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Planetary opportunities in crop water management: Potential to outweigh cropland expansion

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Global available land and water resources probably cannot feed projected future human populations under current productivity levels. Moreover, the planetary boundaries of both land use change and water consumption are being approached rapidly, and at the same time competition between food production, bioenergy plantations and biodiversity conservation is increasing. Global cropland is expected to expand to meet future demands, while considerable yield gaps remain in many world regions. Yield increases in Sub-Saharan Africa, for example, are currently mainly based on expansion of arable land into currently non-agricultural areas – while small-scale irrigation and water conservancy methods are considered very promising to boost yields there.

In the here presented modeling study we investigate, at global scale, to what degree different on-farm options to better manage green and blue water might contribute to a global crop yield increase under conditions of current climate and projected future climate change. We consider methods aiming for a maximization of crops' water use efficiency and an optimal use of available on-farm water (precipitation): reducing unproductive soil evaporation (vapor shift, VS), collecting surface runoff after rain events to mitigate subsequent dry-spells (rain-water harvesting, RWH), increasing irrigation efficiency, and expanding irrigated area into rain-fed cropland (based on water savings from higher efficiencies). Global yield simulations based on hypothetical scenarios of these management opportunities are performed with the LPJmL ecohydrological modeling framework driven by reanalysis data and GCM ensemble simulations. We consider a range of about 20 climate change projections to cover respective uncertainties, and we analyze the effects of increasing CO_2 concentration on the crops and their water demand. Crops are represented in a process-based and dynamic way by 12 crop functional types, each for rain-fed and irrigated areas, with prescribed annual fractions of cropland per 0.5° x 0.5° grid cell. We recalculate from the yield increase how much cropland expansion can be avoided in 30-yr averages.

Our results show that the studied affordable low-tech solutions for small-scale farmers on water-limited croplands can have a considerable effect on yields at the global scale. A simulated global $\sim$15% yield increase from a low-intensity water management scenario (25% of runoff used for RWH, 25% of soil evaporation avoided to achieve VS, slight irrigation efficiency improvement) could outweigh, i.e. possibly avoid, an estimated 120 Mha of cropland expansion under current climatic conditions. A (rather theoretical) maximum-intensity water management scenario (85% VS, 85% RWH, surface irrigation replaced by sprinkler systems) shows the potential to increase global yields by more than 35% without expansion or withdrawing additional irrigation water. Climate change will have adverse effects on crop yields in many regions, but as we sow such adaptation opportunities have the potential to mitigate or compensate these impacts in many countries. Overall, proper water management (sustainably maximizing on-farm water use efficiency) can substantially increase global crop yields and at the same time relax rates of land cover conversion.