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Towards generalizable crop models: an eco-evolutionary optimality approach to carbon allocation

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Abstract: Agricultural production faces mounting pressure from climate change and land degradation, even as global food demand continues to rise. Historical improvements in crop yields have been partially attributed to breeding shifts in biomass partitioning to the different plant organs (Fischer and Stockman, 1986). The relative growth of plant organs largely determines potential for resource acquisition (e.g. leaves for light, roots for water and nutrients) and capacity to buffer against stress (Chandregowder et al., 2023; Moragues et al., 2006), with clear implications for yield potential under climate change. This highly plastic process is difficult to predict with current crop models, as it likely arises from complex interactions among physiological processes, genetic traits, and environmental drivers (Engel et al., 2003; Porker et al., 2020).

We present a novel approach to modelling crop carbon allocation to leaves and roots using an eco-evolutionary optimality principle. By focusing on core physiological functions (photosynthesis, stomatal conductance, plant hydraulics, and canopy radiative transfer) and defining a fitness proxy for carbon allocation, the optimality-based model can integrate the effect of all underlying processes without the need for highly parameterized functions (Harrison et al., 2021). This leads to adaptive carbon allocation dynamics that are governed by plant traits, known mechanisms and the environment, which largely overcomes the need for re-calibration under new conditions. Early results demonstrate the ability of this new model to predict the dynamics of biomass and the yield of wheat in the contrasting wet and dry years, showing skill in representing the drought response of wheat. Technical and theoretical challenges in implementing an optimality principle in a crop model are discussed. Finally, we present the potential for this approach to predict biomass dynamics and yield under multiple environmental drivers and evaluate trait-environment relationships.

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