

M2 internship: Development of an optimality-based model to investigate the contribution of abiotic limiting factors to the current global yield gap

Context

“The future of agriculture faces two great challenges: meeting the substantial increases in food demand while decreasing its global environmental footprint” (Mueller et al., 2012). Several strategies should be combined to take up these challenges, among which, closing the yield gap, defined as the mismatch between potential yield (i.e. a yield only determined by genotype, plant population density, and location-specific solar radiation and temperature regimes) and actual yield (van Ittersum et al., 2013). Factors limiting the yield encompass abiotic (nutrients, water) and biotic factors (pest, diseases, weeds). Yield achieved at a given field is dependent to the use of different resources, such as nitrogen (N) and phosphorus (P) fertilizers and water (H₂O) when supplied through irrigation. The use of resources is far from efficient. E.g. while global soil P inputs through chemical and organic fertilizers are larger than the P contained in global harvest, around 30% of the cropland area has a negative local soil P budget (MacDonald et al., 2011). Nutrient input in excess could trigger losses to the environment (Alewell et al., 2020) while nutrient and water limitation could reduce yield (Kvakić et al., 2018; Wang et al., 2021). Improving the resource use efficiency is one way to increase yield while limiting the environmental footprint of agriculture. **However, an in-depth understanding of the main abiotic factors driving the current yield gap at the global scale is missing in the literature.** It is nevertheless required to improve resource management and to understand how yield can evolve in the future under different socio-economic and climatic scenarios.

Methods

GPCROP is a spatial explicit model (half-degree latitude x longitude resolution) that simulates the potential growth for maize and how the P limitation can have an effect on this potential growth (Ringeval et al., 2025). The model explicitly represents key mechanisms such as the replenishment of the soil P solution by more stable soil P pools, the diffusion of P in soil, and plant adjustments to P limitation. Plant adjustments are mainly represented through an optimized plant daily allocation of carbon (C) and P among plant organs (root, leaf, grain). Trade-off in allocation between root and leaf as function of resource limitation is one component of what is called “eco-evolutionary optimality principles”. These principles are in particular based on the concept that organisms adjust to their environment on short (eco-physiological, days to months) timescale (Harrison et al., 2021). Thanks to these additional assumptions, optimality principles allows to reduce the number of uncertain parameters needed in the current terrestrial biosphere models, and are thus a promising strategy to make their simulations much less uncertain.

The M2 internship will aim to develop GPCROP to further incorporate N limitation. Water will be considered as non-limiting in the framework of this internship. Model development will be done through a parsimonious-parameter approach by mimicking what was done for P but by adapting it to N cycle specificity (in particular soil N dynamics). Implementation will focus on soil N dynamics, N root uptake, and allocation between plant organs. The allocation following N limitation will be evaluated against a long-term field trial in France with different N treatments (Plénet, 1995). While this is a well proven dataset, it has the specificities to provide both measurements over the course of the growing season (vs. “only” at harvest time in most long-term field trials) and for roots, which are valuable to evaluate the plant adjustments simulated. Long-term field trial at Broadbalk (Van Grinsven et al., 2022) with combination of 6 N and 3 P treatments will be used to assess NxP limitations simulated. A network of long-term field trials with N treatments (Van Grinsven et al., 2022) will be used to evaluate N limitations simulated under different environments. At the end of the internship, global simulations to estimate the N, P and NxP limitation of the potential yield under irrigated conditions could be performed.

Key-words : global agronomy, nutrient limitation, mechanistic model, global food security, optimality

Skills : First experience (or at least strong interest) in programming (Python and shell scripts)

Localization : UMR ISPA, Centre INRAE Nouvelle-Aquitaine, Villenave d'Ornon (near Bordeaux)

Additional information : A proposal to get a funding for a PhD related to this internship was recently submitted. The PhD would aim to consider P, N and H₂O limitations together, following the further implementation within GPCROP of an eco-evolutionary optimality-based approach applied to the C assimilation–H₂O transpiration trade-off (see e.g. (Joshi et al., 2022; Stocker et al., 2020)).

For any information and to apply, please, send an e-mail to: bruno.ringeval@inrae.fr

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