DIVERSify Milestone no. MS24

RURAL INNOVATION

Resources to support breeding for intercropping

Intercropping of cereals and legumes is an expanding agricultural practice and one of several prominent methods of crop diversification. Marketing of crop cultivars that contribute towards optimizing mixture benefits is thus an emerging and growing market opportunity for breeders and seed producers.

Research and applications have shown that intercropping tends to increase resource use efficiency and reduce levels of pests and pathogens, ultimately resulting in higher yields with fewer inputs. This is largely owing to ecological mechanisms such as complementarity and facilitation, in which the involved plant partners utilise different resource pools and promote the growth and reproduction of each other. Therefore, successful intercropping depends critically on crop traits that contribute to such positive interactions.

It is not straightforward to define which traits and trait combinations are the most beneficial and hence should be targeted by breeding for intercrops. Many are not even considered in traditional breeding for sole cropping, and it is unlikely that existing cultivars are the most suitable for intercropping. In other words, there appears to be a large untapped potential for setting up specific breeding programmes that can secure availability of cultivars and seed optimized for intercropping.

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The H2020-funded project DIVERSify has focused on crop traits and management practices that promote success of plant teams such as intercrops and grassland mixtures. Project activities include coordinated scientific field trials (in WP2) and on-farm trials (in WP4) of intercrops and their sole cropped components, as well as modelling development, calibration and testing (WP3). The results have been discussed with crop scientists, breeders, and other stakeholders, and are published as scientific papers and publicly available reports. Some of the project outputs can support breeding for crop mixtures, as described below.

PERSPECTIVES OF BREEDERS AND CROP SCIENTISTS

We organised a workshop dedicated to 'Breeding for crop mixtures: Opportunities and challenges' as part of the European Conference on Crop Diversification in Budapest, Hungary (September 2019). The workshop brought together ca. 25 crop scientists, breeders and organisations representing farmers and agronomists, who were tasked with identifying the major advances in mixture breeding and the key knowledge gaps from stakeholders' perspectives. Existing and novel breeding targets were discussed and the opportunities for novel breeding methods, such as population breeding, and participatory breeding approaches were highlighted, as well as the challenges of managing genotype-environment interactions and developing new market opportunities. The workshop findings have been summarised in a blog post (Kiær *et al.* 2020a) on the project website and will be reported in a peer-reviewed opinion article.

STANDARDISED FIELD PROTOCOLS

Coordination of field activities is crucial to be able to evaluate trait and performance data from parallel field trials across sites and/or years, such as those operated in the DIVERSify project. For this purpose, we developed a set of 46 standardized protocols for trait assessment, which were used in all scientific field trials in the project (Kiær *et al.* 2020b). This has contributed to increasing the quality of the collated dataset and acting as documentation for the many field assessments. Being publicly available at the project website (plant-teams.org), it can serve as a tool for future coordinated field assessments.

HARMONISED DATA STRUCTURE

Harmonising the format and structure of reported field trial data is equally important to facilitate the merging, analysis and sharing of datasets. More and more datasets are being shared online, however, accessibility and practical use of these datasets is encumbered by the fact that many of them lack clear semantics and metadata standardisation. Data from all field trials carried out as part of the project were reported following standardised data templates (see Kiær *et al.* 2020b, Pappagallo *et al.* 2021, Theilgaard *et al.* 2018) and quality checked meticulously before merging and sharing.

SHARING AND VISUALISATION OF INTERCROP DATA

Field trial data produced in the project were combined in a curated database (Kiær *et al.* 2021) and made publicly available via the project legacy page at zenodo.org/communities/diversify. This corpus of data can serve as basis for investigating additional questions on ideotype performance across sites and years, and as a reference for future breeding activities.

Since no existing online data sharing platforms were designed specifically for intercrop data, two specialised database interfaces were developed in DIVERSify to facilitate the access and visualisation of crop mixture data.

CropMixer (cropmixer.source.gr) is a decision aid tool developed to guide the overview of existing data and the choice of crop partners for cultivation in specific situations. It consists of datasets from the scientific field trials and on-farm trials, as well as a wide range of historic data from trials conducted previously by project partners.

DIVERSiplotter is an online tool to allow users to explore and interact with intercropping field trial data collected as part of the scientific field trials of the DIVERSify project. This expandable platform (latest version can be accessed at ics.hutton.ac.uk/diversify) currently includes integrated data for 94 traits, 11 crop species, and 48 varieties distributed among three intercropped plant teams and seven countries across Europe (Raubach *et al.* 2021).

IDENTIFICATION OF SUCCESSFUL INTERCROP TRAITS AND IDEOTYPES

It is not straightforward to predict which trait combinations are the most beneficial in intercropping under specific environmental or management conditions; and hence which traits should be targeted by breeding for intercrops. It is clear, however, that mixture ideotypes (i.e., ideal phenotypes or morphotypes) are unlikely to resemble monoculture ideotypes.

To describe and predict crop varieties and cultivars which offer a suitable combination of traits for plant team cropping, and to speed up initial germplasm selection, the project (in WP3) has generated a predictive tool: the Minimalist Mixture Model, M^3. This framework allows users to design and test new plant teams (trait combinations) *in-silico*, simulating the performance of intercrops and pure cultures as a function of plant parameters, management factors and environmental conditions, including future climate scenarios. The rationale and structure of the model is described in Berghujis *et al.* (2020) and Vico & Berghuijs (2020); and its usage to explore the performance of ideotypes is exemplified in Vico & Berghuijs (2021). The source code and a technical description has been made freely available at zenodo.org.

It is increasingly clear that successful plant teams, including intercrops, depend largely on a range of beneficial ecological mechanisms. The plant partners in an intercropping system can be seen as a very simplified version of an ecological community, in which external and intrinsic drivers affect the expression of plant traits that in turn affect reproductive yield. A key recommendation from the DIVERSify project is therefore to focus on specific influential plant traits and trait combinations that optimize these. Intercrop performance is the product of even more factors than sole crops, and particular focus should be given to traits that promote synergistic plant-plant interactions (facilitation and complementarity). Then, additional focus can be given to traits that promote beneficial direct and indirect interactions across trophic levels, such as competitiveness against weeds and increased support of natural enemies.

PRACTICE ABSTRACTS

DIVERSify produced more than 30 practice abstracts based on the EIP-AGRI common format (Bickler *et al.* 2021), of which some are relevant to breeding for mixture.

In the area of Processes, Techniques and Agronomy, the project generated practice abstracts with recommendations on choosing clover varieties for living mulches (PA17), optimizing species mixture composition for resilient low-input grasslands (PA25), and 'How diverse should components of mixtures/intercrops be? How many components? Should they be evenly mixed?' (PA31). In the area of Ecosystem Services, practice abstracts were generated on Yield stability under extreme weather conditions (PA27) and Wheat faba bean cropping in dry areas (PA30).

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