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Potential land-use-climate interactions simulated for the 21st century

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Many factors determine Earth's sustainable population size, one of the most fundamental being the availability of food. With the largest extent of our food supply stemming from agricultural production, suitable soils, energy and fresh water constitute the most essential factors for food security. These inputs, especially the availability of fresh water, depend on climatic conditions and understanding their vulnerability to climate change presents a major challenge of climate research. At the same time, agricultural activity is not only depending on suitable climatic conditions, but it also has substantial impacts on climate through the alteration of land-surface characteristics including the redistribution of water via irrigation.

For different representative concentration pathways, i.e. RCP2.6, RCP4.5 and RCP8.5, we investigated the limitations that climatic conditions and water availability impose on the potential expansion and productivity of croplands during the 21st century and which impact the expansion of, especially irrigation based, cultivated areas has on climate. For the investigation, we used the Max-Planck-Institute for Meteorology's Earth system model. The model was adapted to simulate the maximization of the cropland area and agricultural water use under prevailing climate conditions, while limiting future withdrawals to the fraction of renewable fresh water which exceeds environmental requirements. These modifications allowed us to consider the two-way feedback between climate and agriculture.

We found that, when only considering climate imposed limitations, the total cropland area could be extended substantially throughout the 21st century. Here, the largest cropland expansion was simulated for South America and sub-Saharan Africa, where the rising water demand resulting from increasing temperatures are largely met by increasing precipitation and irrigation rates. When accounting for the CO_2 fertilization effect, only few agricultural areas have to be abandoned, while increasing temperatures allow expanding croplands even into high northern latitudes. Without the CO_2 fertilization effect there is no increase in the overall cropland fraction during the second half of the century but areal losses in increasingly water-stressed regions can be compensated by an expansion in regions, previously too cold. However, global yields are more sensitive and, without the benefits of CO_2 fertilization, they may decrease when green house gas concentrations exceed the RCP4.5 scenario. The simulated increase in irrigation has a significant climate impact as it strongly reduces surface temperatures, in comparison to a simulations without irrigation, and leads to a substantial increase in terrestrial precipitation during the 21st century.