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Discovery and application of a generalised nitrogen response function for global cereals

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A crucial relationship for agronomic and food system analysis is the response of crop yield (Y) to the addition of nitrogen fertiliser (Nrate). Long-term field experiments (LTEs) are essential for correctly determining the economic and environmental performance of alternative agricultural practices. However, the vast majority of N response data are derived from trials lasting only one or two years (STEs). Typically, marginal N response from STEs is about twice as low as for LTEs, implying that caution is justified when basing regional agronomic and environmental effects of changing N regimes on STEs.

In view of the generic principles governing N transformations and uptake when N input, crop yield and soil N pools are in a near steady state, we hypothesised the existence of a generic LT N response relationship for global cereals. To test this hypothesis, we scaled N response by using indexed yield (Y/Ymax) and total N availability (sum of N input from fertiliser and non-fertiliser sources – here referred to as SN), and fitted scaled N response by 2nd order polynomials with zero intercept (curve referred to as SNR).

We first derived SNRs for winter wheat between 1985 and 2018 at Rothamsted experimental station in the UK (running for >150 years: R^2 0.954 for wheat in rotation and R^2 0.903 for continuous wheat), and for continuous corn between 2000 and 2010 at the Southwest Research-Extension Center in Kansas, USA (running for >50 years; R^2 0.934). Next we found similar SNRs (R^2 0.818) for the combined results of 25 less extensive LTEs (running >15 years) for winter wheat, barley and corn in Europe, USA and Asia, with maximum yields between 2.8 to 12.8 t/ha, N rates from 0 to 300 kgN/ha and under a wide range of practice, soils and climate. We did not find LTEs for Africa, but could demonstrate applicability of our SNRs. For paddy rice we had 4 LTEs but the resulting SNR was different.

SNRs can be transformed back to unscaled N response curves for common situations where no LTEs are available, by using site specific estimates of specific SN (mainly from N deposition biological N fixation) and Ymax. The scaled, generalised N response relationship was used to construct a globally applicable function and diagram between agronomic efficiency and Ymax. This can be used to support the development of strategies to increase regional cereal sufficiency, balancing efforts to increase Nrate and Ymax.

Finally, we developed LT N response approaches, including N removal and N losses, to assess economically optimum N rates from the farm perspective, accounting for the cost of N fertiliser use, and the societal perspective by also accounting for the cost of N pollution. For this we could only use N data from the LTEs at Rothamsted. Ranges of these optimum N rates show that the safe operating space of N fertiliser application narrows when aiming at the combined ambitions of adequate farm income, regional cereal sufficiency and acceptable levels of N pollution.