Responses to the comments of RC2

Comment 1: The authors motivate the study by describing that the underlying mechanisms behind the effect of cropland expansion on cropping potential remain unexplored (line 23). However, there is very little discussion about the underlying mechanisms. The simulated results by the earth system model are directly used as a forcing to cropping potential model and the assessment about the change in cropping potential is done. I would suggest to add relevant discussion about following points.

C1.1: The tropics and sub-tropics seem to show a clear tendency where wet regions get warmer and dry regions get cooler as a result of cropland expansion. Some discussion should be added for why this could be the case?

Reply: The warming tendency in low-latitude tropics (mentioned as wet regions by the reviewer) is mainly associated with the warming effect of the reduced surface evaporation due to cropland expansion (Fig. S16f). The sub-tropics shows less cropland expansion. Therefore, the cooling tendency in the sub-tropics (mentioned as dry regions by the reviewer) are dominated by large-scale atmospheric adjustments such as the cool advection (Fig. S16a). The local cooling effect of cropland expansion by reducing sensible heat fluxes weakens the upper-troposphere westerly jet and thus results in cool advection in the sub-tropics. The cooling effect leads to decreased atmospheric heat storage, as well as decreased water vapor due to the reduced atmospheric water vapor holding capacity (saturation vapour pressure). Therefore, the longwave downwelling flux is decreased, contributing to the cooling in the sub-tropics (Fig. S16e). We added some discussion in Section 3 Results of revised manuscript.

Added in manuscript: Additionally, the increase in saturation vapour pressure enhancing water vapor led to an increase in longwave downwelling flux. The warming tendency in tropics and sub-tropics is mainly associated with the warming effect of the reduced surface evaporation due to cropland expansion.

C1.2: The warming in tropics (e.g India) can-not be attributed to changes in latent heat flux alone (line 200). Figure S16 clearly shows a decrease in solar radiative heating which primarily reflects decrease in cloud cover. The effect of deforestation on cloud-cover have already been emphasized (Duveiller et al 2021) and cloud-radiative effects have been shown to significantly affect surface temperatures (Ghausi et al., 2023).

Reply: The adjustment of solar radiation in response to cloud cover changes directly affects surface temperature, and then indirectly influences near-surface air temperature via the near-surface turbulence of sensible and latent heat (Fig. S16c&f) (Ghausi et al., 2023). Here, the shortwave radiative heating on near-surface air temperature results from reduced precipitation which leads to the increased concentration of absorptive aerosols such as black carbon and dust (Liu et al., 2019). We added the description in the revised manuscript.

Added in manuscript: Warming in the tropics and subtropics was governed by changes in solar radiation affected by cloud cover and latent heat flux stemming from deforestation (Ghausi, Tian, Zehe, & Kleidon, 2023).

C1.3: About warming of northern Eurasia: Changes in warm-air temperature advection mostly results in increased downwelling longwave radiation (Rld) as result of increase in atmospheric heat storage. Therefore, these are confounding effects and not really the independent of each other (See also Tian et al., 2022; Tian et al., 2023). This point should be made clear.

Reply: The warming of northern Eurasia due to the warm advection leads to increased atmospheric heat storage, as well as enhanced water vapor due to the greater atmospheric water vapor holding *capacity (saturation vapour pressure). Therefore, the longwave downwelling flux is increased, contributing to the warming. The positive feedback has been additionally discussed in the revised manuscript.*

Added in manuscript: Additionally, the increase in saturation vapour pressure enhancing water vapor led to an increase in longwave downwelling flux.

C1.4: Over Europe, the sensible heat flux has reduced substantially. Do authors have an explanation for that?

Reply: The surface roughness of cropland is smaller than that of the forest. Therefore, the expansion of cropland with decreased forest cover enhances aerodynamic resistance to sensible heat diffusion from the land surface to the atmosphere, leading to cooling effects (Fig. S16c).

C1.5: Line 208: There is no discussion about the factors that cause the cooling trend over these regions.

Reply: The significant cooling in central and eastern Asia, the Middle East, North Africa, and most of the United States primarily results from the combined effects of reduced sensible heat fluxes, decreased longwave downwelling fluxes, and cool advection. We added in the revised manuscript.

C1.6: Other biophysical factors that can mediate changes in temperatures in response to changing vegetation type should be discussed (Kleidon et al., 1998; Lee et al., 2011; Chen et al., 2020).

Reply: The contributions of surface sensible and latent heat fluxes to air temperature changes involve the impacts of many biophysical factors, such as surface albedo, surface emissivity, aerodynamic resistance, and surface resistance (Lee et al., 2011; Chen et al., 2020). This is because these biophysical factors directly affect surface temperature, and then indirectly influence near-surface air temperature by the near-surface turbulence of sensible and latent heat (Zeng et al., 2017; Li et al., 2019). The discussion has been added in the revised manuscript.

Added in manuscript: At the same time, a significant cooling trend is shown in central and eastern Asia, the Middle East, North Africa, and most of the United States, resulting from the combined effects of reduced sensible heat fluxes, decreased longwave downwelling fluxes, and cool advection.

C2: Line 223: The cropping potential is described using a cumulative value. Is it the cropland pressure index discussed in lines (170). Does it have a dimension? There should be some information provided to interpret its values.

Reply: The cropping potential value is not the cropland pressure index. The cropping potential, in this article is climate cropping potential, denotes the utmost capacity for multi-cropping achievable after thorough climate resource assessment. While the cropland pressure index presents the pressure for cropping potential capacity (based on the cropland distribution) to carry the current population in each region, which is calculated by dividing the total population by cropland potential area over the regions. To prevent ambiguity, we have added a conceptual explanation of the cropping potential. The explanation of cropland pressure has been added in revised manuscript.

Added in manuscript: Climate cropping potential denotes the utmost capacity for multi-cropping achievable after thorough climate resource assessment.

Added in manuscript: Cropland pressure index is calculated by dividing the total population by cropland potential area over the regions. The cropland pressure index presents the pressure for cropping potential capacity (based on the cropland distribution) to carry the current population in each region.

C3: Figure 3 b,c: How are changes in cropping potential attributed to individual variables? To what extent are the 5 variables (describing temperatures) correlated?

Reply: Here we categorize the variables used to calculate cropping potential into three groups: P (precipitation), LGP (number of days), and TS (accumulated temperature). Employing Bottleneck analysis, a systematic approach aimed at identifying primary limiting factors, we determine which types of variables influence the overall increase in cropping potential. Furthermore, this attribution is not limited to individual variables, but considers 1 (precipitation), or 2 (TS or LGP), or 3 (green or purple), and even 6 (gray) variables.

Regarding the correlation among temperature description variables, although these variables are all temperature-based, they vary in dimensions. We introduced these variables because GAEZ specifies their necessity for calculating cropping potential (Fischer et al., 2021). As depicted in the Figure 3, most of the temperature-related attribution results are depicted in orange (representing all temperature description variables). Therefore, bottleneck analysis is conducted solely based on GAEZ variables, which does not imply a lack of correlation among them.

Minor:

M1: There seems to be some typesetting error in equations 1 and 2.

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

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

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

M2: The legend size in figure 3b and 3c should be increased.

Reply: We have enlarged the figure b and c in Fig.3, Fig.S20 and Fig.S21 as suggested.

References:

- *Ghausi, S. A., Tian, Y., Zehe, E., & Kleidon, A. (2023). Radiative controls by clouds and thermodynamics shape surface temperatures and turbulent fluxes over land. Proceedings of the National Academy of Sciences, 120(29), e2220400120.*
- *Liu, S., Liu, X., Yu, L., Wang, Y., Zhang, G. J., Gong, P., et al. (2021). Climate response to introduction of the ESA CCI land cover data to the NCAR CESM. Climate Dynamics, 1-19.*
- *Lee, X., Goulden, M., Hollinger, D. et al. Observed increase in local cooling effect of deforestation at higher latitudes. Nature 479, 384–387. https://doi.org/10.1038/nature10588 (2011).*
- *Chen, C., Li, D., Li, Y., Piao, S., Wang, X., Huang, M., Gentine, P., Nemani, R.R. and Myneni, R.B., Biophysical impacts of Earth greening largely controlled by aerodynamic resistance. Science advances, 6(47), p.eabb1981 (2020).*
- *Zeng, Z., Piao, S., Li, L. Z. X., Zhou, L., Ciais, P., Wang, T., et al. (2017). Climate mitigation from vegetation biophysical feedbacks during the past three decades. Nature Climate Change, 7(6), 432–436.*
- *Li, Y., Piao, S., Chen, A., Ciais, P., & Li, L. Z. X. (2019). Local and teleconnected temperature effects of afforestation and vegetation greening in China. National Science Review, 7(5), 897–912.*

- *Fischer, G., Nachtergaele, F. O., van Velthuizen, H., Chiozza, F., et al.(2021). Global Agro-ecological Zones (GAEZ v4)-Model Documentation.*