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Simultaneous improvement in water use, productivity and albedo through canopy structural modification

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Agricultural lands provide a tremendous opportunity to address challenges at the intersection of food and water security and climate change. Global demand for the major grain and seed crops is beginning to outstrip production, while population growth and the expansion of the global middle class have motivated calls for a doubling of food production by the middle of this century. This is occurring as yield gains for the major food crops have stagnated. At current rates of yield improvement this doubling will not be achieved.

Plants have evolved to maximize the capture of radiation in the upper leaves, resulting in sub-optimal monoculture crop fields for maximizing productivity and other biogeophysical services. Using the world's most important protein crop, soybean, as an example, we show that by applying numerical optimization to a micrometeorological crop canopy model that significant, simultaneous gains in water use, productivity and reflectivity are possible with no increased demand on resources.

Here we apply the MLCan multi-layer canopy biophysical model, which vertically resolves the radiation and micro-environmental variations that stimulate biochemical and ecophysiological functions that govern canopy-atmosphere exchange processes. At each canopy level photosynthesis, stomatal conductance, and energy balance are solved simultaneously for shaded and sunlit foliage. A multi-layer sub-surface model incorporates water availability as a function of root biomass distribution. MLCan runs at sub-hourly temporal resolution, allowing it to capture variability in CO_2, water and energy exchange as a function of environmental variability.

By modifying total canopy leaf area, its vertical distribution, leaf angle, and shortwave radiation reflectivity, all traits available in most major crop germplasm collections, we show that increases in either productivity (7%), water use (13%) or albedo (34%) could be achieved with no detriment to the other objectives, under climate conditions observed for the United States Corn Belt.