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High-throughput image-based phenotyping to predict crop performance in new

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Predicting crop performance for new environments and new genotypes is becoming increasingly important in plant breeding. Anticipating future performance is essential in the face of changing climate. Traditionally, multi-environment trials (MET) have been combined with statistical models to infer and predict genotype performance in different environments.

However, MET data are typically not available for most breeding stages. High-throughput phenotyping offers an alternative perspective to monitor genotype-by-environment (GxE) interactions. The state of a phenotype in a given environment can be viewed as the accumulated response of its genotype to environmental covariates. Modern measurement techniques allow to capture both - environmental covariates and phenotypes - with high temporal and spatial resolution.

Here, we provide two use cases that demonstrate the potential of exploring the temporal dimension of plant development in breeding.

(1) Temperature is a major driver of plant development in the stem elongation phase of winter wheat. We measured the height development of 352 European cultivars over four years to quantify genotype-specific *per se* temperature responses. Our results indicate that breeders have influenced the temperature response through co-selection for phenology in the past. In addition to the known major genes related to vernalization, photoperiod, or dwarfing, a genome-wide association study (GWAS) revealed additional unknown loci associated with temperature response. Predictions of winter wheat phenological stages (jointing, heading, and senescence) with cultivar-specific temperature responses explained GxE interactions better than thermal time.

(2) Intermediate traits, such as response parameters, are expected to be more stable across environments than target traits, such as yield. In a second study, we hypothesized that phenomic selection (PS) may allow selection for genotypes with advantageous response patterns in a defined population of environments. A set of 45 winter wheat cultivars was grown at 5 year-sites.

A trained PS model was able to predict overall yield performance, yield stability, and grain protein content with state-of-the-art accuracy. In summary, observing phenotype development over time at a few sites has the potential to reduce the need for large METs.

However, the processing of dense time-series data is resource and knowledge demanding.
As an outlook, we give insights on end-to-end (deep) learned image-based prediction approaches that have great potential to facilitate such research.