, 1850, 1990, and 2015 would inevitably influence the climate's reaction. Thus, we ran the Atmospheric Model Intercomparison Project (AMIP)-type (Eyring et al., 2016) experiments, using fully prognostic atmosphere and land models with prescribed, seasonally varying present-day climatological (1981-2001 mean) sea surface temperatures and sea ice concentrations (Hurrell et al., 2013).

Comment 2: L130-145: The forms of Equations (1) and (2) do not seem correct.

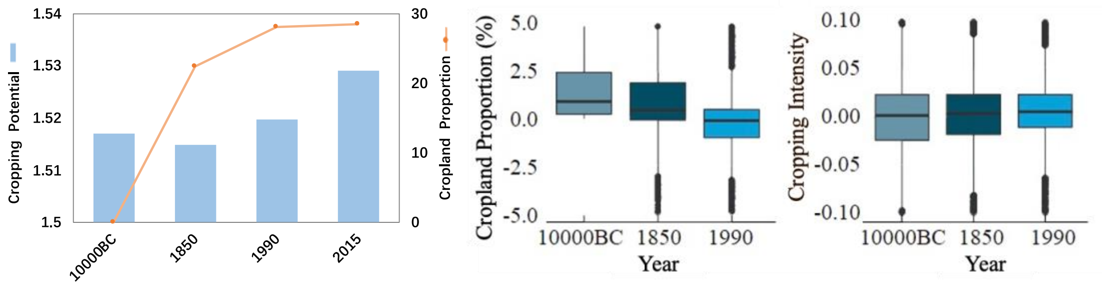
Reply: Sorry for uploading the wrong equations due to DOC version issues. We have corrected them as following and also in revised manuscript.

$$\delta\bar{T} \approx \gamma^{-1}\left(-\delta\left(\overline{\vec{\boldsymbol{V}_h}\cdot\nabla_h T}\right)+\delta\left(\overline{S_p\omega}\right)+\delta\overline{Q_s}+\delta\overline{Q_{ld}}+\delta\overline{F_{sh}}+\delta\overline{Q_q}\right) \quad (1)$$

$$\delta\bar{P} \approx \delta(\overline{-W\nabla\cdot\vec{V}})+\delta(\overline{-\vec{V}\cdot\nabla W})+\delta\bar{E} \quad (2)$$

Comment 3: Fig. 3a: The inset blue bars (global mean cropping potential) show no change from 10000BC to 2015. Please check if there is an error. In addition, as the map shows, only very limited locations show significant change in cropping potential (indicated by solid black dots) from 10000BC to 2015. This is also seen from Fig. 4. So I wonder if the conclusion that "a 28% increase in cropland expansion has led to a 1.2% enhancement in global cropping potential" (L24) is overstated. The low significance needs to be clarified.

Reply: Actually, the variation of average cropping intensity worldwide is relatively small. And due to the fluctuation in cropping intensity worldwide, calculating global averages may dilute local variations. While individual bar charts exhibit some variability, the representation on the graph becomes limited when error bars are added. To avoid ambiguity, we have adjusted the scale of the statistical graph for better representing changes between years. And we added two alternative methods as follows that more directly illustrate changes in cropping intensity between different years, rather than focusing on the absolute values each year.



Also, summing up all the pixels in Figure gives the global average cropland potential value added from 10,000 BC to 2015 being 0.012. To prevent ambiguity, we added the analysis of low significance of 90% and 85% confidence level, the significant change in cropping potential (indicated by solid black dots) from 10000BC to 2015 could be seen (We added Fig.S22 in Supplementary Information). And we also added a note to warn of the limitations of 95% significance for our current conclusions in revised manuscript.

Added in manuscript: Additionally, significant changes in cropping potential are observed only in prominent climate change regions globally. This study reveals the overall trend conclusion from a global perspective, and the accurate benefits brought by cropland expansion need to be analysed based on specific regional conditions.

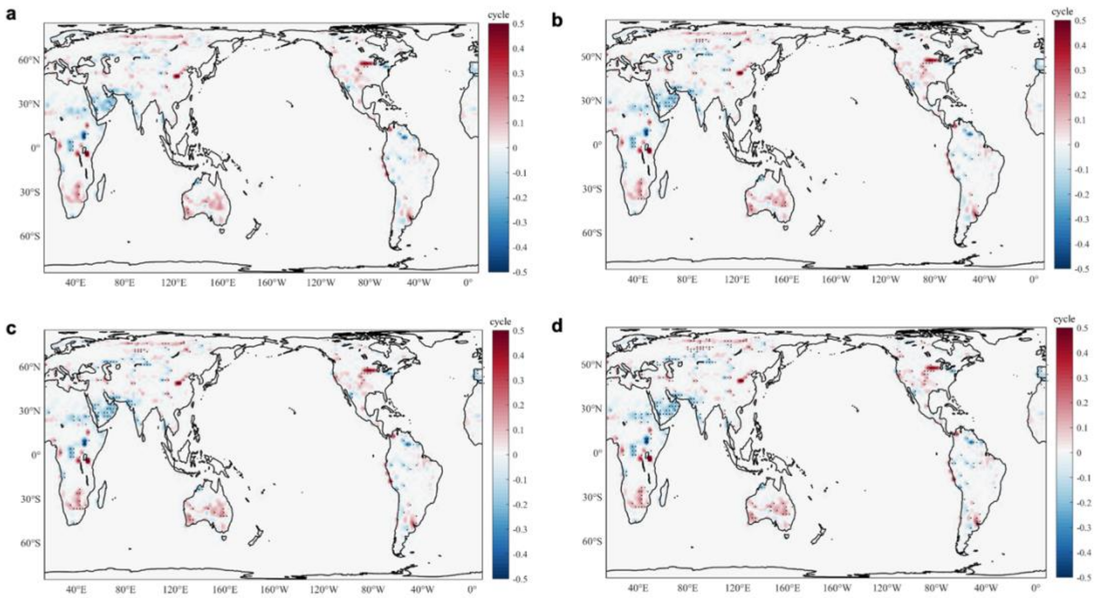


Fig. S22. Cropping potential changes with (a)95%, (b)90%, (c)85%, (d)80%confidence level from 10000BC to 2015.

Comment 4: L275-278 and Fig. 4: It is indicated that cropping potential growth rate is greater in high latitudes than in low latitudes. I wonder if this statement is robust. This can be confirmed by investigating the relationship between cropping potential growth rate and latitude.

Reply: From Fig.4, we could find the cropping potential growth rate is greater in high latitudes than in low latitudes. However, it is not an alone result, since some previous research has found similar conclusions: Chen et al. found the zones with a higher latitude show possible increased multiple cropping intensity (Chen, 2018); IPCC reported that climatic warming could potentially benefit agriculture at higher latitudes by promoting greater cropping intensity (IPCC, 2014); And climate *change could transform cropland from single cropping to multiple cropping at higher latitudes (Zhang & Ma, 2019). Also, we have added some references as the reviewer suggested in revised manuscript:*

Added in manuscript: The figure shows that it nearly follows the trend of decreasing cropping potential growth from high latitudes to low latitudes (Chen, 2018; IPCC, 2014; Zhang & Ma, 2019).

Comment 5: Fig. 4: The inset plot about the cropland pressure index between "rich" and "poor" regions needs further clarification (e.g., what the x-axis is).

Reply: The x-axis is the countries sort the top ten of the 'rich' (green line) and 'poor' (blue line) cropland pressure index. The number in the blue area is the cropland pressure index gap between 'rich' and 'poor' regions. Also, we have added the axis description in Fig.4 of revised manuscript.

Added in manuscript: In the inner plot, the x-axis represents the countries sort the top ten of the 'rich' (green line) and 'poor' (blue line) cropland pressure index. The number in the blue area displays the cropland pressure index gap between 'rich' and 'poor' regions.

Comment 6: The analyses are based on only one model, which weakens the conclusion overall. This limitation needs to be acknowledged. In addition, while the climatological mean bias in temperature and precipitation has been corrected, a detailed model evaluation including the spatial distributions and PDFs of temperature and precipitation is needed, to provide basic information about the reliability of the results.

Reply: Previous studies have evaluated CESM, demonstrating its reliability and accuracy in simulating climate change. In this paper, we provide reasons for using CESM for simulations and include relevant references to underscore the reliability of analyses based on CESM experimental results (Hurrell et al., 2013; Kay et al., 2015).

Added in manuscript: The reliability of the CESM has been confirmed in numerous previous studies, making it suitable for applications such as climate change simulation and climate model analysis (Hurrell et al., 2013; Kay et al., 2015).

Moreover, as suggested by reviewers, relying solely on one model has limitations. Therefore, we have added explanations regarding these limitations. In the future, multi-model climate simulation can help to provide a better understanding of the climatic effects of cropland expansion.

Added in manuscript: However, it is worth noting that all information presented is based on climate cropping potential and experiments are conducted using only one climate model, which may lead to biased outcomes. Specific circumstances must also be determined based on factors such as soil conditions and altitude when implemented on the ground.

For the temperature and precipitation, we used the widely applied 'delta method' for climate model bias correction with AgERA5. For the detailed model evaluation, we added the spatial distributions and PDFs of temperature and precipitation as suggested. The spatial distributions and PDFs results are shown in the new Fig. S11.

Added in manuscript: We use the spatial distributions and PDF (Probability Density Function) to verify the correctness of the corrected temperature and precipitation. The PDFs results and the Bias-corrected temperature with precipitation based on AgERA5 are shown in Fig. S8-11.

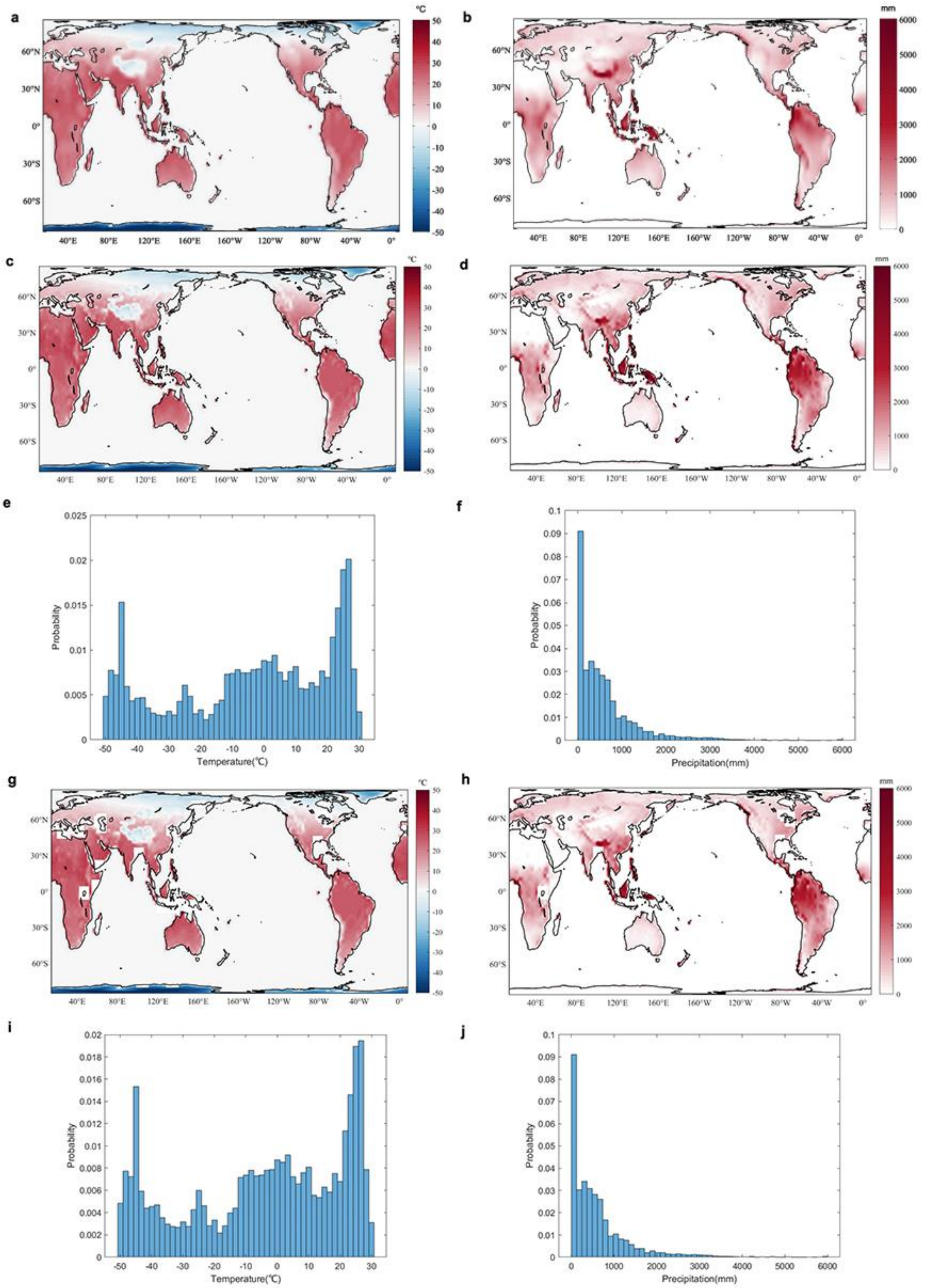


Fig. S11. Bias-corrected T and P in 2015 based on ERA5. (a) uncorrected temperature (b) uncorrect precipitation (c) corrected temperature (d) corrected precipitation (e) PDF of corrected temperature (f) PDF of corrected precipitation (g) ERA5 temperature (h) ERA5 precipitation (i) PDF of ERA5 temperature (j) PDF of ERA5 precipitation.

References:

- *Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J., & Taylor, K. E. (2016). Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. Geoscientific Model Development, 9(5), 1937–1958.*
- *Rohrschneider, T., Stevens, B., & Mauritsen, T. (2019). On simple representations of the climate response to external radiative forcing. Climate Dynamics, 53, 3131-3145.*
- *Hurrell, J. W., Holland, M. M., Gent, P. R., Ghan, S., Kay, J. E., Kushner, P. J., . . . Lindsay, K. (2013). The community earth system model: a framework for collaborative research. Bulletin of the American Meteorological Society, 94(9), 1339-1360.*
- *Chen, B. (2018). Globally increased crop growth and cropping intensity from the long-term satellite-based observations. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 4, 45-52.*
- *IPCC, I. (2014). Climate change 2014: Synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change.*
- *Zhang, X., & Ma, X. (2019). Misplaced optimism in agricultural land usage driven by newly available climate resources: A case study of estimated and realized cropping intensity in northern and northeastern China. Climate Risk Management, 25, 100194.*
- *Kay, J. E., Deser, C., Phillips, A., Mai, A., Hannay, C., Strand, G., et al. (2015). The Community Earth System Model (CESM) Large Ensemble Project: A Community Resource for Studying Climate Change in the Presence of Internal Climate Variability. Bulletin of the American Meteorological Society, 96(8), 1333–1349. https://doi.org/10.1175/bams-d-13-00255.1*